Thesis for the Degree of Doctor of Philosophy

Factors Affecting Labor Productivity in Iran Construction Industry

by

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Interdisciplinary Program of Construction Engineering and Management

The Graduate School

Pukyong National University

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by

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ABSTRACT

Construction projects, as a labor-intensive industry, are directly involved with workforce management. Hence, the labor productivity issue is of remarkable interest in both the construction industry and academia because of its impact on time, cost, and quality of project. Due to the importance of labor productivity, an intensive literature review has been done to identify critical factors. However, a lack of previous studies on the causal relationships between labor productivity factors in the Iranian construction industry was discovered through the literature review. Hence, the study objective is to prioritize and highlight the factors most affecting construction labor productivity in Iran. The potential factors were identified and a questionnaire was prepared, including 33 factors, and it was then distributed among construction project managers who have more than 5 years of experience in the Iranian construction industry. Out of 200 questionnaires, 157 questionnaires were returned by participants. Of these, 152 valid collected data sets were analyzed through the Analytical Hierarchy Process (AHP) as a decision-making tool and the Structural Equation Model (SEM) as a multivariate analysis technique, in parallel for accuracy and reliability of findings. Findings from both tools, AHP and SEM, were compared. Eventually, ''Labor Characteristics,'' by 0.384 priority weights, was selected as the most prioritized criteria; ''Tools and Equipment'' was selected among six factors as the most common significant factor between both AHP and SEM, ranked by 0.191 priority weights in AHP and a 0.82 factor loading in SEM. Furthermore, ‘‘Lack of required tools and/or equipment’’ has been ranked as the most significant sub-criteria with 0.444 weights; ‘‘Delay’’ has been chosen as the most significant latent variable in SEM with a 0.83 factor lading. Moreover, the Key Labor Productivity Index (KLPI) proposed as a measurement index in order to evaluate and estimate the level of productivity level in construction sites. The results of the study would be valuable for any participants in the construction industry and academia, particularly civil engineers who are involved in Iranian or Middle Eastern construction projects.

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Chapter 1 : INTRODUCTION

1.1 Background and Objectives

Iran, as a developing country in the Middle East, with Gross Profit Per capita of 5,252.4, has numerous construction projects. The Construction industry is considered as the largest industries in Iran, including over 10 million labors who are involved in the construction projects. Basically, Iran construction projects could be divided into government infrastructure projects and building construction projects. However, in the both sections of Iranian construction projects, construction labors have a key role in proceeding and delivering any projects success. Hence several academic studies have been performed and investigated regarding to the concept of productivity, motivation, and efficiency of the workforce. Although various studies had been done in the developed and developing countries, however, just few of them addressed construction labor productivity in Iran.

This study aimed to prioritize and highlight the most significant factors affecting construction labor productivity in Iran construction industry. To this aim, the study has the following objectives:

Objective 1: To identify the potential factors affecting construction labor productivity in the construction projects in Iran

Objective 2: To evaluate the most significant factors affecting construction labor productivity in the construction projects in Iran

Objective 3: To underline the interrelationship between the CLP factors in the construction projects in Iran

Objective 4: To prioritize the most significant factors affecting construction labor productivity in the construction projects in Iran

Objective 5: To accomplish a comparison between the findings from the different applied analysis methods in sake of clarifying the most effective CLP factor(s)

1.2 Scope and Methodology

In accordance with study objectives, initially an intensive literature review conducted to realize the concept of productivity, productivity ratios, construction labor productivity, calculation methods, and factors affecting labor productivity. Several influencing factors identified from the previous studies in developed and developing countries which will be discussed in the chapter 2.

This study conducted by both qualitative and quantitative analysis. A pilot study applied to check and validate the questionnaire survey by seven experts who have more than 10 years' experience in Iran construction industry. The experts meanwhile reviewing the questionnaires, they omitted and added some factors in order to upgrade the questionnaire survey. Ultimately, the revised questionnaire with 33 potential factors was distributed to the construction project managers who are involved in the Iranian construction industry and have more than 5 years' experience. The participants were asked to assess the factors, based on the five-point Likert-scale, from 1 (not applicable) to 5 (extremely effective). Out of 200 questionnaires, 157 questionnaires were fully completed and returned. Incomplete data was eliminated to ensure that the data set was suitable for statistical analysis. With 152 fully completed responses, we got an overall response rate of 78.5% which is quite reasonable.

In this study, the researcher applied different methods for data analysis in parallel for accuracy and reliability of findings. Hence, Initially the mean score calculated for all potential factors. Then, an Exploratory Factor Analysis (EFA) was conducted to reduce the number of variables and detect the structure in the relationships between variables in order to classify them. The Analytical Hierarchy Process (AHP) as a decision making tool and the Structural Equation Model (SEM) as a multivariate analysis technique have been applied. Based on the EFA results, the two mentioned methods, AHP and SEM, were implemented and analyzed. A Confirmatory Factor Analysis (CFA) was conducted to confirm the factor structure extracted from the EFA. The overall research process is displayed in Figure 1-1 .

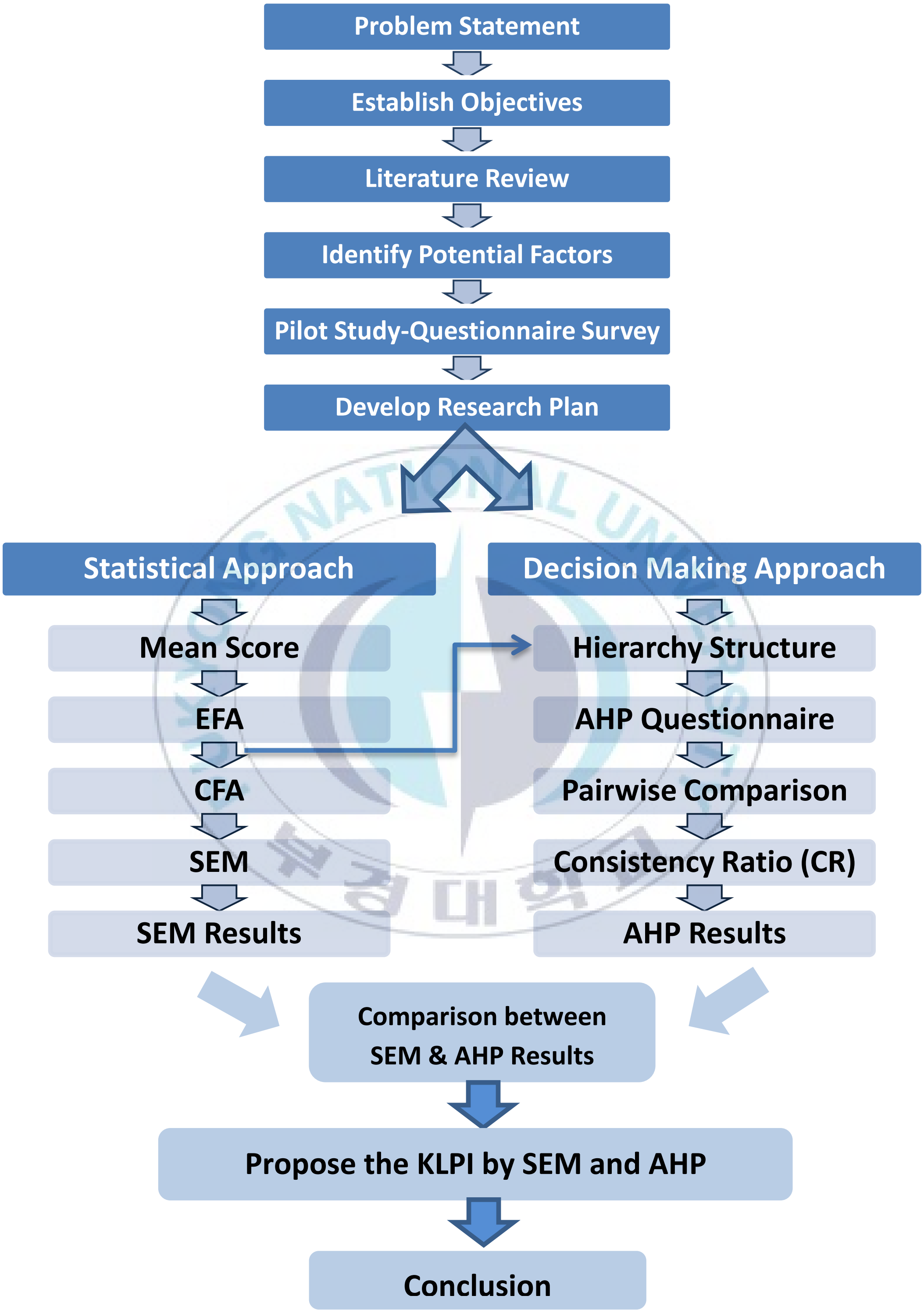

Figure 1-1 Research Methodology Diagram

CHAPTER 2

Chapter 2 : LITERATURE REVIEW

2.1 Introduction

Productivity is generally defined as the ratio of output to input (Rojas & Aramvareekul, 2003). It is one of the most frequently discussed topics in the construction industry because of its importance to profitability. The Construction Industry Institute (2006) mentioned that productivity is one of the most frequently used performance indicators to assess the success of a construction project because it is the most crucial and flexible resource used in such assessments.

As many of the operations within the construction industry are decidedly labor-intensive, labor productivity is considered one of the best indicators of production efficiency (Maloney, 1983; Rojas & Aramvareekul, 2003). It is gaining increasing attention in construction as the industry faces multiple problems related to its workforce (Allmon, Haas, Borcherding, & Goodrum, 2000; Rojas & Aramvareekul, 2003; Teicholz, Goodrum, & Haas, 2001). Moreover, labor productivity is a fundamental piece of information for estimating and scheduling a construction project (Song & AbouRizk, 2008) and becomes a prime factor because labor costs generally cover 30% to 50% of overall project costs in construction (Harmon & Cole, 2006).

2.1.1 Labor Productivity

Basically, productivity defines as a proportion of out to input or input to output. However, more several equations have been retrieved from this basic definition. Generally there are various definitions of productivity and each company uses its own internal system to measure it (H. R. Thomas & Mathews, 1986). There are two forms of productivity used in the previous studies; productivity=output/input, productivity=input/output. The other different definitions can be identified regarding the productivity in the construction activities, one refers to the productivity when the work is implemented and the other one refers to the value of the work based on the cost (Knutson, Schexnayder, Fiori, & Mayo, 2009). On the other hand, productivity refers to the output or hours that each worker needs to do in order to complete the job. Usually different countries measure the productivity rate of their workers based on dollar production for each worker-hour or whole price per element of production (Knutson et al., 2009). Tenah (1985) believes that based on the theoretical definitions, productivity refers to the relationship between output and input. According to the Bureau of

Labor Statistics of the US, the amount of productivity is usually related to the physical or real amounts of things and facilities (productions), associated with the physical or actual amount of feedback (workload, energy, wealth).

In the construction engineering and management domain, productivity is usually taken to mean labor productivity, which means units of work placed or produced per labor-hour. However, the inverse of labor productivity, labor-hours per unit (unit rate), is also commonly used (Halligan, Demsetz, Brown, & Pace, 1994).

In the manufacturing domain, labor productivity is defined as a measurement of economic growth of a country. It measures amount of products manufactured within an hour by labor. The U.S. Department of Labor defined labor productivity as the real output in national currency per hour worked. Bureau of Labor Statistics (BLS) measures labor productivity based on three basic measures–output, total labor hours, and total compensation (BLS, 2012). The output measures are real value added, and total labor hours refer to hours worked by all employees. The total compensation includes employer expenditure for direct pay, employer social security expenditure, and labor-related taxes and subsidies (BLS, 2012).

In the mining domain, the study of productivity in the bituminous coal mining industry became important at the macro or industry-wide level because: (a) productivity is important because of its relationship to the price of the energy resource, and (b) productivity is the key element in forecasting changes in labor demand in the industry as a whole and for specific areas to be impacted by regional shifts of production (Hannah, 1981). Labor productivity is generally defined as an average product of labor and expressed as the coal output (in tons) for physical units of labor input (in hours worked) (Hannah, 1981). It is simply measured by value added per hour worked (Topp, 2008).

In the agriculture domain, labor productivity is measured based on the agricultural output per labor force or worker (Craig & Weiss, 1993; Shafi, 1984). As labor productivity indices in the agricultural sector are generally used for the description of economic performance, Dorward (2013) proposed an indicator relevant to agricultural workers for agricultural development and its wider contribution to the economics, terms as “Cereal Equivalent Productivity of Agricultural Labor (CEPAL).” It is defined as the ratio of the agricultural value added to the product of agricultural workers and cereal prices. When measuring labor productivity in the USA, the labor productivity in non-agriculture is considered higher than in agriculture, which creates a condition of "labor productivity gap" and is defined as the ratio of labor productivity in agriculture and non-agriculture (Herrendorf & Schoellman, 2011).

Several research projects were conducted regarding "production frontier" in the agricultural domain. The production frontier is considered as a bounding function and is defined as the maximum output obtained from a given set of inputs (Colelli, 1995; Kumbhakar, Ghosh, & McGuckin, 1991) in which cost function acts as an input parameter and profit function acts as an output parameter. The lower the cost function and the higher the profit function means the production frontier is higher (Colelli, 1995). The production frontier provides information regarding technologies that are used by the best performing firms and best practice technology against which the efficiency of the firm is measured (Colelli, 1995).

2.1.2 Definitions of Productivity and Labor Productivity

There is no standard definition of productivity because each business defines it differently (Park, Thomas, & Tucker, 2005). However, productivity is defined in many ways because different measures of productivity serve different purposes. It is broadly defined as a terminology for the measurement of the effectiveness on employing the management skills, workers, materials, equipment, tools, and working space in order to produce a finished building, plant, structure, or other fixed facility at the lowest feasible cost (Liu & Song, 2005; Oglesby, Parker, & Howell, 1989)

Total factor productivity and partial factor productivity are two measures of construction productivity discussed by Talhouni (1990) and Rakhra (1991). Total factor productivity deals with the outputs and all inputs, whereas partial factor productivity deals with outputs and single or selected inputs. H. R. Thomas et al. (1990) defined productivity in terms of the total factor productivity, which is usually adopted by the Department of Commerce, Congress, and other governmental agencies as follows:

Equation 1

$$Total\ factor\ productivity\ (TFP) = \frac{Total\ Output}{Labor + Materials + Equipment + Energy + Capital}$$

In an economic model, total factor productivity is measured in terms of dollars because dollars are the only measure common to both inputs and outputs (H. R. Thomas et al., 1990).

Equation 2

$$Total\ factor\ productivity = \frac{Dollars\ output}{Dollars\ intput}$$

Based on requirement, productivity is defined differently. The Federal Highway Administration defines it as (H. R. Thomas et al., 1990):

Equation 3

$$Productivity = \frac{Output}{Design + Inspection + Construction + Right\ of\ way}$$

In an economic model, productivity is defined as:

Equation 4

$$Productivity = \frac{Lane\ miles}{Dollars}$$

Labor productivity definition by economists and accountants' point of view is the ratio between total resource input and total product output (Hanna, Menches, Sullivan, & Sargent, 2005). There is a similar definition by Bureau of Labor Statistics (BLS) in the U.S (2006) as "real output per actual hours worked." Construction labor productivity is adopted as an economic idea at the industry level and calculated by the equation below. Gross product originating by industry (GPO) is expressed in chained dollars to eliminate the effect of inflation when comparing data from different time periods (Yi & Chan, 2013) :

Equation 5

$$\mathbf{CLP} = \frac{\mathbf{GPO}}{\sum_{i=1}^{12} \mathbf{E}_i \mathbf{H}_i}$$

Where;

GPO = gross product originating by the construction industry in chained

dollars;

Ei = average number of employees in month i;

and Hi = average number of hours worked in month i.

Since labor is the dominant input in the labor-intensive construction operation, construction productivity is primarily dependent on human effort and performance (Abdulaziz M Jarkas, 2010). Thus, the definition of productivity is modified in terms of labor as an input as per requirement.

In general, productivity is measured in three different levels (Huang, Chapman, & Butry, 2009): task or activity level (deals with specific construction activities), project level (deals with construction of a new facility or renovation of an existing facility), and industry level (deals with total portfolio of the projects). Based on these levels of studies, three different productivity measurement models are determined, which are: (a) multifactor productivity model, (b) project-specific model, and (c) activity-oriented model (Liu & Song, 2005). According to the multifactor productivity model, productivity is defined as the ratio between total outputs and total inputs and is generally applicable to evaluate the efficiency of use of resources in the construction industry level (Liu & Song, 2005).

The project specific model defines productivity as the ratio between the outputs expressed in a physical unit and inputs expressed in labor, equipment, and materials (H. R. Thomas et al., 1990) as follows:

Equation 6

$$\text{Productivity} = \frac{\text{Output}}{\text{Labor} + \text{Equipment} + \text{Materials}}$$

This approach is adopted by governmental agencies or private sectors for conceptual estimates on individual projects. The designers use historical productivity data in order to estimate and design the specific project. In an economic model, the productivity is defined as (H. R. Thomas et al., 1990):

Equation 7

$$\text{Productivity} = \frac{\text{Square Feet}}{\text{Dollars}}$$

In an activity-oriented model, the productivity is generally expressed in units of output per labor cost (in dollar) or per work-hour (H. R. Thomas & Kramer, 1988). The productivity at the activity level is frequently referred to as labor productivity because construction activities are generally labor intensive and measure the input as labor hours or labor cost and output as installed quantities (H. R. Thomas & Mathews, 1986) as follows:

Equation 8

$$\text{Labor Productivity} = \frac{\text{Output}}{\text{Labor Cost}}$$

Equation 9

$$\text{Labor Productivity} = \frac{\text{Output}}{\text{Work hour}}$$

If there are various related activities, such as formwork, steel reinforcement, and concrete placement, then those are combined following the earned-value concept (H. R. Thomas et al., 1990). Some constructors use the performance factor in order to measure the productivity as follows:

Equation 10

$$\text{Performance factor} = \frac{\text{Estimated Unit Rate}}{\text{Actual Unit Rate}}$$

In other words, labor productivity is expressed as the ratio of physical output to work-hours, in which the productivity ratio is measured as the ratio of actual work-hours to the estimated work-hours (Goodrum, Zhai, & Yasin, 2009). The actual work-hours is collected from the field, and estimated work-hours (also called earned work-hours) is calculated based on the quantity of a task and productivity performance provided by construction estimation manuals or a company's productivity databases. Performance factor is a ratio rather than absolute value, which makes it possible to compare across different projects or companies, and the impact of unique project characteristics is adjusted.

