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Developing Activity Construction Labor Productivity Model: A Case Study on Meles Zenawi Leadership Academy Construction Project

By

Birhan Goshu Adisu

A thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

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Developing Activity Model for Predicting Construction labor Productivity

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Abstract

Productivity is an influential variable showing the economics of production activities. Higher productivity levels imply increased profitability and the ability to pay higher wages to workers. In the Ethiopian building industry, construction labor productivity loss is one of the severe problems. Since labor is more flexible and volatile than other project-cost components, it's necessary to understand the effects of the labor situation, which exist in the construction site and identify problem area that causes delay. To deal with this challenge, the study presents the methodology for the development of activity construction labor productivity models. To attain this objective, the subsequent procedures were followed: identifying seven process parameters that influence construction labor productivity, determine the observation method, determination of the minimum number of observations for study. The research conducted extensive field data collection from Meles Zenawi leadership academy construction projects in Addis Ababa covering a period of 4-months; and documented information using work sampling studies, foreman delay surveys, craftsman questionnaires, and productivity measurements. The validity of the data was tested to establish a 95 % confidence level. This helps to know errors that can be encounter during observation and hence, increase the reliability of data. A multivariable linear regression model for formwork, reinforcement, and concreting activities was developed to predict construction labor productivity. However, the models for concreting and reinforcement activity were limited to predict construction labor productivity. Travel, waiting and material handling for column formwork activities predict construction labor with a high degree of accuracy of 95.81% and R-square value of 98.5%. This indicates that the relationship between independent variables (travel, waiting, and material handling activity) and construction labor productivity of the developed models is good and the predicted construction labor productivity values fit with the real-life data. Overall significance tests and scatters plots were conducted to see the relationship between direct work and construction labor productivity. The result proves that direct work activity was not significantly correlated with construction labor productivity. Unavailability of material, poor site layout, crew failure to follow instructions, incomplete drawings, the low skill level of crew, waiting for other crews, and tools were the main causes of delay in the study area.

Keywords: Productivity, Work Sampling, Regression,

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Declaration

I, Birhan Goshu, declare that this thesis is my own original work and that it has not been presented and will not be presented to other universities for a similar or any other degree award.

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Birhan Goshu

Dedication

To my wife.

To my daughter

To, my great parents.

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List of Abbreviation

AA	Average Accuracy Percentage
ANN	Artificial Neural Network
CII	Construction Industry Institute
CLP	Construction Labor Productivity
CQ	Crafts Questionnaire
DS	Desired Sample Size
DV	Dependent Variable
FDS	Forman Delay Survey
FIS	Fuzzy Inference System Based On If-Then Rules and Linguistic Variables
IDV	Independent Variable
LBN	Labor Based Productivity
MAPE	Mean Absolute Percentage Error
NN	Neural Network
O	Output Parameter Representing CLP
P	Process Parameters Representing Work Sampling Proportions
P-h	Personal Hour
R	Correlation Coefficient
SPSS	Statistical Package for the Social Sciences
WS	Work Sampling
WSP	Work Sampling Proportions

Chapter 1 Introduction

1.1 Background

Construction productivity is the key indicator of the performance of the construction industry. To enhance this performance, the industry should be innovative similar to other industries like information technology. Although the industry progressive in recent decades, construction projects are, quite labor-intensive (Chan, 2004). Labor is one of the best flexible and largest cost factors in a construction project (Gouett et al, 2011). Therefore, studying and understanding of construction labor productivity provide better decisions for planning. To enhance labor productivity, an organization would know the present productivity status by comparing it with standard productivity (Gouett et al, 2011). However, predicting construction productivity is a challenging task due to the dynamic and stochastic nature of variables that affect construction labor productivity. For labor-intensive construction activities, the challenge of predicting construction labor productivity is more critical because multiple factors affect productivity, and these factors affect one another stochastically (Abdel-Razek, 2004). Those factors categorized input parameters and process parameters (Tsehayae, 2015). Input parameters refer to several factors and practices (e.g. crew size, crew composition, co-operation among craftsperson, location of project scope, complexity of task, weather, risk management practice, etc.), which either directly or indirectly influence construction labor productivity. Process parameters refer to work sampling proportions briefing the particular utilization of labor work hours and offer detailed inspection of what happens during the input to output conversion process (Tsehayae, 2015).

Work sampling is maybe a process that large amounts of observations are made at arbitrary time intervals over a period or a gaggle of machines, workers, or operations. Activity Analysis, an advanced form of work sampling, is another useful method developed by the construction industry institute (CII, 2010). Activity analysis is that the percentage of time that laborers spend on a specific activity like direct work, preparatory work, tool and equipment, material-handling, waiting, travel, and personal and provide a strategy for productivity improvement (CII, 2010). For construction managers, the direct-work rate is most vital because it quantifies the number of time workers is actively installing materials toward the completion of the project (Gouett et al, 2011). The direct-work rate often calculated employing a statistical work measurement method referred to as work or activity sampling. Observations of work are categorized, and therefore, the direct-work rate is calculated as the number of direct-work observations divided by the entire number of observations.

Recently, major construction and consulting companies to achieve improvement have adopted work sampling by benchmarking direct work rates with several construction projects. Therefore, activity analysis is taken as a valuable labor assessment system for labor productivity improvement study (CII, 2003). The main focus of this research was to present a methodology for the development of the construction labor productivity model. This introductory chapter offers a summary of the overall research. It comprises the research background, problem statement, research objective, limitation, and structure of the thesis.

1.2 Problem Statement

The Ethiopian construction industry is facing serious problems like cost and time overruns (Mekides, 2016). Accordingly, productivity improvement within the construction industry would be one of the vital ways of solving these problems. Hence, to improve the construction labor productivity, it is better to know the impact of both factors parameters (temperature, management, labor, and crew, etc.) and work sampling categories (direct work, preparatory work, tool and equipment, material handling, waiting, travel and personal) on construction labor productivity (Tsehayae et al, 2015). Therefore, this study focus on process parameters (direct work, preparatory work, tool and equipment, material handling, waiting, travel, and personal) that affect construction labor productivity. Process parameters (P) refers to observing the characteristics of labor's working behavior and categorized into seven activities and then see the impact of this behavior on construction labor productivity (Al-Zwainy, 2016).

1.3 Work Sampling Proportion

Work sampling proportion is a statistical method employed to conduct random observations of workers and determine the percentage of each seven work sampling categories (direct work, preparatory work, tool and equipment, material handling, waiting, travel, and personal) to the total observation of labor (Adrian, 2004). Work sampling proportions summarize the actual utilization of labor work hours using proportions of work time spent on performing work categories like direct work, support, etc., and provide an in-depth examination of what happens during the input to the output conversion process of an activity (Tsehayae, 2015).

1.4 Objective of the Study

The main goal of this study was to present a methodology for the development of activity construction labor productivity models that enable a better understanding of the process parameters (direct work, preparatory work, waiting, etc.) that influence construction labor productivity.

1.4.1 Specific Objective

Based on the problems stated, this study will be undertaken with the following specific objectives.

1. Develop activity construction productivity model by taking construction labor productivity (CLP) as an outcome variable and seven work sampling categories (direct work preparatory work, tool, and equipment, material handling, waiting, travel, and personal) as independent variables.
2. Test the fundamental assumption of activity models—that construction labor productivity (CLP) improves if more time is spent on direct work activities. There are two contrasting views of the relationship between direct work and construction labor productivity. The first view, conclude that direct work can predict construction labor productivity. The second assumption indicated that direct work is not related to productivity.
3. Identify the causes of delay in the study area.

1.5 Project Background

The data of this study were gathered from the project of building contractor, during 2018 between August 2018 and November 2018-time frame. The project is located in Addis Ababa, Ethiopia, and a project cost of 1.39 billion ETB. It is called Meles Zenawi leadership academy and it includes nine blocks (from the block 'A' to 'I') with heights ranging from seven stories to eleven stories. The academy will accommodate up to 4,000 students and its contract duration is three calendar years. The contractor mobilized a batch plant and equipment that would work fully for nine blocks at once. However, due to the design change of the blocks A, B, C, D, and I which is not ready yet, the plants, as well as equipment, are not working at their full efficiency. Hence, only block E, F, G, and H are at the construction stage so that the data of these studies were collected in these blocks.

During the data collection phase, two years already elapsed and the construction progress was 7% of the total volume of work because of blocks A, B, C, D, and I which were not started yet so that the cumulative project progress becomes low. The project manager explained that the project faced issues of incomplete design due to poor communication between the contractor and the consultant. Most of the buildings have been revised but the consultant did not yet submit the final drawings the consultant also supports this idea.

1.6 Research Limitation

1. Thomas (1991) has investigated the effects of overtime on construction labor productivity and the author has found that overtime was not only costly due to increased payment rate, but it also decreases construction labor productivity. For this study, data were collected daily, overtime study and factors were not included.

2. The study excluded those different purpose buildings like residential, commercial, storage buildings due to time constraints. Instead, this research focuses on institutional buildings.

3. The study did not include other trade like electrical, mechanical, and piping activities because of two reasons: (1) time constraint and (2) mechanical and piping activities were not ongoing activities, and also electrical activities were limited on conduit laying stage.

4. The model only considered confidence interval of 95% (a P-value < 0.05). However, productivity depends on not only the significant factors but also non-significant factor at a certain P-value.

1.7 Structure of the Thesis

Five chapters are written to present this thesis. Those are an introductory part of productivity, literature review, research methodology, data analysis, and result, and conclusion and recommendation.

Chapter 1 Introduction: Discuss construction labor productivity, problem statement, research background, limitation of the study, and structure of the thesis.

Chapter 2 Literature Review: Summarize literature reviews on the present construction models, productivity theories that are applied to predict construction productivity from professional journals, and a research paper is conferred.

Chapter 3 Research Methodology: Introduces the method utilized to produce the findings of the study supported general and specific objectives.

Chapter 4 Result and Discussion: Construction productivity models are developed with regression analysis while this research focuses on the concreting, formwork, and reinforcement activities.

Chapter 5 Conclusion and Recommendation: Summarizes the results and finding related to the process model for predicting construction productivity. Additionally, some areas that can be investigated in the future are mentioned.

Chapter 2 Literature Review

2.1 Introduction

The study focus on the process approach, involving process and output parameters, to see the influence of work sampling categories on construction labor productivity. Process variable states to work sampling proportions briefing the real utilization of work hours and provide a detailed investigation of the conversion process from input to output (Faye and Aminah Robinson, 2015).

These chapters explore the conceptual definition of construction labor productivity, existing construction models, work sampling proportion, and construction labor productivity with multivariate analysis. This model has a target on the identification of process parameters that affect productivity.

2.2 Definitions of Productivity

Productivity is maybe an ordinarily used term that is defined in many various ways. According to Abdel-Razek (2004), productivity is that the fraction of outputs of product to inputs of resources. It is taken as a fraction of the number of outputs produced to a specific measure of the number of inputs. It additionally defines the relationship between output and time it takes to accomplish it. Time may be a sensible divisor as a result of its standard measurement and it’s outside human management. The less time it takes to complete the specified result, the more productive the system. Rojas (2004) states productivity as a proportion of the particular quantity of output to some index of input use. In alternative words, productivity is simply the proportion between the quantity made and the quantity of any resources utilized throughout production. Generally, productivity will be outlined as the magnitude relation of outputs to inputs wherever outputs might be in units or money price of product or revenue made. Input might be in units about the price of labor, equipment, materials, and capital, therefore it's important to state the inputs and outputs measured once shrewd productivity.

Productivity is ordinarily thought to be a measure of an organization’s potency and measured at the national, organizational, project level. Productivity measured and quantifying the impact of such factors on productivity. At the national or macro, the level is used to form international appraisals and to trace management selections. At the organization level, productivity is also measured to either compare inter structure performance. Horner (2006) states that productivity may be a common link between price, time, and a key to performance. Krishna (2015) but, suggests that productivity isn't similar to performance.

Productivity is commonly regarded as a measure of an organization's efficiency and measured at the national, organizational, project level. Productivity measured and quantifying the impact of such factors on productivity. At the national or macro, the level is used to make international appraisals and to track management decisions. At the organization level, productivity may be measured to either compare inter organizational performance. Horner (2006) states that productivity is a common link between cost, time, and the key to improving performance. Krishna (2015) however, suggests that productivity is not the same as performance. Many workers perform actively but have low productivity due to ineffective work methods. The productivity may be high, however, with low performance, due to the use of automatic machinery, which controls the work. Quite often productivity measures and identified as labor productivity. This fact implies that industries characterized, as labor-intensive may not be treated equally concerning less labor-intensive industries.

2.3 Concept of Productivity

Construction labor productivity is multifarious and versatile. Hence, different approaches might be applied to forecast construction labor productivity (Hazrati, 2016). It has been taken in various contexts depends on the needs sought-after. The objectives successively govern the parameters concerned in its valuation in the relevancy of the quality used for its assessment. Owing to its importance to fight and world prosperity, the aim of productivity has been a matter of interest since the beginning of industrialization (Durdyev, 2011). It is one of the foremost noticeable basic variables leading to economic production activities. High productivity will be a considerable supply of competitive advantage for firms and the well-being of society.

The construction firms of productivity trends have outstanding effects on national productivity and the economy as a whole. The exaggerated pressure of worldwide competition forced companies and consultants to put bigger importance on productivity enhancements. Intensive discussions have resulted in multiple interpretations of the concept of productivity; despite the very fact that each scholar and practitioners use the term. It is interchangeably used with similar terms like profitableness and performance. Although the means of productivity is confusing, it couldn't be troublesome to acknowledge that includes the notion of avoiding wastes through suitably utilizing input resources, maximizing outputs in usable type, build most profit, and job security of the employees with higher financial gain (Tangen, 2006). By doing this, the welfare of the enterprises and the national development will be maintained.

2.4 Productivity and Construction

Productivity is one of the foremost influential variables leading to economic production activities (Kumar, 2000). Higher productivity levels let constructor's profitableness, increase competitiveness, and pay higher salaries to employees whereas finishing activities sooner (Rojas 2008). It may be often used but poorly outlined term that's typically confused with profitableness and performance (Pekuri, et al, 2011). Pekuri, et al, (2011) additionally outlined productivity as an obscure thought that looks-obsessed with the reviewer's purpose of reading and also the context within which it's used. Therefore, the definition of productivity might be clear inside the context outlined to produce the correct meaning. To grasp however productivity is outlined in an exceeding text, essential to explore the definitions of productivity and the way they're getting used within the industry.

2.5 Construction Labor Productivity

According to Jarkas (2012), construction productivity is mostly reliant on human effort and performance. Yi and Chan (2014) state labor productivity as an essential productivity index because of the concentration of human resources needed to finish a specific task. To calculate productivity, one should know cubic yards of concrete used in concrete placement activity and the work-hours needed to place concrete. Constructors are frequently interested in labor productivity at their project site.

2.6 Productivity Measurement on Construction Site

Even if each construction firm allowed developing their particular technique for quantifying construction work production on construction place, which is a better habit to establish a scheme that helps to use through time well as in varied situations. The substantial practice is needed to gather data nationwide through time to bring desired outcomes (Jarkas, 2012). The gathered production data comprise factors like the output of a worker, the influence of project scope, nature and place, and supplementary main project effects. To develop construction output, the measurement shall be valuable for collecting data. Finally, the data collected by construction firms should be correlated with actual output to get some predictable relation.

Consequently, this helps a construction firm to compare its output to the industry standard (Jarkas, 2012).

2.6.1 Activity Level Productivity

Measuring productivity at the activity level requires productivity to be more narrowly defined. Labor productivity, a suitable measure for this purpose, is defined as the ratio between work hours (output) and quantity (input) of individual activities shown in the following equation 2.1 (Thomas. 1991 and CII. 2013). This productivity focuses on individual activities such as formwork, concrete work, and reinforcement. It is a type of single-factor productivity and is also called unit rates. Labor productivity, one of the most objective and direct methods of measuring construction productivity (Liou and Borcherding, 1986), is the most widely used in the construction industry. Construction companies maintain this productivity internally to maintain their competitiveness in bidding or performing projects.

$$\text{Labor Productivity (Unit Rates)} = \frac{\text{Quantity}}{\text{workhours}} \ldots\ldots \text{Eq}(2.1)$$

2.6.1.1 Conversion Process of Input to Output of Construction Activity

The conversion from input to output process is the heart of managing any construction activity (Latzko, W. J. & Saunders, D. M. 1995).

The elementary process consists of three components: Input, Conversion, and Output.

Figure 2.1 Simple Process of Input to Output of Construction Activity

Input is that the process receives to implement the conversion. It has five components. These are material, machine or equipment, method, environment, and people.

1. **Material** is which one buys from a supplier. The supplier can be an outside source or it can be the department preceding the one under consideration. The material may be a physical item such as a steel bar, cement, forms, etc.
2. **Machine or equipment** refers to the equipment and tools used to process the material to transform it into the output. Equipment and tools can be trucks, crane, grinders, etc.
3. **The method** is the manner in that material to convert into output. Management often outlines the methods in the form of blueprints, formularies, or procedures. At other times management assumes that workers have a basic skill set which they will apply to convert the material into output.

4. **The Environment** is twofold: (1) physical and (2) managerial. The physical environment deals with issues of space, cleanliness of surroundings, temperature, and other similar factors that can have an impact on the performance of the worker and the output. The managerial environment deals with worker management interaction.
5. **Labor**. The people that operate the equipment or use tools to change the input to output.

Conversion is the interaction of the people with the other components of the input to change the material into the output.

The output is the result of the input (productivity) and the conversion thereof. We measure the output to determine that the process gives us the desired result.

2.7 Factors that affect construction labor productivity

Various scholars have divided factors that affect construction labor productivity into different groups. From previous research, numerous factors that affect labor productivity on construction projects were found. Knowing these issues helps to complete the project within the allocated budget and required contract duration. The classification of these factors in categories is supportive in giving a well understanding and in managing such factors.

Enshassi (2011) categorized the factors into 10 groups – that is, labor, leadership, motivation, time, materials, supervision, project, safety, quality, and external factors. Labor factors comprise a lack of labor experience, labor unfaithfulness, faults amongst labor, lack of competition, and labor personal problems. Leadership factors include poor communication between labor and superintendents and the absence of periodic conferences with labor. Motivation includes payment delay, lack of financial motivation systems, lack of places for eating and relaxation, and lack of training sessions. Time comprises misuse of schedule, work overtime, and increasing the number of labor to accelerate work, and working 7 days per week without taking any holidays.

Durdyeu (2011) states that a study on-site labor productivity in New Zealand categorized the factors in two groups: internal factors and external factors. Internal factors are categorized into project finance, workforce, technology project characteristics, and project management. External factors are unforeseen events (turmoil, inflation, natural hazards) economic and political influence.

Research conducted on the United Arab Emirates construction industry has presented that the factors affecting employee productivity are categorized into four different categories

(Ailabouni, 2009). These are environmental factors, group factors, and individual factors, and organizational factors. All these factors are summarized as shown in Table 2.1 below.

Table 2.1 Factors that Affect Construction Labor Productivity (Gorges, M. 2015)

Group	Factors
Material	Material shortages, tools and equipment scarcities, unsuitability of materials location, lack of material, delay in the arrival of materials
Management	Construction managers lack leadership, lack of labor supervision, working overtime, crew size, and composition, unsuitability of storage location, accidents as a result of poor site safety program, the proportion of work subcontracted, construction method, payment delay, incentive programs, competency of labor supervision, poor scheduling and coordination, inspection delay, misunderstand between labor or superintendents, work overtime, and lack of places for eating and relaxation for laborers.
External	High or low temperature, high humidity, high wind, rain, on-site accidents, ground conditions, natural disasters, energy crises or costs, fluctuations in the exchange rate, design changes, training sessions, security (crime and theft), access to finance, market inflation, access to utilities (electricity and water), and corruption.
Labor	The motivation of labor, the skill of labor, physical fatigue, a shortage of experienced labor, level of education, labor age, lack of competition, labor disloyalty, and labor personal problems.
Technological	Discrepancy between different documents, alteration through operation, low coordination among professionals, design complexity level, rework, site layout, and a site restricted access.
Organization Work	Discipline or hierarchy order, delegation, reward schemes, competencies of supervisor or managers, and management involvement and awareness.

2.8 Overtime Studies for Construction Productivity

Overtime is defined as the application of labor at a rate of more than eight hours a day, five days a week (Hanna, A. S., et al, 2005). Thomas (1992) defined overtime as "overtime schedule that lasts longer than several weeks". In the same way, the author defined "Extended Overtime" as "a work schedule that extends over more than 40 hours of work per week. The schedule is planned and lasts for at least three consecutive weeks, and typically longer" Thomas (1992).

Numerous researchers have investigated the effects of overtime on construction labor productivity and they have found that over time not only is costly due to increased payment rate, but it also decreases construction labor productivity. Lee (2005) stated that physical fatigue is the main reason for productivity loss during overtime operation. Moreover, Lee (2007) stated that fatigue de-motivates workers and it leads to increased error and poorer quality of work, which causes rework later). Kossoris (1944) stated that working overtime causes an increase in absenteeism rate because workers need time off to take care of personal things. Furthermore, over time causes loss of productivity through inability to provide materials, tools, equipment, and information on time which causes workers to work without accurate information and lack of tools (Thomas, H et al, 1997)

2.9 Techniques to Measure Labor Productivity

There are numerous methods available to evaluate and measure construction operations performance. The selection of the appropriate method for a particular project is another challenging task. Selection criteria were 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 of factors that have an 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.