The Construction Management Research Unit at Dundee University measures labor productivity in three different approaches (R. M. W. Horner & Talhouni, 1996). The first approach deals with total time, also called total paid time (input). The second approach deals with available time, estimated as total time minus unavoidable delays, meal breaks, and weather. The third approach deals with the productive time, which is obtained by subtracting avoidable delays from available time.

Equation 11

$$\text{Labor Productivity} = \frac{\text{Output}}{\text{Total Time}}$$

Equation 12

$$\text{Labor Productivity} = \frac{\text{Output}}{\text{Available Time}}$$

Equation 13

$$\text{Labor Productivity} = \frac{\text{Output}}{\text{Productivity Time}}$$

In existing practice, hourly outputs are widely used to measure labor productivity in construction research (Hanna, Chang, Sullivan, & Lackney, 2008; H. R. Thomas & Yiakoumis, 1987), considering a labor hour as the input unit and the physical quantity of the completed work as the output. This implies that the labor productivity consists of the number of actual work-hours required to perform the appropriate units of work. Moreover, defining the term "hours" as the hours actually worked, the labor productivity in the U.S. is defined by the BLS (2006), as real output per hour worked. This approach excludes vacation, holidays, and sick leave, but includes paid and unpaid overtime.

Generally, in construction researches regarding to the labor productivity, hourly outputs have been used to measure labor productivity (Hanna et al., 2008; Sonmez & Rowings, 1998; H. R. Thomas & Yiakoumis, 1987). According to Eastman and Sacks (2008), this approach of measurement of labor productivity by hourly output avoids many external factors that cause cost variance when comparing with cost-based output measures. This implies that the hourly output is the most reliable approach for the measurement of productivity for construction activities (Yi & Chan, 2013). Thus, based on the simple input and output concept, labor productivity for construction operational activities is defined by:

Equation 14

$$\text{Labor Productivity} = \frac{\text{Installed quantity}}{\text{Actual work hours}} = \frac{\text{Output}}{\text{Work hour}}$$

2.1.3 Labor Productivity as Gauging Construction Process Efficiency

On the basis of construction activity, the unit of measurement may vary while measuring productivity at the project level. For example, Yi and Chan (2014) found the average production rate for pouring columns lower than that for pouring walls because of job characteristics. The labor productivity is a measure of work process efficiency, which is defined as the ratio of the value labor produced to the value invested in labor. Thus, the American Association of Cost Engineers (AACE) (2011) defines productivity as a "relative measure of labor efficiency, either good or bad, when compared to an established base or norm" (p. 27). Moreover, this relative measure creates great difficulty in tracing it as an absolute value over time, and there is a possibility of gathering information on the movements of the established base or benchmark values (Allmon et al., 2000). In an attempt to overcome such a condition, labor productivity is redefined as a ratio of actual over expected productivity.

According to Yi and Chan (2013) measuring productivity is challenging and the unit of measurement depends on the construction activity. For instance, concreting activity could be measured in concrete placed (m3/hours), while a structural steel placement activity could be measured in meters of steel placed (m/hour). Here is the labor productivity definition by project managers and construction professionals as below:

Equation 15

$$\text{Performance Ratio im} = \frac{Actual\ productivity\ im}{Expected\ productivity\ im}$$

Where;

i = workday under consideration;

and m = activity in project

The expected productivity is determined from the work-hours and quantities installed on days when no changes or rework, disruptions, or bad weather were reported. The performance ratio is a dimension-less measure that is determined by dividing actual productivity by baseline productivity. It defines a basis for comparing productivity data for different job types, eliminating the differences between production rate levels (Yi & Chan, 2013). The main feature of this approach is that the progress of work is based on the installed work, not the work hours consumed, and progress and performance can be determined regardless of the type of work performed.

In order to gauge construction process efficiency, benchmarking is necessary to compare observed value with the standard value (Bernold & AbouRizk, 2010). There are some process indicators to measure efficiency of construction operations.

Equation 16

$$\text{Efficiency of Direct Labor} = \frac{\text{Direct hours budgeted}}{\text{Direct real hours}}$$

Or

Equation 17

$$\text{Efficiency of Direct Labor} = \frac{\text{Budgeted cost direct hours}}{\text{Cost real direct hours}}$$

2.1.4 Productivity Benchmarking

Benchmarking is an important continuous improvement process that enables companies to enhance their performance by identifying, adapting, and implementing the best practice identified within a participating group of companies (CBPP, 2002; CII, 2002; (Knuf, 2000; Smith, 1997). It is generally defined as a systematic and continuous measuring process comparing the output of one organization to the output of another organization anywhere in the world to acquire information that will help the organization to take action to improve its performance (Bernold & AbouRizk, 2010; Idiake & Bala, 2012; A. V. Thomas &

Sudhakumar, 2013). In short, comparison and improvement are the keys behind the process of benchmarking for any topic.

According to H. R. Thomas (2012), the labor productivity benchmarking study can be conducted by using three key performance indicators–productivity variability, baseline productivity, and project waste index (PWI). Baseline productivity is generally calculated implementing Thomas's (1999) baseline productivity method. But, there are several methods to calculate baseline productivity, such as Thomas's Baseline Productivity Method (H. R. Thomas, Riley, & Sanvido, 1999), Measured Mile Analysis (Liu & Song, 2005; Zink, 1986), Control Chart Method (Gulezian & Samelian, 2003), Data Envelopment Analysis (DEA) Method (Huang et al., 2009), and K-Means Clustering Method (Liu & Song, 2005). Measured Mile Analysis gives "productivity factor" by comparing the cumulative actual work-hours with the earned work-hours. Considering baseline productivity as a norm level, a productivity control chart is developed with a center line and control limits, in which the center line value gives the arithmetic mean of the daily labor productivity and the control limits are represented by plotting with three standard deviations of the labor productivity population from the center line (Gulezian & Samelian, 2003).

Baseline productivity is considered as the best productivity when there are no or few disruptions that adversely affect labor productivity (Thomas, 2000). Thomas's baseline productivity is determined with respect to 10% of the total workdays that have the highest daily output or production, the number of days in the baseline set being not less than five (H. R. Thomas & Završki, 1999). Since this baseline productivity is subjective in nature, it cannot be verified that 10% of the whole daily productivity is a reasonable or well-accepted percentage to represent the best performance a contractor could achieve (Liu & Song, 2005). According to Liu and Song (2005): "Every project is different. This 10% sample is presumably 10% of the time that similar work is being performed, not 10% of the total project, which may consist of a series of quite dissimilar work categories. However, Thomas (2000) is unclear on this. This procedure selects contents of the baseline subset as n workdays that have the highest daily production or output. Daily output might be maximized by crew size. Therefore, certain days could be selected as the baseline, which are not truly indicative of the achieved productivity."

In order to overcome this weakness, Liu and Song (2005) presented K-Means Clustering Methods for baseline productivity calculation. Meanwhile, data envelopment analysis (DEA) was introduced by Lin and Huang (2009) for deriving baseline productivity, which compared with the other four baseline productivity deriving methods–measured mile baseline, Thomas baseline, control chart baseline, and K-means clustering. This DEA method was found to be the best method in terms of objectivity, effectiveness, and consistency to find baseline productivity that represents the best performance a contractor can possibly achieve. This DEA method was capable of deriving productivity of multi-input and multi-output activities, and able to raise the scale of labor productivity from the level of single factor productivity to total factor productivity.

Variability in productivity is a determinant of performance of a construction project. Poorly performing projects exhibit higher variability in productivity when compared to projects that perform well (A. V. Thomas & Sudhakumar, 2013). The project waste index (PWI) or the project management index (PMI) is a dimensionless measure of the amount of labor waste associated with an activity/project (A. V. Thomas & Sudhakumar, 2013). If the data are not affected by the work environment and are affected primarily by the work content or design complexity, the project parameter has limited usefulness unless it can be compared to similar parameters computed from other projects or other activities on the same project, which demands the condition for PMI (H. R. Thomas, 2000). A lower value of PWI indicates better performance of the project. The value of PMI should not be a negative.

Equation 18

$$\text{PMI} = \frac{\text{Cumulative productivity} - \text{baseline productivity}}{\text{baseline productivity}}$$

Where, cumulative productivity is defined as a ratio of combination of all the work hours charged to an activity to the total quantities installed to date. This approach predicts the final productivity rate upon completion of the activity and shows how the work is progressing as a whole (H. R. Thomas, 2000).

Equation 19

$$\text{Cumulative productivity} = \frac{\text{Total work hours charged to a task}}{\text{Total quantity installed}}$$

Meanwhile, the concept of measured mile is also applicable for a continuous period of time when the labor productivity is un-impacted, which compares the impacted period with the un-impacted periods if both have the same resources and are from the same project, but have different working conditions and are impacted due to the owner (H. R. Thomas, 2010).

Moreover, while considering a variety of work in a single workday by the crew, there can be problems in analyzing the performance (H. R. Thomas, 2000). For example, a concrete formwork crew works on wall formwork, column, and slab formwork simultaneously; a sheet metal crew erects several sizes of ducts plus louvers, dampers, and vents. During this condition, a weighted average approach is used to combine the quantities into an equivalent amount of one type or size unit (called the standard item).

Equation 20

$$\text{Conversion factor ij} = \frac{unit\ rate\ for\ the\ item\ in\ question\ ij}{unit\ rate\ of\ the\ standard\ item\ j}$$

Where, i is the item number and j is the manual number

2.1.5 Labor and Equipment Productivity Metrics

Metrics are essential terminologies while determining productivity benchmarking. Metrics are defined as standards of measurement to provide assessment of the measurement of efficiency, performance, progress, or quality of a plan, process, or product. Cost, schedule, safety, changes, and rework are performance metrics for construction activities (Park et al., 2005). The CII benchmarking research has revealed that construction performance has been impacted by best practice use (CII, 2002). Park et al. (2005) described the construction productivity metrics for seven categories, which are concrete, structural steel, electrical, piping, instrumentation, equipment, and insulation.

Moreover, labor and equipment productivity metrics are also key factors for the improvement of construction productivity. R.S. Means (2009) and the CII (2003) published task level metrics. Most task-level metrics are single factor measures and focus on labor productivity (Huang et al., 2009). Huang et al. (2009) stated that "CII fixes the output (e.g. cubic yards of concrete put in place) and measures the labor hours required to produce that output" (p. 32). If labor and equipment both come under productivity estimation, this measure is termed multifactor productivity.

There are many factors that affect construction labor productivity, such as mental fatigue, physical fatigue, stress fatigue, boredom, overtime, morale and attitude, stacking of trades, joint occupancy, beneficial occupancy, concurrent operations, absenteeism and turnover, mobilize/demobilize, errors and omissions, start/stop, reassignment of manpower, late crew build-up, crew size inefficiency, site access, logistics, security check, learning curve, ripple effect, confined space, hazardous work area, dilution of supervision, holidays, shorter daylight hours, weather and season changes, rain, shift work, working in operating area, over-manning, tool and equipment shortage, area practices, proximity of work, alternating, staggered, and rotating work schedules (Borcherding & Garner, 1981; Oglesby et al., 1989). The typical labor factors that affect labor productivity can be considered while developing labor productivity metrics. Thus, the labor productivity metrics are determined based on type of activity or task, output, and input functions.

There are key performance indicators (KPI) for overall labor effectiveness (OLE) that measures the utilization, performance, and quality of the workforce and its impact on productivity (Takim & Akintoye, 2002). It allows managers to make operational decisions by giving them the ability to analyze the cumulative effect of these three workforce factors on productivity output, while considering the impact of both direct and indirect labor. It supports lean and sigma methodologies and applies them to workforce processes, allowing managers to make labor-related activities more efficient, repeatable, and impactful.

However, there are not sufficient materials available to illustrate the labor productivity metrics because those metrics are identified and quantified based on project characteristics and requirements. For example, when the labor productivity is measured in terms of physical output for labor cost as an input parameter, the output per labor cost can be considered as one labor productivity metric. Similarly, if time is a major function during evaluation of labor productivity, then output per labor work-hour can be considered as another example of labor productivity metrics. Thus, number of laborers employed, labor working hours, and labor costs are the main elements of labor productivity metrics. In reality, labor and equipment generally come together during analysis of productivity of construction operations. But, there are differences in labor and equipment productivity metrics in the sense of understanding, which are discussed in the following section.

There are various factors that significantly influence equipment productivity. Based on these, equipment productivity metrics are designated. Vorster (2014) categorized construction equipment metrics into three broad groups, which are activity metrics, input metrics, and output metrics. For simplicity, the difference between labor and equipment productivity metrics can be discussed under these broad groups.

2.1.5.1 Activity metrics

These metrics are designated based on involvement of the equipment in the construction activity. Deployment, utilization, and net utilization of the equipment are three different sub metrics under this activity metric (Vorster, 2014). Deployment of equipment is defined as the percentage of time the machine is actually deployed on site and required to work relative to the total ownership period. Utilization of equipment is quantified by defining it as the percentage of time the machine is actually used relative to the time it is on site and able to work. Specifically, it is necessary to estimate the net utilization of equipment, which is defined as the percentage of time the machine is actually used relative to the time it is deployed on site.

Equation 21

$$\text{Deployment} = \frac{\text{Time a machine is on site and required to work}}{\text{The total ownership period}} = \frac{\text{T}}{\text{E}}$$

Utilization defined as the Percentage of time the machine is actually used relative to the time it is on site and able to work:

Equation 22

$$\text{Utilization} = \frac{\text{Time a machine is actually used}}{\text{Time a machine is required and able to work}} = \frac{\text{W}}{\text{T} - \text{D}}$$

Availability = Hrs capable of working / Target hours = (T- D) / T

Utilization = Hours Worked / Hrs capable of working = W /(T- D)

Where;

W: working time

T-D: Required and able to work

T: Target Deployment on Site

E: Ownership period

Labor productivity has a significant contribution in the activity or task level of work, generally in the labor-intensive construction operation. But, it is not suitable to present labor productivity metrics similar to deployment or utilization activity metrics for the equipment. However, it is possible to measure labor mobilization time to site or time utilized by labor in actual work completion.

2.1.5.2 Input metrics

Metrics, which are designated based on input provided to equipment, are called input metrics. These are sub classified into labor factor and repair cost. The labor factor is the ratio of repair and maintenance labor hours spent on the equipment to the hours worked by the equipment (Vorster, 2014). The repair cost is defined as the direct cost of repair parts and labor per hour worked by the equipment.

Let RMh be the repair and maintenance labor hours spent on the equipment, Rpl be the direct cost of repair parts and labor spent on the equipment in the period and W be the actual hours the equipment worked during the period. Then, labor factor and repair cost are quantified by using the following relations:

Equation 23

$$\text{Labor Factor} = \frac{\text{RMh}}{\text{W}}$$

Equation 24

$$\text{Repair cost} = \frac{\text{Rpl}}{\text{W}}$$

Meanwhile, the labor factor presented here for equipment input metrics is due to the involvement of labor in operating the equipment. Similarly, in labor productivity metrics, equipment factor can be considered. The labor cost may be another input metric or labor productivity metrics, which has a significant effect on labor productivity. The labor cost metric may be defined as the direct cost spent in labor for actual hours the labor worked.

2.1.5.3 Output metrics

These metrics are designated based on output given by the equipment, which are sub classified into availability, down ratio, and reliability (Vorster, 2014). The availability is defined as the percentage of time the equipment is able to work relative to time on site. The down ratio is defined as the ratio of the equipment's down duration per hour worked by the equipment. The frequency with which the equipment breaks down and disrupts production is termed as reliability. The loss in availability may be due to setup time and breakdown of equipment.

Let T be time the equipment is on site and required to work, D be the time the equipment is down and incapable of working when it is required to work, W be the actual hours the equipment worked during the period, and V be the number of times a machine breaks down and disrupts production. Then, these metrics are quantified by the following relations:

Equation 25

$$\text{Availability} = \frac{\text{T} - \text{D}}{\text{T}}$$

Equation 26

$$\text{Down ratio} = \frac{\text{D}}{\text{W}}$$

Equation 27

$$\text{Reliablity} = \frac{\text{V x 100}}{\text{W}}$$

Similar to equipment availability, the labor availability hours metric may be defined as the ratio of actual time spent to contributory work (total time – time spent in non-contributory work) to the total time. Other equipment metrics are not suitable in the context of labor productivity metrics. However, the time spent in labor rest may be synonymous to the time the equipment is down.

The performance rate is the quantity produced during the running time versus the potential quantity given the designed speed of the equipment. A low performance rate reflects speed losses, such as idling, minor stoppages, and reduced speed operation. In the context of labor productivity metrics, the performance rate may be simply defined as the actual output achieved for labor hours input.

Equation 28

$$\text{Performance Rate} = \frac{\text{Total Output}}{\text{Potential Output at Rated Speed}}$$

2.2 Identification of Factors Affecting Construction Labor Productivity

Several researchers are enthusiastic in the context of labor productivity. Due to the importance and vital role of labor in project enhancement, numerous studies have been done in various countries. R. Horner and Talhouni (1993) identified that the most significant perceived factors influencing labor productivity in the UK are; Skill of labor, Build-ability, Quality of supervision and Method of working. Lim and Alum (1995) discovered seventeen issues that could affect construction productivity, and the greatest concerns are namely; Difficulty in recruitment supervisors, Difficulty in recruiting workers because of a high rate of labor turnover, absenteeism at work site, communication problems with foreign workers and inclement weather that requires work stoppage for one day or more. Dai, Goodrum, and Maloney (2007) conducted a survey and identified eighty-three factors in the United States, and the most significant factors are as follows; Supervisor direction; Communication; Safety; Tools and consumables; and Materials. Durdyev and Mbachu (2011), discovered that internal constraints have a much higher impact on onsite productivity than the external factors. The internal constraints included: reworks level of skill and experience of the workforce, adequacy of method of construction; build-ability issues and inadequate supervision and coordination. Dai et al. (2007) identified several factors affecting labor productivity and it has been discovered through the principal factor analysis that ten latent variables have a negative impact on productivity in the following descending order; Construction Equipment, Materials, Tools and Consumables, Engineering Drawing Management, Direction and Coordination, Project Management, Training, Craft Worker Qualification, Superintendent Competency, and Foreman Competency.

Subsequently, the studies concerning labor productivity performed in some developing countries are being compared to construction productivity problems with developed countries. Kaming, Olomolaiye, Holt, and Harris (1997b) realized that factors affecting the productivity of craftsmen in Indonesia comprise; lack of materials, rework, absenteeism of operatives, and lack of suitable tools. Besides, Alwi (2003) further allocated the key factors impinging upon construction productivity in Indonesia into the following categories: (1)

Characteristics of contractors; (2) Inadequate management strategy; (3) Organization's focus. Makulsawatudom, Emsley, and Sinthawanarong (2004) identified five factors among twenty-three factors as the most critical factors, namely in Thailand; Lack of materials, Rework, Absenteeism of operatives, Lack of suitable tools and equipment and Crew interference. Abdul Kadir, Lee, Jaafar, Sapuan, and Ali (2005) discovered fifty productivity factors on Malaysian residential projects and five of the most significant factors were; Shortage of material; Non-payment to suppliers causing stoppage of materials delivery to sites; Change orders by consultants; late issuance of construction drawings by consultants; and the incapability of site management. In Uganda, Alinaitwe, Mwakali, and Hansson (2007) ranked the following five factors as being the most significant: Incompetent supervisors; Lack of skills; Rework; Lack of tools/equipment; and Poor construction methods.

In addition, some researchers in Middle Eastern countries performed studies regarding labor productivity in order to evaluate the factors affecting labor productivity. Enshassi, Mohamed, Mustafa, and Mayer (2007), identified forty-five factors affecting labor productivity within building projects in the Gaza Strip. The main factors negatively affecting labor productivity were: Material shortage, Lack of labor experience, Lack of labor surveillance, Misunderstandings between labor and superintendent, and Alteration of drawings and specifications during execution. Abdulaziz M. Jarkas and Bitar (2012) found that the most effective factors out of forty-five discovered factors were: Clarity of technical specifications, extent of variation/change orders during execution, coordination level among various design disciplines, lack of labor supervision and proportion of work subcontracted. According to El-Gohary and Aziz (2013) the most significant factors in regards to the effects on construction labor productivity in Egypt comprised of: labor experience and skills; incentive programs; availability of the material and ease of handling; leadership and competency of construction management; and competency of labor supervision. Mahmood Zakeri, Olomolaiye, Holt, and Harris (1996) using the relative index ranking technique, ranked the following five factors as major determinants of Iranian operatives' efficiency: Materials shortage; Weather and site conditions; Equipment breakdown; Drawing deficiencies/change orders; and Lack of proper tools and equipment. M Zakeri, Olomolaiye, Holt, and Harris (1997), identified five of the most important motivation factors of Iranian construction operatives, namely; fairness of pay, Incentive and financial rewards, on-time payment, good working facilities, and safety. Ghoddousi and Hosseini (2012) determined and explored the most critical grounds affecting sub-contractors productivity in descending order as; Materials/Tools, Construction technology and method, Planning, Supervision system, Reworks, Weather, and Jobsite condition. The potential factors affecting labor productivity from previous studies have been summarized in the Table 2.1. Table 2.2 shows a summary identified factors affecting labor productivity from the previous studies in developed and developing countries, based on the level of importance ranking.

Table 2.1 Factors affecting labor productivity with descriptions

No.	Factors	Description
1	Age	Age is considered as one of the workers personal characteristics (Mahmood Zakeri et al., 1996)
2	Lack of experience	craftsmen's experience influences construction labor productivity (Paulson Jr, 1975)
3	Disloyalty	Disloyalty defines as "The quality of not being loyal to a person, country, or organization; unfaithfulness" (Dictionary, 2014).
4	Drug Addiction or Alcoholism	Gavioli (2014) investigated the risks related to the drug usage among construction workers and declared that the drug causes illness, work-related injuries, absenteeism and disability and the contribution of all will decrease worker productivity. According to SAMHSA (1999), substance abuse, including drug and alcohol, is pretty high in construction industry. Approximately one third of the construction gangs use illegal drugs (Cook, Hersch, & McPherson, 1999; Neptin, 2005)
5	Absenteeism	Labor productivity can be negatively affected by absenteeism (R. Horner, Talhouni, & Whitehead, 1987). Frankel (1921) considered it as " quit without notice".
6	Misunderstanding Labors	Multiple meanings or references of words and expressions contribute to the misunderstanding; it is due to "referential indeterminacy" or in some cases "vagueness of categorization" (Schane, 2002).
7	Rework	Rework is one of the significant factors which directly contributes to cost and time overrun (Hwang, Thomas, Haas, & Caldas, 2009). Changes and errors are the main causes of rework in construction projects (Love, Holt, Shen, Li, & Irani, 2002).
8	Control Delays	Assaf & Al-Hejji (2006) defined delay as; "time overrun either beyond completion date specified in a contract, or beyond the date that the parties agreed upon for delivery of a project".

9	Incomplete drawing	"incomplete drawing" and "late issuance of instruction" is prevalent causes of delay relating to architect, structural engineer, and services engineer.
10	Payment delay	Implementation and performance of any project can be strongly influenced by payment delay or nonpayment (Enshassi & Abuhamra).
11	Disputes with the owners	Contractual obligations disputes and disagreements can be occurred due to the complexity of construction contracts (Semple, Hartman, & Jergeas, 1994). Unpredictability and misunderstandings are the two major category of disputes and claims (Sykes, 1996).
12	Poor site condition	Poor site condition or poor site layout can reduce construction labor productivity, such as; walking long away to lunch rooms, tool cribs, laydown areas, washrooms, entrances and exits, etc. (McDonald & Zack, 2004)
13	Lack of required material	Lack of an effective material management can cause adverse condition which contributes to loss of productivity (H. R. Thomas, Sanvido, & Sanders, 1989).
14	Lack of required tool/ equipment	Labors productivity may suffer due to; unavailable construction tools or equipment, wrong tools and improper equipment size (McDonald & Zack, 2004).
15	Inadequate construction methods	The selected methods by contractors are called "Construction methods", for instance; scaffolding techniques, concurrent block and brickwork construction and material staging methods (Sanders & Thomas, 1991).
16	Shortage of water supply	Lim and Alum (1995) investigated the disruption of water supply as one of the productivity issues facing by contractors.
17	Working overtime	Long-term consequences of scheduled overtime performance can be detrimental (H. R. Thomas, 1992).
18	Weather conditions	Construction activity performance below -23° and above 43 ° considered as the extreme weather condition. For example, Thomas et al. (1999) studied about different delivery methods in steel structure erection projects and identified that snow and cold temperature caused loss of productivity.
19	Accidents construction	Construction accidents arise due to: " lack of knowledge or training" " lack of supervision" " lack of means to carry out the task safely" " error of judgment, carelessness, apathy or downright reckless" " short term and transitory nature of the construction industry" " lack of a controlled working environment"

		" the complexity and diversity of the size of organizations" (Sawacha, Naoum, & Fong, 1999).
20	Ambiguity of Project objective	defined as: "absence of knowledge about functional variables" or "a lack of awareness of the project team about certain states of the world or causal relationship" (Schrader, Riggs, & Smith, 1993); " Information inadequacy" (Pich, Loch, & Meyer, 2002).

Productivity usually refers to the product of several related elements. Following discussion refers to the affecting factors related to the productivity issues that have been extracted from the previous studies.

When we are focusing on the construction projects, several factors may have negative effects on the productivity. By reviewing a number of studies that have been done before, we can see that overtime working usually has negative effect on the productivity of construction projects. Items which have been more focused are tiredness; lots of absence; not having good morale; not having effective supervision on the workers' practices; not having good working instructions, having high amount of work; having several accidents during the work (R. Horner & Talhouni, 1993). By having high amount of work, we may have better output, but if we continue this procedure, our costs will be increased and our productivity would be decreased (Hinze, 2011). Usually the allocated time for construction workers on creative doings has the averages of 30% out of the total project time. Usually different workers have 3.5 hours of effective work out of the total 8 hours and 20% of their time would be spent on the unrelated events to their work (Alinaitwe et al., 2007).

While different delays happen during the project implementation, workers would have different pressures in order to finish their tasks on time and based on the identified schedule. Based on the specialized scheduling viewpoint, by using schedule we can force different workers to avoid any delay in the work and they have to prepare the work on time. Though, in several projects, timetables are not completely supply loaded. As a result, a completely efficient timetable shows the delays of the and whether they can finish it on time or not. Schedule density may end to force additional efforts for the anticipated job by the worker due to limitation of the general period, letting the contractor for completing the entire lasting effort. Schedule density, when related with intensely, often causes better output fatalities because of lacks of substantial equipment or tools to provide the additional work's, resultant in problematic for preparation and organizing the job, and unobtainability of knowledgeable works (National Electrical Contractors Association, 1983).

For doing the work well, all of the construction workers should have enough space to complete his work without any problem. When different workers try to do a task in the same place, different interferences would happen and they cannot do their task well and as a result amount of productivity decreases significantly. Furthermore, when different people with different obligations are forced to work on the same place, interferences would be increased that results in lower productivity. Interference in majority of cases happens due to the bad managements of the supervisors in different buildings. As an example, a steel-fixture worker has to wait for setting the strengthening bars when the carpenter’s outline is not complete. Different activity types and also construction approaches also affect work output (Sanders & Thomas, 1991).

Different accidents usually have negative effects on the productivity rate of the construction sites. Several types of accidents may happen at the construction sites, like accidents that lead to death and ensuing in an entire work strike. If during the accident, person should be moved to the hospital and injured badly decrease the amount of productivity to a high extent. Small accidents that happen because of pins and steel ropes usually affects working procedure. And therefore decreases amount of productivity (Sanders & Thomas, 1991). In some cases when we have not enough lighting, decreased productivity rate would be decreased, as enough lighting is usually needed for doing efficient works. Usually by using several safety officers we can identify the essential protection rules and it is necessary for the workers to follow them to decrees amount of accidents and also increase productivity in the construction sites.

Using inefficient tools which usually have quality of the used components considered as effective factors for reducing the productivity. The productivity rate of inefficient equipment is low. Old equipment is subject to a great number of breakdowns, and it takes a long time for the laborers to complete the work, thus reducing productivity. Poor-quality material used for work is the other factor because poor materials generally lead to unsatisfactory work and can be rejected by supervisors, thus reducing the productivity.

Managers’ skill and attitudes have a crucial bearing on productivity. In many organizations, productivity is low even though the latest technology and trained manpower are made available. Low productivity is because of inefficient and indifferent management.

Experienced and committed managers can obtain surprising results from average people. Employees' job performance depends on their ability and willingness to work. Management is the catalyst to create both. Advanced technology requires knowledgeable laborers who, in turn, work productively under professionally qualified managers. It is only through sound management that optimum utilization of human and technical resources can be secured.

Literature shows that a lack of labor experience is the factor which negatively affects labor productivity and proves that, to achieve good productivity, labor plays a significant role. Contractors should have sufficiently skilled laborers employed to be productive. If skilled labor is unavailable and a contractor is required to complete specific task with less-skilled labor, it is possible that productivity will be affected. The absence of any crew member may impact the crew's production rate because workers will, typically, be unable to accomplish the same production rate with fewer resources and with different crew members. There are different misconceptions about the workers that usually make differences regarding the tasks and the work boundaries of each worker. It usually leads to different problems and reduces labor productivity very much. Accordingly absence of recompense and age of the workers that have been increase significantly negatively affect productivity of the labor due to the labor quickness, liveliness, and being on time (Jay & Render, 1993).

Motivation considered as one of the most important elements that can affect productivity rate of the construction activities. In the motivation concept, it is very important that personal labor goals should be in line with the company goals. Different factors in the companies can affect motivation of the workers in the company such as: absence of a monetary motivation scheme, non-provision of good transport, and absence of exercise meetings (DeCenzo & Holoviak, 1990).

Mainly several projects have different types of designs, special types of drawings and arrangement modifications during production. If wrong specifications would be applied the rate of productivity would be relatively low, as the construction workers are not aware of what they exactly want to do. Consequently, contractors would have delay for performing the relate tasks and they would be forced to postpone it until better performance. When work changes happen, usually 30% of loss happens regarding the productivity of the construction (H. R. Thomas et al., 1999). One of the most important processes regarding the construction activities refers to the inspections of the work by the supervisors. As an example, the contractor cannot cast concrete before doing different kinds of examinations regarding the formwork and also steel work, so inspection affects the productivity in this issue to a high extent (Mahmood Zakeri et al., 1996). When the required work has not been completed due to the special drawing and also specifications and drawings, supervisors should ask the workers to redo the task. In some activities when the supervisor is not present to do his related tasks, the working procedure may be interrupted totally like concrete casting and backfilling. On the other hand, by having delay in the inspection procedure, starting the new work would be delayed too.

It is very important in the construction industry to do material management completely. When we do not have necessary resources, equipment's, or construction tools for the construction activities, the productivity of the project can be affected to a high extent. Selection of the appropriate type and size of construction equipment often affects the required amount time the project, so, it is vital for site executives to be aware of the features of the main kinds of tools that are usually used in the construction sites. For increasing the productivity rate of the construction sites, it is favorable to choose tools with the good features and their dimensions most appropriate regarding the work circumstances at a structure place. Usually workers need minimum amount of equipment to work efficiently for completing the allocated job. By providing imperfect tools, the productivity rate may be affected negatively (Lim & Alum, 1995; Yates & Guhathakurta, 1993). Usually both size and materials of the construction sites has significant effect on the construction productivity as workers usually need additional time to transfer vital resources from unsuitable storage positions and therefore it leads to the productivity loss (Sanders & Thomas, 1991).

When the working schedule is not good and there are some limitations regarding the serious construction tool or work, the productivity rate would be decreased dramatically. According to the Association for the Advancement of Cost Engineering (AACE), Inappropriate preparation of project-initiation processes usually causes low amount of work productivity. Moreover, poor site plan would result to affect productivity procedure. In these situations, workers have to walk or even drive a lengthy distance to lunch places, rest parts, toilets, arrivals, and departures, which affect productivity negatively (McDonald & Zack, 2004).

Different natural elements that affect construction productivity, according to the related literature are weather circumstances of the job-site and also geographic circumstances. We can name other affecting factors on the productivity such as: as petroleum, water, and raw materials. In bad weather conditions like extremely warm conditions, productivity rate can be affected to a high extent.

For completing different construction sites we have to pay attention to the weather condition in which construction activity takes place. During the when we have strong winds and heavy rains; amount of productivity reduces, mainly regarding outdoor activities like formwork, T-shape task, concrete casting, outside coating, exterior painting, and outside tiling. Sometimes this weather condition affects the work significantly (Sanders & Thomas, 1991).

Political Factors: Rule and instruction, stability of government, etc. are vital regarding good productivity in the construction manufacturing. When governments consider several taxes for the construction related activities, it would affect willingness of the workers to work and development of plants (Kumar, 2004).

Table 2.2 Identified factors from the previous studies based on the level of importance ranking

Country	U.S	New Zealand	Malaysia	Gaza strip	Kuwait	Uganda	Egypt	Thailand	Singapore	Iran	U.K	Indonesia
Ref	(Dai et al., 2007)	(Durdyev & Mbachu, 2011)	(Abdul Kadir et al., 2005)	(Enshassi et al., 2007)	(Abdulaziz M Jarkas & Bitar, 2011)	(Alinaitwe et al., 2007)	(El-Gohary & Aziz, 2013)	(Makulsawatudom et al., 2004)	(Lim & Alum, 1995)	(Mahmood Zakeri et al., 1996)	(R. Horner & Talhouni, 1993)	(Kaming et al., 1997b) (Kaming & Olomolaiy)
Total factors	83	56	50	45	45	36	30	23	17	13	13	11
Rank												
1	Construction equipment	Rework	Material shortage at site	Material shortages	Clarity of technical specifications	Incompetent supervisors	Laborer experience and skill	Lack of material	Difficulty in recruitment supervisors	Lack of materials	Skill of labor	Lack of material
2	Engineering drawing management	level of skills and experience of the workforce	Non-payment (financial problem) to suppliers causing the stoppage of material delivery to site	Lack of labor experience	The extent of variation/ change orders during execution	Lack of skills of the workers	Incentive programs	Incomplete drawing	difficulty in recruiting workers	weather and site conditions	Build-ability	Lack of tools
3	Tools and consumables	adequacy of method of construction	Change order by consultants causing project delay	Lack of labor surveillance	Coordination level among design disciplines	Rework	Availability of materials and their ease of handling	Incomplete supervisors	high rate of labor turnover	equipment breakdown	quality of supervision	Equipment breakdown

Country	U.S	New Zealand	Malaysia	Gaza strip	Kuwait	Uganda	Egypt	Thailand	Singapore	Iran	U.K	Indonesia
4	Materi als	Build-ability issues	Late issuance of constructio n drawing by consultants	Misunderst anding between labor and superintend ents	Design complexi ty level	Lack of tools/equi pment	Leadershi p and competen cy of constructi on managem ent	Lack of tools and equipment	absenteeis m at work site	drawin g deficie ncies/c hange orders	method of working	Rework
5	lack of moneta ry incenti ve, (to foreme n)	issues around coordinat ion, supervisi on and performa nce monitorin g and control	Incapability of contractor's site managemen t to organize site activities	Drawings and specificatio ns alteration during execution	Stringent inspectio n by the Engineer	Poor constructi on method	Compete ncy of labor supervisi on	Absenteeis m	communica tion problems with foreign workers	lack of proper tools and equipm ent	incentive scheme	Changing of workers
6	lack of motivat ion of young worker s (to foreme n)	Resource Manage ment Act	Late issuance of progress payment by client to contractor	Payment delay	Delay in respondin g to requests for informati on (RFI)	Poor communi cation	Construct ion technolog y (construc tion method and material)	Poor communica tion	inclement weather that requires work stoppage	Inspect ion delay	site layout	Interference
7	Absent eeism(t o foreme n)	Ground condition s	Late supply of materials in the market	Labor disloyalty	Compatib ility and consisten cy among contract document s	Stoppage s because of work being rejected by consultan ts	Labor operating system (daily wage, lump sum)	Instruction time	Health issues	Absent eeism	complexi ty of constructi on informati on	Absenteeism

CHAPTER 3

Chapter 3 : STATISTICAL ANALYSIS APPROACH

3.1 Mean Score

Form the literature review, several factors affecting labor productivity extracted from the previous studies. An initial questionnaire prepared based on the factors retrieved from the previous study (Table2). A Pilot study conducted; seven experts, who have more than 10 years' experience in Iran construction industry, were interviewed and requested to express their opinion about the questionnaire whether it is qualified enough for surveying or not. The experts omitted some irrelevant factors in Iran construction, and added some factors in order to upgrade the questionnaire survey. Alternatively, the revised questionnaire with 33 potential factors was distributed to the construction project managers in Iran who have more than 5 years' experience in construction projects in Iran. The participants were asked to assess the factors, based on the five-point Likert-scale, from 1 (not applicable) to 5 (extremely effective). Out of 200 questionnaires, 157 questionnaires were fully completed and returned. The Invalid collected data were removed from the data set. Consequently, the valid collected data set analyzed by IBM Statistics 20 (SPSS).