2.9.1 Work Sampling

Work sampling is defined as “a productivity measurement technique used for the quantitative analysis, in terms of the time of the activities of worker or equipment” (H. R. Thomas and Holland, 1980). The method estimates the proportion of time workers are spending on activities such as installing materials, planning work, waiting, traveling, etc. (Liou and Borcherding, 1986; Picard, 2004). Work sampling is a statistical technique where an observer collects a series of random observations from the worker population (Jenkins and Orth, 2003; Picard, 2004). For each observation, the observer instantaneously determines the activity of the worker and then records it in one of several activity categories. The categories included in the most general work sampling study are direct-work, preparatory-work, tools-and-equipment, material-handling, waiting, traveling, and personal time. The proportion of time spent in each category is then determined by the percentage of observations of that activity from all of the observations. For example, if 331 direct-work observations are collected from 1000 observations, it is known that workers on that project spend an average of 33.1% of their time installing materials. Further, the statistical accuracy of this measurement can be determined by the number of samples collected.

Benefits of work sampling include:

Provides detailed information similar to continuous observation studies, but in less time and at a smaller cost;

- Ability to canvas an entire construction site.
- No disruption of the work activities of labor or foreman.
- Craft more likely to accept work sampling compared to continuous observation; and
- The desired level of accuracy possible through statistical techniques (Gouett, M. C.,et al, 2011).

Disadvantages of work sampling include:

- Less efficient on sites where labors are spaced further apart.
- Provides no information on specific crews.
- Observations need to adhere to stringent levels of accuracy.

2.9.1.1 Define Activity Categories

The classification of activity categories is essential to establish the activity groups based on what the results are used for (CII, 2010). Goutt et al (2011) has agreed to separate direct-work as its classification, though it may be known as effective or direct installation, and it is sometimes called “tool time”. The second classification is supportive work (also known as essential contributory work, or indirect work). This classification generally consists of preparatory-work, tools and equipment, and material handling. The final classification is a delay, but it has also been known as non-productive, ineffective, or idle. The remaining activity categories of waiting, travel, and personal are usually included here.

Direct-work

Direct-work is the act of exerting physical effort directed towards an activity or physically assisting in these activities. Specific examples of direct-work include:

- Removing trash, cleaning forms, placing concrete, assisting with excavations, distributing water, and assisting other crafts with direct-work.
- Carpenters erecting or dismantling scaffolding, erecting or stripping formwork, erecting or dismantling temporary structures, installing doors and finishes, or assisting with concrete pours.
- Pipefitters or boilermakers fitting, grinding or welding an installation, connecting a pump or other equipment, installing blinds, actively involved in a hydro test, or physically assisting with these activities.
- Teamsters driving trucks to laydown yards to pick-up materials, delivering materials, or transporting personnel.
- Ironworkers erecting, bolting, welding, or positioning steel, rigging material, flagging an operator.
- Ironworkers positioning, tying, or placing reinforcing bars or physically assisting with these activities.
- Concrete finishers actively engaged or assisting in a concrete pour, finishing concrete, covering or protecting concrete, or grouting.
- Operators lifting or transporting materials, or actively positioning equipment.
- Oilers actively engaged in maintenance of equipment, assisting with the placement of equipment, providing flagging, or rigging support.

Preparatory-work

Activities are related to receiving assignments and determining requirements before performing tasks.

Specific examples of direct-work include:

- Receiving instructions at the gang box or foreman's station.
- Receiving drawings, specifications, or other task-related and necessary information.
- Inspecting the work area with supervision, safety, or other craft workers to determine task requirements.
- Discussing material, tool, or equipment needs.

Tools-and-equipment

This category includes activities associated with obtaining, transporting, and adjusting tools or equipment in preparation for performing direct-work.

- Locating a grinder or other tool in a gang box and transporting it to the task area.

- Running welding leads to the work area or adjusting the welding machine.
- Connecting electrical supply or air supply to tools or construction equipment.
- Obtaining and transporting slings, shackles.
- Putting on safety harnesses, face shields protective equipment (PPE).
- Adjusting the location of a scissor.

Material-handling

This category includes transporting materials from one part of the facility to another. Examples of activities included are:
All craft persons physically carrying steel, pipe, insulation, etc. from one location to another.

Waiting

The activity category of waiting is defined as periods of waiting or idleness, even if attentive Work by others. Examples include:

- Waiting for instruction or job assignments from foreman or other supervisors.
- Waiting for a truck, crane, or bus to arrive to transport material or personnel.
- Waiting to gain access to the work area or for another craft to finish work.
- A pipefitter waiting for a welder.
- Electricians waiting for a cable pull.
- A rigger waiting for a crane hook to return for the next lift.

Travel

Travel activities include walking or riding empty-handed or without tools, materials, or technical information. Specific examples include:

- Any craftsperson walking or riding with an empty hand (carry normal tool belt tools, such as a carpenter with a hammer or an ironworker with a spud wrench, is considered travel.
- An operator of any equipment using the equipment to travel around the perimeter of the site.
- Workers traveling to and from work areas during normal working hours.

Personal

The personal category includes time taken during normal work hours. It includes:

- Rest periods or coffee breaks during normal work hours.
- Smoke breaks or snack breaks during normal work hours.

- Restroom or water breaks during normal work hours.
- Obvious socializing and non-attentiveness to work in the area.
- Sleeping during normal work.
- Donning or doffing or adjusting personal cloth.

2.9.2 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 (Tailor 1980). It was developed by. 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 (Meyers, 1992 and 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 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 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 deficiencies 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.

2.10 Activity Model

Activity models relate labor time utilization measures like work sampling proportions (i.e., process parameters) to construction labor productivity. How construction workers spend their working time is a great concern to construction companies. Under the influence of lean thinking in the construction industry, interest in labor time utilization and eliminating waste is rising (Yi and Chan 2014). Work sampling (WS), a widely used work-study method in the construction industry, uses random observation to investigate how labor uses its work time. Work sampling establishes the percentage of work time spent on categories, and direct work (tool time), which represents the proportion of work time spent exerting physical effort directed toward the completion of an activity, has been used as a surrogate measure of construction labor productivity (Thomas 1981; Gouett M.C et al, 2011).

The activity model is based on work sampling and is readily applicable to labor-intensive activities. A valid activity model is required to show that direct work times and outputs are related in some predictable fashion (Thomas et al. 1991; Yi and Chan 2014). There are two opposing views on the validity of activity models. For the most part, the literature argues that work sampling (WS) can be used to predict productivity (Josephson and Björkman 2013). Liou and Borcherding (1986) statistically proved that work sampling (WS) results strongly correlate with unit-rate productivity for power plant construction projects. By using 41 data points for concrete work elements, the Liou and Borcherding (1986) demonstrated a relationship between unit productivity (concrete man-hours/cubic yard) and different work sampling activity categories (direct work, material or equipment handling, late and break)

A detailed study on the Canadian housing sector showed that process variables could be used to indicate actual site productivity and crew learning rates (Handa and Abdalla 1989). A study on concreting operations of four commercial construction sites in Alberta, Canada, also developed an activity model, with a correlation coefficient of 0.90 between productivity (m3/hr) and tool ratio or direct work proportion (Silva and Ruwanpura 2006). Shahtaheri. (2014) assumed that labor performance can be improved by increasing the direct-work rate, and developed a fuzzy inference model to estimate appropriate baselines and set realistic goals for direct-work rate.

Conversely, Thomas (1991) stated that direct work is not related to productivity; using data from seven databases (five papers and two data sets) containing over 158 work sampling studies, mainly from nuclear power plant projects. An activity model study on wall building activities using work sampling observations also concluded that work sampling is not a strong predictor of productivity (Al–Ghamdi 1995). According to Al–Ghamdi (1995), the study which used work sampling data of six masons in 35 field experiments showed a correlation of coefficient of 0.498, -0.675, and -0.914, between direct or effective work categories and productivity, between support or essential contributory work categories and productivity, and delay or ineffective work categories, respectively.

2.11 Regression Analysis

Regression analyses are a set of statistical techniques that allow one to assess the relationship between one dependent variable (DV) and several independent variables (IDVs). The goal of regression is to arrive at the set of regression coefficient values, for the independent variables that bring the dependent variable values predicted from the equation as close as possible to the dependent variable values obtained by measurement (Tabachnick and Fidell, 2013).

According to Pallant (2005), the application of multiple regression to a data set involves a general two-step process. Initially, it is important to determine how well the model fits the data. If the model fit is questionable or of low quality, another model needs to be employed to better fit the data. After a quality fit is achieved, the coefficients of regression can be examined and applied to predict the values of the dependent variable.

The general form of the multiple regression equation is provided below (Gregory P., 2016):

$Y = b0 + b1X1 + b2X2 + bkXk$….Eq(2.2)

Where Y is the dependent variable; bo is the regression constant; b is the regression coefficient for the independent variables; X is the independent or predictor variables and k is the number of independent variables.

2.11.1 Correlation Analysis

The correlation coefficient is a statistical measure of the strength of a linear relationship between explanatory and outcome variables (James F, 2006). It measures the degree of correspondence between the ordering of two random variables. Correlation can be strongly correlated, weakly correlate, or no correlate by considering as one variable increases what happens to the other variable: nevertheless, the existence of a strong correlation does not specify a causative link between the variables. In short forms, it denoted by “r” and is by design constrained as follows.

-1<= r<=1, Furthermore, positive values denote positive linear correlation; negative values denote negative linear correlation; a value of zero denotes no linear correlation; the closer the value is to 1 or –1, the stronger the linear correlation.

2.11.2 Coefficient of Determination

The coefficient of determinations more valuable than the correlation coefficient in the sense that it gives a more reasonable statistical description of the relationship between the outcome and explanatory variable (AbouRizk and M.SongL, 2001). It denoted by R^2 and that is simply the square of a correlation coefficient. While the correlation coefficient only indicates the strength of the relationship in terms of a wisely chosen adjective, the coefficient of determination gives the variability in outcome variable clarified through the variability in explanatory variables.

2.11.3 Test of Significance Level

In linguistic, "significant" means essential, while in Statistics "significant" means probably true. A research finding may be true without being important. When statisticians say an outcome is "highly significant", they mean it is very probably true. They do not necessarily mean it is highly important.

Significance levels illustrate how likely an arrangement in the data is due to chance. The most common level used to mean something is good enough to believe is "0.95". This means that the outcome has a 95% chance of being true which means that the finding has a confidence degree 95% of being true. No statistical package will show you "95%" or ".95" to indicate this level. Instead, it will show you ".05," meaning that the result has a five percent (.05) chance of not being true "error", which is the converse of a 95% chance of being true. To find the significance level, subtract the number shown from one. For example, a value of ".01" means that there is a confidence degree 99% (1-.01=.99) chance of it being true.

In other words, the significance level "alpha level" for a given hypothesis test is a value for which a P-value "calculated value" less than or equal to is considered statistically significant. Typical value levels for are 0.1, 0.05, and 0.01. These value levels correspond to the probability of observing such an extreme value by chance. For example, if the P-value is 0.0082, so the probability of observing such a value by chance is less than 0.01, and the result is significant at the 0.01 level.

2.11.4 The Outputs of Regression

Running the regression might not essentially the simplest way to answer that question rather interpreting an output by doing a t-test, F- test an ANOVA and coefficient is vital (Cambell, 2008).

Unstandardized Coefficient for each one-unit increase within the explanatory variable, the construction labor productivity increase (if the sign of the coefficient is positive) or decrease (if the sign of the coefficient is negative) in some predictable fashion.

Standard Error (residual) if the regression were performed frequently on different datasets this can represent the standard deviation of the estimated coefficients.

T-Ratio the ratio of coefficient to the plain error that shows how large the coefficient is relative to what proportion it varies in repeated sampling. If the coefficient varies in repeated sampling, then its t-statistics going to be smaller, and if it varies little in repeated sampling, then its t-statistics going to be larger.

P-Value the p-value is that the outcome of the test of the subsequent null hypothesis: in repeated sampling, the mean of the estimated coefficient is zero. Generally, a p-value lower than some threshold, like 0.05 or 0.01 will mean that the coefficient is "statistically significant."

Confidence interval the 95% confidence interval is the set of values that lie within 1.96 standard deviations of the estimated.

R square this statistic represents the proportion of deviation within the outcome variable which is described via model (the remainder represents the proportion that's present within the error). It's also the square of the coefficient of correlation.

Variance Inflation Factors (VIFs) will not detect collinearity among predictors in regression models study explanation of collinearity and diagnostics like VIFs focused on numeric forecasters as being "co-linear" or "co-planar", with little attention paid to VIFs when a dummy variable is included within the model

2.11.5 Multilinearity

Variance inflation factors won't recognize collinearity among predictors during a multiple rectilinear regression model (Craney, 2002). High variance inflation factors indicate a rise within the variances of estimated regression coefficients owing to collinearity among predictor variables, over variances obtained when predictors are orthogonal (Hazati and

Ayoub, 2016). Models with collinearity have estimators with lower precision, with consequent problems in testing hypotheses. Activities that have a variance inflation factor greater than 10, indicating high multicollinearity (Tsehayae and Keith, 2015).

2.12 Factor Model

The factor model may be a multivariate regression method for modeling of construction productivity (Hazati and Ayoub, 2016). Quantification of things involves the statistical analysis of crew productivity and related factors and is represented mathematically within the following form:

M, = KH {q) + 2 tvc, + 2/(y)………………. Eq. (2.3) Where M = the particular crew productivity for a time t; and KH = the productivity for broad preparations of labor accomplished under standard conditions. Where productivity improves due to repetition, IUR may be a function of the number of quantities installed quantity. The factors expressed as binary (zero-one), integer, or continuous variables (H. Randolph Thomas, William F. Maloney, Members ASCE, 1990).

Data from thirteen projects compiled by (Sanders, S.R., and Thomas R.H, 1993) to review factors affecting masonry productivity. However, none of the info collected won't to develop the model. The databases including 465 samples were divided into two parts none disrupted or establish critical parameters, before proceeding with data collection and abnormal working days. Abnormal conditions were frequent results of disruptions like congestion, lack of materials, and inclemency. Only normal working days consisting of 286 samples were to develop the factor model.

2.13 Neural Network

An artificial neural network has a tough modeling technique with a dynamic learning mechanism and effective recognition capabilities to look at productivity under any specific situation (Chan, A and Scott 2004). Though neural network requires many numbers of data, newer construction productivity studies may emphasize the utilization of artificial neural networks (NNS).

Knowels (2001) presented a two-stage neural network model for forecasting construction productivity for concrete formwork activity in commercial walls and slabs, and industrial pipe handling and welding activities. AbouRizk and M.SongL (2001) established a three-layered feed-forward, back-propagation neural network model with a fuzzy output layer to estimate the likelihood of the assembly rate of concrete formwork activity. Sonmens and Rowings (2007), established productivity models for concrete pouring, formwork, and concrete finishing activities using neural networks. This model indicated that the neural network has the potential for a quantitative evaluation of the nonlinear effect of multiple interacting factors on construction productivity.

Moselhi, O, and Khan, Z (2012), utilized neural network for modeling the influence of change orders on -intensive tasks supported historical company-specific data. Ezeldin and Sharara (2006) developed construction productivity estimation models for formwork assembly, steel fixing, and concrete pouring activities using feed-forward back-propagation neural networks. This specified that the concrete pouring construction productivity model was the smallest amount of accurate one as compared to others. Oral (2012) compared the performance of feedforward neural networks, generalized regression neural networks, and self-organizing maps in forecasting construction crew productivity for plastering crews and showed that the self-organizing maps had better prediction ability. Gerk (2014) also compared the performance of feed-forward neural networks and radial basis neural networks in modeling the productivity of masonry crews and presented that radial basis neural networks performed better, although both slightly overestimated the masons' productivity.

Heravi and Eslamdoost (2015), studied the productivity of concreting work for gas, steam, and combined cycle power plant construction projects using neural networks. Neural networks are liable for an efficient tool for multifarious problems, like modeling construction productivity where the relationships between inputs and output cannot represent easily by mathematical functions (Moselhi, O., and Khan, Z., 2012). However, there are limitations to its application for construction productivity studies.

2.14 Inference Systems

As construction productivity modeling is a multifaceted problem with limited data availability; construction productivity modeling is an extraordinary target for another artificial intelligence technique: inference systems. Two types of inference systems are recognized as expert systems and fuzzy inference systems. While fuzzy inference systems are based on fuzzy logic and if-then rules, expert systems based on traditional two-valued logic systems. Expert systems used in construction productivity to forecast activity duration and productivity for masonry construction.

El-Rayes and Mosehli, (2001) also applied a database of climatic historical data and combined it with knowledge-based rules to create an expert system, called weather that could estimate the lost productivity due to rainfall on highway construction.

Researchers have found the use of fuzzy logic useful due to its focus on human thinking and natural language than the traditional two-valued logic systems (Mao, 1999). However, there are few applications of fuzzy logic in the construction productivity-modeling field (Yi and Chan, 2014). Mao (1999) of concrete wall formwork activity, and used assumed membership functions together with a rule-base developed based on historical data; however, the data used did not cover all input factors. Fayek, A. Robinson, and Oduba, A., (2005) also used fuzzy inference systems to model industrial pipe rigging and welding activities construction productivity, the models presented high linguistic accuracy but the numeric accuracy was low.

However, several limitations in inference systems were also observed. Expert systems are mainly advantageous in very narrowly defined problems; additionally, experts used to develop the systems might lack the ability to map the inputs with output, and expert systems cannot be adapted to changing environments (Lu, 2001).

2.15 Field Surveys

The work sampling approaches identify proficiencies in the site execution. However, it is unable to recognize the main reason for the delay operation (Gupta, 2019)). For example, work sampling might show that workers consumed the time late as the necessary material was not available. However, the technique able not to identify the actual source of delay (Gupta, 2019).

Field surveys are prepared ways of concerning the foreman or craftsman in the site valuation and output enhancement method. Craftsmen are perhaps the persons best aware of their work operation. Crafts simply recognize reasons for delays and problems in their evolvement in the construction site. Similarly, a foreman is a person in which most aware of the crew and the difficulties which limit progress in their output (Gupta, 2019).

2.15.1 Foreman Delay Survey

Foreman delay surveys are daily reports by the foreman which recapitulate issues that are badly affecting the productivity of their crew (Goutt, 2011). These productivity issues are outside the control of the foreman, and therefore imitate management's proficiency at planning work, and assigning tools, equipment, and materials (Gupta, 2019). At the end of each period, the foreman estimates the number of hours his crew was delayed. After the time lost to each delay has been estimated, the foreman multiples the lost time by the number of members in a crew to determine the overall time the crew lost to that delay. This is summarized in the following equation:

An hour delay =numbers hours' x number of a crew member

These specific delays summed; nevertheless, the relevant information is the amount of time lost on each specific delay, so that major delays are targeted first.

Foremen have the best knowledge of productivity issues affecting their crews. Foreman delay surveys allow the foreman to communicate these issues through a succinct list of items so that steps may be taken to correct these issues. If management effectively minimizes these issues, it is logical that the number of work-hours would decrease.

The benefits of the foreman delay survey include:

- ✓ A simple technique to measure and recognize outcomes.
- ✓ Data acquirement is fast and at a low cost.
- ✓ Can canvas the entire job site.
- ✓ Delivers specific delay evidence.

Disadvantages of foreman delay surveys include:

- ✓ More paperwork for foremen.
- ✓ Foremen may be concerned with consequences from the management; and potential for inaccurate results due to estimations.

2.15.2 Craftsman's Questionnaire

Craftsman's questionnaires were first developed in the 1960s, around the same time as foreman delay surveys. Similar to foreman surveys, craftsman's questionnaires attempt to enumerate time lost through requesting the opinion of someone confidentially involved in the workforce. Goutt (2011) indicated that simply asking the opinion of craft workers helped to ascertain weaknesses of the work process, create idea show to solve productivity issues, and disclose workers' frustration over lack of tools, equipment. It believed that most beneficial since it helped create a stronger site to management relationship.

Formal craftsman questionnaires aim to find inadequacies in the workforce. Questions of typical craftsman questionnaires emphasis on issues with materials, tools, equipment, scaffolds, rework crew interferences, information flow, inspection, and employee relations programs. The survey is meant to be anonymous so that workers can openly express their opinions. Typically, the only demographic questions asked are trade and area of the site. In this way, inadequacies are identified and may be improved upon.

Further, the surveys offer management with the ability to do the job for contrasts of working conditions, methods, and materials management. Regularly the surveys also recognize demotivating policies. One construction industry Institute research team recently worked to evolve old craftsman questionnaires into a more sophisticated valuation tool called the voice of the worker. In one study, the research team found improvements in the areas of construction equipment, project management, tools and consumables, supervisory direction, materials, and engineering drawing management within two months of initially completing a voice of the worker assessment.