First of all, Crobach's Alpha test had been done to determine the internal consistency of items in the survey to measure its reliability. The α is 0.898 which is $0.8 \leq \alpha < 0.9$ and according to Field (2009) the reliability is good and it means that the test is 89% reliable (Table 3.1).

Table 3.1 Analyzing the reliability of the questionnaire

Reliability Statistics	
Cronbach's Alpha	N of Items
.898	33

After checking the reliability of questionnaire, the Mean Index for each factors were calculated by software. Basically, the Mean index (average Index) is calculated based on equation as follow:

Equation 29

$$\text{Mean Index} = \frac{\sum a_i x_i}{\sum x_i}$$

Where;

$a_i =$ constant expressing the weight given to i

$x_i =$ the frequency of response for i = 1,2,3

According to Majid and McCaffer (1997) the factors with more than 3.5 mean index are considered as the “High or very effective” rating group. Therefore, the factors with less than 3.5 score average mean index should be removed from the potential factors list, based on the appropriate classification of rating, shown on the Table 3.2. Hence, the factors less than 3.5 omitted and then data analysis proceeded with 20 factors.

Table 3.3 shows the potential factors affecting construction labor productivity in Iran, including each factor’s mean score, which is listed in descending order.

Table 3.2 Appropriate classification of the rating

Rating	Rating Scale	Classification
1	Very low or extremely in effective	1.00≤Average Index score<1.5
2	Low or ineffective	1.50≤Average Index score<2.50
3	Medium or moderately in effective	2.50≤Average Index score<3.50
4	High or very effective	3.50≤Average Index score<4.50
5	Very high or extremely effective	4.50≤Average Index score<5.00

Table 3.3 Potential factors affecting construction labor productivity, with Mean Scores in Descending Order

no.	Factors	Mean
1	Lack of required tools equipment	4.03
2	Lack of experience	4.01
3	Drug Addiction or Alcoholism	4.00
4	Absenteeism	3.87
5	Payment delay	3.86
6	Lack of required material	3.85
7	Misunderstanding between the owner, the contractor and the workers	3.78
8	Disputes with the owners	3.74
9	Poor site condition	3.72
10	Shortage of water supply	3.69
11	Accidents construction	3.68
12	Age	3.67
13	Ambiguity of Project objective	3.66

14	Weather conditions	3.61
15	Inadequate construction methods	3.56
16	Quality of required work	3.56
17	Rework	3.55
18	Misunderstanding Labors	3.54
19	Incomplete drawing	3.53
20	Control Delays	3.52
21	Working overtime	3.48
22	Inspection Delays	3.47
23	Insufficient lighting	3.46
24	Design changes	3.43
25	Variation Drawing	3.41
26	Inadequate transportation facilities	3.40
27	Change order from owners	3.38
28	Personal Problems	3.36
29	Differing site condition from plan	3.35
30	Change order from the designers	3.34
31	Poor access	3.34
32	Lack of competition	3.27
33	Disloyalty	2.90

3.2 Exploratory Factor Analysis (EFA)

3.2.1 Introduction

Factor analysis is a class of multivariate procedures which aim to identify the underlying structure in a data matrix (Hair, Anderson, Babin, & Black, 2010) and they also aim to reduce the number of variables and detect the structure in the relationships between variables to classify them.

According to Conway and Huffcutt (2003) EFA as an exploratory method has advantages of generating theories, and arriving at a more parsimonious understanding of a set of measurement items (Fabrigar, Wegener, MacCallum, & Strahan, 1999).Therefore, Factor Analysis is performed to analyze the latent relationship between the large numbers of success factors.

3.2.2 EFA analysis

As mentioned in chapter 2 (2.3), the factors with less than 3.5 score average mean index were removed from the potential factors list. Therefore, the Exploratory Factor Analysis was conducted with twenty factors.

The KMO and Bartlett's test attempted to check whether the factor analysis is applicable or not. The KMO measure was 0.824 which should be higher than 0.6 and Bartlett's test was less than 0.05 and thus, extremely significant (

Table 3.4). Therefore, the variables have a correlation and EFA is quite applicable.

Table 3.4 KMO and Bartlett's test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.824
Bartlett's Test of Sphericity	Approx. Chi-Square	915.748
	df	190
	Sig.	.000

In the following steps of factor analysis, the Principal Component Method of extraction and the Varimax method of rotation have been applied in this study. Table 3.5 shows the total variance explained. From the Table 3.5 , it is considerable that six extracted factors have Eigenvalues greater than 1.00 and these six components, by 61.56% variance, could be represented of 61.56 percent of data. Table 3.6 is rotated component matrix and shows the factor loading for each variable.

Table 3.5 Total Variance Explained

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.520	27.598	27.598	5.520	27.598	27.598	2.430	12.150	12.150
2	2.009	10.046	37.644	2.009	10.046	37.644	2.139	10.694	22.844
3	1.461	7.304	44.949	1.461	7.304	44.949	2.122	10.609	33.453
4	1.145	5.724	50.672	1.145	5.724	50.672	2.097	10.484	43.938
5	1.107	5.535	56.208	1.107	5.535	56.208	2.076	10.378	54.315
6	1.070	5.352	61.560	1.070	5.352	61.560	1.449	7.244	61.560

Table 3.6 Rotated component matrix

Rotated Component Matrix						
	Component					
	1	2	3	4	5	6
Lack of required tools and/or equipment	.711					
Inadequate construction method	.625					
Weather conditions	.624					
Shortage of water and/or power supply	.606					
Age		.708				
Lack of experience		.707				
Drug Addiction		.691				
Absenteeism		.605				
Rework			.743			
Incomplete drawings			.736			
Control delays			.712			
Payment delays				.710		
Poor site conditions				.676		
Misunderstanding between the owner, the contractor and the workers				.525		
Accidents during construction					.725	
Ambiguity of Project objective					.639	
Disputes with the owners					.587	
Misunderstanding between labors						.842

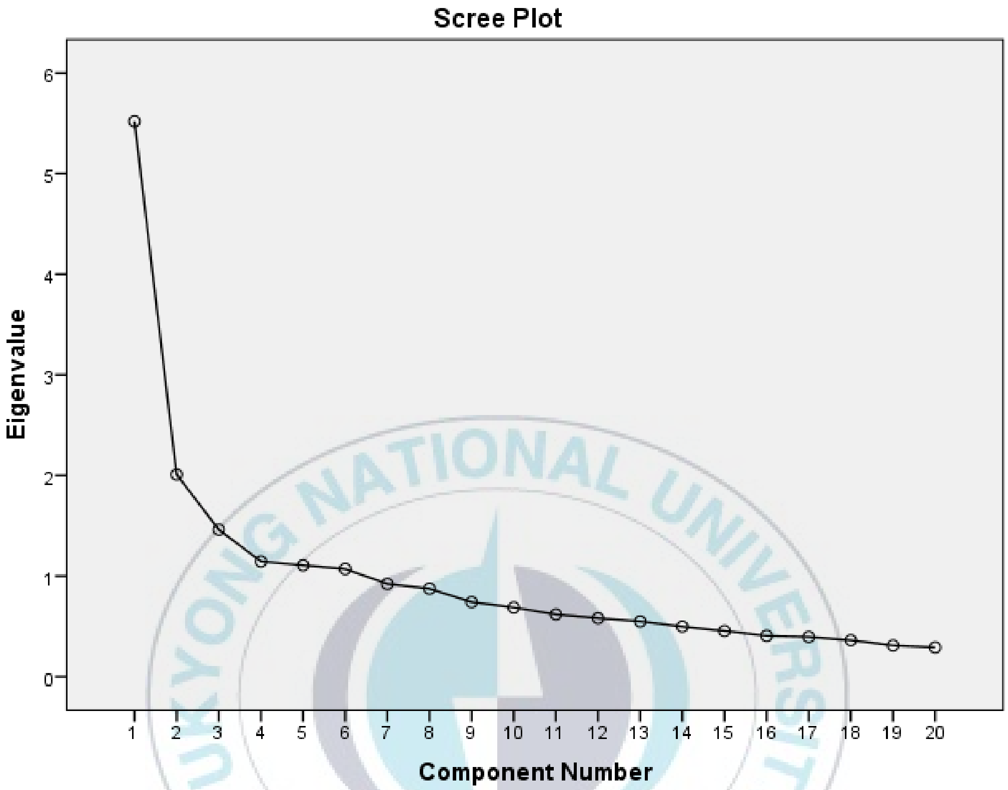

Figure 3-1 Scree Plot

Figure 3-1shows the scree plot. The scree plot displays the eigenvalues associated with a component or factor in descending order versus the number of the component or factor. Scree plot in principal component analysis and factor analysis to visually assess with components or factors explain most of the variability in the data.

3.2.3 EFA Results

From the factor analysis outcomes, the identified factors categorized in six major components. These six factor groups (components) will be specified as the major category with particular names, which will be analyzed by other different analysis methods in the following chapters. These methods will be described precisely in the next chapters.

3.3 Confirmatory Factor Analysis (CFA)

3.3.1 Introduction

In the Structural Equation Modeling, the first step is the measurement model validating and the second step is the assumed structural model testing. Confirmatory Factor Analysis (CFA) is a pure measurement model containing un-gauged covariance between each of the possible latent variable pairs. Hence, the CFA was conducted as a measurement model, and also to confirm the factor structure extracted in the EFA. According to Hair (2010), a single variable should be removed from the Structural Equation Model. Therefore, a single factor, namely "Misunderstanding between Labors," was removed from the sub-structural equation model (Figure 3-2). The modified measurement model is shown in Figure 3-3 .

3.3.2 CFA Analysis

3.3.2.1 Internal Consistency

The Internal Consistency of all latent variables is determined by Crobach's Alpha (α), before the initiation of CFA analyzes. Consequently, the Crobach's Alpha (α) calculated for Tools & Equipment, Labor Characteristics, Management, Delay, and Safety & Communication is shown in Table 3.7.

Cronbach's Alpha with a value of more than 0.7 is considered as "acceptable" and the range from 0.6 to 0.7 is "questionable"; most of the values here are almost close to 0.7 or more than 0.7, and according to Loewenthal (2001) Cronbach's Alpha from 0.6 and 0.7 it is not hopeless.

Table 3.7 Crobach's Alpha (α) of each latent variable

Latent Variables	Crobach's Alpha (α)
Tools & Equipment	0.686
Labor Characteristics	0.621
Management	0.685
Delay	0.657
Safety & Communication	0.741

3.3.2.2 Discriminant validity:

One of the limitations of factor analysis is how to name the factors and it may be challenging. Factor names may not precisely reflect the variables within the factor, or "Split loading" which is known for interpretation difficulties of some variables, because they may load to more than one factor (Yong & Pearce, 2013). These variables might be correlated with others to make a factor in spite of having underlying meaning to the factor (Tabchnick & Fidell, 2006).

Discriminant validity discovers which factors are distinct and uncorrelated. In other words, variables should relate more strongly to their own factor than to another factor. One of the methods to examine discriminant validity is the Factor Correlation Matrix. Hence, the Factor Correlation Matrix is applied by Principal Axis Factoring for the extraction method and Promax is applied for the Rotation method. Promax is normally applicable when researchers are not certain. Correlations between factors should not exceed 0.7, and if it is greater than 0.7 it will indicate a majority of shared variance (Gaskin, 2012). As it is shown in **Table 3.8**, there is no correlation greater than 0.7 which suggests that the factors are not correlated and they are valid.

Table 3.8 Factor Correlation Matrix

Factor	1	2	3	4	5	6
1	1.000	.430	.170	.541	.427	.208
2	.430	1.000	.410	.287	.508	.307
3	.170	.410	1.000	.326	.398	.444
4	.541	.287	.326	1.000	.382	.232
5	.427	.508	.398	.382	1.000	.327
6	.208	.307	.444	.232	.327	1.000

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

In order to improve the model fit; first, variables which had standardized regression weights of less than 0.5 were removed. Those variables are namely "Absenteeism" (abs) and "Disputes with the owners" (dwo) which were eliminated from Sub-structural equation modeling in Figure 3-2 and modified into Figure 3-3. The second step for improving model fit is adjusting the covariance (Modification indices). To this aim, an appropriate goodness-of-fit index of structural equation modeling is used to confirm the model fit. Finally, the satisfactory structural model is identified and assessed by Modification indices. Model fit indicators are comprised of: p value, relative chi-square ($\chi 2/df$), Goodness of Fit Index (GFI), Incremental Fit Index (IFI), Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA) and Tucker-Lewis coefficient (TLI). The criterion values of goodness-of-fit and goodness-of-fit indices are shown and compared in Table 3.10. Model fit indicators are shown as the following formulas below (Bentler, 1990; Bentler & Bonett, 1980; Bentler & Raykov, 2000; Bollen, 1989; Brown & Cudeck, 1993; Hu & Bentler, 1999; James, 2011; Jöreskog & Sörbom, 1984; Tanaka & Huba, 1985):

Likelihood Ratio X2 Chi-squared Test (baseline VS saturated models):

Equation 30

$$\mathrm{Xbs}^2 = 2\{\log \mathrm{Ls} - \log \mathrm{Lb}\}$$

Likelihood Ratio X2 Chi-squared Test (specified VS saturated models):

Equation 31

$$\mathrm{Xms}^2 = 2\{\log \mathrm{Ls} - \log \mathrm{Lm}\}$$

Where; Lb: Log Likelihood for the baseline model

Ls: Log Likelihood for the saturated model

Lm: Log Likelihood for the specified model

dfbs= dfs-dfb

dfms=dfs-dfm

Equation 32

$$\mathrm{CFI} = 1 - \frac{\mathrm{Xms}^2 - \mathrm{dfms}}{\mathrm{Xbs}^2 - \mathrm{dfbs}}$$

Equation 33

$$\mathrm{RMSEA} = \sqrt{\frac{(\mathrm{Xms}^2 - \mathrm{dfms})}{(\mathrm{N}-1)\mathrm{dfms}}}$$

Equation 34

$$\mathrm{TLI} = \frac{\left(\frac{\mathrm{Xbs}^2}{\mathrm{dfbs}}\right) - \left(\frac{\mathrm{Xms}^2}{\mathrm{dfbs}}\right)}{\left(\frac{\mathrm{Xbs}^2}{\mathrm{dfbs}}\right) - 1}$$

Equation 35

$$\mathrm{IFI} = \Delta 2 = \frac{\hat{\mathrm{C}}\mathrm{b} - \hat{\mathrm{C}}}{\hat{\mathrm{C}}\mathrm{b} - \mathrm{d}}$$

Where; $\hat{C}$ and d: discrepancy and the degrees of freedom for the model being evaluated

$\hat{C}b$ and db: discrepancy and the degrees of freedom for the baseline model

Equation 36

$$\mathrm{GFI} = 1 - \frac{F\hat{}}{F\hat{}b}$$

F$\hat{}$: minimum value of the discrepancy function

F$\hat{}$b: evaluating F with ∑(g)=0, g=1,2,…,G

In this study, CFA model designed and analyzed in AMOS (version 22) software. All variables' names, in the AMOS software, were inserted as the abbreviation form, due to avoid the software errors. Therefore, variables are coded as the abbreviation form as shown in Table 3.9.

Table 3.9 Variables Abbreviation Coding in CFA

No.	Variable name	Abbreviation code
1	Lack of required tools and/or equipment	lrtle
2	Inadequate construction method	icm
3	Weather conditions	ec
4	Shortage of water and/or power supply	sws
5	Age	age
6	Lack of experience	loe
7	Drug Addiction	da
8	Absenteeism	abs
9	Rework	re
10	Incomplete drawings	id
11	Control delays	cd

No.	Variable name	Abbreviation code
12	Payment delays	pd
13	Poor site conditions	ps
14	Misunderstanding between the owner, the contractor and the workers	mbocl
15	Accidents during construction	adc
16	Ambiguity of Project objective	aop
17	Disputes with the owners	dwo

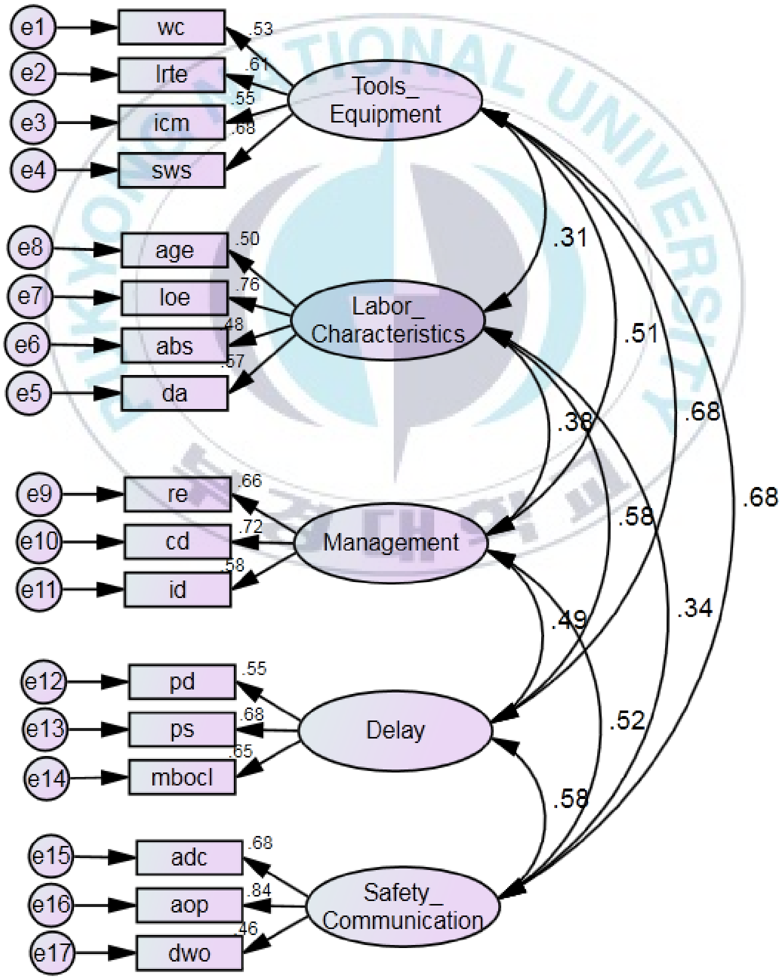

Figure 3-2 Sub structural equation modeling of labor productivity

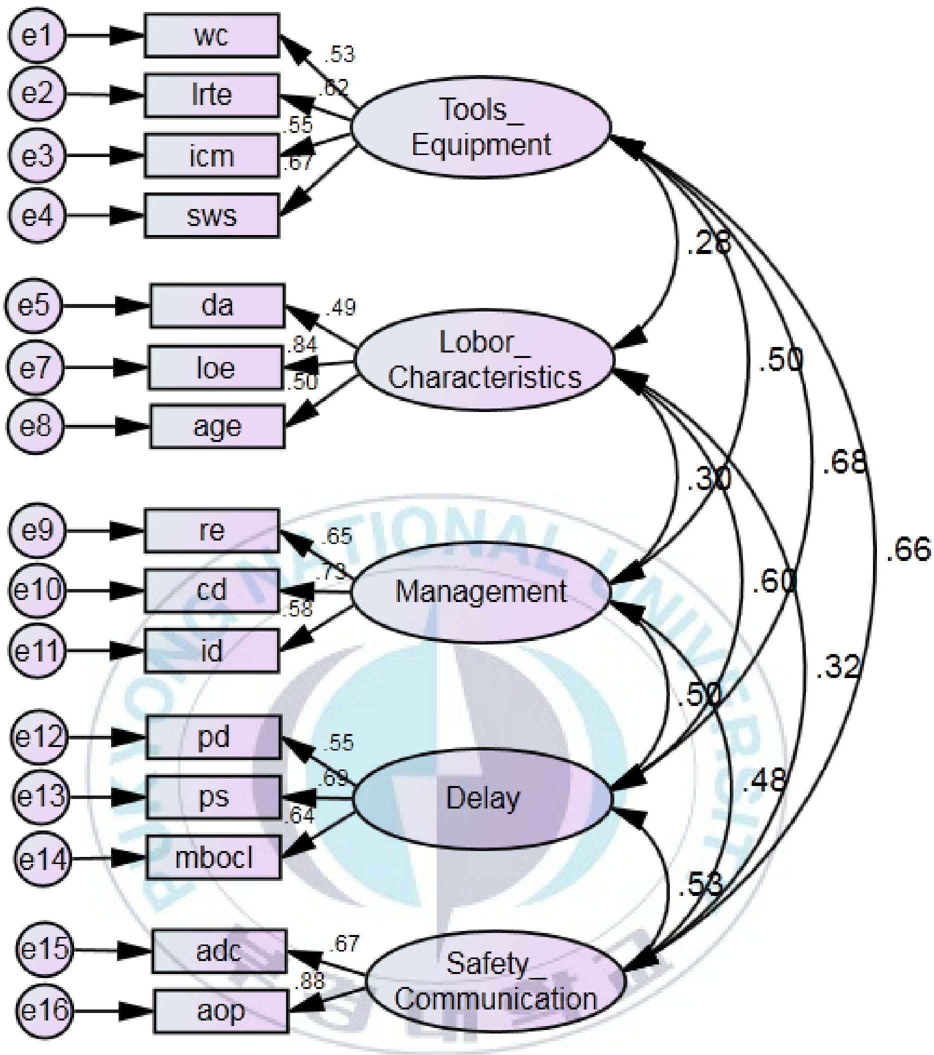

Figure 3-3 Final Measurement Model pertaining to "labor productivity"

Table 3.10 Goodness-of-fit Criteria and Goodness-of-fit Indices for Measurement Model

No	Criteria	Criterion value indicating goodness-of-fit between model and sampled data	Index values representing goodness of-fit of Measurement Model
1	p value	**$0.05 < p \leq 1.00$** (Arbuckle, 2011; Hair, 2010)	**0.238**
2	$\chi2$/df (Relative chi-square)	**$0 < \chi2/df \leq 2$** (Arbuckle, 2011; Hair, 2010; Ullman, 2006)	**1.108**
3	GFI (Goodness of Fit Index)	**$0.90 \leq GFI \leq 1.00$** (Hair, 2010; Schermelleh-Engel, Moosbrugger, & Müller, 2003)	**0.932**
4	IFI (Incremental Fit Index)	**$0.90 \leq IFI \leq 1.00$** (Hair, 2010; Hooper, Coughlan, & Mullen, 2008)	**0.984**
5	CFI (Comparative Fit Index)	**$0.90 \leq CFI \leq 1.00$** (Hair, 2010; Schermelleh-Engel et al., 2003)	**0.983**
6	RMSEA (Root Mean Square Error of Approximation)	**$0 \leq RMSEA \leq 0.08$** (Hair, 2010; Schermelleh-Engel et al., 2003; Schumacker & Lomax, 2004)	**0.026**
7	TLI (Tucker-Lewis coefficient)	**$0.90 \leq TLI \leq 1.00$** (Hair, 2010; Schumacker & Lomax, 2004)	**0.977**

3.3.3 CFA Results

From the CFA results, factors categorized into five main groups namely: Tools and equipment, Labor characteristics, Management, Delay, and Safety and communication. The goodness of fit for the measurement model calculated, compared with the criteria, and was acceptable. From the measurement model, it is discovered that “Lack of experience” and “Ambiguity of Project objective” were the more significant with highest factor loading in CFA model. However, the CFA measurement model will be designed as the Structural Equation Model which will be discussed in the following chapter.

3.4 Structural Equation Modeling (SEM)

3.4.1 Introduction

Structural Equation Modeling (SEM) is a methodology for representing, estimating, and testing a network of relationships between variables. Through the SEM, the researcher could examine the direct and indirect interrelationships which exist between multiple dependent and independent variables (Gefen, Straub, & Boudreau, 2000). SEM's foundation lies on two familiar multivariate techniques; factor analysis and multiple regression analysis (Hair, 2010). According to Hair (2010), the three distinguished characteristics of SEM models are: i) To estimate multiple and interrelated dependence relationships; ii) To represent unobserved concepts in these relationships, and to account for measurement errors in the estimation process; iii) To define a model to explain the entire set of relationships. It could be used as a more powerful alternative to path analysis, multiple regression, factor analysis, covariance analysis and time series analysis. In fact, SEM is a multivariate analysis which combines path analysis and confirmatory factor analysis simultaneously; through the path analysis, the regression weights will be discovered; and through the confirmatory factor analysis (CFA), the structure or group of factors or variables will be confirmed (Xiong, Skitmore, & Xia, 2015).

Hence, SEM, as a statistical analysis tool, has been applied in construction engineering and management research these days. Molenaar (2000) mentioned that SEM is a statistical analysis tool that is underutilized in construction engineering and management research these days. Xiong et al. (2015) reviewed 84 articles which addressed construction problems and applied SEM. Xiong et al. (2015) discovered that SEM applications have been increasing over time. Moreover, it has been applied to a variety of issues and aspects in construction management such as; trust in construction contracting by Wong et al. (2008), a composite model using SEM and fuzzy logic for supplier selection by Punniyamoorthy et al. (2011), feasibility and project success for Public-Private Partnership (PPP) studied by Ng, Wong, and Wong (2010), construction contracting by Cheung et al. (2012), construction partnering assessed by Chen et al. (2012), relationship between an institution and its constituents studied by Oei and Ogunlana (2006), the implementation of Enterprise Resource Planning software and the goal of competitive advantage performed by Ram et al. (2014), and contract disputes between owners and contractors investigated by Molenaar et al. (2000).

Furthermore, Xue et al.(2015) applied SEM to analyze the factors for measuring environmental and social influences of subway construction and their interrelationships. Deng et al. (2013) evaluated the capabilities of port logistics among five Chinese coastal port clusters by SEM. In construction safety management, Li and Xiang (2011) investigated the main causes of poor construction site safety using SEM in order to examine the importance of each aspect of the causes. Samee & Pongpeng (2016a) explored the causal relationships among components of construction equipment management, project performance and corporate performance. Samee & Pongpeng (2016b) also performed a survey of Construction Equipment Selection and Contractor Competitive Advantages and analyzed it through SEM. Waroonkun and Stewart (2008) proposed a conceptual model for International Technology Transfer in construction projects in Thailand.

3.4.2 SEM analysis

The criterion values of goodness-of-fit and goodness-of-fit indices for the structural model calculated, and compared with the criteria thresholds. Table 3.12 shows that goodness-of-fit indices for the structural model are valid.

As mentioned above, the Structural Equation Model includes a measurement model and a structural model. The measurement model displays how latent variables are measured by observed variables (**Figure 3-3**) and relationships between those latent variables are demonstrated by the structural model (**Figure 3-4**). In this step, the Structural Equation Model (Figure 3-4) is examined to explore the causal relationship based on the five Hypotheses as shown below:

H1: "Labor Productivity" has a positive relation with "Tools & Equipment"

H2: "Labor Productivity" has a positive relation with "Labor Characteristics"

H3: "Labor Productivity" has a positive relation with "Management"

H4: "Labor Productivity" has a positive relation with "Delay"

H5: "Labor Productivity" has a positive relation with "Safety & Communication"

In order to accept the alternative hypothesis, the p-value should be less than 0.05. The Hypothesis test and Standardized Regression Weights of latent variables are presented in Table **3.11** as the overall final structural model. According to this table, all five Hypotheses have a p-value of less than 0.05 and were accepted. The Hypothesis test revealed that Sample data supported the hypotheses. Moreover, Standardized Regression Weights of latent variables are as follows, in descending order shown in Table **3.11**: Delay (0.832), Tools & Equipment (0.822), Safety & Communication (0.726), Management (0.622), and Labor Characteristics (0.505).

Table 3.11 Hypothesis test and Standardized Regression Weights of latent variables

Hypothesis	Latent Variables	p-value	Hypothesis test (p-value < 0.05)	Standardized Regression Weights	Rank
H1	Tools & Equipment	0.021	Accept	0.822	2
H2	Labor Characteristics	0.008	Accept	0.505	5
H3	Management	0.003	Accept	0.622	4
H4	Delay	0.037	Accept	0.832	1
H5	Safety & Communication	0.002	Accept	0.726	3

Table 3.12 Goodness-of-fit Criteria and Goodness-of-fit Indices for Structural Model

No	Criteria	Criterion value indicating goodness-of-fit between model and sampled data	Index values representing goodness of-fit of Structural model
1	p value	**$0.05 < p \leq 1.00$** (Arbuckle, 2011; Hair, 2010)	**0.122**
2	χ2/df (Relative chi-square)	**$0 < \chi 2/df \leq 2$** (Arbuckle, 2011; Hair, 2010; Ullman, 2006)	**1.181**
3	GFI (Goodness of Fit Index)	**$0.90 \leq GFI \leq 1.00$** (Hair, 2010; Schermelleh-Engel et al., 2003)	**0.920**
4	IFI (Incremental Fit Index)	**$0.90 \leq IFI \leq 1.00$** (Hair, 2010; Hooper et al., 2008)	**.971**
5	CFI (Comparative Fit Index)	**$0.90 \leq CFI \leq 1.00$** (Hair, 2010; Schermelleh-Engel et al., 2003)	**.969**
6	RMSEA (Root Mean Square Error of Approximation)	**$0 \leq RMSEA \leq 0.08$** (Hair, 2010; Schermelleh-Engel et al., 2003; Schumacker & Lomax, 2004)	**.034**
7	TLI (Tucker-Lewis coefficient)	**$0.90 \leq TLI \leq 1.00$** (Hair, 2010; Schumacker & Lomax, 2004)	**.962**

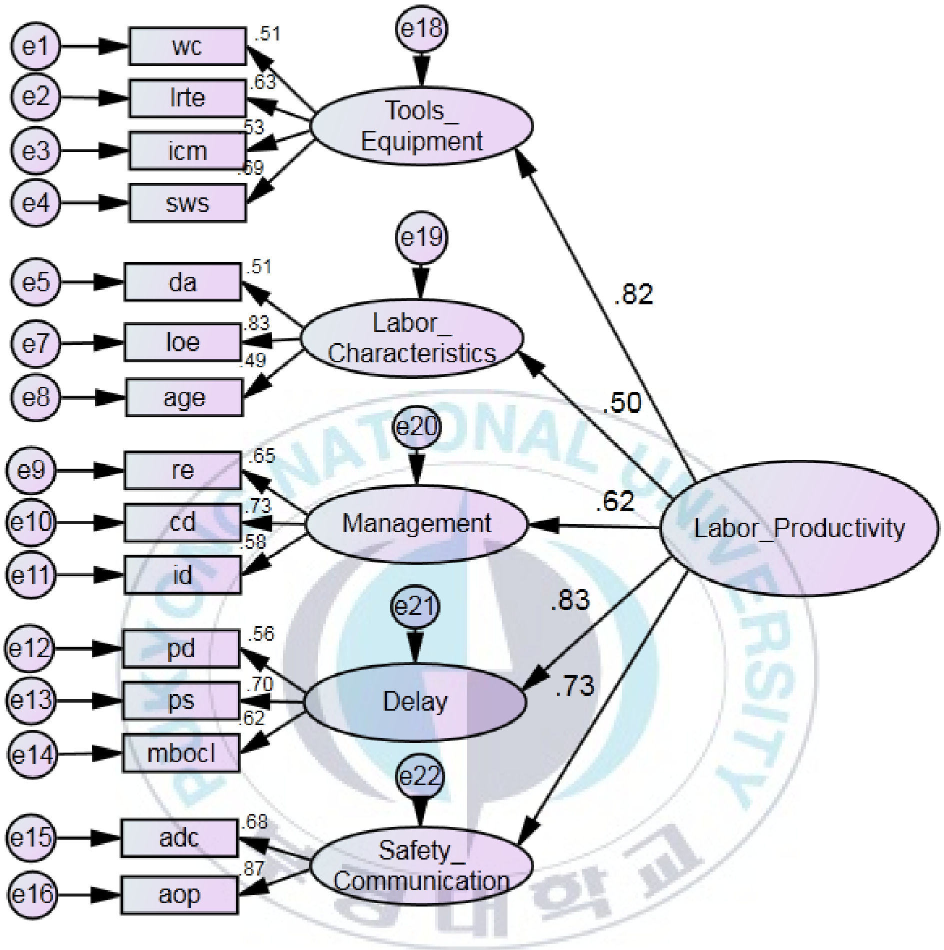

Figure 3-4 Structural Equation Modeling of Labor Productivity

3.4.3 SEM Results

Through the SEM analysis, five main latent variables, and their sub-factors (observed variables) were analyzed through the path analysis to determine the relationships between variables.). From the SEM analysis, “Delay”, with 0.832 Standardized Regression Weights, is the most significant factor. Subsequently, the “Tools & Equipment”, “Safety & Communication”, “Management”, and “Labor Characteristics” are the important factors with 0.822, 0.726, 0.622, and 0.505 Standardized Regression Weights respectively.

CHAPTER 4

Chapter 4 : DECISION MAKING APPROACH

4.1 Introduction

Application of Analytical Hierarchy Process (AHP) in the construction management

Use of statistical analysis in order to identify critical features in construction engineering practice is reasonably widespread (Hanna et al., 2005; Iyer & Jha, 2005). The Analytic Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons which relies on the judgments of experts to derive priority scales (Saaty, 2008). One of the advantages of AHP is that the analysis doesn't need a statistically significant sample size (Dias Jr & Ioannou, 1996). The simplicity of the AHP approach is that, unlike other 'conjoint' methods, the qualities (or levels) of different attributes are not directly compared. The AHP approach thus removes the need for complex survey designs and can even be applied (in an extreme case) with only a single respondent (TiL Saaty, 1980; Schot & Fischer, 1993; Zahedi, 1986).

Applications of AHP in construction management studies are pretty remarkable as many researchers and project managers apply this tool. Here, several construction management studies that implemented AHP are addressed briefly as follows; According to Al-Harbi (2001), AHP is a potential decision making method in project management. Al-Harbi applied AHP for prequalification of contractors for a project. Doloi (2008) believed that poor construction labor productivity causes delay and cost overrun. Doloi discovered, by using AHP, that planning and programming has the highest impact on productivity. Cheng & Li (2002), examined a model by AHP regarding the construction partnering process and critical success factors. Skibniewski & Chao (1992) evaluated advanced construction technologies by applying AHP, in relation to the risk of traditional economic analysis techniques. Pan (2008) proposed a Fuzzy AHP to select the most preferable bridge construction method in Taiwan. Al Khalil (2002) developed an AHP model to select the most suitable project delivery method. Chiang et al. (2017) applied AHP in order to prequalify and select the construction contractors. Raviv et al. (2017) implemented AHP to evaluate the risk potential of safety incidents for cranes. Tamošaitienė al. (2017) proceed used a hybrid multi-criteria decision-making model by AHP in relation to supply chain management issues.

4.2 AHP analysis

The process of AHP has been followed according to Saaty (2008). First, describing and determining the objective of study; which in this study is factors affecting labor productivity. Secondly, the hierarchy from the top to the Criteria and alternatives, as it is shown in Figure 4-1. The factors have been categorized in a total of 6 components based on the Exploratory Factor Analysis findings, and according to the rotated component matrix (Table 3.6). Moreover, an interrelated component name was selected for each set of factors. Thus, the hierarchy structure of factors affecting labor productivity (Figure 4-1) was designed based on EFA components.

The third step of AHP is constructing a set of pairwise comparison matrices; in this step an AHP questionnaire based on the hierarchy structure (Figure 4-1) was designed and distributed among the experts who are Project Managers of the construction companies. The participants have been asked to rank the relative importance of each of the criteria and sub-factors (alternatives) from 1 to 9 scales in order to make the pairwise comparison, based on the Nine point scale by Saaty (1994) (

Table **4.1**). A total of 25 questionnaires were distributed and 18 of them were returned. The feedback questionnaire from professionals were estimated by using the Consistency Index (CI) and Consistency Ratio (CR) to ensure their reliability and validity (Saaty, 2008). Hence, the Inconsistency ratio was calculated for each respondent. Six respondents were rejected because their CR was less than 10 percent. Therefore, the analysis was continued on the remaining 12 respondents.