Benefits of craftsman's questionnaire include:

- ✓ Data is simple to gather and examine.
- ✓ Can cover the entire site.
- ✓ Outcomes can be separated by craft or area.
- ✓ Delivers craft with a voice on important subjects (Goutt 2011).

Disadvantages of craftsman's questionnaire include:

- ✓ Craft may be concerned about the repercussions of management.
- ✓ Lower management may resent surveys.

2.16 Challenges of Predicting Construction Productivity

According to AbouRizk and Song (2001), the current trend of estimating and scheduling depends on several sources to get productivity values, including an estimator's judgments, public shed productivity data, and historical project data.

Forecasting productivity of construction activities due to the dynamic and stochastic nature of variables that affect construction productivity is a challenging task. In terms of intensive construction activities, the challenge of estimating and forecasting construction productivity is more critical because multiple issues affect productivity, and these factors affect each other stochastically.

The quantitative impact of one factor on productivity for numerous factors investigated by different researchers, but in a construction site, all factors may occur simultaneously. Since the goal is forecasting productivity, it is essential to consider the effects of all factors that have a possibility of happening. The need for a system that not only depicts cause-effect relationships among different influences but also visualizes the stochastic interactions among factors and productivity is crucial for forecasting construction productivity. Besides, there are situations where estimators use linguistic variables like “poor management skills” in their evaluation of productivity. In these situations, causal relationships among variables, randomness, and vagueness cause predicting construction productivity a challenging task.

2.17 Identified the Gap

As it studied in different countries, construction projects have been experiencing significant cost and time overruns, with low labor productivity identified as a major reason for project delays and cost overruns. To minimize these problems previous productivity studies mainly focus on factor and activity models, with input parameters (factors and practices), and process parameters to model the relationship between productivity and work sampling proportions (WSP). However, most of this study was not conducted in the Ethiopian construction industry.

Most of the study in the Ethiopian construction industry focuses on input parameters (factors that affect construction labor productivity) though construction labor productivity is also affected by process parameters (input to output conversion process). Therefore, this study presents a methodology development of the construction labor productivity model to see the impact process parameter (work sampling categories) on construction labor productivity.

2.18 Research Ethics Procedure

For the factor survey data collection phase, the following study ethics procedure was applied to the researcher to have respondents’ willingness in the research process by forming a good rapport through an introduction, explanation of the purpose of the study, and the benefits they obtain from this study. All information gotten from the respondents will be treated with confidentiality without disclosure of the respondents’ identity and, no information will modify or change.

For the field data collection phase, several processes were adopted. Several routes are required and selected randomly so that craft workers cannot forestall the time of observation and change their behavior accordingly (Jenkins and Orth, 2003). The observer should not use the same root repetitively, not to craft workers have the opportunity to signal fellow workers of an awaiting observation. This is the hawthorn effect and is a serious consideration for any activity using random routes that will help to reduce or eliminate this statistical bias (Groover, 2007). With a random route, the craft worker will be unaware of any pattern. When a route is randomly selected, it is also suggested that the start location be randomly selecte

CHAPTER 3 Research Methodology

3.1 Introduction

This chapter introduces the method used to produce the findings of the study based on general and specific objectives. The objective of the study is to present a methodology for the development of the construction labor productivity model. To attain this objective, the following procedures were followed.

1. Literature Review: Summarize literature reviews on the present construction models, productivity theories that are applied to predict construction productivity from professional journals, research reports, conference proceedings, theses, dissertations, and methods of productivity data analyses. The review enabled the researcher to better understand the current status of the field research.

2. Identification of Seven Process Parameters: Seven process parameters (direct work, preparatory work, tools and equipment, material handling, waiting, travel, and personal) that influences construction labor productivity were identified as shown in Table 3.1.

3. Determined Observation Method: Modified crew observation method was selected for observation to be economical and practical (Tsehayae, 2015). Hence, the modified crew observation technique was implemented and the observation emphases on representative crews performing on formwork, reinforcement, and concrete activities.

4. Determined Minimum Number of Observation for Study: Determining an adequate number of observations is critical to the significance of data collection for research. As more data from observations are collected, the results become more accurate due to the reduction of error. However, there is a balance between statistical accuracy and the cost/effort to collect observations. In most industries, an error of ± 5% at a confidence level of 95% is generally acceptable (CII, 2010).

5. Selecting Project and Activity: Meles Zenawi leadership academy (one project) as a case study and three activities: concreting, formwork and reinforcement activities were selected.

6. Data Collection Method: Data were collected from observation (to understand how workers spending their time during the workday), foreman delay survey and crafts questionnaire to (identify the causes of delay), and from a physical measurement of construction labor productivity.

7. Checking the Validity of the Data: The validity of data was checked by calculating the actual percentage error of each seven work sampling proportion and compare it with a 5% error (95% confidence level).

8. Developed Model: Based on the results, Linear and nonlinear Regression models were develop to predicting construction labor productivity of formwork, reinforcement, and concreting activities and discuss the results from testing this model.

9. Conclusions, Recommendations, and Future Research: Conclusions and recommendations were provided for this research. The conclusions included the result of the developed model, factors that cause delays in the study area. Besides, corrective actions and future research were recommended for other researchers who are interested in further research on this topic. The methodology can be explained clearly in the diagram shown in Figure 3.1.

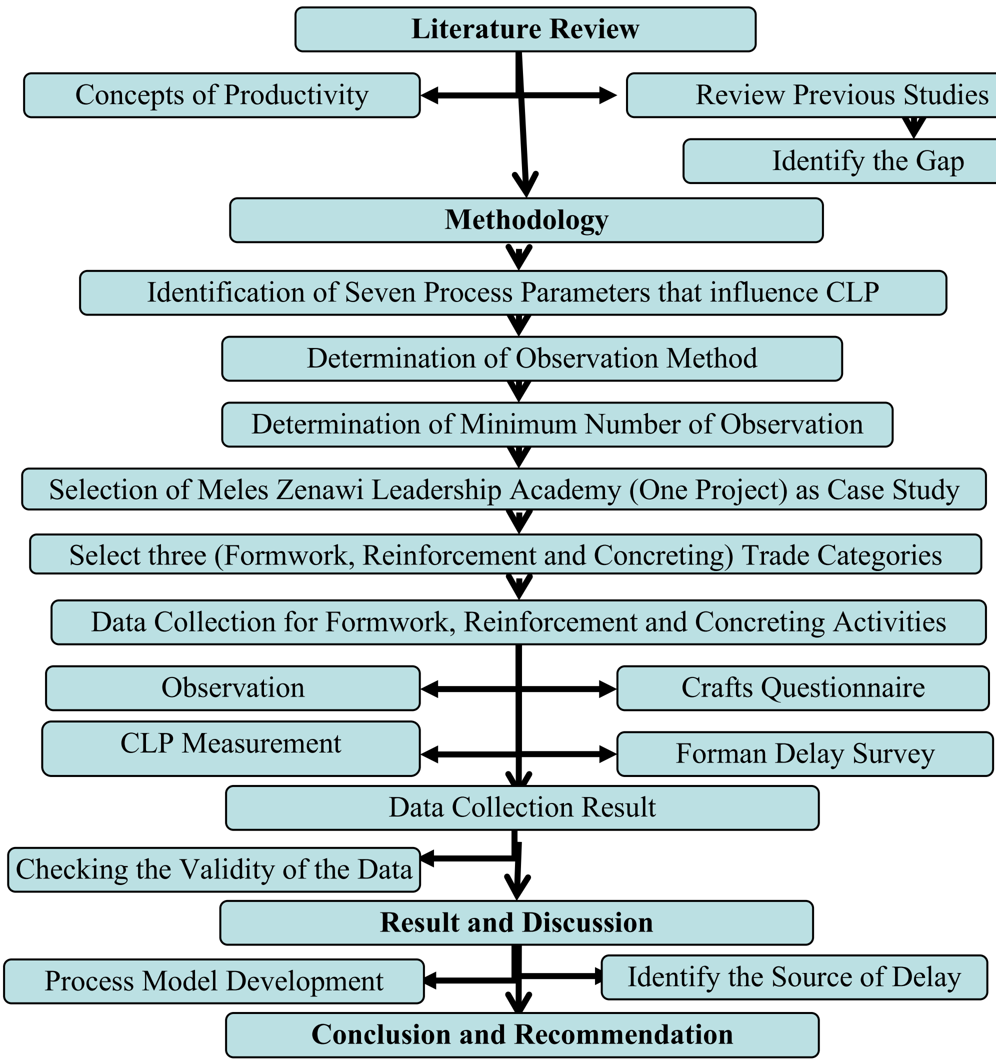

Figure 3.1 Research Methodology

3.2 Identification of Process Parameter that Influences Construction Labor Productivity

How time is used during the input-to-output conversion process is significant to knowing construction labor productivity; work-study methods are generally used for this purpose. Existing work-study data collection methods linked to construction labor productivity include work sampling, a five-minute rating, time studies, method productivity delay model, and crew balance charts (Tsehayae, 2015, and AbouRizk, 2001). For this study, work sampling is chosen because, the method show ineffectiveness and problem areas for the delay, it is simple, requires fewer resources to apply, and provides hasty results (Goutt et al, 2011). In work sampling (WS) studies, observers make continuous decisions in classifying the tasks a worker is carrying out and assign them to anyone of the work sampling categories. Thus, it is imperative that the work sampling categories are kept to a minimum and the definitions of the work sampling categories are standardized (Josephson and Björkman, 2013).

Construction industry Institute (2010) presented the guide to activity analysis, which standardized the technique for accompanying work sampling studies, and developed standard seven work sampling (WS) categories—direct work, preparatory work, tools and equipment, material handling, waiting, travel, and personal to study any construction activity (refer to Table 3.1). Therefore, these seven work-sampling categories are adopted in this study as process parameters, are used to see worker's behavior during the input to the output conversion process of an activity, and develop the input-process-output construction labor productivity models (Goutt et al, 2011). In Table 3.1, the identification labels of each process parameter are also included.

Table 3.1 Process Parameters (Work Sampling Proportions) Influencing Construction Labor Productivity (CLP)

Source	**(CII, 2013)**	
Work sampling categories (Process Parameter)	**Tasks**	Activity categories
Direct Work (X1)	Direct work is the performance of exerting physical effort focused on an activity or physically assisting in these activities involves workers installing materials, but also comprises the physical effort of support groups.	Productive Activities
Preparatory Work (X2)	Activities are related to getting assignments and determining necessities before performing tasks. Preparatory work includes stretching activities, safety talks, and consultations to explain or plan the allocated task at the work location. These discussions can take place between craft workers or between supervisors and craft workers.	Supportive Activities
Tools and Equipment (X3)	This category includes activities related to obtaining, transporting, and adjusting tools or equipment in preparation for performing direct work.	
Material Handling (X4)	This category includes transporting materials from one part of the facility to other moving items in the general area of the task or into their final position.	
Waiting (X5)	The activity category of waiting is defined as periods of waiting or idleness. Even if other workers are concentrating on the ongoing work.	Delayed Activity
Travel (X6)	Travel activities include walking or riding empty-handed or without tools, materials, or technical information.	
Personal (X7)	The personal category includes time taken or idleness during normal work hours and normally not attentive to work (this excludes normal breaks and a lunch period).	

3.3 Determining observation method

For observations to be economical and practical, selecting the observation method is vital in a work sampling study (Goutt et al, 2011). Therefore, three observation methods, namely the tour, crew, and modified crew observation methods are recommended (CII, 2010).

The Tour Approach: Observation method an observer samples on a random route throughout the construction site so that every worker may be included in the study. This approach gives the site management a good understanding of its effectiveness at planning for the entire site (Thomas, 1981 and Goutt et al, 2011). However, Thomas (1982) disapproves of the tour approach for two reasons. Firstly, he argues that walking the entire site means that the observer is unable to become familiar with workers, their work categories, and their daily tasks (Thomas 1982). Secondly, Thomas (1982) argues that because the tour approach includes samples from both critical and non-critical activities, management may assume that critical activities are progressing faster than actual because the inclusion of non-critical activities can distort the results (H. R. Thomas and Holland, 1982). To address these issues, a new sampling technique called the crew approach was proposed.

The Crew Approach: Studies only the activities of a few crews, usually those with critical path tasks (Thomas, 1982). In using this approach, the observer only samples a few crews and therefore becomes familiar with the workers. Using the crew approach usually means a more specific objective which will help to identify the delays and their causes. Thomas (1991) does admit that one drawback to this system is that only three to five crews can be sampled by one observer. It would be costly and impractical for management to have enough observers to cover the entire site in this manner.

The modified Crew Approach: In this approach, an observer would use the crew approach on several crews, all from the same worker. The observer would select one crew for each specific task that particular trade was completing at that time. For instance, if bar-benders were being studied, one crew bending reinforcement, one crew cutting reinforcement, one crew placing reinforcement, etc., would all be selected. Then these crews would be sampled, and the activity rates from the entire workers would be inferred based upon these results, despite the whole worker not being sampled (Thomas, H. R. 1991, Goutt et al, 2011). For this study, the modified crew observation method is adopted, and the work sampling observation centers on the study of representative crews performing selected activities.

3.4 Minimum Sample Size Determination

Thomas (1982) made the main contribution through his discussion about the sources of error in work sampling studies. Usually, an error can be considered as random or systematic. Systematic error is the bias that consistently occurs in a study. Thomas (1982) attempted to list the sources of systematic error, which he labeled as bias or omission errors:

- Human limitations (i.e. not all corners of a site can be observed).
- Procedural deficiencies which do not anticipate all possible issues that could arise while
- Sampling.
- Observer bias.
- Observer fatigue.

- Identification of the population in the study or not.
- Abnormal worker behavior (Thomas Jr. et al., 1982).

Sampling (random) error is the range of deviation of the filed observation from the real observation (Thomas Jr. et al., 1982). If the same character were observed multiple times, the range of results would develop the observation error. Observation errors are quantifiable using statistical equations. However, in many statistical sampling techniques, like work sampling, the observer selects a random error to limit to and determine the number of observations required. Many constructions and industrial engineering journals provide the following equation for determining a sufficient number of observation based on desired error (5%), for binomial distribution and (Picard, 2004; Thomas Jr. et al., 1982, Goutt et al 2011):

n= ((Za/2) P (1-p))/d^2 ……………….. (3.1)

where $Z\alpha/2$ is the standard normal variable corresponding to a confidence level of at 5% error, p is the expected each seven work sampling category percentage before the data collection stage, and d is the error between the actual observation percentage (work sampling percentage after observation) and the estimated observation percentage (estimated before observation). For a confidence level of 95%, $\alpha = 0.05$, and corresponds to a $Z\alpha/2 = 1.96$. The expected percentage p is unknown before the data collection stage, therefore, a value of 50% (0.5) used as a worst-case scenario ensuring the number of samples will be overestimated. As stated, the generally accepted values for these variables in the construction industry are $p = 0.5$, $Z\alpha/2 = 1.96$, and $d = 0.05$, which results in a total minimum sample size of 384 observations (Oglesby et al., 1989; Picard, 2004). Determining an adequate number of observations is critical to the accuracy of the work sampling study. As more observation is collected, the results become more accurate as observation error is reduced. However, there is a balance between statistical accuracy and the cost to collect samples. In most industries, an error of ± 5% at a confidence level of 95% is generally acceptable (Gouett, M. C., et al, 2011).

Equation 3.1 is applicable when the characteristic being sampled follows a binomial distribution; however, work sampling is multinomial distribution as there are seven work sampling categories (Gouett, M. C., et al, 2011). In sampling, a binomial distribution applies to two attributes. Either the observation falls into one attribute, or it doesn't and therefore is the other attribute. Binomial distribution would be valid for productive or unproductive categories, and direct-work or not direct-work categories. Work sampling generally has more than two categories, if the observation is not direct-work, it can be one of several other categories (preparatory work, or material handling or waiting or personal.) and so is multinomial. Therefore, Thomson (1987) develops equation 3.2 to determine a sufficient number of observations n in the worst-case scenario (50% of probability).

$$N = \max\{\frac{Z^2(1/m) \text{ or } Z\,1/\mathrm{m}(1-\frac{1}{\mathrm{m}})}{d^2} \ldots\ldots\ldots\ldots\ldots..3.2\}$$

$$N = \max\{\frac{1.96^2\left(\frac{1}{3}\right) \text{ or } 1.96\frac{1}{3}\left(1-\frac{1}{3}\right)}{0.05^2} = 510 \text{ or } 174.22$$

Where m is the value of work sampling categories (m=2 if the number of categories is two and m=3 if the number of categories greater than or equal to three. For this study, the number of categories is seven which is greater than three. Hence, m=3)

For a 95% confidence Z=1.96 and error of d = 0.05, and n = 510 observations by taking the maximum number of observations. If 510 or greater observation is collected in the field, then, the error for each seven work sampling category percentages (direct work, preparatory work, tools and equipment, material handling, waiting, travel, and personal) would be less than 5% (the observations have 95% chance free from error).

3.5 Selection of Project and Activities.

This research aims to present a methodology for the development of activity construction labor productivity models based on the process-output system variables. Thus, to achieve this objective, Meles Zenawi's leadership academy as a case study was purposively selected because this project had many labors with various positions, close proximity to the researcher and comprise the principal trade types (formwork, reinforcement, and concreting) for study. Besides, these trade categories (formwork, reinforcement, and concreting) were selected because these trades are, common among several projects, comprise of labor-intensive activities, and have higher man-hour for trade, and were comprised of major ongoing activities in the project. Major ongoing activities in this project were formwork, reinforcement, concrete pouring, and electrical activities (that is limited on conduit laying stage).

3.6 Data Collection Method

Methods used for data collection include observation, foreman delay survey, crafts questionnaire, and direct measurement for construction labor productivity. Work sampling helps to understand how workers spending their time during the workday while foreman delay survey and crafts questionnaire were used to identify the causes of delay in the construction site. For observation, only daily labors, carpenters, bar-benders, and masons were considered. However, foreman's, engineers, and management are not to be included in the study, since those skilled laborers do not complete direct-work activities, and are excluded as to not skew the results (Gouett et al, 2011). Each of the data collection method, mentioned above, explain briefly in the following section.

3.6.1 Execute Study for Work Sampling Observation

A comprehensive data collection, to Eighteen (18) carpenters, twenty-two (22) bar benders, and twelve (12) masons and sixty-five (65) daily labors on average, have been performed to understand the pattern of workers spending their time during the workday. The focus is not on what the person is doing but rather on the specific category (either in direct work or preparatory work or waiting etc.) he is falling in at any instant of observation.

The duration of the data collection covered four months (five-day workweek) from August 2010 to November 2011 E.C. A typical five-day workweek consisted of forty hours. The working day began at 8 am and ended at 5 pm and one hour allocated for a lunch break. Overtime work was not observed.

Work sampling assesses the portion of time, which is direct contributory comparative to the whole period that the labor participates in the process. To accomplish this, the following approach can be adopted (Gupta, 2019):

1. Established data collection form that would facilitate conducting the observations on site
2. Categorize the worker's activity as one of seven types of activity: direct work, preparatory work, tool, and equipment material handling, waiting, travel, and personal.
3. Took arbitrary observations of laborers participating in a particular execution in the site. The observation shows the labors' activity type, i.e. Direct work, preparatory work, tool, and equipment material handling, waiting, travel, and personal (Gupta, 2019).
4. Documented entire observations on the data collection form.
5. Add up all observations under each mode and calculate the percentage of activity. Before the beginning of the workday, the observer prepared enough blank data collection sheets for each one hour of study (Gouett, M. C., et al, 2011). The data collection form (Table 3.2) contains spaces to insert the date, time of each one-hour observation period, and task name. Just before the first study period of the day, the observer went to the arbitrary start location, of an arbitrarily selected route. The observer then walks along the pre-defined route, illustrating the activity of each worker seen (CII, 2003). As observers close a craft worker, they instantaneously categorize the craft and activity category of the craft. This is done from a distance of 15 meters because

this is close enough to make an accurate recording, but not close enough to cause worker discomfort (Gouett, M. C., et al, 2011). The observation must be made at first sight of the worker, and the observer must not reason about what the worker was doing, nor wait for a second to see what he does next. This is extremely important to ensure the accuracy of the results. For this study, the data collection form is shown in Table 3.2 and included a detailed presentation of the forms and instructions on how the forms should be filled.

Table 3.2 Work Sampling Data Collection Form

Date - 28/01/2011 E.C		Task Type -Formwork			Location – First floor			Working shift - Morning				
Observation Number		1	2	3	4	5	6	7	8	9	Sum	Percentage
Observation Time		08:08	08:19	08:26	08:34	08:38	08:43	08:50	09:00	09:06		
Work Sampling	Direct work											
	Preparatory work											
	Tools and equipment											
	Material handling											
	Waiting											
	Travel											
	Personal											
	Sum											

From Table 3.2, it can be noted that nine rounds of observations were recorded on an hourly basis for 4 months. The observer randomly noted labors at different paths on-site for each round by observing them, recording their activities into the standard mentioned categories, and denoted it by writing in the corresponding work sampling categories. Consequently, nine rounds were repeated for each hour and the number of observation at the end of the hours were recorded to display the number of labors corresponding to each category. The same exercise was repeated for all the hours of observations for four months and eventually summed up to reveal the total observations under the standard activity analysis procedure.