Only a Consistency Index (CI) and Consistency Ratio (CR) of less than 0.1 can be acceptable. If it is more than 0.1 , it means there is inconsistency in pair-wise comparison (Saaty, 1994) . The CI and CR would be calculated by the following equations:

Equation 37

$$\text{Consistency Index (CI)} = \frac{\lambda\text{max} - \text{n}}{\text{n} - 1}$$

Equation 38

$$\text{Consistency Ratio (CR)} = \frac{\text{CI}}{\text{RI}}$$

Where; λmax: highest eigenvalue

n: number of responses

Judgment consistency could be checked by taking CR of CI with the suitable value in the Table 4.2.

Table 4.1.Nine point scale by Saaty (1994)

Intensity of Importance	Definition
1	Equal Importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance

Table 4.2 Average random consistency (RI) (TL Saaty, 1980; Saaty, 1994)

Size of Matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

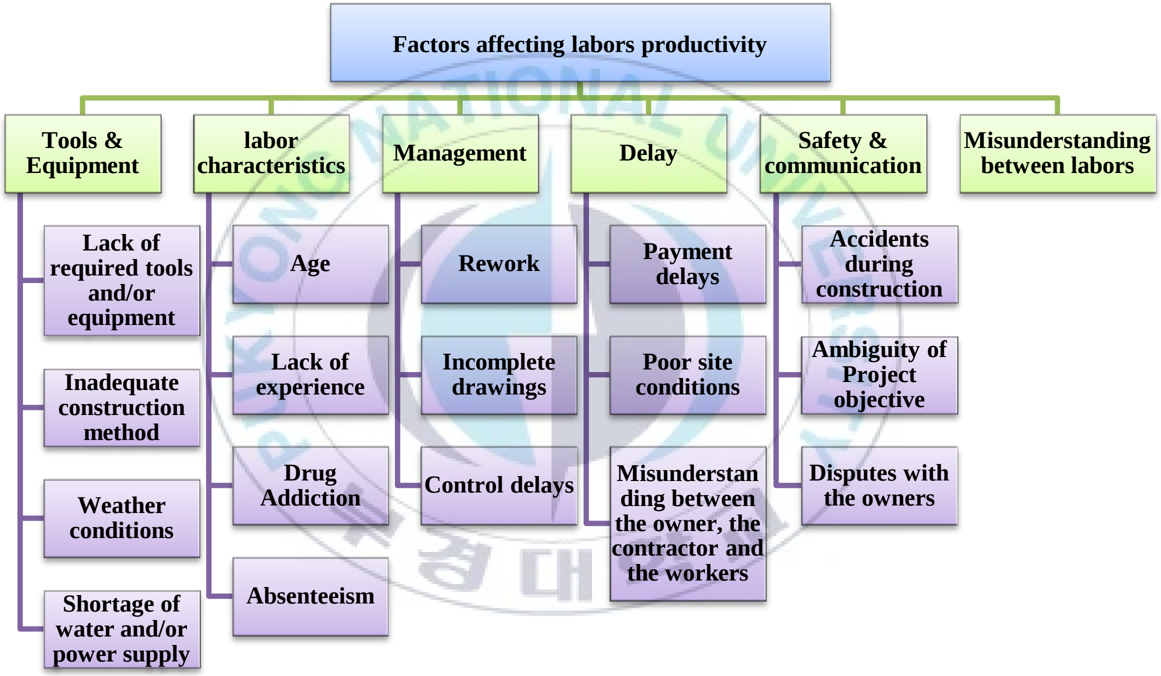

Figure 4-1 Hierarchy structure of factors affecting labors productivity

The judgments of several individuals should be combined to obtain a single judgment for the group. Judgments must be combined so that the reciprocal of the synthesized judgments is equal to the syntheses of the reciprocals of these judgments. It has been proved that the Geometric mean, not the frequently used arithmetic mean, is the only way to do that (Saaty, 2008). Accordingly, the Geo mean of the twelve responses was calculated by Excel to synthesize them. Geo mean can be calculated by the following formula:

Equation 39

$$\mathrm{Pi} = \sqrt[n]{\prod_{j=1}^{n} \mathrm{aij}}$$

Where; aij: comparison between object i and j

Pi: Priority of object i

n: number of responses

Therefore, all individual judgments combined to a single synthesized judgment. The synthesized judgment was imported to the Expert Choice (vresion11) software in order to analyze and find out the priorities of the criteria with respect to the goal of the study. Additionally, the Inconsistency Ratio has been shown for the criteria and sub-criteria's, which should be approximately 0.1 or less (less than 10 percent).

Table 4.9 shows the overall assessment for the Criteria with respect to the aim of the study, which was to prioritize factors affecting labor productivity. According to this table, the "Labor Characteristics," by 0.384 weights, is the most significant criteria, and then "Tools & Equipment" and "Management" with the same weights of 0.191 are the second and third dominant criteria. In addition, the inconsistency ratio for the criteria has been analyzed which by 4 percent is quite reasonable and it's less than 10 percent. Moreover, Misunderstanding between labors, Delay and Safety & Communication are ranked as the fourth to sixth priority respectively.

Similarly, the pairwise comparisons were done for each five criteria's sub-factors. The inconsistency ratio for each group has been checked as well. All of the CRs were less than ten percent and all were acceptable. In the "Tools &Equipment" group, "Lack of required tools and/or equipment" was the most significant sub-factor in this group by 0.444 weights. In the "Labor Characteristics" group, "Absenteeism," with the weight of 0.388, was the dominant sub-factor. In the "Management" group, the "Control delay" with 0.297 weights was ranked as the significant sub-factor. Based on the findings, between the "Delay" sub-factors, the "Payment delays" with the weights of 0.691 was the most superior sub-factor. Finally, the "Ambiguity of project objective" was the most significant sub-factor among the Safety & Communication's sub-factors (Table 4.9).

Table 4.3 Priorities with respect to: Factors affecting labors productivity

1	Labor Characteristics	0.384
2	Tools & Equipment	0.191
3	Management	0.191
4	Misunderstanding between labors	0.123
5	Delay	0.06
6	Safety & Communication	0.05

Inconsistency = 0.04
with 0 missing judgments.

Table 4.4 Priority Weights of Tools and Equipment

Priorities with respect to:
Factors affecting labors productivity

>Tools & Equipment

1	Lack of required tools and/or equipment	0.444
2	Inadequate construction method	0.312
3	Weather conditions	0.122
4	Shortage of water and/or power supply	0.122

Inconsistency = 0.02
with 0 missing judgments.

Table 4.5 Priority Weights of Labor Characteristics

Priorities with respect to:
Factors affecting labors productivity

>Labor Characteristics

1	Absenteeism	0.388
2	Drug Addiction or Alcoholism	0.304
3	Lack of experience	0.220
4	Age	0.088

Inconsistency = 0.06
with 0 missing judgments.

Table 4.6 Priority Weights of Management

Priorities with respect to:
Factors affecting labors productivity

>Management

1	Control Delays	0.297
2	Rework	0.540
3	Incomplete drawings	0.163

Inconsistency = 0.00877

with 0 missing judgments.

Table 4.7 Priority Weights of Delay

Priorities with respect to:
Factors affecting labors productivity
>Delay

1	Payment delays	0.691
2	Poor site conditions	0.160
3	Misunderstanding between the owner, the contractor and the workers	0.149

Inconsistency = 0.00527
with 0 missing judgments.

Table 4.8 Priority Weights of Safety and Communication

Priorities with respect to:
Factors affecting labors productivity
>Safety & Communication

1	Ambiguity of Project objective	0.55
2	Disputes with the owners	0.24
3	Accidents during construction	0.21

Inconsistency = 0.02
with 0 missing judgments.

Table 4.9 Summary Table Priority weights of Criteria and Sub-Criteria

Priorities with respect to:

Level 1: Prioritize factors affecting construction labors productivity

Level 2:	Priority Weights
Labor Characteristics	0.384
Tools & Equipment	0.191
Management	0.191
Misunderstanding between labors	0.123
Delay	0.060
Safety & Communication	0.050

Inconsistency = 0.04 with 0 missing judgments.

Level 3:

> Tools & Equipment	
Lack of required tools and/or equipment	0.444
Inadequate construction method	0.312
Weather conditions	0.122
Shortage of water and/or power supply	0.122

Inconsistency = 0.02 with 0 missing judgments.

> Labor Characteristics	
Absenteeism	0.388
Drug Addiction	0.304
Lack of experience	0.220
Age	0.088

Inconsistency = 0.06 with 0 missing judgments.

> Management	
Control Delays	0.297
Rework	0.540
Incomplete drawings	0.163
Inconsistency = 0.00877 with 0 missing judgments.	
> Delay	
Payment delays	0.691
Poor site conditions	0.160
Misunderstanding between the owner, the contractor and the workers	0.149
Inconsistency = 0.00527 with 0 missing judgments.	
> Safety & Communication	
Ambiguity of Project objective	0.55
Disputes with the owners	0.24
Accidents during construction	0.21
Inconsistency = 0.02 with 0 missing judgments.	

4.3 AHP Results

From the AHP findings, the authors discovered that “Labor Characteristics,” “Tools & Equipment” and “Management” are the most dominant group affecting labor productivity in the Iranian construction industry. Subsequently, the sub-factors are ranked as the following; “Lack of required tools and/or equipment”, “Absenteeism”, “Control Delays”, “Payment delays”, and “Ambiguity of Project objective”.

CHAPTER 5

Chapter 5 : DISCUSSION & RECOMENDATION

5.1 Comparison between SEM & AHP Findings

Through the SEM analysis, five main latent variables, and their sub-factors (observed variables) were analyzed through the path analysis to determine the relationships between variables. To this aim, a sub-structural model was designed based on the Exploratory Factors Analysis. The sub-factors were categorized in groups according to the EFA results. A sub-structural equation model was designed and various indexes such as p value, $\chi 2$/df, GFI, IFI, CFI, RMSEA and TLI has been compared with the standard Criterions to check the goodness-of-fit between sampled data and the model. The results from Table 3.10 and Table 3.12 indicated that both the measurement model and the structural equation model proved their goodness-of-fit satisfactorily and therefore, the proposed framework is supported. Five proposed Hypotheses were examined by the Hypothesis test and all p-values of Hypotheses were less than 0.05 and were accepted (Table 3.11). From the SEM analysis, "Delay," with 0.832 Standardized Regression Weights, is the most significant factor. Subsequently, the "Tools & Equipment", "Safety & Communication", "Management", and "Labor Characteristics" are the important factors with 0.822, 0.726, 0.622, and 0.505 Standardized Regression Weights respectively.

From the AHP findings, the authors discovered that "Labor Characteristics," "Tools & Equipment" and "Management" are the most dominant group affecting labor productivity in the Iranian construction industry. Subsequently, the sub-factors are ranked as the following; "Lack of required tools and/or equipment", "Absenteeism", "Control Delays", "Payment delays", and "Ambiguity of Project objective".

According to Jay and Render (1993) labor characteristics include skills, experience, satisfaction, and motivation, and they considered the labor characteristics to be one of the major productivity groups. An experienced management team with proper supervision and leadership has a direct critical impact on labor productivity. On the contrary, an unskillful manager leads the organization and project to loss of productivity. Therefore, “Management” is recognized as one of the main categories affecting labor productivity in previous studies (Abdul Kadir et al., 2005; R. Horner & Talhouni, 1993; Abdulaziz M. Jarkas & Bitar, 2012) .On the other hand, the selection of the appropriate type and size of construction equipment often affects the required amount of time for the project, so, it is vital for site executives to be aware of the features of the main kinds of tools that are usually used in the construction sites. In order to increase the productivity rate of the construction sites, it is favorable to choose tools with good features and to ensure that their dimensions are the most appropriate for the work circumstances at a structure place. By providing imperfect tools, the productivity rate may be affected negatively (Lim & Alum, 1995; Yates & Guhathakurta, 1993).

Findings, from AHP and SEM, were compared and revealed in Table 5.1. According to this table, “Tools and Equipment” has been selected as the most common significant factor in both AHP and SEM methods. From the AHP analysis findings, “Tools and Equipment” was discovered as the second most prioritized criteria in level 2. Additionally, “Lack of required tools and/or equipment” is the most significant sub-criteria in level 3. Similarly, from the SEM findings, “Tools & Equipment” was selected as the second most prominent latent variable and “Lack of required tools and/or equipment” as the second most significant observed variable as well. Hence, Tools and Equipment have a significant and direct impact on the construction labors productivity. Lack of proper tools or out of service equipment has a negative impact on the labor productivity. Dai et al. (2007) found that “misplaced tools,” “restrictive policy on consumables,” “poor tool quality,” and “lack of extension cords” have a significant impact on construction productivity. Tools are mainly provided to the craftsmen who are involved on a full time basis (Alinaitwe et al., 2007). Productivity depended on efficient usage of tools and equipment, hence, a lack of proper tools and equipment would have a critical impact on labors productivity (Mahmood Zakeri et al., 1996). Kaming and Olomolaiye (1997a) discovered that lack of equipment and tools is one of the specific productivity problems in Indonesia.

Moreover, in spite of the fact that "Control delay" was discovered as the significant sub-factor in the Management group in the AHP analysis, "Delay," with the highest Regression weights, is the most significant latent variable through the SEM analysis as well. Although, "Delay" was not the most significant criteria in AHP, it has been chosen as the most significant latent variable in SEM. In addition, in both AHP and SEM, "Control Delays" was selected as the third significant factor (**Table 5.1**). Delay in construction could be contained; Project delay, Payment delays, Inspection delays, Supervision delays, Delay in responding to requests for information (RFI) and etc. Enshassi et al. (2007) identified payment delays as one of the most significant factors affecting labor productivity. Zakeri et al. (1996) discovered "Inspection delay" as one of the predominant factors influencing Iranian construction operative's productivity. Kaming and Olomolaiye (1997b) identified Supervision delays as one of the factors influencing craftsmen in Indonesia. Furthermore, Change order by consultants causes project delay (Abdul Kadir et al., 2005).

Table 5.1 Comparative Summary in descending order

Findings from AHP				Findings from SEM			
AHP-Level 2		AHP-Level 3		SEM-Latent Variables		SEM-Observed Variables	
Labor Characteristics	**0.384**	Lack of required tools and/or equipment	0.444	Delay	0.83	Ambiguity of Project objective	0.87
Tools & Equipment	0.191	Absenteeism	0.388	Tools & Equipment	0.82	Lack of required tools and/or equipment	0.83
Management	0.191	Control Delays	0.297	Safety & Communication	0.73	Control delays	0.73
Misunderstanding between labors	0.123	Payment delays	0.691	Management	0.62	Poor site conditions	0.70
Delay	0.06	Ambiguity of Project objective	0.55	Labor Characteristics	0.50	Shortage of water and/or power supply	0.69
Safety & Communication	0.05						

5.2 Measurement Methods and Improvement Techniques of Labor Productivity

There are numerous methods available to evaluate and measure construction operations performance. Selection of the appropriate method for a particular project is another challenging task. Selection criteria was established to determine the suitable method for the measurement of construction productivity (Song & AbouRizk, 2008), which are: (a) The output should be quantifiable and highly correlated with the labor hours; (b) The output measurement should be independent from factors that have influence on the productivity, such as site conditions and labor skills; and (c) the measurement procedure should be cost effective and easy to track. Based on project characteristics, different techniques of measurement are implemented. For example, some techniques require continuous observation and some require intermittent observation of a worker or a crew involved in a task.

5.2.1 Time and Motion Study

Time and motion study is a terminology derived from industrial engineering, which is comprised of both time study and motion study together. It was developed by Frederick W. Taylor in 1880. A time study is also called a stopwatch study in which the time required by a skilled, well-trained operator working at a normal pace doing a specific task is measured. The main objective of time studies is to set time standards in the production area and to record the incremental times of the various steps or tasks that make up an operation (Mayers, 1992; Oglesby et al., 1989).

Two observation studies are generally implemented during labor productivity measurement for the standard times of activities, which are direct observation and work study. In the first method, “the period of observation is continuous throughout the workday by a trained observer in order to record to the nearest minute the time that the workers spent on direct work, indirect work, and ineffective work" (Chui, 2010). In the second method, the observation does not span the complete length of the workday with no continuous observation. Noor (1998) stated that the work study measurement is suitable for those operations having the definite cyclic period, and the length of the periods of observation corresponds to the work cycle of the operation monitored; thus, it can be used in order to determine the most appropriate working method and possible alternative working methods. There are several limitations of time and motion studies (Chui, 2010; Oglesby et al., 1989), which are:

• There will be deficiency or differences in identifying the starting and ending points of cycles. This limitation can be addressed by employing a single observer or several trained observers.

• Geary (1962) recommended a maximum of five workers in a crew per observer to achieve accurate observation. More than one observer or employing another method of recording would assist in collecting data in such a complex situation.

• Time and motion studies are based on information gathered by the observers and detailed notes, which precisely recorded each activity and site condition.

• Studying complex operations or recording a large amount of data in a limited time, can result in the observer's objectivity due to physical limitations or biases. In order to avoid such a natural scenario, the observer must follow the rule with no re-evaluation, hindsight, or second thoughts once the observation has been made.

This complex process can be simplified by employing video cameras and recording the performance of workers. By reviewing the video recorded data, the observer can conduct the time and motion study without missing any step.

5.2.2 Work Sampling Method

Work sampling is a statistical technique employed to conduct periodic observations of workers and is a key tool to establish crew size or to determine the effectiveness of a specific crew size at the workplace (Adrian, 2004). In essence, work sampling is a useful technique in determining the proportion of the direct work from indirect work and ineffective work, analyzing factors that cause indirect and ineffective work, and identifying opportunities to reduce indirect and ineffective work (Chui, 2010; Picard, 2004).

Allmon et al. (2000) defined the direct work as productive tasks or actions, such as picking up tools at the area and measurement on the area where the work is taking place, holding materials in place, inspecting for proper fit, putting on safety equipment, and all clean-up. Indirect work is defined as supervision, planning, travel with handling materials or tools, and walking empty-handed to get materials or tools (Allmon et al., 2000; Chui, 2010). Ineffective work is defined as waiting for other trade, standing, sitting, working unrelated actions, personal time, late starts, and early quits (Allmon et al., 2000).

Noor (1998) mentioned two modified work sampling techniques, which are group timing technique (GTT) and the five-minute rating technique. The group timing technique is suitable for operations with repetitive actions and short cycle time ranging from 30 seconds to three minutes (H. R. Thomas & Daily, 1983). The five-minute rating technique is employed to monitor each crew member with a minimum of five-minutes or duration in minutes equal to the size of the crew, whichever is greater. It is generally recommended to be applied between four to eight times a day and can be used to evaluate the effectiveness of a crew without depending on whether the operations are cyclic or acyclic (Noor, 1998; Sprinkle, 1972; H. R. Thomas & Daily, 1983).

5.2.3 Activity Sampling

While considering a typical activity of a project, work sampling can be considered as activity sampling. According to Oglesby et al. (1989), activity sampling is suitable to apply for crews or projects of any size because it depends upon the number of individual observations, which is not related to sample size. The recommended sample observation size is at least 384, which can be made by either a crew of 100 workers and four times, or a crew of 10 workers and 39 times, and confidence limit of 95%, such that there is an error plus or minus 5% (Oglesby et al., 1989). There must be an equal likelihood of the observed workers. Those observations must have no sequential relationship. They should be consistent in the work situation characteristics during observation. The sampling rating should start with the first seen person and should be conducted for each worker. Types of tasks or an activity should also be recorded during the observation period.

5.2.4 Delay Survey Method

Delay survey methods, such as "worker delay survey/craftsmen's questionnaire surveys" and "foreman delay survey," are conducted by first line supervisors of the project to identify the sources of problems from the workers' viewpoints and monitor the workers' performance (Noor, 1998). The total amount of time lost by each crew in each day is recorded with reasons of delay. The magnitude of problems causing delays are evaluated by the management team and multiplied by the number of workers while considering a crew of more than one worker. This method demands a high cost and is very challenging to maintain confidentiality and anonymity for the workers because of disturbance during work (Chui, 2010; Noor, 1998). It is also necessary to avoid the game of blaming each other and maintain consistency during data collection and report preparation in order to make this delay survey method effective. In addition, a combination of time study and productivity measurement techniques are employed to develop a method productivity delay model (MPDM) in which five possible types of delay, such as environment, equipment, labor, material, and management are determined (Adrian & Boyer, 1976).

5.2.5 Audio-visual Methods

The construction field operations are recorded using audio-visual methods like time-lapse film with one to five seconds intervals and time-lapse video with various time intervals. The recorded audio-visuals can be used to analyze the productivity improvement of construction operations, train workers, and present evidence for construction claims and contract disputes (Everett (Everett, Halkali, & Schlaff, 1998; Noor, 1998).

The data may loss due to equipment failure, technical incompetence, weak illumination, and human error (Noor, 1998). It requires high initial costs and technical competence in order to get quality pictures of the workers' movements and an entire construction process. This technique of capturing visual data is widely accepted nowadays. It can be utilized to visualize the actual status of the project (Everett et al., 1998) at distant office locations by transmitting high-resolution, full-motion live pictures or videos from construction sites through the Internet.

5.2.6 Secondary Data / Historical Data

Productivity data analyses are generally conducted by using historical projects' data and published productivity data as a secondary source. R.S. Means Company publishes annual construction cost and productivity data that are collected from constructors and trade organizations. Those published data consist of average productivity rates of the industry but not the performance of any particular contractor (R.S. Means, 2007). In general, R.S. Means Building

Construction Cost Data is taken as the reference, which provides unit labor costs, unit equipment costs, and physical output data based on the most used, quoted, and respected unit price guide available to the construction industry for the purpose of cost estimating, budgeting, and scheduling (Chui, 2010) (Chui, 2010; RS Means, 2007).

There are several sources to collect productivity data, which are contract documents, progress reports, project databases, and time studies (Song & AbouRizk, 2008). Secondary data is suitable when: (a) research scope demands a large volume of historical data; (b) there are limitations of cost, time, and accessibility for data collection; and (c) there are available reliable sources for secondary data.

5.2.7 Automated Methods

Measuring productivity of construction operations is a challenging task because the activity measurement manual methods are time consuming and laborious. This scenario demands an automated framework to measure productivity. With the advancement of technology, video cameras as well as the Kinect sensor are employed to acquire data of labor-intensive construction operations.

5.2.7.1 Using video cameras

A Wireless Real-time Productivity Measurement system was developed to overcome limitations of the existing on-site audio-visual methods (Kim, Bai, Huan, & Peddi, 2009), which includes a digital camera, a video camera, a data processor, an AC transformer, a computer, and wireless modems. This research proved statistically significant that the developed system generates the identical productivity measurements compared to the results from the stopwatch method (Kim et al., 2009). The WRITE system has specific features: (a) not disrupting the construction operations, (b) determining the real-time on-site construction productivity, and (c) sharing collected data by all parties via the Internet at any time (Kim et al., 2009). It helps to enhance the capability of the project owner, project manager, architect, or engineer to manage the project.

Peddi (2009) proposed a framework to determine the construction labor productivity in real-time by developing human poses analyzing algorithms. With the implementation of computer vision concepts and artificial intelligence, Peddi (2009) developed an automated on-site productivity measurement system, in which a sequence of construction activity images is acquired and sent to a laboratory to generate human poses associated with construction activities. The labor productivity is determined in real-time by classifying the human poses into effective, ineffective, and contributory works and compared with in coming images using the built-in neural network algorithms. As this approach is based on real-time data and does not rely on historical data, a project manager can implement the corrective actions if there is lower labor productivity. Yang, Arif, Vela, Teizer, and Shi (2010) proposed algorithms to track multiple workers on construction sites in order to optimize construction operations. A semi-automated video interpretation method was proposed by Gong and Caldas (2011) to interpret productivity information, working processes, cycle times, and delays. This method deals with vision-based construction object recognition and tracking methods.

5.2.7.2 Using the Kinect sensor

Escorcia, Davila, Golparvar-Fard, and Niebles (2012) developed an automated method for vision-based recognition of construction worker's actions for building interior construction operations using color and depth data from a Microsoft Kinect sensor. With the vision-based approach and machine learning techniques, the body poses of workers are estimated by identifying the actions and movement of workers, which assesses labor productivity, safety, and occupational health at indoor environments.

Weerasinghe (2013) developed a framework to determine location information of workers, construction workers' tool-time, site related information, construction activities, and productivity data in order to assist project managers and planners to develop effective strategies for the improvement of labor productivity.

Considering the limitation of RGB-D sensors, Starbuck, Seo, Han, and Lee (2014) proposed a stereo vision-based marker-less motion capture approach utilizing optical images and depth data obtained from stereo vision cameras in order to develop kinematic models of construction workers' tasks. This is also helpful to evaluate productivity, safety, and workplace design of labor-intensive operations.

Khosrowpour, Niebles, and Golparvar-Fard (2014) proposed a method for the activity analysis of construction workers to identify the factors affecting labor productivity using RGB-D sensors. Khosrowpour et al. (2014) developed algorithms to detect body postures in real-time. Then, a kennel density estimation model is trained to model classification scores from discriminatively trained bag-of-poses action classifiers. Most discriminative sequences of actions are labeled with a hidden Markov model (HMM) and tested for construction operations.

Blommestein (2014) proposed an automatic labor performance measurement and risk assessment framework using range imaging from the Kinect camera. This framework measures the performance of a worker by continuous sampling, employing a work sampling technique. The states (busy, static, idle, or out of frame) of workers are identified by classifying poses of a worker based on the speed of a worker's hand movement.

5.3 Estimation and Improvement of Labor Productivity Proposed by this Study

Based on the findings of this study, author proposed two evaluation methods to improve the labor productivity level. First, it is the evaluation of labor productivity index by weighing from the AHP results. The second is the evaluation of labor productivity index by weighing from the SEM results.

The Key Labor Productivity Index (KLPI) could be measure through the field evaluation and field score. The field evaluation criteria are from 0 to 10 scales which can be evaluated by construction manager or site manager in the construction site. The field score is measured by each criterion weight multiplies by field evaluation and then all field scores sum up as the total. The KLPI weights are equal to the each group (criteria in AHP) weights. So, the KLPI Evaluation Value is calculated by the total field score multiplies by KLPI weight. Eventually, all of the KLPI Evaluation Values sum up as the "Grand Total." Therefore, the construction manager can estimate and examine the level of labor productivity based on the Grand Total result and it can ranked from bad to excellent, reference to the Field Evaluation Criteria (0-10). Whole of this measurement process is formulized in MS Excel as an evaluation form. The sample form is shown in Table 5.2.

The similar measurement process can be applied by SEM results. However, in SEM we have Standardized Regression Weights, so they need to be converted to the weights and then the same process for measuring the KLPI weight and KLPI evaluation Value similarly applies. It is also formulized in the MS Excel and shown in Table 5.3.

5.3.1 AHP Weighting Index:

Table 5.2 Labor Productivity Evaluation Index by AHP

<table>
<tr><td colspan="3">Construction site name and address:
Full name of Contractor/Subcontractor:
Evaluation type:
Reporting period:</td><td colspan="2">Evaluation reporting officer:
Name:
Designation:
Office name and address:
Reporting date:</td><td colspan="2">Field Evaluation Criteria*:
Bad: 0-2
Poor: 2-4
Fair: 4-6
Good: 6-8
Excellent: 8-10</td></tr>
<tr><td rowspan="10">Level 2</td><td>AHP-Key
labor productivity
Index</td><td>Weight</td><td>Field Evaluation * (1-10)</td><td>Field Score (II *III)</td><td>KLPI weight</td><td>KLPI Evaluation Value (IV*V)</td></tr>
<tr><td>I</td><td>II</td><td>III</td><td>IV</td><td>V</td><td>VI</td></tr>
<tr><td>Tools & Equipment</td><td>0.191</td><td colspan="4" rowspan="7"></td></tr>
<tr><td>Labor Characteristics</td><td>0.384</td></tr>
<tr><td>Management</td><td>0.191</td></tr>
<tr><td>Delay</td><td>0.06</td></tr>
<tr><td>Safety & Communication</td><td>0.05</td></tr>
<tr><td>Misunderstanding between labors</td><td>0.123</td></tr>
<tr><td>Total</td><td>1.00</td></tr>
<tr></tr>
<tr><td rowspan="3">Level 3</td><td>AHP-Key
1. Tools & Equipment
Index</td><td>Weight</td><td>Field Evaluation * (1-10)</td><td>Field Score (II *III)</td><td>KLPI weight</td><td>KLPI Evaluation Value (IV*V)</td></tr>
<tr><td>I</td><td>II</td><td>III</td><td>IV</td><td>V</td><td>VI</td></tr>
<tr><td>Lack of required tools</td><td>0.444</td><td></td><td></td><td>0.191</td><td></td></tr>
</table>

	and/or equipment					
	Inadequate construction method	**0.312**				
	Weather conditions	**0.122**				
	Shortage of water and/or power supply	**0.122**				
	Total	1.00				
	AHP-Key **2. Labor Characteristics** Index	Weight	Field Evaluation * (1-10)	Field Score (II *III)	KLPI weight	KLPI Evaluation Value (IV*V)
	I	II	III	IV	V	VI
	Absenteeism	**0.388**				
	Drug Addiction	**0.304**				
	Lack of experience	**0.22**				
	Age	**0.088**				
	Total	1.00			**0.384**	
	AHP-Key **3. Management** Index	Weight	Field Evaluation * (1-10)	Field Score (II *III)	KLPI weight	KLPI Evaluation Value (IV*V)
	I	II	III	IV	V	VI
	Control Delays	**0.297**				
	Rework	**0.54**				
	Incomplete drawings	**0.163**				
	Total	1.00			**0.191**	
	AHP-Key **4. Delay** Index	Weight	Field Evaluation * (1-10)	Field Score (II *III)	KLPI weight	KLPI Evaluation Value (IV*V)

	I	II	III	IV	V	VI
	Payment delays	**0.691**				
	Poor site conditions	**0.16**				
	Misunderstanding between the owner, the contractor and the workers	**0.149**				
	Total	1.00			**0.06**	
	AHP-Key **5. Safety & Communication** Index	Weight	Field Evaluation * (1-10)	Field Score (II *III)	KLPI weight	KLPI Evaluation Value (IV*V)
	I	II	III	IV	V	VI
	Ambiguity of Project objective	**0.55**				
	Disputes with the owners	**0.24**				
	Accidents during construction	**0.21**				
	Total	1.00			**0.05**	
	AHP-Key **6. Misunderstanding between labors** Index	Weight	Field Evaluation * (1-10)	Field Score (II *III)	KLPI weight	KLPI Evaluation Value (IV*V)
	I	II	III	IV	V	VI
					0.123	
Grand Total						

5.3.2 SEM Weighting Index:

Table 5.3 Labor Productivity Evaluation Index by SEM

Construction site name and address: Full name of Contractor/Subcontractor: Evaluation type: Reporting period:			Evaluation reporting officer: Name: Designation: Office name and address: Reporting date:			Field Evaluation Criteria*: Bad: 0-2 Poor: 2-4 Fair: 4-6 Good: 6-8 Excellent: 8-10	
Code	SEM-Key **labor productivity** Index	Standardized Regression Weights	Weight	Field Evaluation* (1-10)	Field Score (IV *V)	KLPI weight	KLPI Evaluation Value(VI* VII)
I	II	III	IV	V	VI	VII	VIII
	Tools & Equipment	0.82	**0.23**				
	Labor Characteristics	0.50	**0.14**				
	Management	0.62	**0.18**				
	Delay	0.83	**0.24**				
	Safety & Communication	0.73	**0.21**				
	Total	3.5	1.00				
Code	SEM-Key **Tools & Equipment** Index	Standardized Regression Weights	Weight	Field Evaluation* (1-10)	Field Score (IV *V)	KLPI weight	KLPI Evaluation Value(VI* VII)

I	II	III	IV	V	VI	VII	VIII
lrte	Lack of required tools and/or equipment	0.63	**0.27**				
wc	Weather conditions	0.51	**0.22**				
icm	Inadequate construction method	0.53	**0.22**				
sws	Shortage of water and/or power supply	0.69	**0.29**				
	Total	2.36	1.00			**0.23**	
Code	SEM-Key **Labor Characteristics** Index	Standardized Regression Weights	Weight	Field Evaluation* (1-10)	Field Score (IV *V)	KLPI weight	KLPI Evaluation Value(VI* VII)
I	II	III	IV	V	VI	VII	VIII
da	Drug Addiction	0.51	**0.28**				
loe	Lack of experience	0.83	**0.45**				
age	Age	0.49	**0.27**				
	Total	1.83	1.00			**0.14**	
Code	SEM-Key **Management** Index	Standardized Regression Weights	Weight	Field Evaluation* (1-10)	Field Score (IV *V)	KLPI weight	KLPI Evaluation Value(VI* VII)
I	II	III	IV	V	VI	VII	VIII
re	Rework	0.65	**0.33**				
cd	Control delays	0.73	**0.37**			**0.18**	

id	Incomplete drawings	0.58	**0.30**				
	Total	1.96	1.00				
Code	SEM-Key **Delay** Index	Standardized Regression Weights	Weight	Field Evaluation* (1-10)	Field Score (IV *V)	KLPI weight	KLPI Evaluation Value(VI* VII)
I	II	III	IV	V	VI	VII	VIII
pd	Payment delays	0.56	**0.30**				
ps	Poor site conditions	0.70	**0.37**				
mbocl	Misunderstanding between the owner, the contractor and the workers	0.62	**0.33**				
	Total	1.88	1.00			**0.24**	
Code	SEM-Key **Safety-Communication** Index	Standardized Regression Weights	Weight	Field Evaluation* (1-10)	Field Score (IV *V)	KLPI weight	KLPI Evaluation Value(VI* VII)
I	II	III	IV	V	VI	VII	VIII
adc	Accidents during construction	0.68	**0.44**				
aop	Ambiguity of Project objective	0.87	**0.56**				
	Total	1.55	1.00			**0.21**	
Grand Total							

5.3.3 Labor Productivity Level Improvement Diagram

The study also proposed a flow chart diagram in order to improve the level of labor productivity. The flow chart diagram designed based on the two concepts; first, Strength, weakness Opportunity and Threat (SWOT) as a strategic planning technique; and second the Plan-Do-Check-Action (PDCA) concept an as iterative four-step management method in order to control and improve the labor productivity level in construction projects.

SWOT analysis (or SWOT matrix) is a strategic planning technique used to help a person or organization identify the Strengths, Weaknesses, Opportunities, and Threats related to business competition or project planning. It is intended to specify the objectives of the business venture or project and identify the internal and external factors that are favorable and unfavorable to achieving those objectives. Users of a SWOT analysis often ask and answer questions to generate meaningful information for each category to make the tool useful and identify their competitive advantage. Strengths and Weakness are frequently internally-related, while Opportunities and Threats commonly focus on environmental placement.

Strengths: characteristics of the business or project that give it an advantage over others.

Weaknesses: characteristics of the business that place the business or project at a disadvantage relative to others.

Opportunities: elements in the environment that the business or project could exploit to its advantage.

Threats: elements in the environment that could cause trouble for the business or project.

The degree to which the internal environment of the firm matches with the external environment is expressed by the concept of strategic fit. Identification of SWOTs is important because they can inform later steps in planning to achieve the objective. First, decision-makers should consider whether the objective is attainable, given the SWOTs. If the objective is not attainable, they must select a different objective and repeat the process. SWOT Matrix is shown in Figure 5-1

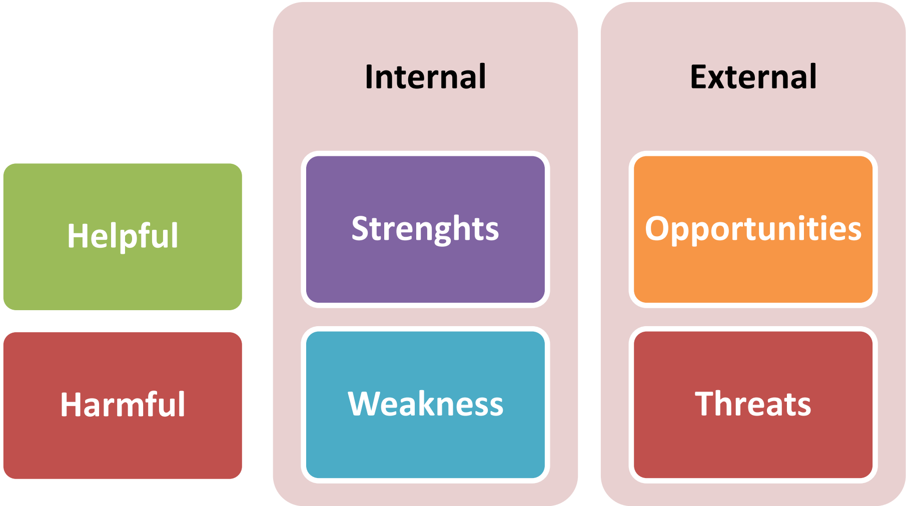

Figure 5-1 SWOT Matrix

Dr. Walter A. Shewhart and Dr. W. Edward Deming advocated PDCA concept for productivity management, and continuous quality improvement of process and products. PDCA is the "golden cycle for improvement." It is a methodical approach for problem solving and continuous improvement (Figure 5-2). PDCA wheel should be considered a never-ending cycle for improvement towards an ideal condition.