3.6.2 Foreman Delay Surveys

Foreman delay surveys aim to document the source of delays for each crew under study, as a foreman is the person furthermost aware of the crew and the difficulties that cause delays (Dozzi and AbouRizk 1993; Gupta, 2019). Foreman delay surveys help to collect accurate information on sources of delay and aid the measurement and improvement of productivity (Oglesby, 1989). Foreman collected either daily for several weeks, daily with weekly reporting, or as needed (CII, 2013). For this study, such surveys are collected daily, and at the end of the daily data collection process, the foreman estimated the number of hours lost due to the delay sources included in the survey, for each of the crews under observation. The number of workers affected and then summed to determine the overall lost work-hours of each shift multiplies each lost hour value. For this study, the data collection forms for the foreman delay survey are shown in Table 3.3.

Table 3.3 Foreman Delay Survey Form

	Person-Hours Lost per day			
Source of Problem	No. of Hours Lost	No. of Workers	Total Person-Hour lost	Average lost percentage
Rework (design error or change)				
Construction equipment breakdown				
Crew failure to follow instructions				
Finding materials				
Insufficient/incomplete drawings				
Low skill level of crew				
Waiting for construction equipment				
Waiting for decision				
Waiting for instruction				
Waiting for materials (warehouse)				
Waiting for other crews				
Waiting for tools				
Made by				
Date				

3.6.3 Craftsman Questionnaires

The purpose of the craftsman questionnaire is to classify the occurrence of common factors that inhibit the productivity of craft workers and to estimate the work-hours lost per craftsman per day (Hanna, 2010). Craftsman questionnaires are useful for identifying possible reasons for inefficiencies, delays, and available solutions, and offer a means of verifying other management reporting procedures and their results (CII, 2013). Craftsman questionnaires are collected either daily for several weeks or when needed (CII, 2013). In this study, the questionnaire is completed daily in an interview format to Eighteen (18) carpenters, twenty-two (22) bar benders, and twelve (12) masons. These laborers purposively selected because they permanent work throughout the work. For this study, the researcher has used the data collection form as shown in Table 3.4.

Table 3.4 Crafts Questionnaire Data Collection Form

Check appropriate in the box for yes or no and fill the box the required information	Yes	No
Material		
Is material always available when you need it?		
How many hours do you estimate are lost per week due to material not being available?	________hrs	
Tool and Equipment		
Are tools or equipment's always available when needed? Or the right ones for the job?		
Are there any specific tools or equipment in short supply or down? To repair?		
How many hours do you estimate are lost per week due to tools not being available or acceptable for the job?	________hrs	
Instruction		
Are work instructions properly communicated?		
Is work delayed due to confined space requirements?		
How many hours do you estimate are lost per week due to delays in instruction or permit?	________hrs	
Crew		
Do crew members follow instructions properly?		
Are foreman's and engineers transfer instructions to the labors properly?		
How many hours do you estimate are lost per week due to crew related problems?	________hrs	
Rework		
Is rework frequently done?		
How many hours do you estimate are lost per week due to rework?	________hrs	

3.6.4 Measurement of Construction Labor Productivity

The efficiency of activity level systems, concentrating on the labor crew of the construction process, is measured using construction labor productivity (CLP). In this study, construction labor productivity is defined as the ratio of units of output to units of input work hours—as shown in Eq. (3.3), where higher values are better than lower values.

$$\text{Construction labor productivity (CLP)} = \frac{\text{Output (installed quantity)}}{\text{Total lour work hour}} \dots\dots Eq. (3.3)$$

According to CII (2013), for the crew-output variable, the units of measurement for reporting quantities should be simple, easy to apply, and accurate. Numerous quantity measurement systems such as, units completed, percent complete, level of effort, incremental milestone, and start or finish percentage are help to calculate the output, in terms of installed quantities. The physical measurement of units completed is the favored output measurement, and is pertinent for activities with definite scope, few subtasks, single craft or trade, the short duration for completing every installed quantity can be quickly determined by counting or using elementary math (Tsehayaet al, 2015). For this study, the physical measurement of units was used to determine the installed quantities. The total labor work-hours were recorded based on the total person-hours the crew worked minus lunchtime and the recordings were made by the data collector.

3.7 Procedures that Used to Calculate Activity Percentage

The result of data from observation, foreman delay survey, and crafts questionnaire and productivity measurement will be present in the following ways by taking slab formwork activities as an example.

3.7.1 Calculating Procedure for Work Sampling Studies

When all one-hour observation periods have been completed, the results are organized, the distribution of time spent on activities is calculated, graphic presentations of the total overall results and the hourly breakdown are established, and the results are analyzed looking for productivity inhibitors. To illustrate the process of arranging and calculating the results, data from a field observation will be worked through. The study was comprised of 8 one-hour shifts over 38 days, thus there were 304 one-hour observation periods. The particular study used for this example was slab formwork. The completed data collection form in Table 3.2 was taken from this study. The calculations will show how to calculate percentages for the entire site.

3.7.1.1 Calculating Total Activity Observations

The observer randomly noted labors at different paths on-site for each round by observing them, recording the number of labors parallel to their activities, and denoted it by writing in the corresponding work sampling categories (either in direct work or preparatory work, etc.).

To calculate the total activity percentages for the entire study, the stages to follow include:

1. Adding hourly observations per work sampling categories on the observation worksheets to get daily each work sampling observation.
2. Adding total daily activity observations across all days to get total observations.
3. Calculating study activity percentages.

Table 3.5 Daily Activity Observation for Slab Formwork

Slab Formwork Activity Results													
	Daily Observation of Slab Formwork												
Work Sampling	day1	day2	day3	day4	day5	day6	day7	day8	day9	day10	day11	day12	da
Direct Work	32	22	31	34	28	21	24	21	27	20	26	29	
Preparatory Work	9	9	6	4	8	8	9	8	3	5	11	6	
Tools and Equipment	12	3	2	8	6	5	6	5	6	5	4	8	
Material Handling	7	10	9	9	9	6	9	6	3	10	7	5	
Waiting	9	9	13	1	12	6	14	6	9	2	10	13	
Travel	4	8	7	5	12	3	12	3	4	10	7	4	
Personal	5	12	3	6	7	2	7	2	8	3	1	3	
Work Sampling	day14	day15	day16	day17	day18	day19	day20	day21	day22	day23	day24	day25	da
Direct Work	32	35	19	24	33	27	22	17	23	26	24	25	
Preparatory Work	5	7	6	5	8	2	8	7	7	5	8	8	
Tools and Equipment	8	9	5	6	7	9	5	2	6	5	9	6	
Material Handling	9	6	8	10	10	3	12	11	12	10	7	4	
Waiting	16	13	9	14	9	4	10	12	16	15	10	9	
Travel	4	7	7	11	5	5	8	12	5	4	6	5	
Personal	9	4	3	3	6	1	2	7	7	9	8	4	
Work Sampling	day27	day28	day29	day30	day31	day32	day33	day34	day35	day36	day37	day38	
Direct Work	22	31	25	23	24	26	27	17	31	23	20	16	
Preparatory Work	8	6	5	8	4	7	4	4	9	4	5	4	
Tools and Equipment	4	9	10	11	5	7	9	9	9	6	4	6	
Material Handling	10	8	8	4	8	5	5	8	6	5	8	7	
Waiting	12	14	12	6	10	8	8	7	11	14	7	10	
Travel	6	10	9	3	3	3	7	6	10	8	6	2	
Personal	3	5	3	2	1	3	6	3	2	3	3	5	
Total Observation													
Summary of Activity Result													

Table 3.5 shows that there is a day to day variation of observation for the following possible reason. First, the characteristic being observed is not the workers, but instead the workers' behavior in the work at any one time. Hence, the worker's behavior that is being observed may change from time to time. Second, the number of workers that are being observed may vary due to the scope of work, absenteeism of workers, and completion time of activity. Finally, observer bias during observation may cause these variations.

The number of observations in each box on the example observation worksheet (Table 3.5) is summed and the result is placed in the right column of Table 3.5. These values are added to determine the number of observations for a specific activity across all crafts. For example, consider the number of direct work, preparatory work, tool and equipment, material handling, waiting, travel, and personal observations for the whole study period shown in Figure 3.6 for slab formwork.

$\text{Direct Work(DW)} = DW(D1 + D2 + D3 + \cdots D38), = 32 + 22 + 31 + \cdots 16 = 965$

$\text{Preparatory Work(PW)} = PW(D1 + D2 + D3 + \cdots D38), = 9 + 9 + 6 + \cdots 4 = 244$

$\text{Tool and Equipment(TE)} = TE(D1 + D2 + D3 + \cdots D38), = 12 + 3 + 2 + \cdots 6 = 252$

$\text{Material Handling(MH)} = MW(D1 + D2 + D3 + \cdots D38), = 7 + 10 + 9 + \cdots 7 = 288$

$\text{Waiting(W)} = W(D1 + D2 + D3 + \cdots D38), = 9 + 9 + 13 + \cdots 10 = 380$

$\text{Travel(T)} = T(D1 + D2 + D3 + \cdots D38), = 4 + 8 + 7 + \cdots 2 = 248$

$\text{Personal(P)} = P(D1 + D2 + D3 + \cdots D38), = 5 + 12 + 3 + \cdots 5 = 170$

$$\begin{aligned}\text{Total observation } &= \text{DW} + \text{PW} + \text{TE} + MW + W + T + P,\\ &= 965 + 244 + 252 + 288 + 380 + 248 + 170 = 2547\end{aligned}$$

A total of 2547 observations were collected in the 38 days of observation for slab formwork. This calculation is repeated for all activities and the result is reported in Table 3.6.

Table 3.6 Total Activity Observation

Trade Category	Activity Description	Number of Observation
Formwork	Fixing formwork for slab	2547
	Fixing formwork for column	1345
	Fixing formwork for shear wall	379
Reinforcement	Placing reinforcement for slab	1824
	Placing reinforcement for column	1534
	Placing reinforcement for beam	452
Concreting	Placing concrete for slab	2265
	Placing concrete for column	1928

From Table 3.6, it can be noted that limited observations are available for shear wall formwork and beam reinforcement activities because these values are less 510 observations for a 95% confidence level. Therefore, it will not be considered for model development.

3.7.1.2 Calculating Study Activity Percentages

Each activity percentage is calculated by the total of each activity category, taken from Table 3.5, and dividing by the total number of observations. This calculation can be represented by the following equation 3.4.

$$\text{Activity Percentage} = \frac{Each\ Activity\ Total}{Total\ Observation} \ldots\ldots\ldots\ldots\ldots\ldots.(3.4)$$

An example calculation for the direct-work percentage is given as follows:

$$Direct\ Work = \frac{965}{2547} \text{X } 100\% \ = 37.9\%$$

The site visited uses eight-hour shifts, therefore approximately 3 hours (0.38 x 8 hrs.) of each craft workers' day is spent directly installing materials to advance the project. The remaining time (5 hrs. per day) spent on supportive and delayed activities. For the remaining work sampling categories (preparatory work, tool and equipment, material handling, waiting, travel, and personal), the calculation is repeated similarly and is reported in the right-hand column of Table 3.7.

Table 3.7 Activity Percentage for Slab Formwork

Summary of Activity Result		
Work Sampling	Each Activity Observation	Percentage of Each Observation
Direct work	965	37.9%
Preparatory work	244	9.6%
Tools and equipment	252	9.9%
Material handling	288	11.3%
Waiting	380	14.9%
Travel	248	9.7%
Personal	170	6.7%
Total	2547	

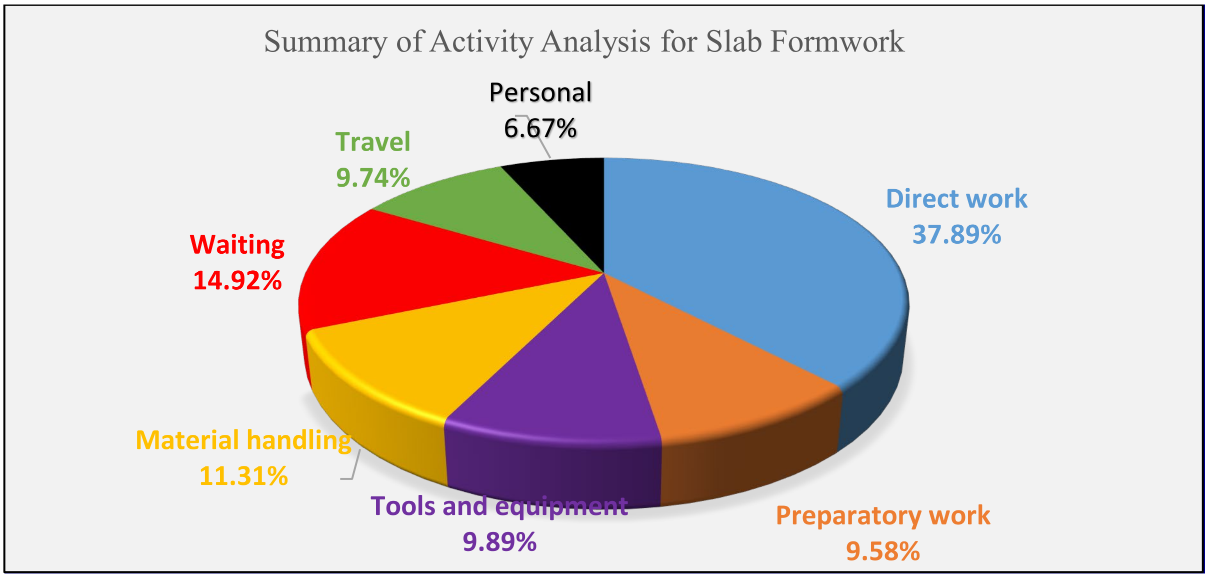

Figure 3.2 Pie Chart Illustrating Slab Formwork Activity Results

The pie chart shown in Figure 3.2 helps to demonstrate the percentage of a labors time spent in each category, and how reducing one category means there is more free time to complete direct-work activities. The pie chart for the example using the results in Table 3.7 is presented in Figure 3.2.

3.7.1.3 Calculating Actual Errors of Activity Percentage for Slab Formwork

With the activity percentages considered, the actual error of each percentage may be calculated using the binomial distribution. Seven (direct work, preparatory work, tool and equipment, material handling, waiting, travel, and personal) error calculations are completed, each considering only one group, which creates two attributes. For example, when considering the category of direct work, the observation either was direct-work (one attribute) or was not direct-work (the other attribute) (Gouett, M. C et al, 2011). The equation for error using the binomial distribution is as follows:

$$d = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} \ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Where d is the error, $Z\alpha/2 = 1.96$ correspondings to a confidence level of 95%, p is the activity percentage being considered, and n is the total number of observations. For this particular case, the total number of observations is 2547

The error for each activity percentage is calculated as follows

$$d(direct\ work) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.38(1-.38)}}{2547^{1/2}} = 1.88\%$$

$$d(Preparatory\ work) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.09(1-.09)}}{2547^{1/2}} = 1.11\%$$

$$d(Tool\ and\ Equipment) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.099(1-.099)}}{2547^{1/2}} = 1.16$$

$$d(Material\ Handling) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.11(1-.11)}}{2547^{1/2}} = 1.21\%$$

$$d(Waiting) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.15(1-.15)}}{2547^{1/2}} = 1.4\%$$

$$d(Travel) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.07(1-.07)}}{2547^{1/2}} = 0.99\%$$

$$d(Personal) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.1(1-.1)}}{2547^{1/2}} = 1.16\%$$

Every error reports the interval that activity percentage is valid at a stated confidence level. For instance, the direct-work rate is 38% ± 1.88% at a confidence of 95%. Because the sample size for the study is large, all errors are lesser than the typical construction industry rate of

5.0%. This calculation is repeated for column formwork and slab concreting activity included in the appendix.

3.7.1.4 Calculating Hourly Activity Percentage of Work Sampling Proportion

Hourly activity percentages can be calculated in the following ways.

1. The number of observations along each hour during the 38 days of study is required. For example, in the study hour of 8 am to 9 am, 267 observations for direct work were collected over the 38 days of study. This is illustrated by the following calculation.

$$Hourly\ Total\ (from\ 8am\ to\ 9am) = 67 + 53 + 29 + 47 + 33 + 19 + 18 = 267$$

2. Each activity percentage is calculated by summing the 38 hourly activity categories and dividing by the total number of hourly observations. This calculation can be represented by the following equation.

$$Hourly\ Activity\ Percentage = \frac{Day1 + Day2 + Day3 \ldots\ldots..Day38}{Total\ Number\ of\ Hourly\ Observation}\ x\ 100\%$$

$$Direct\ Work\ Activity\ Percentage\ (from\ 8am\ to\ 9am) = \frac{67}{267}\ x\ 100\% = 25\%$$

Table 3.8 Hourly Distribution of Slab Formwork Activity

	Time																
	8am-9am		9am-10am		10am-11am		11am-12pm		lunch	1pm-2pm		2pm-3pm		3pm-4pm		4pm-5pm	
WS	HA	P	HA	P	HA	P	HA	P		HA	P	HA	P	HA	P	HA	P
X1	67	25%	96	36%	115	39%	109	34%		81	28%	103	35%	141	42%	80	30%
X2	53	20%	45	17%	30	10%	30	9%		53	18%	34	11%	23	7%	28	10%
X3	29	11%	28	10%	30	10%	30	9%		26	9%	31	10%	33	10%	33	12%
X4	47	18%	33	12%	27	9%	29	9%		39	14%	34	11%	33	10%	27	10%
X5	33	12%	28	11%	46	16%	78	24%		49	17%	46	15%	53	16%	48	18%
X6	19	7%	23	8%	29	10%	32	10%		16	6%	31	10%	31	9%	42	15%
X7	18	7%	17	6%	20	7%	18	6%		26	9%	19	7%	20	6%	14	5%
Sum	267		270		297		325		-	291		297		334		271	

HA= stands for Hourly Activity, P= Percentage of slab formwork activities

Where x1 = Direct work, x2 = Preparatory work, x3 = Tools and Equipment, x4 =Material handling, x5 = Waiting, x6 = Travel and x7 = Personal:

The remaining hourly activity percentages from 8 am to 9 am study hours are calculated as below.

$$\text{Preparatory Work (from 8 am to 9 am)} = \frac{53}{267}\ \text{x}\ 100\% = 20\%$$

$$\text{Tool and Equipment (from 8 am to 9 am)} = \frac{29}{267}\ \text{x}\ 100\% = 11\%$$

$$\text{Material Handling (from 8 am to 9 am)} = \frac{47}{267}\ \text{x}\ 100\% = 18\%$$

$$\text{Waiting (from 8 am to 9 am)} = \frac{33}{267} \text{ x } 100\% = 12\%$$

$$\text{Travel (from 8am to 9am)} = \frac{19}{267} \text{ x } 100\% = 7\ \%$$

$$\text{Personal (from 8 am to 9 am)} = \frac{18}{267} \text{ x } 100\% = 6.9\%$$

These calculations are repeated for all study hours as shown in the previous Table 3.8

3.7.2 Calculating Construction Labor Productivity

Based on the physical measurement of units completed, construction labor productivity for slab formwork activities was calculated as shown in equation 3.7. Each productivity is calculated by production dividing by crew size and 8 working hours. For example, for day one productivity calculated as shown below.

$$Constuction\ labor\ productivity = \frac{Production}{Total\ Man\ Hours} \ldots\ldots\ldots\ldots\ldots (3.7)$$

$$CLP = \frac{Production}{crew\ size\ x\ 8hr} = \frac{42.56}{4\ x\ 8hr} = 1.33 \text{ M2/hr}$$

These calculations are repeated for all days and activities, the result shown in Table 3.9 for slab formwork. For column formwork and slab concreting activity, the results were included in appendix A.1 and A.2 for respectively.

Table 3.9 Result of Construction Labor Productivity for Slab Formwork

Day	Crew size	Production (M^2)	CLP(M^2/hr)	Day	Crew size	Production (M^2)	CLP (M^2/hr)
1	4	42.56	1.33	20	3	41.28	1.72
2	5	54	1.35	21	4	42.88	1.34
3	4	25.6	0.8	22	5	56	1.4
4	5	51.2	1.28	23	7	84	1.5
5	4	50.24	1.57	24	4	52.48	1.64
6	4	42.56	1.33	25	4	42.88	1.34
7	5	65.6	1.64	26	5	53.6	1.34
8	6	63.84	1.33	27	8	86.4	1.35
9	3	42.24	1.76	28	7	43.68	0.78
10	4	50.24	1.57	29	4	52.16	1.63
11	5	72	1.8	30	6	64.32	1.34
12	5	62	1.55	31	7	54.88	0.98
13	7	74.48	1.33	32	4	39.36	1.23
14	4	55.04	1.72	33	5	65.2	1.63
15	5	62	1.55	34	3	45.12	1.88
16	6	36.48	0.76	35	4	54.08	1.69
17	5	67.6	1.69	36	5	60	1.5
18	4	55.04	1.72	37	5	72	1.8
19	5	75.2	1.88	38	4	55.04	1.72
CLP= construction labor productivity,hr= hour, and M^2=square meter							

3.7.3 Factors and Extent of Delay on Construction Sites by Foreman Delay Survey

Foreman delay survey (FDS) relies on a questionnaire that is to be filled out by the job foreman at the end of a working day according to a particular survey schedule (Gouett, M.C et al 2011). The questionnaire helps to identify the number of hours of a day lost due to delays. Once a form has been filled out, the information is extracted in the form of percentages and action taken to ensure that sources of delays are properly dealt with. A result of foreman delay is shown in Table 3.10.

The data obtained from the foreman delay survey (FDS) contain the total number of production hours lost per day through the influence of nine factors. The factors have been ranked in Table 3.10, following the level of disruption (lost hours) to production.

Table 3.10 Factors and Extent of Delay on Construction Sites by Foreman Delay Survey

Source of Problem	Task Type - Formwork			
	No of labors	Maximum Man Hours = (No of labors x 8Hrs shift)	Average Daily lost Man Hours	Average daily Delay (%)
Waiting and finding for materials	14	112	45	8.70%
Waiting for instruction	11	88	29	5.60%
Crew failure to follow instructions	6	48	25.8	5.00%
Waiting for decision	10	80	16.2	3.10%
Insufficient incomplete drawings	8	64	14.6	2.80%
Breakdown of tools	5	40	13	2.50%
Waiting for tool and other crews	4	32	11.4	2.20%
Rework	6	48	5	1.00%
Construction equipment breakdown	1	8	0.1	0.00%
Sum	65	520	160	30.78%

Each lost man-hours' percentage is calculated by the lost hour per day and dividing by the sum of maximum man-hours available for work. For example, for Waiting and finding for materials calculated as

$$Average\ \ Dely\ per\ Day = \frac{Lost\ \ Hours\ Per\ day}{Sum\ of\ Maximum\ Man\ Hours} x100\% = \frac{45}{520} x = 8.7\%$$

These calculations are repeated for reinforcement and concreting activities.

3.8 Data matrix for SPSS

The data matrix is an association of scores in which lines represent subjects and columns represent variables (Tabachnick, 2013). For this study, the data matrix contains a percentage of observation and result of construction productivity appropriate for statistical data analysis through Statistical Package for the Social Sciences (SPSS) as shown in Table 3.11.

Table 3.11 Data Matrix for Slab Formwork Activities

Observtion Date	X1	X2	X3	X4	X5	X6	X7	CLP
1	0.45	0.17	0.06	0.11	0.15	0.11	0.02	1.33
2	0.32	0.16	0.07	0.17	0.16	0.04	0.08	1.35
3	0.30	0.12	0.04	0.14	0.12	0.11	0.16	0.8
4	0.36	0.06	0.13	0.14	0.02	0.08	0.09	1.28
5	0.36	0.07	0.11	0.14	0.16	0.09	0.07	1.57
6	0.36	0.09	0.09	0.18	0.04	0.18	0.05	1.33
7	0.42	0.09	0.08	0.12	0.14	0.11	0.05	1.64
8	0.36	0.09	0.14	0.12	0.19	0.06	0.04	1.33
9	0.41	0.10	0.12	0.10	0.14	0.07	0.06	1.76
10	0.38	0.16	0.06	0.13	0.15	0.10	0.01	1.57
11	0.42	0.09	0.12	0.07	0.19	0.06	0.04	1.8
12	0.34	0.12	0.11	0.14	0.20	0.08	0.02	1.55
13	0.37	0.10	0.07	0.10	0.15	0.13	0.08	1.33
14	0.36	0.10	0.07	0.11	0.14	0.14	0.08	1.72
15	0.40	0.05	0.04	0.14	0.12	0.11	0.16	1.55
16	0.36	0.13	0.13	0.09	0.09	0.06	0.06	1.76
17	0.41	0.13	0.19	0.11	0.10	0.13	0.04	1.69
18	0.39	0.06	0.10	0.11	0.19	0.05	0.11	1.72
19	0.40	0.09	0.10	0.05	0.16	0.07	0.14	1.88
20	0.37	0.10	0.14	0.11	0.19	0.05	0.04	1.72
21	0.40	0.15	0.12	0.12	0.12	0.06	0.04	1.34
22	0.37	0.13	0.12	0.16	0.15	0.07	0.06	1.4
23	0.32	0.08	0.12	0.14	0.20	0.04	0.10	1.5
24	0.43	0.08	0.11	0.12	0.01	0.07	0.08	1.64
25	0.41	0.12	0.15	0.09	0.12	0.05	0.06	1.34
26	0.44	0.08	0.03	0.13	0.18	0.10	0.04	1.34
27	0.35	0.10	0.08	0.18	0.15	0.06	0.08	1.35
28	0.25	0.10	0.15	0.10	0.15	0.12	0.13	0.78
29	0.27	0.11	0.09	0.12	0.20	0.17	0.05	1.63
30	0.36	0.09	0.11	0.18	0.04	0.18	0.04	1.34
31	0.34	0.15	0.08	0.13	0.18	0.10	0.03	0.98
32	0.36	0.10	0.07	0.11	0.14	0.14	0.08	1.23
33	0.29	0.09	0.08	0.12	0.14	0.11	0.05	1.63
34	0.35	0.10	0.12	0.06	0.16	0.13	0.08	1.88
35	0.41	0.17	0.09	0.11	0.13	0.06	0.04	1.69
36	0.47	0.09	0.09	0.15	0.13	0.06	0.02	1.5
37	0.32	0.10	0.13	0.09	0.19	0.10	0.06	1.8
38	0.35	0.10	0.07	0.10	0.16	0.14	0.08	1.72

Where x1 = Direct work, x2 = Preparatory work, x3 = Tools and Equipment, x4 =Material handling, x5 = Waiting, x6 = Travel, and x7 = Personal

Each daily productivity was taken from Table 3.9 and each work sampling proportion is calculated from Table 3.6 by taking the ratio of each work sampling observation to total observation for that day. For example, for day one, the direct work proportion calculated as

$$Day1(Direct\ Work) = \frac{Day\ one\ Direct\ Work\ Observation)}{Day\ one\ Total\ Number\ of\ 0bservation} = \frac{32}{78} = 0.45$$

These calculations are repeated for all observation and activities included in the appendix

Chapter 4 Result and Discussion

4.1 Introduction

This chapter describes results obtained from field observation and field surveys using Statistical Package for Social Science (SPSS) and Microsoft excel. This thesis aims to present a methodology for the development of process construction labor productivity models. This chapter presents the activity analysis, causes of delay in the site, construction labor productivity model development in line with the research objective. To achieve this objective, construction works of concreting, formwork, and reinforcement trade categories were selected. The trade categories, description of the activities, and the number of total data collected are shown in Table 4.1.

Table 4.1 Profile of Activities Studied for Process Modeling

Trade Category	Activity Description	Number of Data Instance
Formwork	Fixing formwork for slab	38
	Fixing formwork for column	72
	Fixing formwork for shear wall	21
Reinforcement	Placing reinforcement for slab	55
	Placing reinforcement for column	52
	Placing reinforcement for beam	18
Concreting	Placing concrete for slab	30
	Placing concrete for column	36

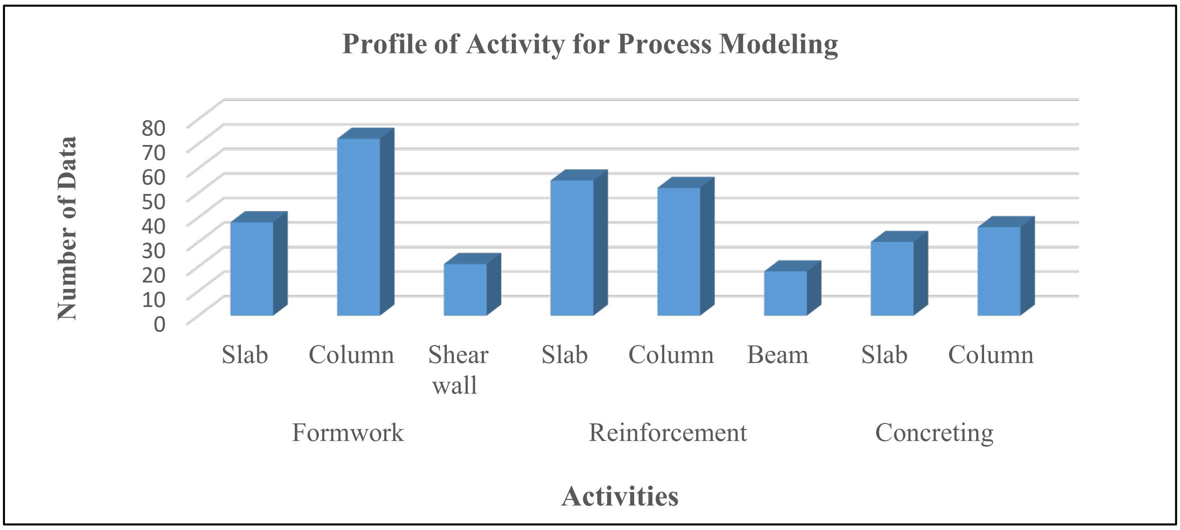

Figure 4.1 Profile of Activity Analysis

For this study, average hourly construction labor productivity and corresponding average hourly observation were considered as data. Therefore, for day one study period, work sampling proportion for direct work, preparatory work, tool and equipment, material handling, waiting, travel, and personal are 0.45, 0.17, 0.06, 0.11, 0.15, 0.11, and 0.02 respectively as shown in Table 3.11. The corresponding construction labor productivity is 1.33 M^2/hr. for slab formwork. This is considered, as one data and the total data instance is 38 for slab formwork. The same is true for other activities.

A total of 131, 125, and 66 data instances were recorded for formwork, reinforcement, and concreting trade categories, respectively. For each data-gathering occasion, work sampling was prepared for the crew understudy, and parameters, total person-hours, and installed quantities were recorded. For formwork, reinforcement, and concreting activity categories, 4271, 4193, and 3810 random work sampling observations respectively were prepared. Then, checking the data whether it is adequate to conduct linear regression or not based on the following assumption. The first assumption, the number of data in the situation must be higher than three times the number of independent variables otherwise; the regression coefficients would be untrustworthy (Mendenhall, 2011). The second assumption, the minimum number of data instances for any regression analysis is 30 (Green, 1991).

For this study, the numbers of the independent variables are seven so that the minimum number of data should be greater than 21 according to the first assumption. Therefore, beam reinforcement activities and shear wall formwork activities violate both of the above assumptions as shown in Figure 4.1, hence we've not considered it anymore. The other activities-column formwork, slab formwork, column reinforcement, slab reinforcement, slab, and column concreting activities were fulfilled the above two conditions of the minimum required several data for any regression analysis. Data on the outcome variable (productivity) and independent variables (direct work, preparatory work, tools and equipment, material handling waiting, travel, and personal) were considered. Productivity was calculated by dividing total quantities completed by the total work hours spent for a task as shown Equation (3.7).

4.2 Results from Work Sampling

Work sampling was applied in the construction industry to identify problem areas on time than the productivity metrics (Cheng,T et al, 2011). Choy and Ruwanpura (2006), McDonald and Zack (2006), CII (2010), and Tague et al. (2002) conducted that the composition of productive tool time on a construction site generally falls between 40% and 60% of the total work time. The studies also concluded that a considerable amount of time is spent mostly on nonproductive activities, such as searching for material, idling, and waiting for instructions. As a result, the construction and project management industries have already begun to experience an era of intensified research and development to handle the risks associated with construction (Nasirzadeh.F et al, 2016). Activity analysis also helps to illustrate the proportion of a craft worker's time spent in each category, and how reducing one category means there is more free time to complete direct-work activities. This can be illustrated for formwork, concreting, and reinforcement activities as shown in the following ways.

4.2.1 Activity Analysis for Formwork Activity

Activity analysis which illustrates the overall activity percentages determined from the study. Table 4.2 illustrates how large the proportion of each activity is, and how other activities need to be reduced to increase the direct-work rate. Activity analysis also shows an hourly distribution of activity percentages for a typical workday. This chart, called the column chart, is used to compare how activity percentages vary throughout the day.

Table 4.2 Average Formwork Activity Percentage

Work Sampling Categories		Slab Formwork		Column Formwork		Shear wall Formwork	
Seven Categories (SC)	Three Categories(TC)	SC	TC	SC	TC	SC	TC
Direct Work	Direct Work	37.9%	37.9%	38.2%	38.2%	32.1%	32.1%
Preparatory Work	Supportive Work	9.6%	30.8%	9.3%	32.1%	12.5%	27.1%
Tools and Equipment		9.9%		10.9%		6.4%	
Material Handling		11.3%		11.9%		8.2%	
Waiting	Delayed Work	14.9%	31.3%	15.4%	29.7%	10.1%	40.8%
Travel		9.7%		8.6%		13.1%	
Personal		6.7%		5.7%		17.6%	
SC and TC stands for Seven and Three, Work Sampling Categories Respectively							

Table 4.2, the direct work proportions observed in the slab formwork, column formwork, and shear wall formwork activity were 37.9%, 38.2%, and 32.1% respectively. These are lower than the general construction industry trend, where direct work proportions are reported to fall between 40 to 60% (CII 2010). Shear wall formwork also practiced the lowest direct work rate among formwork activities because of more indirect activities, reducing the time for direct work. It also reveals that the percentages of delayed work activity are high (40.8%) as compared

to slab and column formwork. A delayed activity percentage of 40.8% means that in a typical eight-hour work shift at this site, slightly more than 3 hours, is lost to delayed work activity. This is due to the high percentages of personal and traveling activity. High traveling percentages are often a result of the poor site layout. Due to the tool or material room is in an inconvenient location, high travel activity percentages will result. Other reasons include the longer distance from working areas to the site office. Further, necessary facilities like drinking water, toilet, etc., were not provided in the working area leading to increased traveling. Finally, late starts at beginning of workday, around lunch, and early quits at the end of the day increase personal activity. With the total site results considered, the analysis shifts focus to the hourly distribution of work activities as shown in Figure 4.2.

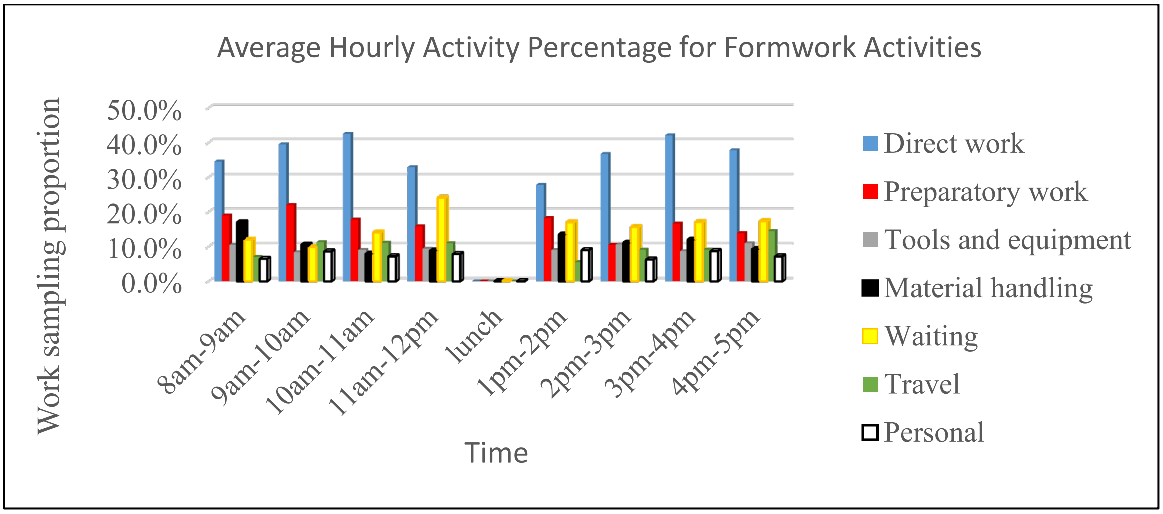

Figure 4.2 Average Hourly Activity Percentage for Formwork Activities

The hourly distribution chart indicates a slow start to the workday. This is indicated by a direct-work rate in the first hour of less than 35%. The chart also indicates that at the beginning of the day the preparatory work, and material handling activity percentages are higher than the overall average. This is logical since at the beginning of the day workers need to plan their work, get material, and move it to the work area, participate in safety talks, and do any necessary stretching. However, it would be ideal if these activities at the beginning of the day were minimized, so that the direct-work rate could ramp up faster. Further, the waiting activity percentage immediately before lunch is much too excessive. Hence, Supervisors should increase their presence on-site during this time.

The high travel activity percentage also recorded right at the end of the workday. Traveling is excessive right at the end as workers walk to from site to store or vice versa, to return the tool and material to the store. The tools-and-equipment activity percentage is also highest at the end of the day, which is typical of most construction projects since workers need to return tools.

4.2.2 Activity Analysis for Concreting Activity

Table 4.3 helps to illustrate the proportion of a craft worker's time spent in each category, and how reducing one category means there is more free time to complete direct-work activities. Further, Hourly distribution for concreting activity, is reported in the column chart shown in Figure 4.3, providing insights into the activity distribution per hour.

Table 4.3 Concreting Activity Percentage

Work Sampling Categories		Slab Concreting		Column Concreting	
Seven Categories (SC)	Three Categories (TC)	SC	TC	SC	TC
Direct work	Direct Work	45.44%	45.44%	42.90%	42.90%
Preparatory work	Supportive work	13.80%	33.40%	8.68%	31.70%
Tools and Equipment		13.70%		14.68%	
Material Handling		5.90%		8.34%	
Waiting	Delayed Work	8.73%	21.16%	11.50%	25.40%
Travel		8.68%		9.19%	
Personal		3.74%		4.71%	
					100.00%
SC and TC stands for Seven and Three, Work Sampling Categories respectively					

It is noted from Table 4.3 that the direct work proportions for concreting activities were had a high direct-work rate as compared to formwork and reinforcement activities. This is due to the reduction of delayed work compared to other activities more time available for direct installing activity. The direct proportion for slab and column concreting was 45.44% and 42.9% respectively. These values are in line with the general construction industry trend, where direct work proportions are reported to fall between 40% to 60% (CII 2010). Despite having high direct-work rates, the tools-and-equipment and preparatory-work rates are high. The excessive tools-and-equipment percentage could be caused by a poor tool management program which is not providing fully functioning tools. The layout of the site may need to be considered. The travel activity percentage also appears to be slightly high. Workers may be traveling long distances to tool rooms and gang boxes which is recorded as a travel observation when walking there empty-handed, and a tools-and-equipment observation when returning. Hourly distribution of concreting activity, shown in Figure 4.3, can give information activity distribution per hour and can be used to highlight the hours of maximum and minimum preparatory work and tool and equipment activity.

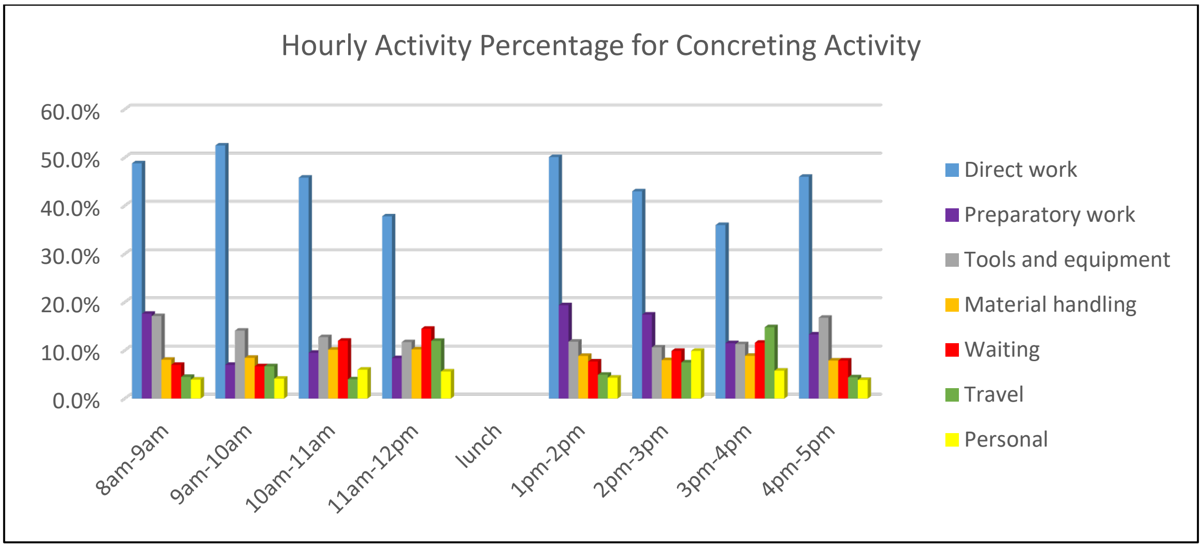

Figure 4.3 Average Hourly Activity Percentage for Concreting Activities

The hourly distribution of work activities, shown in Figure 4.3, indicates that the direct work rate rump up very quickly at the beginning of the day and after lunch. Besides, high levels of direct work are obtained in the early morning (9 am to 10 am). However, toward the end of the morning (10 am to 12 pm) waiting and tool end equipment activity percentages are highest. Hence, an increase in the tool and equipment and waiting activity percentages may drive the construction labor productivity down. Therefore, the manager should take the necessary action to minimize it.