Plan is to establish objectives and process or countermeasures with expected outcome based on the past performances or future forecasting of work.

Do is to implement the processes or countermeasures planed.

Check is to measure the effectiveness or achievement of processes or countermeasures planed between the actual results and expected results to ascertain any differences.

Act is to analyze the differences to identify the causes of "Gap," and take necessary action to improve changes.

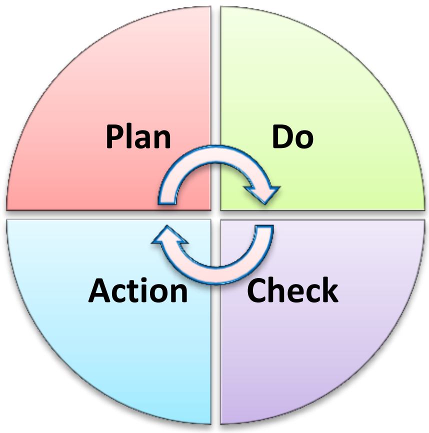

Figure 5-2 PDCA Cycle for Problem Solving and Continuous Improvement

As it is shown in Figure 5-3, the first step is identification of factors affecting labor productivity. Based on the SWOT strategic technique, the internal and external factors consider for level of labor productivity (LOLP) estimation. The external factors include macroeconomic matters, technological change, legislation, sociocultural changes, changes in the marketplace, and, changes in competitive position. The internal factors as strengths or as weaknesses are depending upon their effect on the organization's objectives. In this study internal factors would be Engineers' abilities, Advanced Project Management, Modern Technology, Skillful work team, Use of Modern Machinery, Inexperienced Workers, Possibility of Injury at Work, Lack of Coordination. The next step is collecting the data and analyzing the LOLP. If the LOLP is qualified and meet the criteria standard level, then the project will be continued. Otherwise LOLP should be improved. At this stage, PDCA applies in order to improve LOLP. The "Plan" is strategies for improvement of Tools & Equipment, Labor Characteristics, Management, Delay, Safety & Communications, and Misunderstandings between labors. The "Do" stage is the execution of techniques such as: Choosing tools with good features, efficient usage of tools and equipment, Improving labors' experience, satisfaction, and motivation (by training or workshops), Eliminating Rework, Fully complete drawings, Controlling Delays, Payment on-time, Inspection delays, reducing change orders, Enhancing safety of construction site and reducing disputes, and, Clarifying tasks and activities to avoid misunderstandings. In the "Check" stage, the proposed measurement method by this study applies to estimate the KLPI weight and Grand Total evaluate, by both SEM and AHP, with the evaluation criteria from 0 to 10. Moreover, the measurement and improvement techniques from other studies would be applicable, such as: Time and Motion Study, Work Sampling Method, Activity Sampling, Delay Survey Method, Audio-visual Methods, Secondary Data / Historical Data, Automated Methods

In the "Action" stage, the strategy plan could be revised and modified. If the LOLP reach to the satisfaction level, the project will be continued, otherwise PDCA cycle will repeat till to get the satisfaction level. Whenever the PDCA improvement cycle is completed, the LOLP will be checked whether it is satisfying or not. If it is on satisfaction level the project will continue and deliver to end. But if it is not satisfying, the PDCA improvement cycle will apply again, till reaching to desired satisfaction level of labor productivity.

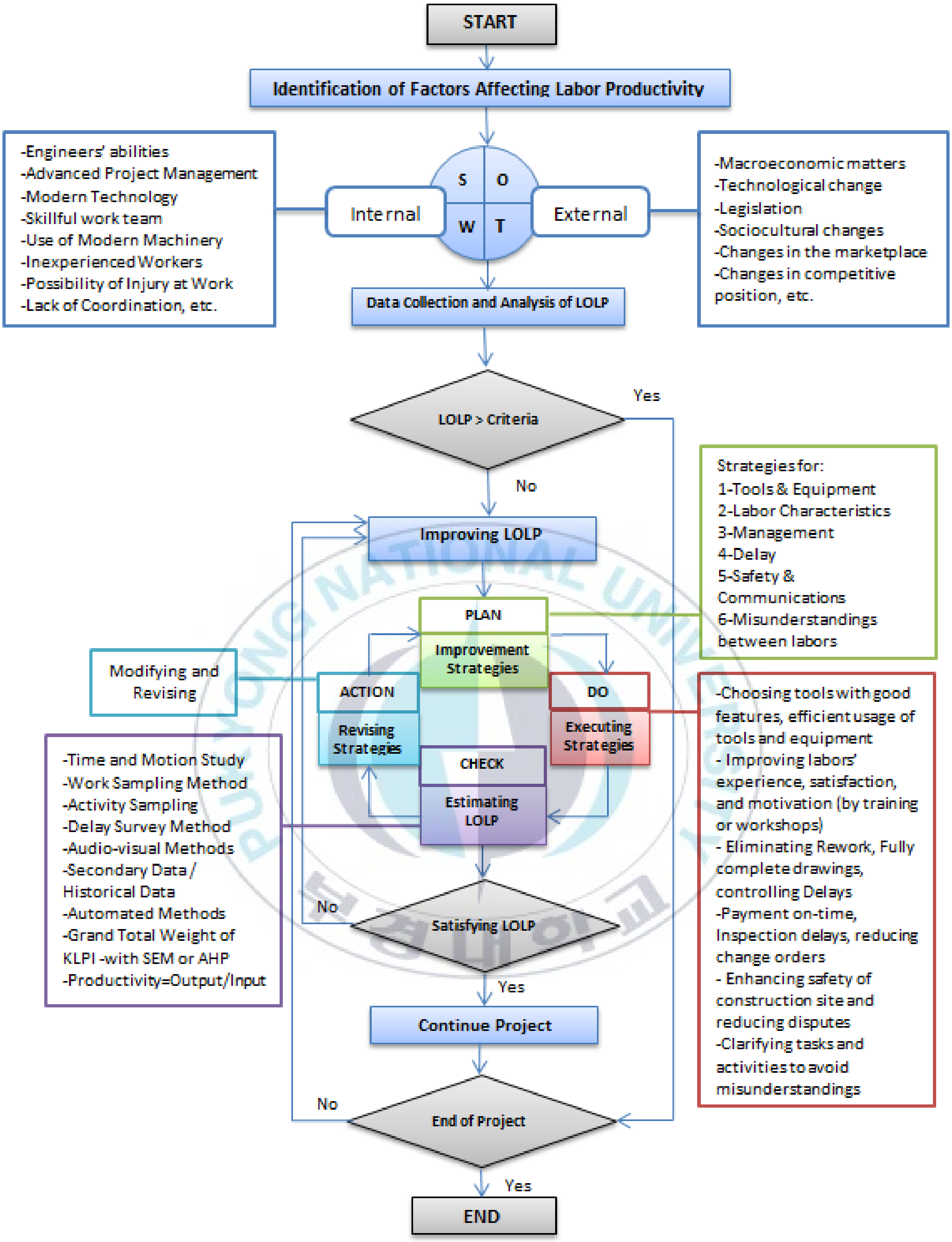

Figure 5-3 Improving Labor Productivity Level Flowchart Diagram

CHAPTER 6

Chapter 6 : CONCLUSION

Since the construction industry is labor intensive and improving labor productivity has a direct and effective impact on project time, cost, and quality, the labor productivity issue is of remarkable interest in both the construction industry and academia. This study attempted to prioritize and highlight the factors most affecting construction labor productivity in Iran. Hence, the Analytical Hierarchy Process (AHP) and Structural Equation Model (SEM) were applied as the analytical tools. The results from both AHP and SEM were discovered and compared in parallel for accuracy and reliability of findings. Eventually, "Labor Characteristics" was selected as the most prioritized criteria. From the compared outcomes it was found that the most common significant factors influencing construction labor productivity in Iran are "Tools & Equipment" and "Delay." There is a need to notice, inform, and train our foremen and sub-contractors about the importance of productivity issues. It is also necessary for construction sites to be well equipped with the latest modern tools and equipment. Indeed, controlling and reducing delay has the ability to increase the labor productivity and the time cost deduction as well. The results of this study would be useful for civil engineers, construction project managers, consultants, contractors and any parties who are involved in Iranian or Middle Eastern construction projects, based on the similar structure of construction sites of that area.

The study also proposed the Key Labor Productivity Index (KLPI) as a measurement index in order to evaluate and estimate the level of labor productivity in construction sites. Moreover, the improvement techniques suggested, based on the Plan-Do-Check-Action (PDCA) management method, to achieve the highest desired level of labor productivity efficiently.

Despite completing all the objectives set out, this study has some limitations. , Firstly, the research uses only data from questionnaire surveys; there is a lack of case studies to be analyzed to get practical view about Level of Labor Productivity (LOLP) in the construction sites in Iran. Second, this study was conducted in context of Iran; therefore the findings may not be generalized to other geographical locations.

Recommendations are also made herein for further researches; Investigation of various case studies to get practical view of LOLP in Iran construction projects; associate a comparison between the result of this study in Iran and other countries in the Middle East, due to the similar structure of construction sites, to strengthen the validity of the findings.

APPENDIX

Questionnaire Survey 1:

Factors affecting labors productivity in construction sites

عوامل موثر بر بهره وری کارگران ساختمانی: مطالعه موردی ایران

Dear Colleague,
This survey is part of an academic research aims to evaluate the factors affecting labors productivity. The questionnaires are required to be filled with exact relevant facts as much as possible.
All data included in these questionnaires will be used only for academic research and will be strictly confidential. I highly appreciate for your participation in this survey.

همکار گرامی،
این نظرسنجی بخشی از یک تحقیق دانشگاهی با هدف بررسی عوامل موثر بر بهره وری کارگرمیباشد.تقاضا میشود پرسشنامه مطابق باحقایق رایج و دقیق
مربوطه پر شود .همه داده های موجود در این پرسشنامه تنها برای تحقیقات علمی استفاده می شود و محرمانه خواهد بود.
صمیمانه از شرکت شما در این نظرسنجی سپاسگزاریم.
پاینده باشید.

Part A) General Information

بخش الف (اطلاعات عمومی

1. - Experience:
Mark only one oval.
☐ 1-5 years
☐ 6-10 years
☐ 11-15 years
☐ > 16 years

2. -Which type of project are you mostly involved in?

Check all that apply.

☐ Building/Apartment/tower ساختمان / آپارتمان / برج

☐ Transportation حمل و نقل

☐ Harbor/ Dam بندر / سد

☐ Oil & gas نفت و گاز

3. - Quantity of construction labors in your recent project

Mark only one oval.

☐<100

☐100-500

☐500-1000

☐>1000

4. - Level of Education: * میزان تحصیلات:

Mark only one oval.

☐Associate degree کاردانی

☐Bachelor لیسانس

☐Master ارشد کارشناس

☐PhD دکترا

Part B) Evaluate Factors Affecting Labors Productivity

قسمت ب) بررسی عوامل موثر بر بهره وری کارگر

Dear colleague,
please rank these items as below:

همکار گرامی،
لطفاً آیتم های زیر را مطابق شرح زیررتبه بندی کنید.
قابل پرداختن نمیباشد : ۱
تاثیر نمی گذارد :۲
در حد متوس ط :۳
تاثیر گذار است :۴
کاملاً تاثیرگذار است : ۵

1. Age * سن

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

2. Personal problems * مشکلات شخصی

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

3. Lack of experience * کمبود تجربه

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

4. Disloyalty * ناسپاسی

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

5. Drug Addiction or Alcoholism * اعتیاد

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

6. Absenteeism * غیبت

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

7. Misunderstanding between labors * سوء تفاهم بین کارگر

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

12. 8. Lack of competition among the labors * نبود رقابت در میان کارگران

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

9. Rework * دوباره کاری

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

10. Control delays * کنترل تاخیر

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

11. Inspection delays from the authorities * تاخیر بازرسی مقامات

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

12. Variations in the drawings * تغییرات در طراحی

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

13. Incomplete drawings * طراحی های ناقص

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

14. Payment delays * تاخیر در پرداخت

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

15. Design changes * تغییرات طراحی

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

16. Disputes with the owners * اختلافات با پیمانکار

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

17. Misunderstanding between the owner, the contractor and the workers سوء تفاهم بین مالک، پیمانکار و

کارگران *

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

18. Change order from the designers * تغییرات ازجانب طراحان

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

19. Change orders from the owners * تغییرات ازجانب کارفرما

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

20. Poor site conditions * شرایط ضعیف سایت (کارگاه

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

21. Lack of required construction materials * کمبود مصالح ساختمانی مورد نیاز

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

22. Lack of required tools and/or equipment's * فقدان ابزار مورد نیاز و / یا تجهیزات

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

23. Differing site conditions from the plan * تفاوت شرایط سایت از طرح

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

24. Poor access within construction job site * دسترسی ضعیف درسایت

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

25. Insufficient lighting * روشنایی ناکافی

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

26. Inadequate construction method * روش ساخت و ساز ناکافی

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

27. Inadequate transportation facilities for workers * امکانات حمل و نقل ناکافی برای کارگران

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

28. Quality of required work * کیفیت کار مورد نیاز

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

29. Shortage of water and/or power supply * کمبود آب و یا منبع انرژی

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

30. Working overtime * اضافه کاری

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

31. Weather conditions * شرایط آب و هوا

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

32. Accidents during construction * حوادث در طول ساخت و ساز

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

33. Ambiguity of Project objective * ابهام درهدف پروژه

Mark only one oval.

☐1: Not applicable;

☐2: Does not affect it

☐3: Moderate

☐4: Somewhat affects it;

☐5: Directly affects

Questionnaire 2:

AHP Survey for Weightings of

Factors affecting Construction labors productivity

Dear Sir/ Madam:

This survey aims to assign the weight of each identified Factors affecting labors productivity by the AHP. Please rate the importance of each factor to each other as per given scales.

Description:

<u>Part 1.</u> Weightings

Rating scale

1	3	5	7	9
Both indicators are equally important	Weak importance (slightly better than other)	Strong importance(better than other)	Very strongly important (much better than other)	Absolutely important (much better than other)

<u>Example</u>: If you assess “Tools & Equipment” much more important than “Labour Characteristics” factor, please choose your answer as follows:

Factors affecting labors productivity	Level of importance																	Factors affecting labors productivity
	9		7		5		3		1		3		5		7		9	
Tools & Equipment			x															Labour Characteristics

Or if you assess “Labour Characteristics” absolutely much more important than “Tools & Equipment”, please choose your answer as follows:

Factors affecting labors productivity	Level of importance																	Factors affecting labors productivity
	9		7		5		3		1		3		5		7		9	
Tools & Equipment																	x	Labour Characteristics

Please tick (x) at the appropriate cell with regard to the importance level of the “Factors affecting labors productivity”.

Factors affecting labors productivity	Level of importance																	Factors affecting labors productivity
	9		7		5		3		1		3		5		7		9	
Tools & Equipment																		Labour Characteristics
Tools & Equipment																		Management
Tools & Equipment																		Delay
Tools & Equipment																		Safety & Communications
Tools & Equipment																		Misunderstanding between labors
Labour Characteristics																		Management
Labour Characteristics																		Delay
Labour Characteristics																		Safety & Communications
Labour Characteristics																		Misunderstanding between labors
Management																		Delay
Management																		Safety & Communications
Management																		Misunderstanding between labors
Delay																		Safety & Communications
Delay																		Misunderstanding between labors
Safety & Communications																		Misunderstanding between labors

Tools & Equipment:

Factors affecting labors productivity	9		7		5		3		1		3		5		7		9	Factors affecting labors productivity
Lack of required tools and/or equipment																		Inadequate construction method
Lack of required tools and/or equipment																		Weather conditions
Lack of required tools and/or equipment																		Shortage of water and/or power supply
Inadequate construction method																		Weather conditions
Inadequate construction method																		Shortage of water and/or power supply
Weather conditions																		Shortage of water and/or power supply

Labour Characteristics:

Factors affecting labors productivity	9		7		5		3		1		3		5		7		9	Factors affecting labors productivity
Age																		Lack of experience
Age																		Drug Addiction or Alcoholism
Age																		Absenteeism
Lack of experience																		Drug Addiction or Alcoholism
Lack of experience																		Absenteeism
Drug Addiction or Alcoholism																		Absenteeism

Management:

Factors affecting labors productivity	Level of importance																	Factors affecting labors productivity
	9		7		5		3		1		3		5		7		9	
Rework																		Incomplete drawings
Rework																		Control delays
Incomplete drawings																		Control delays

Delay:

Factors affecting labors productivity	Level of importance																	Factors affecting labors productivity
	9		7		5		3		1		3		5		7		9	
Payment delays																		Poor site conditions
Payment delays																		Misunderstanding between the owner, the contractor and the workers
Poor site conditions																		Misunderstanding between the owner, the contractor and the workers

Safety & communication:

Factors affecting labors productivity	Level of importance																	Factors affecting labors productivity
	9		7		5		3		1		3		5		7		9	
Accidents during construction																		Ambiguity of Project objective
Accidents during construction																		Disputes with the owners
Ambiguity of Project objective																		Disputes with the owners

Part 2. Personal Information

Please tell the researcher some information about you. Please mark "X" in the answer you choose:

1. Which organization are you working for?

☐ Owner ☐ Consultant ☐ Contractor ☐ Other: ………………………

2. Your experience?

☐ < 5 yrs ☐ 6-10 yrs ☐ 11-15 yrs ☐ 16-20 yrs ☐ > 20 yrs

3. Which type of project are you mostly involved in?

☐ Building/Apartment Construction ☐ Industrial construction ☐ Transportation

☐ Harbor/ Dam ☐ Oil & Gas ☐ Other: ……………………..….

4. Which size of project are you mostly involved in?

☐ < 1 Mil USD ☐ 1-5 USD ☐ 5-20 USD

☐ 20-100 USD ☐ > 100 USD

5. Your position in your organization?

☐ Staff/ Junior level of management

☐ Middle level of management

☐ Senior level of management

6. Your level of education?

☐ High school ☐ Intermediate/ College ☐ University degree

☐ Master's degree ☐ other: …………………………………………………………

Thank you for your participation!

-------& End &------

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