4.2.3 Activity Analysis for Reinforcement Activity

As presented in Table 4.4, support activities share a large percentage following direct work and delay activity with values 35.1%, 33.5%, and 31.4% respectively for slab reinforcement. In beam reinforcement, the percentages of delayed work activity are high (43.5%) as compared to others. A delayed activity percentage of 43.5% means that in a typical eight-hour work shift at this site, slightly more than 3.4 hours (43.5% x 8) is lost to delayed work activity. This is due to the high percentages of waiting and personal activity. The direct work proportion for the column, beam, and slab reinforcement was 33.5%, 35.1%, and 29.2% respectively. These are also lower than the general construction industry trend, where direct work proportions are reported to fall between 40 to 60% (CII 2010).

Table 4.4 Average Reinforcement Activity Percentage

Work Sampling Categories		Slab Reinforcement		Column Reinforcement		Beam Reinforcement	
Seven Categories (SC)	Three Categories (TC)	SC	TC	SC	TC	SC	TC
Direct work	Direct Work	33.3%	33.5%	35.1%	35.1%	29.2%	29.2%
Preparatory work	Supportive Work	8.8%	35.1%	9.0%	34.7%	8.3%	27.3%
Tools and equipment		9.8%		10.4%		10.1%	
Material handling		16.5%		15.3%		17.0%	
Waiting	Delayed Work	12.8%	31.4%	13.8%	30.2%	16%	43.5%
Travel		11.3%		10.4%		11.5%	
Personal		7.3%		6.0%		13.9%	
SC and TC stands for Seven and Three, Work Sampling Categories respectively							

It is intuitive that to increase labor productivity, areas of lower productivity throughout the day should be avoided as much as possible. This can be done by proper planning and monitoring of overall work activities. Management should investigate into the fluctuating rate throughout the day and should take necessary action to minimize it. Further, it is recommended that site management should direct the labor to work in proper hours rather than starting the work late or leaving early from the site. Hourly direct work providing insights into the direct work distribution per hour and can be used to highlight the hours of maximum and minimum delay activity.

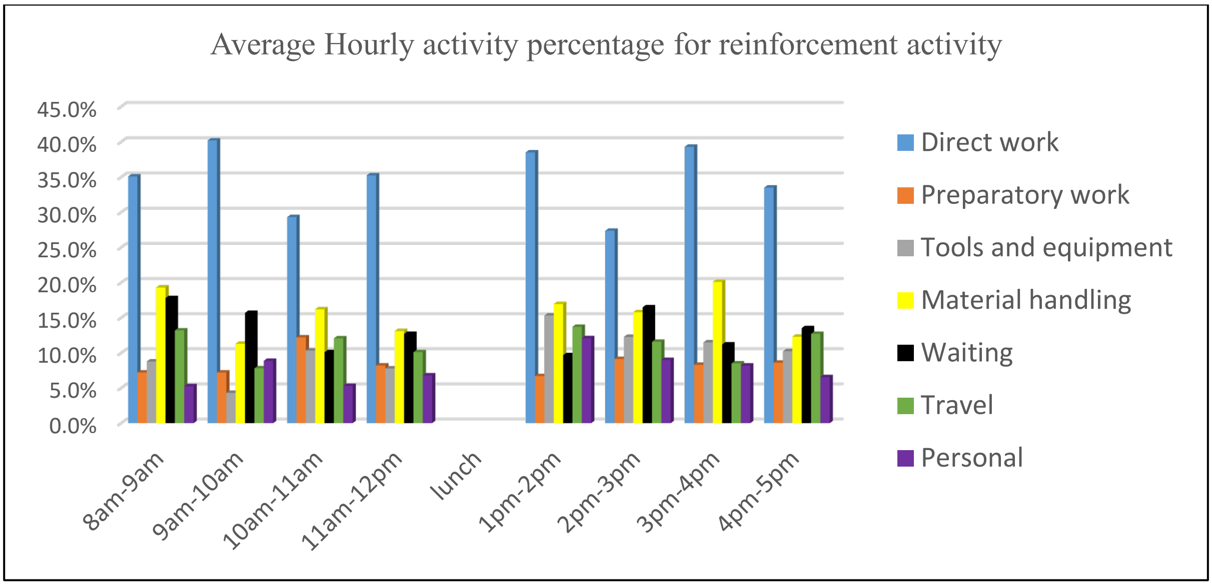

Figure 4.4 Average Hourly Activity Percentage for Reinforcement Activities

The hourly distribution of work activities, shown in Figure 4.4, indicates that the direct work rate rises very quickly at the beginning of the day and after lunch. This seems to indicate that workers have the notion to push and work harder to get all their work done for the day. Other good aspects seen in this chart is that the workers do not appear to be starting late or quitting early for the workday, nor the lunch break. Also, there is very little personal activity at the beginning of the day. This means management is getting work assignments to employees quickly. However, this is not reflected in the personal activity percentage after lunch. Management should consider this period after lunch and determine if any techniques are being used at the beginning of the day which is not being applied immediately after lunch.

4.3 Causes of Delay in the Study Area

The main shortcoming of activity analysis is that, unable to specify causes of delay in the construction site (CII, 2010). Hence foreman delay survey and crafts questionnaires were used to supplement the result of the work sampling proportion. The data obtained from the foreman delay survey (FDS) comprise the total percentage of production hours lost per day through the influence of factors. The factors have shown in Figure 4.5, following the level of lost hours to production.

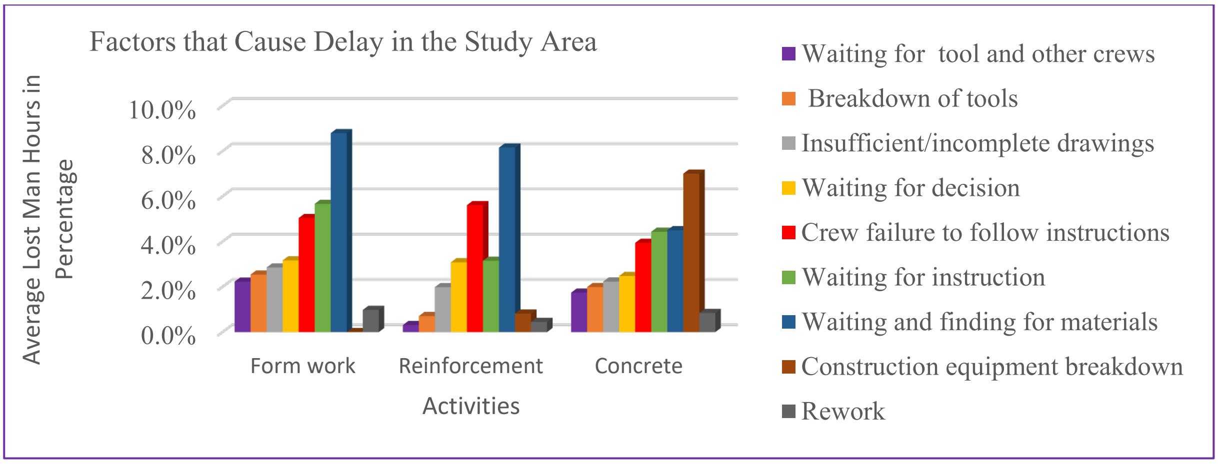

Figure 4.5 Sources of Problem

From the results in Figure 4.5, waiting and finding material, ranked first for formwork activities and reinforcement activities, and second for concreting activities. Waiting for instruction ranked second and third for formwork and reinforcement activities respectively. However, the breakdown of tools and equipment is higher for concreting activity as shown in Figure 4.5. Hence, Information and materials are essential at every phase of construction work. To raise labor productivity on construction sites, proper material management, and adequate information to labors become essential.

4.4 Crafts Questionnaire

The intention is to recognize leading issues, which hinder the output of laborers and evaluate the man-hours lost for each labor in a week due to particular reasons. The key issues that affect construction labor productivity shown in Table 4.5.

Table 4.5 Results from Crafts Questionnaire

Problem	Personal hours lost per week	Percentage of hours lost per week
Material shortage	4.5	9.4%
Unavailability or unsuitability of tool	3.2	6.7%
Unavailable of Equipment or down for repair	2.5	5.2%
Rework (design error)	1.4	2.9%
Total lost hours per week	11.6	24.2%
Total working hours per week per one craft	48	

The result in Table 4.5 revealed that material shortage (9.4%) and unavailability or unsuitability of tool (6.7%) are areas of major concern: this is due to the poor site layout.

From the result of the foreman delay survey and crafts question, the following causes of delay were identified in the study area. Those are, poor site layout, crew failure to follow instructions, finding materials, incomplete drawings, incorrect number of crew and low skill level of crew and waiting for, construction equipment, decision, instruction, materials, other crews, and tools.

4.4.1 Poor Site Layout

Labors travel long distances to acquire items that they frequently use because the store is not close enough from the construction site. This affects construction productivity because laborers waste much time on moving rather than working.

Disorganized material yard: excessive work-hours spent searching for specific materials, and costs due to materials ultimately deemed lost. In terms of excessive material-handling rates, the use of many work hours to find materials is concerning. If material yards were organized, materials could be located quickly.

Another contributor to poor labor productivity is damaged or incorrect materials. When a worker receives a material that is either damaged or incorrect, the worker may return the material and ensure another gets ordered. In terms of productivity, this disturbs the work sequence and causes waiting and extra planning as a new task for the crew is identified. Materials should be received, stored, retrieved when needed, and then conveyed to the site.

4.4.2 Crew Failure to Follow Instructions

Mostly the crew failed to follow instructions from engineers and foreman due to lack of, information and experience. These factors result in labors spending additional time to identifying which tools, equipment, and materials were essential for the job. Therefore, the management should concern detail work breakdown that comprises an outline of the work tasks, and the required tools, equipment, and materials, much of this planning has to be done at the workers. If work breaks down provided upfront, the level of detail of these packages should be analyzed, and increasing the level of detail should be considered.

4.4.3 Incomplete and Insufficient drawing.

Interview from the project manager and site engineers revealed that the project faced issues of the incompleteness of the design and poor communication between the contractor and the consultant. Most of the buildings revised but the consultant did not submit yet the final drawings as soon as possible. The consultant also supports this idea.

4.4.4 Incorrect Number of Crew

Poor planning is the most common source of delay in construction. Sometimes crews found themselves waiting on other crews. Crews often had to wait for other crews to complete work that is a prerequisite for their work. On the other hand, the crew may need another crew to vacate space physically require.

4.4.5 Inexperienced Labor

Information obtained from the project manager and foreman, most daily labors were not trained very well and inexperienced. The inexperience of craft workers severely affect output and diminished the quality of work produced. To minimize this problem, provide proper training to workers and inexperienced workers, commonly consult with more experienced workers to answer questions regarding.

4.4.6 Broken Tools and Equipment

The tool management program must monitor and remediate broken tools (Gouett, M. C.,et al 2011). A formal process needs to be instituted to evaluate the situations of tools repeatedly and have them repaired or replaced as required.

When labor receives a broken tool, two situations exist. Firstly, struggling with tools when accomplishing tasks, needing to constantly adjust it, or make minor repairs at the workforce (Gouett, M. C.,et al 2011). The second option is that the worker returns the tool. If the tool originated from the tool room, it should be noted that the tool is broken and should not go back out to the worksite until repaired or replaced. However, if the tool came from the gang box, it may not be recorded, and eventually, another worker will select that tool and have the same issues, thus wasting more time. It should be site policy that all broken tools be brought to the tool room, recorded, and have the item replaced in the gang box as soon as possible. For this study, the breakdown of the tool is the main problem for concreting activities as shown in Figure 4.3.

4.5 Development of Multivariable Linear Regression Model

Multiple regression is also a family of systems that can be used to discover the association between one continuous outcome variable and several independent variables (Aiken, L. S., &

West, S. G, 1991). Multiple regression is based on correlation but allows a more sophisticated investigation of interrelationship surrounded by a set of variables (Miguez, 2013). This sorts it ideal for the investigation of more multifaceted real-life, rather than laboratory-based, research questions. To conduct multivariable linear regression, the following procedure is used as illustrated in Figure 4.6.

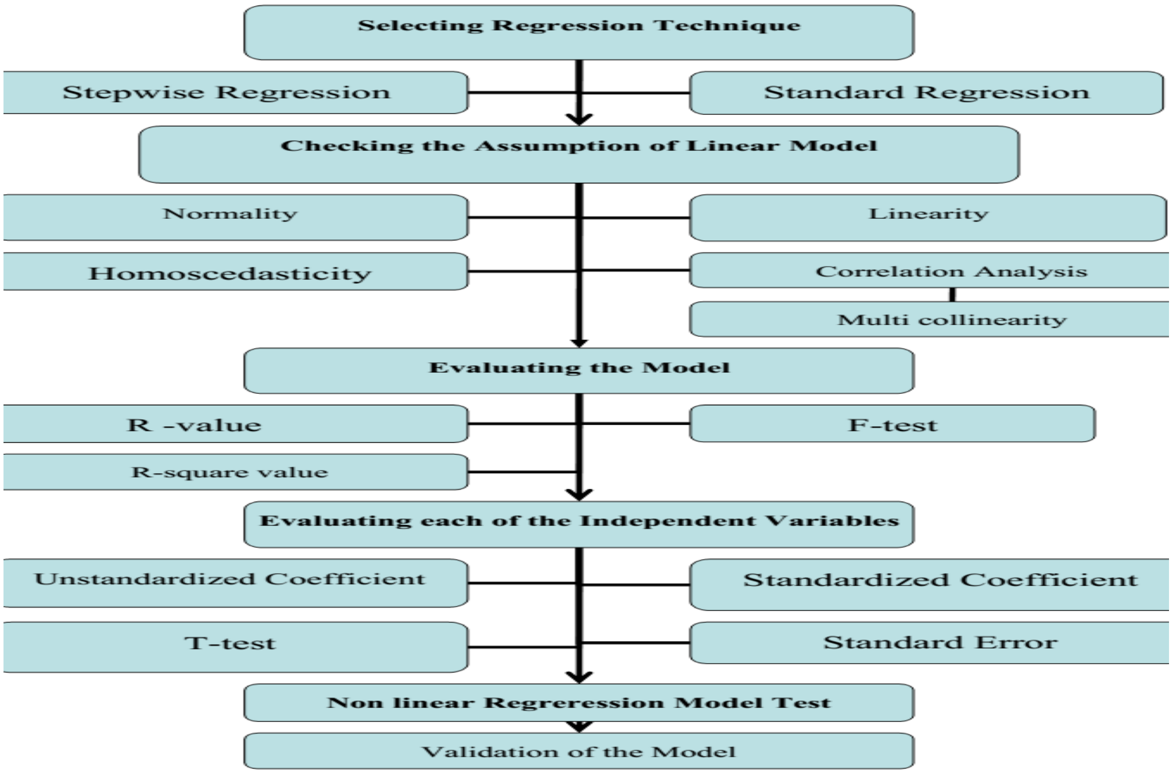

Figure 4.6 Multivariable Linear Regression Modeling Process

4.5.1 Linear Regression Variable Selection Methods

Multiple regressions offer information roughly the model as a whole and the comparative influence of the variables that make up the model (Aiken, 1991). As an extension of this, multiple regression help to test whether adding a variable contributes to the forecast of the model, over and above those variables already included in the model. In addition, multiple regressions use to statistically control for an additional variable when exploring the predictive ability of the model (Al-Zwainy, 2016). Two different types of multiple regression analysis techniques can be used, depending on the independent variable entered into the analysis. The two main types of multiple regression analyses are standard and stepwise regression (Miguez 2013).

4.5.1.1 Standard Multiple Regression

In standard multiple regression, all the independent variables are entered into the equation at the same time (Miguez, 2013). All independent variables evaluated in terms of its predictive power, over and above that offered by all the other independent variables. This is the most commonly used multiple regression analysis where predictors are lowest. This approach for a set of variables and wanted to know how much variance in a dependent variable was able to explain as a group or block (Pallet, 2005). This approach explained how much unique variance in the dependent variable each of the independent variables explained.

4.5.1.2 Stepwise Multiple Regression

In stepwise regression, the researcher provides a list of predictive variables and then lets the program to select which variables enter, and in which order goes into the equation, based on a set of statistical criteria (Tabachnick and Fidell, 2001). Decisions about which variables are included and which are omitted from the equation are based solely on statistics computed from the particular sample drawn. For this study, a stepwise regression technique is selected because this method helps to obtain the 'best' equation to predict the dependent variable (Shmueli, 2010).

4.5.2 Assumption of Multi-Variable Linear Relationship

Multiple regression is one of the full activity of statistical methods (Hayes, 2013). It has several expectations about the data, and it is not tolerant if those assumptions are violated. It is not the method to use on small samples, where the distribution of scores is much skewed. The following major assumptions should be fulfilled before conducting a linear regression technique (Pallant, 2005). Those are normality, linearity, Homoscedasticity, correlation, and multicollinearity. The SPSS procedures for testing this assumption are discussed in detail in the following ways.

4.5.2.1 Normality

Dependent variables have to be commonly distributed as entire and commonly distributed for each worth of variable (Stevens, 1996). This implies the normal distribution of the variable and linear relationship with the explanatory variables. If the relationships are linear and the variable is generally distributed for each worth of the variable, then the distribution of the residuals (the residual is that the discrepancy between the actual and the predicted productivity within the model) ought to be nearly normal. This is often assessed by employing a graph of histogram the standardized residuals.

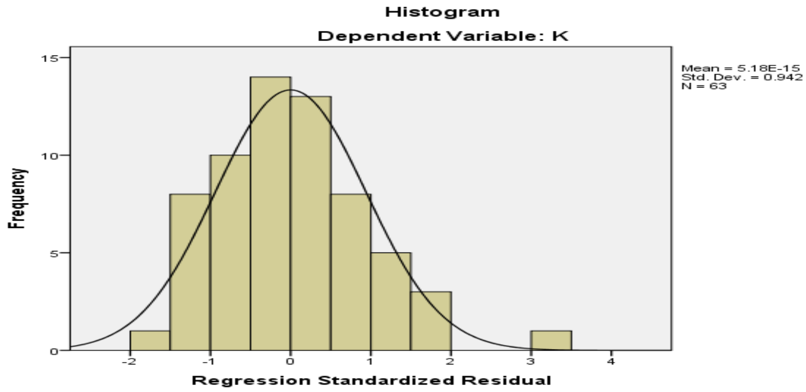

Figure 4.7 Histogram of Residuals with Normal Curve for Column Formwork Activities

The shape of the histogram in Figure 4.7 illustrates the marginal distribution of the residuals follows a normal distribution. Therefore, the belief of normality isn't profaned for column formwork activities. The graph of a histogram for slab concreting, included in the appendix, also show a similar result.

4.5.2.2 Homoscedasticity

For every worth of predictor, the distribution of the explanatory variables should have roughly equal variability (Aiken, 1991). To ascertain this assumption, the residuals may be plotted against the result (productivity) values and the explanatory variables. Once standardized observed productivity is plotted with predicted productivity, the information would type a line from the lower-left corner to the upper-right corner, if the model matches the information accurately (Tabachnick, 2013). In the Norman likelihood (probability) plot, Figure 4.8 illustrates that points be a straight diagonal line from bottom left to prime right. This could counsel no major deviations from homoscedasticity for column formwork activities. The normal likelihood graph for slab concreting, incorporated in the appendix, likewise show a similar result.

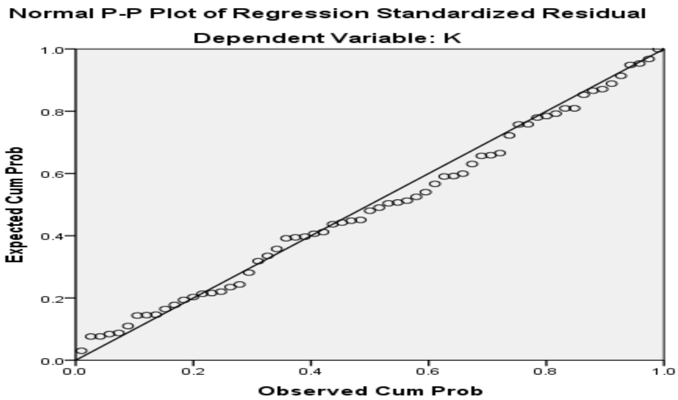

Figure 4.8 Normal Probability Plots Regression Standard Residual for Column Formwork Activities

4.5.2.3 Linearity

The linearity of the relationship between the expected dependent variable and residual prediction is additionally assumed. If nonlinearity is there, the form of the scatterplot is arching rather than rectangular (Tabachnick and Fidel, 2013). Within the scatter plot of the standardized residuals shown in Figure 4.9, the residuals are linearly distributed in rough rectangular with most of the scores concentrated within the center suggesting that there's a linear relationship between standardized predicted values and residuals. The scatter plots for the slab concreting activities, including in the appendix, also showed similar results.

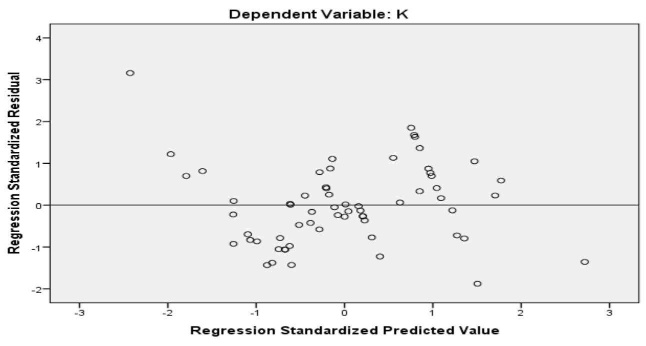

Figure 4.9 Scatter Plot of Predicted Values vs. Residuals for Column Formwork Activities

4.5.2.4 Correlation Analysis (R)

A correlation analysis had a correlation coefficient whose values vary from -1 to +1. A correlation of positive one indicates that the two variables are faultlessly related during a positive linear manner, and a correlation of negative one indicates that two variables are perfectly related during a negative linear manner, whereas a correlation of zero indicates that there's no linear relationship between the two variables being studied (Aggarwal R, 2016). According to Pallant (2005), the value of correlation tells whether the relation between variables is weak (0.1< = r < 0.3), medium (0.3 <= r < 0.5), strong (0.5<= r < 1) or no relationship in any respect. The take a look at multiple regressions is to ascertain correlations between dependent and independent variables different from zero (Pallant, 2005). Table 4.6 illustrates that each one activity has a correlation different from zero indicating that assumption of correlation is achieved. For column formwork activity, the strongest correlation may be seen from the inverse relationship between productivity, and travel, and waiting. Therefore, productivity tends to increase when waiting and travel on-site diminishes, which could be attributed to time available for work wasted rather than the direct installing of material (Chandana S.A and Siriwardana, 2017).

Table 4.6 Correlation: Work Sampling Proportion with CLP for column formwork Activity

		X1	X2	X3	X4	X5	X6	X7	K
X1	Pearson Correlation	1							
X2	Pearson Correlation	.262	1						
	Sig. (2-tailed)	.038							
X3	Pearson Correlation	-.12	-.01	1					
	Sig. (2-tailed)	.367	.978						
X4	Pearson Correlation	.34	-.05	-.067	1				
	Sig. (2-tailed)	.006	.672	.599					
X5	Pearson Correlation	-.23	-.27	-.021	.227	1			
	Sig. (2-tailed)	.077	.035	.873	.073				
X6	Pearson Correlation	-.36	-.25	.073	.279	.912	1		
	Sig. (2-tailed)	.03	.045	.571	.027	.000			
X7	Pearson Correlation	-.54	-.14	-.084	.274	.425	.544	1	
	Sig. (2-tailed)	.000	.277	.511	.030	.001	.000		
K	Pearson Correlation	.335	.264	-.057	.201	-.94	-.969	-.48	1
	Sig. (2-tailed)	.07	.066	.656	.115	.00	.000	.00	

The results of correlation analysis in Table 4.6 and correlation analysis for other activities in the appendix also showed that some of the independent variables are highly correlated to each other. Those variables are, waiting to correlate with travel, direct work correlates with personal and travels for column formwork, and slab formwork activates. Material handling activity percentage correlates with direct work for column reinforcement activities, waiting to correlate with direct work for slab concreting activities. Therefore, multi linearity should check whether the analysis continues or not.

4.5.2.5 Multicollinearity

Multicollinearity represents the situation in that predictor variables are highly correlated. When independent variables are multicollinear, there is an allocation of predictive power (Robert, 2006). This may lead to the contradictory effect, whereby the regression model fits the data well, however, none of the predictor variables has a significant impact in predicting the dependent variable in this case productivity. This is because once the predictor variables are highly correlated, they share fundamentally the same information (Robert,2006). Consequently, together may explain a great deal of the dependent variables, but may not individually contribute significantly to the model. So, the impact of multicollinearity is to reduce any individual independent variable's predictive power by the extent to which it is associated with the other independent variables. That is, none of the predictor variables may contribute uniquely and significantly to the prediction model after the others are included. In multivariable linear regression, it is possible to request the display of "Tolerance" and "variance inflation factor (VIF)" values for each predictor as a check for multicollinearity (See Table 4.7). A tolerance value is assigned to the percentage of variance in the predictor that cannot be accounted for by the other predictors. Hereafter, very small values indicate "overlap" or the sharing of predictive power (Pallant, 2005). Values that are less than 0.10 may merit further investigation. The variance inflation factor (VIF)", is computed as "1/tolerance," and it is suggested that predictor variables whose VIF values are greater than 10 may merit additional exploration.

For this study, the results are presented in Table 4.7 labeled coefficients. The tolerance value for each independent variable is greater than 0.1 and VIF is less than 10 as shown in Table 4.7; indicating that there is no problem of multicollinearity.

Table 4.7 Tolerance and Variance Inflation Factor for Independent Variables

Model Type		Tolerance	Variance inflation factor (VIF)
Column Formwork	Direct Work	.545	1.835
	Preparatory Work	.806	1.241
	Tool and Equipment	.901	1.110
	Material Handling	.772	1.295
	Waiting	.675	1.483
	Travel	.715	1.400
	Personal	.743	1.346
Slab Formwork	Direct Work	.470	2.126
	Preparatory Work	.643	1.554
	Tool and Equipment	.586	1.706
	Material Handling	.613	1.632
	Waiting	.539	1.855
	Travel	.561	1.782
	Personal	.461	2.170
Slab Concreting	Direct Work	.470	2.126
	Preparatory Work	.643	1.554
	Tool and Equipment	.586	1.706
	Material Handling	.613	1.632
	Waiting	.539	1.855
	Travel	.561	1.782
	Personal	.461	2.170

4.5.3 Evaluating the Model

Model summary and ANOVA displays statistics about the results of training, testing, and applying the final network to the holdout sample (Tabachnick, 2013). The Table includes R, R2, and details of the F test of the hypothesis that multiple regression is zero as shown in Table 4.8.

Table 4.8 Regression Model Summary and ANOVA

Activity	Model Summary			ANOVA	
	Correlation (R)	R- Square	Adjusted R-square	F	Sig(P)
Column formwork	.981	.963	.961	506.11	.000
Slab formwork	.450	.202	.180	9.13	.005
Slab Concreting	.659	.434	.356	18.15	.000

4.5.3.1 Test for Correlation Coefficient (R)

The coefficient of correlation imitates the strength of the association between the dependent variable and the combination of the independent variables that have been weighted according to the regression equation (Pallant, 2005). R-values have a potential range of zero to one. The higher coefficients of correlation, the stronger the linear relationship between the set of independent and dependent variables (Alistair, Howard, and Stephen, 2002). Coefficients of correlation of zero indicate no linear relationship between the set of predictors and the dependent variable. The overall test in multiple regressions is to check whether correlations between dependent and independent variables different from zero. For this study, all activities had R-value different from zero as shown in Table 4.8. Therefore, the assumption of correlation is not violated.

4.5.3.2 R-square

R-square is a measure of the strength of the prediction equation and is called the coefficient of determination (Robert, 200). In the regression model, R-square is the square of the correlation coefficient between the observed value of the dependent variable, and the expected value from the fitted regression line. Therefore, the researcher computes the predicted value, and then calculates the square of the correlation coefficient between the predicted value and observed values, R-square is obtained (Robert, 200). If all the observations lie on the regression line, R-square is one (perfect linear relationship). An R-square of zero indicates no linear relationship between the predictor and dependent variables. On the other hand, Larger R^2 values indicating more of a variation of the dependent variable explained by the model (Tabachnick, 2013).

For this study, R- square value was 96.3 percentage for column formwork activities as shown in Table 4.8, which is quite high and it confirms good predictability of the model. That is 96.3%, of the variance in construction labor productivity can be explained by the changes in material handling, waiting, and travel for column formwork activities. The remaining 3.7% of the variation in construction labor productivity is presumed to be due to random variability.

Furthermore, the R-square value for slab formwork and slab concreting activities were 20.2% and 37.7% respectively. This result proves that only 20.2% and 37.7% of construction labor productivity explained by the independent variable. As the R-square value is low, the prediction error is expected to be high, and the effectiveness of the activity models for forecasting actual construction labor productivity is inadequate.

4.5.3.3 F-test

F-testis the ratio between the mean square of regression to the mean square of residual (residual is the difference between observed and expected) (Keith, 2015). F-test is like an initial screening that tells at least one of the independent variables is a significant predictor of the outcome variable (Aggarwal R, 2016). The significance value of F statistic is less than 0.05 which means that variation explained by the model is not simply due to chance. For this study, to assess the statistical significance of the result, it is necessary to look in Table 4.8. This test proves that multiple R in the population different from zero. The model for column formwork, slab formwork, and slab concreting reaches statistical significance (Sig = .0, this means $p < .05$) so, the analysis is continued.

4.5.3.4 Adjusted R-Square

An adjusted R-square statistic that is "correlated" for the complication of the model, and is valuable for comparing the models (Pallant, 2005). Larger values of adjusted R-square indicate better predictive models. Adjusted R-square gives a more precise estimate of predictive accuracy than simply R-square. If the sample of independent variables small, consider reporting this value, rather than the normal R Square value (Keith, 2015). In Table 4.8 the difference between R-square and adjusted R-square higher for slab formwork and slab concreting activities. Therefore, it is better to use adjusted R-square in steady of normal R-square.

4.5.4 Evaluating each of Independent Variables

Identifying variables that contributed to the prediction of construction labor productivity is one of the methods, which helps to evaluate the model. This information is illustrated in Table 4.6

containing unstandardized coefficients, standard error, standardized coefficients, t- value, and sig. (Pallant, 2005).

4.5.4.1 Standardized Coefficients

Standardized means that values for every predictor variables are converted to the same scale to compare those independent variables (Tabachnick, 2013). To comparing the influence of every independent variable, see Table 4.6 the beta column, and find the largest beta value ignoring any negative signs out the front (Pallant, 2005). In this case, the largest beta coefficient is – 0.681, which is for travel activity percentage. This means that travel activity percentage makes a strong contribution to explaining the construction labor productivity, for column formwork activity. The Beta value for material handling activity percentage was lower (.066), indicating that it made less of a contribution to the column formwork activity model (Pallant, 2005).

4.5.4.2 Unstandardized Coefficients (B)

To develop a regression equation, unstandardized coefficient values listed as "B" in Table 4.9 used as coefficients of the variable. The "B" values are the coefficients for every predictor variable multiplied by in the final equation and might use to predict construction labor productivity. However, the corresponding "sig" value of the coefficient be 0.05 or below to have a confidence degree 95 %, this means that the finding has a 95% chance of being true.
The variables with negative regression coefficients influence reducing construction labor productivity. These variables are waiting and travel for column formwork, material handling for slab formwork, and preparatory work for slab concreting activity as shown in equation 4.2. On the other hand, variables with positive regression coefficients (material handling) influence increasing construction labor productivity for column formwork activities. The "Constant" is the intercept equivalent in the equation and the value of the outcome variable when the predictor variable is zero.

4.5.4.3 Standard Error

If the regression were implemented repetitively on different data (that had the same variables), this would denote the standard deviation of the coefficients. It shows in what range the value of the coefficients differs across dissimilar samples. The predictable coefficient is statistically significant if the coefficient is more than two times as large as the standard error, it is statistically significant at the 5 percent level (Jon Bakija, 2013). Taking slab formwork activities as an example, the standard error for the coefficient on material handling is 0.45, which is much less than half the value of the coefficient (3.92), so the estimated effect of material handling is still statistically significant in its difference from zero.

4.5.4.4 Sig. (P-value)

For every independent variable, the value in the column marked “Sig” tells whether this variable is making a statistically significant irreplaceable contribution to the equation. This is dependent on the variables that are included in the equation, and how many overlays among the independent variables (Chandana S.A and Siriwardana, 2017). The smaller the value of “Sig” the better contribution of the predictor. If the Sig. value is less than 0.05, then the variable is providing a significant unique contribution to the prediction of the outcome variable. Whereas sig. greater than 0.05, implied that the variable is not making a significant unique contribution to the prediction of a dependent variable so that drops the variable from the equation. This may be due to overlap with other independent variables in the model. For this study, material handling, waiting and travel for column formwork, material handling for slab formwork, and preparatory work for slab concreting made a unique, and statistically significant, contribution to the prediction of construction labor productivity.

4.5.4.5 T-Ratio

T- Ratio is the ratio between coefficient and standard error that tells how large the coefficient concerning how much it varies in repetitive sampling (Aggarwal R, 2016). If the coefficient differs a lot in repeated sampling, then its T-statistic will be smaller, and if it varies little in repeated sampling, then its T-statistic will be larger. T-Test used to identify whether the predictor significantly correlates to construction labor productivity or not at a pre-established confidence level of 95% (Al-Zwain, 2011).

Table 4.9 Coefficient of Independent Variables

Dependent Variable: Construction labor productivity						
Model(Activity and independent variable)		Unstandardized Coefficients		Standardized Coefficients (Beta)	T-ratio	Sig.
		B	St. Error			
Column Formwork	Constant	1.154	.015		76.70	.000
	Material handling	.296	.119	.066	2.494	.015
	Waiting	-1.403	.257	-.336	-5.468	.000
	Travel	-3.367	.308	-.681	-10.92	.000
Slab formwork	Constant	1.968	.162		12.16	.000
	Material handling	-3.928	1.300	-.450	-3.022	.005
Slab Concreting	Constant	1.026	.135		7.612	.000
	Preparatory work	-5.6	1.330	-.614	-4.260	.000

According to Al-Zwain (2011), at minimum one of the unstandardized coefficients is differ from zero to be valuable for calculating the outcome variable. For this study, column formwork, slab formwork, and slab concreting activities had a non-zero coefficient. Although slab formwork and slab concreting activities statistically significant accord to the coefficients test, these models are limited to predict construction labor productivity due to low R- square value. The model comprised the entire significant explanatory variables shown as bellow:

Column formwork activities "CLP" (M^2/hr) = 1.154 + 0.296X4 -1.403X5 - 3.36X6------Eq (4.2)

Domain, CLP = {X4, X5 and X6}:[5 %< X4<=18%], [1 %< X5<=23%] and [3 %< X6<= 18%]

Slab formwork "CLP" (M^2/hr) = -3.92X4 + 1.97---Eq(4.3)

Domain, CL = {X4}: **[**3 %< X4 < 18**%]**

Slab concreting "CLP" (M^3/hr) = – 5.6X2+ 1.026------------------------------------ Eq(4.4)

Domain, CLP = {X2}: **[**5 %< X2< 16%]

CLP= construction labor productivity, X2 = Preparatory work, X4 =Material handling, X5 = Waiting, X6 = Travel,

As a general statistical guideline, certainly not predict a point that is outside the range of observed values of explanatory variables that are used to fit the regression model (Jim Frost 2013, and Landau, 2004). For this study, the domain of the equation was taken from the descriptive statistics table included in the appendix. For example, for slab concreting activities, the predictor variable is preparatory work as shown in equation 4.4. The range of the data for preparatory work was between 5% and 16% as shown in Table C.1 included in the appendix.

So the value of predicted construction labor productivity for slab concreting activities calculated within this range as shown below.

$$\text{Predicted (K) at (x2} = 16\%) = -\ 5.6\text{X2} +\ 1.026, -5.6\ x\ 0.16 + 1.026 = 0.13 \text{ (minimum value)}$$

$$\text{Pridicted (K)at (x2} = 5\%) = -\ 5.6\text{X2} +\ 1.026 = -5.6x\ 0.05 + 1.026 = 0.76\ m\text{aximum value}$$

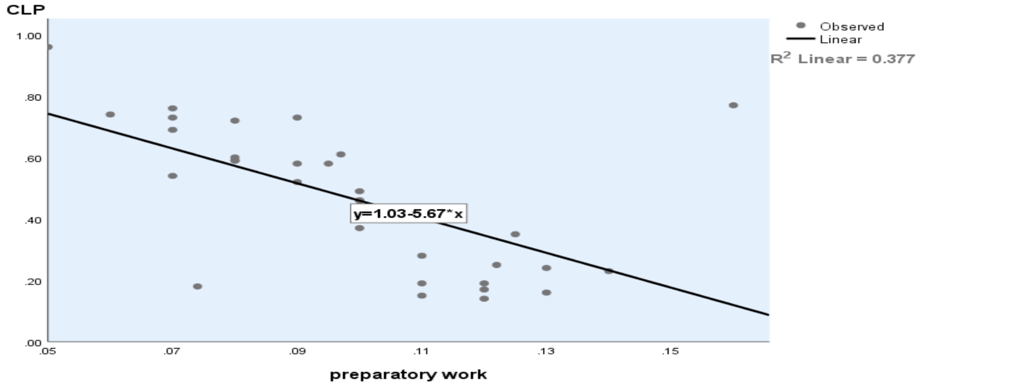

Figure 4.10 Graph of Predicted Construction Labor Productivity for Slab Concreting

Figure 4.10 demonstrates the basic idea of regression with a single explanatory variable. It shows, for each of the observations, the relationship between preparatory work, measured on the horizontal axis, and construction labor productivity, measured on the vertical axis. Each dot represents an observation. The cloud of dots suggests that there is a negative correlation between preparatory work and construction labor productivity. That means that higher values of preparatory work tend to go together with lower values of construction labor productivity. In addition, there is a difference between the actual value of construction labor productivity and the value of construction labor productivity that is predicted by the regression line. The actual value of the dependent variable (in this case, construction labor productivity) minus the predicted value is called the “residual” or “error (Watson, 2007).”

Therefore, the value of predicted construction labor productivity for slab concreting activities was between 0.13 and 0.76 M^3 per hour as shown in Figure 4.10. However, the value of actual construction labor productivity were 0.14 and 0.96 M^3 per hour. The residual is its actual construction labor productivity minus its predicted construction labor productivity, 0.96 -.76= 0.2and 0.14 –0.13= 0.01. It’s the portion of the dependent variable (in this case, construction labor productivity) that is not predicted by the explanatory variable (in this case, preparatory work). Random chance of observation affects predicted construction labor productivity, and the residual reflects the influence of these other factors (Watson, 2007).

4.5. 5 Descriptive Data Analysis

Description of the data is essential, as the nature of techniques applied for inferential analysis is based on the characteristics of data (Kahn, 2003). The minimum and maximum values tell the domain of the equation. On the other hand, the mean denotes the center of gravity of the observation. It is the average of all values in a distribution (Krishnaswamy & Ranganathan, 2006). According to (CII 2010), the mean of direct work fall between 40%- 60% percentage of an hour. However, formwork and reinforcement activities had meant that lower than 40% as shown below Table 4.10.

Table 4.10 Descriptive: Statistics for Slab Formwork

Work sampling	N	Minimum	Maximum	Mean	Std. Deviation
Direct Work	38	.25	.47	.3676	.04658
Preparatory Work	38	.05	.17	.1058	.03001
Tool and Equipment	38	.03	.19	.0995	.03432
Material Handling	38	.03	.18	.1208	.03053
Waiting	38	.01	.20	.1408	.04829
Travel	38	.04	.18	.0945	.03867
Personal	38	.01	.16	.0663	.03672
CLP	38	.78	1.88	1.493	.26658

4.5.6 Validation of Regression Model

Cross-validation using a second sample is highly suggested for statistical regression and is accomplished through several steps (Tabachnick, 2013). First, the info is split into two arbitrary samples; a recommended split is 90% for regression analysis and therefore the remaining 10% because of the cross-validation sample as shown in Table 4.11. Next, statistical regression on the larger sample is run; predicted scores are generated for smaller cross-validation samples using the regression coefficients produced by the analysis. Finally, predicted construction labor productivity (CLP) and actual construction labor productivity (CLP) are correlated to find R-square for the smaller sample. A large discrepancy between R- square for smaller and larger samples indicates overfitting and lack of generalizability of the results of the analysis (Tabachnick, 2013).

For this study, the correlation coefficient between predicted construction labor productivity (CLP) and actual construction labor productivity equal to 99.5%, 45.8%, and 19.2 % for column formwork, slab formwork, and slab concreting activities. This result indicates that the predicted construction labor productivity of column formwork activities are highly correlated (correlation greater than 50%) and closer to the actual construction labor productivity (Tabachnick, 2013).

However, for slab formwork and slab concreting activities, the correlation between predicted construction labor productivity (CLP) and actual construction labor productivity is low.

The coefficients of determination (R^2) between predicted and actual CLP were 99.1%, 24.1%, and 7.8% for column formwork, slab formwork, and slab concreting respectively as shown in Table 4.11. For column formwork, the cross-validation sample is better predicted by the regression equation than the sample that generated the equation. Consequently, output for column formwork activity fitted to actual measurements (Al-Zwain, 2011). In addition, for slab formwork and slab concreting activities, the coefficients of determination are low, errors are expected to be high, and the usefulness of activity models for predicting actual construction labor productivity is inadequate.

Furthermore, the mean absolute percentage error between predicted and actual construction labor productivity (CLP) was 4.19%, 52.7%, and 76.7% for column formwork, slab formwork, and slab concreting activities respectively. In this case, column formwork activities had low mean absolute percentage error and high accuracy percentage. Therefore, this model is better to predict construction labor productivity (Tabachnick, 2013). Contrary to this, slab formwork and slab concreting had high mean absolute percentage error and low accuracy percentage so the model is limited to predict construction labor productivity.

Table 4.11 Number of Observations for each Variable.

Activity	No Observation	X1	X2	X3	X4	X5	X6	X7	CLP
	1	0.34	0.07	0.06	0.13	0.14	0.07	0.08	0.81
	2	0.38	0.05	0.06	0.11	0.17	0.11	0.06	0.63
	3	0.31	0.07	0.12	0.15	0.12	0.05	0.06	0.88
	4	0.33	0.06	0.11	0.11	0.19	0.12	0.1	0.54
	5	0.36	0.08	0.08	0.13	0.13	0.06	0.08	0.88
	6	0.39	0.1	0.03	0.15	0.17	0.1	0.06	0.66
	7	0.37	0.05	0.12	0.15	0.18	0.11	0.07	0.6
Column Formwork	8	0.33	0.08	0.07	0.14	0.2	0.16	0.14	0.47
	1	0.36	0.09	0.14	0.12	0.19	0.06	0.04	1.33
	2	0.36	0.13	0.13	0.09	0.09	0.06	0.06	1.76
	3	0.43	0.08	0.11	0.12	0.01	0.07	0.08	1.64
	4	0.36	0.1	0.07	0.11	0.14	0.14	0.08	1.23
Slab Form work	5	0.45	0.17	0.06	0.11	0.15	0.11	0.02	1.33
	1	0.44	0.12	0.08	0.1	0.15	0.09	0.06	0.14
	2	0.45	0.09	0.06	0.13	0.15	0.08	0.04	0.52
	3	0.39	0.08	0.07	0.06	0.2	0.06	0.04	0.72
	4	0.42	0.13	0.11	0.07	0.14	0.1	0.02	0.18
slab Concreting	5	0.44	0.13	0.11	0.09	0.1	0.08	0.06	0.28

Table 4.12 Actual Productivity and Predicted CLP for Column Formwork Activities

Activity	No Observation	Actual CLP	Predicted CLP	((A-P)/A)
column form work	1	0.81	0.79	0.02
	2	0.63	0.60	0.05
	3	0.88	0.87	0.01
	4	0.54	0.51	0.06
	5	0.88	0.85	0.03
	6	0.66	0.63	0.05
	7	0.6	0.54	0.10
	8	0.47	0.46	0.02
	MAPE(%)			4.19%
Slab form work	1	1.33	1.47	(0.14)
	2	1.76	1.59	0.12
	3	1.64	1.47	0.09
	4	1.23	1.51	(0.35)
	5	1.33	1.51	(0.25)
	MAPE(%)			-52.8%
Slab Concreting	1	0.14	1.02	0.04
	2	0.52	1.2147	(0.64)
	3	0.72	1.2804	(0.59)
	4	0.18	0.9519	(0.59)
	5	0.28	0.9519	(1.19)
	MAPE(%)			-76.6%
A= Actual and P=predicted CLP=Construction Labor Productivity				

The following statistical procedures used to measure the performance of multivariable linear regression models (Al-Zwain, 2011)

1) The Coefficient of Correlation (R)

2. The Coefficient of Determination (R-Square)

3) Mean Absolute Percentage Error (MAPE)

$$MAPE = \frac{\sum_{n=1}^{n}\left(\frac{A-P}{A} X\ 100\%\right)}{n} = \text{ 4.19\% where A = Actual CLP} \ldots \ldots \text{Eq(4.6)}$$

P = predicted CLP, n = Number of observation

4) Average Accuracy Percentage (AA %) for column formwork

$\text{AA\%} = 100\% - MAPE = 100\% - 4.19\% = 95.81\% \ldots \ldots .. Eq(4.7)$

This calculation is repeated in the same way for slab formwork and concreting activities

Table 4.13 Performance of Multivariable Regression Model

Column formwork	Measure	R	R- square Large sample	R-square Small sample	MAPE (%)	AA (%)
	Result	99.5%	95.8%	99.1%	4.19%	95.81%
Slab formwork		45.8%	20.2%	24.1%	52.3%	47.7%
Slab concreting		19.2%	37.8%	7.8 %	76.6%	23.4%

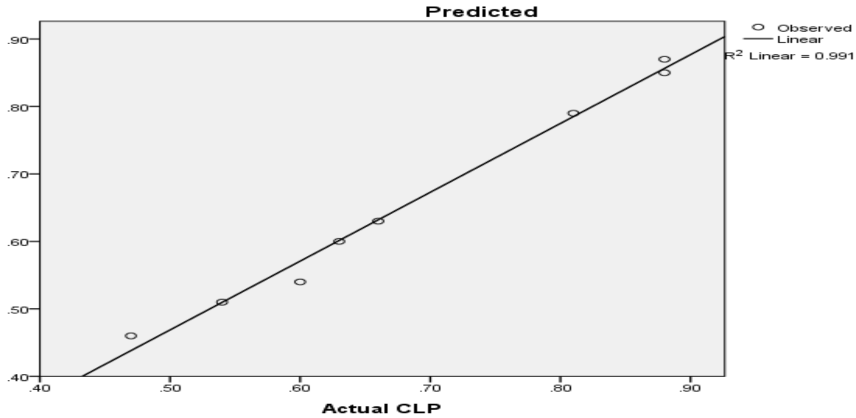

Figure 4.11 Predicted and Actual Construction Labor Productivity for column Formwork Activities

Figure 4.12 Predicted and Actual Construction Labor Productivity for Slab Formwork Activities.

4.5.7 Comparison of Performance between Current Construction Labor Productivity Model and other Study in the past

The researcher used the similar statistics methods adopted by (Faiq 2013, Zwainy 2014, Awad S., 2005 and Rifat, 1996) to determine the average accuracy of this model, as shown in the Table 4.14, where the mean absolute percentage error (MAPE) equal to 4.19% that means the average accuracy (AA) of this model equal to 95.81% is excellent for column formwork. However, for slab formwork and slab concreting activities, the mean absolute percentage error (MAPE %) is higher, and the average accuracy percentage (AA%) is lower as shown in Table 4.14 This result confirms that the model is limited to predicted construction labor productivity as compared to other studies.

Table 4.14 Model Accuracy Results of the Current Study and other related Studies

Study	Activity	Model Performance				
		R	R-square	MAPE (%)	AA (%)	Decision
Current study	Column formwork	99.5%	99.1%	4.19%	95.81%	Good
	Slab formwork	45.8%	24.1%	52.3%	47.7%	limited
	Slab concreting	19.2%	7.8 %	76.6%	23.4%	limited
Other Studies						
(Faiq 2013)		0.906	0.821%	3.74%	96.3%	
(Rifat 1996)		-	51.4%	62.7%	37.6%	
(Faiq 2016)		98.6%	97.32%	9.891%	90.1%	

4.6 Nonlinear Regression Test

Nonlinear regression is a way of finding a nonlinear model of the association between the outcome variable and explanatory variables. Unlike traditional linear regression, which is restricted to estimating linear models, nonlinear regression can estimate models with arbitrary relationships between an outcome variable and explanatory variables (Harrell.J, 2001). Nonlinear produces curve estimation regression statistics and related plots for various regression models: linear, logarithmic, inverse, quadratic, cubic, power, compound, S-curve, logistic, growth, and exponential. A separate model is produced for every outcome variable. For every model: regression coefficients, multiple R, R 2, adjusted R2, standard error of the estimate, analysis-of-variance. The following procedures were used to test whether the data fit the nonlinear regression model or not.

4.6.1 Overall significant Test

The probability value of less 0.05 for the regression insists on the model's acceptability (Miguez, 2013). As shown in Table 4.15, column formwork (waiting, travel, and personal), slab formwork (material handling) and slab concreting (preparatory work) activities had P- values less 0.05. This shows that the model is statistically significant since their p values less than the pre-established confidence level of 95%. The model summary Table 4.15 indicates that five of the selected independent variables made a significant enough contribution to be included in the final model: waiting, travel, and personal for column formwork activities, material handling for slab formwork activities, and preparatory work for slab concreting activities. The best nonlinear regression was selected based on the improvement of R- square values (the higher the R-squared, the better the model fits your data) (Frost, 2013). Based on this, the cubic model for column formwork, a quadratic model for slab concreting, and slab formwork, were selected as shown in Table 4.15.

Table 4.15 Model Summary and ANOVA for Nonlinear Regression

Activity	Variables	Model Type	R-square	F	Sig (P)
Column formwork	X5	Linear	.887	477.765	.000
		cubic	0.949	369.584	.000
	X6	Linear	.938	929.036	.000
		Cubic	.965	544.305	.000
Slab formwork	X4	Linear	.202	9.130	.005
		quadratic	.226	10.486	.003
Slab concreting	X2	Linear	.528	38.052	.000
		Quadratic	.614	26.263	.000

4.6.2 Scatter Plot

To begin with, scatter plots that considered CLP as an outcome variable and work sampling category proportions as the explanatory variable was prepared. Linear and nonlinear regression lines were fitted to every activity's data. The following nonlinear regression models were tested: logarithmic, inverse, quadratic, compound, power, S, growth, exponential, and logistic. The best nonlinear regression lines showing an improvement over linear regression lines in terms of R2-values were selected (Tsehayae, 2015).

If the model fitted to data, the points roughly follow a single line pattern; otherwise, the plot follows a nonlinear pattern (Pallant, 2005). For this study, waiting and travel activity approximately fitted to the cubic regression line as shown in Figure 4.13 for column formwork activities. The fitted relationship in Figure 4.13 follows the data close and produces a high R-squared of 94.9% and 96.5% for waiting and travel activity respectively. This indicates that the cubic regression model is adequate to forecast construction labor productivity for column formwork activities.

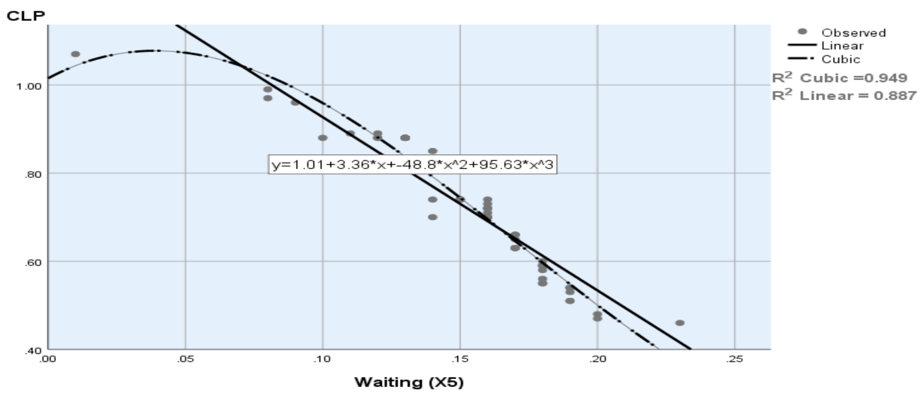

Figure 4.13 CLP as a Function of waiting Proportion for Column Formwork Activity

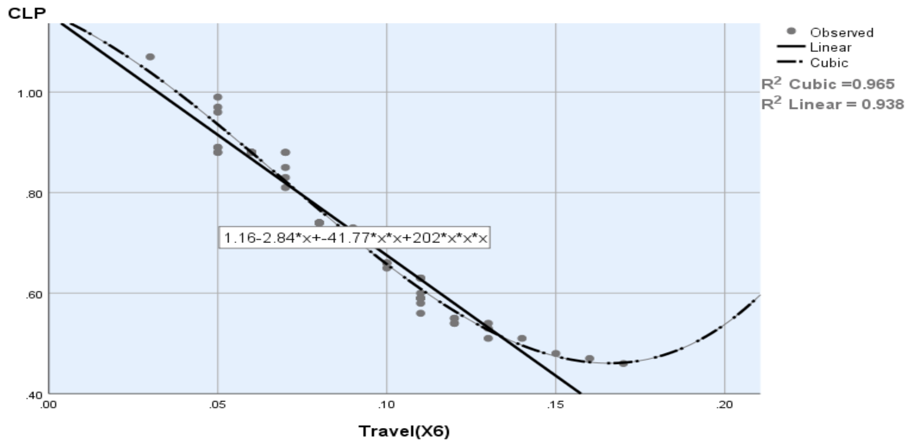

Figure 4.14 CLP as a Function of Travel Proportion for Column Formwork Activity

In addition, for a strong association, the points will form a vague cigar shape, with a definite clattering of points nearby an imaginary straight line (Pallant, 2005). However, the scatter plot included in the appendix also illustrates that the points positioned all over the place, in a blob-type arrangement as shown in Figure F.7 and Figure F.8 for slab formwork and slab concreting activities. Therefore, the data is not fitted to nonlinear regression lines for slab formwork and slab concerting activities. For all eight activities, the other work sampling activity groups namely, direct work, tool, and equipment, personal were not fitted either linear or nonlinear model.

4.7 Direct Work Proportion versus Construction Labor Productivity

Work sampling establishes the percentage of work time consumed on work sampling groups like direct work. Direct work denotes the proportion of work time spent applying physical effort directed toward the completion of an activity. The process model is center on work sampling and is readily suitable for labor-intensive activities. A valid process model is required to demonstrate that direct work times and construction labor productivity are related in some foreseeable approach (Thomas, 1991). There are two contrasting views on the validity of process models. In the first view, the literature argues that work sampling can foretell productivity (Shahtaheri, 2014). Handa and Abdalla (1989) specified that activity models with seven work-sampling categories were used to indicate actual site productivity; however, the established models were statistically insignificant. Silva and Ruwanpura (2006) established an activity model using direct work proportion to forecast concreting operations' productivity. Shahtaheri (2014) expected labor performance enhanced by improving the direct work rate and the established baselines for direct work proportions without testing and validating the relationship between direct work and construction labor productivity. Conversely, Thomas

(1991) indicated that direct work is not related to productivity; using data from seven databases containing over 158 work sampling studies, mainly from nuclear power plant projects, concluded that previous studies lacked validity. Josephson and Björkman (2013) also concluded that work-sampling studies give little importance in measuring productivity. Tsehayae (2015) also develop an activity construction labor productivity (CLP) model by using CLP as a predicted variable and direct work as the predictor variable and the study conclude that direct work is not significantly correlated to CLP.

For this study, the relationship among direct work proportion and construction labor productivity tested using the data collected for eight activities shown in Table 4.16 and by considered construction labor productivity (CLP) as the outcome variable and direct work category proportions as the predictor variable. Scatter plots of linear and nonlinear regression lines were drawn to each activity's data. The following nonlinear regression models tested logarithmic, inverse, quadratic, compound, power, S, growth, exponential, and logistic. The best nonlinear regression lines showing an improvement over linear regression lines in terms of R2-values selected. The scatter plots for column formwork, activities are shown in Figure. 4.9.

Coefficient of determination (R^2) for column formwork activities were .012, .014, .015, .017, .013, .015, .016, .013, .013, and .013 for linear, logarithmic, inverse, quadratic, compound, power, S, growth, exponential, and logistic respectively. From those models, the quadratic regression line that had a larger R^2 (0.17) value show an improvement over the linear regression line was selected. The scatter plots for column formwork activities are shown in Figure 4.16.

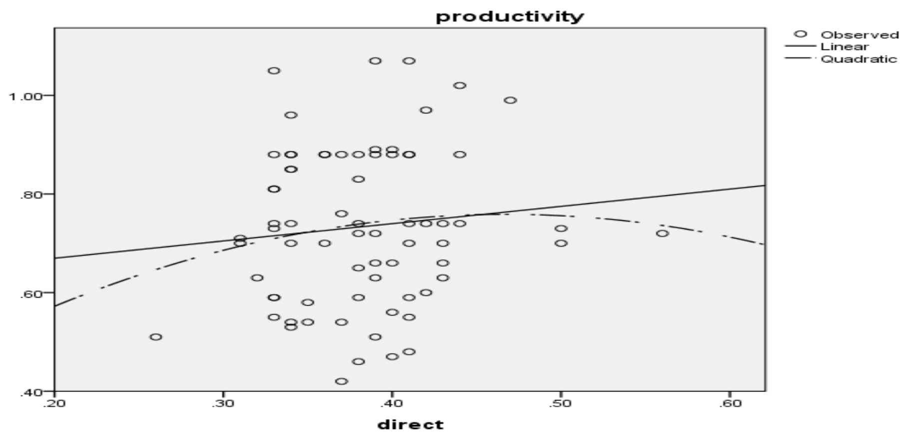

Figure 4.15 CLP as Function of Direct Work Proportion for Column Formwork Activity

It can be apparent from Figure 4.15 that the points are not closely distributed about an underlying straight line, so we say there is no strong association between direct work and construction labor productivity. The scatter plot in the appendix for other activities also shows a similar result.

The coefficient of determination, based on R2 values, shown in Table 4.16 indicated that the linear activity models for slab formwork, column formwork, slab reinforcement, column reinforcement, and slab concrete were 12.4%, 1.2%, 1.9%, 3.7%, 6.3%, and 4.8%respectively, of the variability in construction labor productivity, and all had low R2 values. Congruently, the nonlinear activity models for slab formwork, column formwork, shear wall formwork, slab reinforcement, column reinforcement, and slab concrete, we're able to explain 14.4% ,4.0%,21.1%, 9.2%, 6.5%,3.4%, respectively. Even if there is an improvement in R^2 value, still relatively low. These results demonstrate that the relationship between productivity and direct work is complicated, and an increase in direct work alone might not result in better productivity. This is because productivity is affected by other issues like the method of construction, the skill of labor, etc. This result aligns with Thomas (1991), Tsehayae (2015), Josephson and Björkman (2013) who concluded that direct work is not significantly correlated to productivity.

Table 4.16 CLP as Function of Direct Work Proportion Model Summary

Activity	model	R^2	F-statics	Sig (P)
Slab Formwork Activities	Linear	.124	5.086	.30
	S	.190	8.443	.06
Column Formwork Activities	Linear	.112	7.705	0.5
	Quadratic	0.012	.844	.361
Slab Reinforcement Activities	Linear	.022	.431	.519
	Quadratic	.019	.927	.341
Column Reinforcement Activities	Linear	0.109	2.813	.070
	Quadratic	.037	2.823	.097
Slab Concreting Activities	Linear	.025	.403	.535
	Compound	.063	2.285	.140
Column Concreting Activities	Linear	.062	2.230	.145
	compound	.048	1.507	.229

4.8 Comparison of Productivity Modeling between Linear and nonlinear model

A comparison between linear and nonlinear regression models was made based on estimation performances of the two techniques using four measurements as shown in Table 4.17. Mean Absolut error and average accuracy percentage is calculated by using equation 4.6 and 4.7.

Table 4.17 Estimation Performance of Linear and Non-model

Activity	Model	Measure	R	R-square	MAPE (%)	AA (%)
Column form work	cubic	X5	99.3%	98.5%	0.7%	99.3%
	linear		96.5%	93.2%	2.5%	97.5%
	cubic	X6	98.2%	96.%5	-3.5%	96.5%
	linear		96.9%	93.8%	4.6%	95.4%
Slab form work	logarithmic	X4	47.4%	22.4%	40.5%	59.5%
	linear		45.8%	24.1%	52.3%	47.7%
Slab concreting	quadratic	X2	78.3 %	61.4%	14.7%	84.3%
	linear		19.2%	0.078	76.6%	23.4%

The results of Table 4.17 show that the nonlinear regression technique provides somewhat good outcomes than the linear regression technique in nearly the whole comparison. The outcome indicated that the two models (X5 and X6) showed an important relationship among the explanatory variable and the construction productivity with average accuracy percentages greater than 95%. These outcomes specify that the average accuracy attained by linear and nonlinear modes was good. The greater accuracy achieved through the two models were credited to the greater correlation coefficients between the construction productivity, and the waiting and personal.

4.9 Summary

The process models were conducted by IBM SPSS 24 statistical package software. Stepwise regression was utilized to decide on the impact of the explanatory variables (direct work, preparative work, tool and equipment, material handling, waiting, travel, and personal) on construction labor productivity. The correlation between work sampling proportion (direct work, preparative work, tool and equipment, material handling, waiting, travel, and personal) and construction labor productivity were examined through Pearson correlation. All activates had correlation altered from zero so the hypothesis of correlations was not profane. The introductory investigation was achieved to envision the assumptions of normality, linearity, and homoscedasticity.

Three activity models specifically, column formwork, slab formwork, and slab concreting activities were vital in line with the F- test. The coefficient of determination is high for column formwork activities indicating the sensible foregone conclusion of construction labor productivity. On the other hand, coefficients of determination for slab formwork and slab concreting activities is low and error is perhaps to be high, and so the effectiveness of the activity models for predicting actual construction labor productivity is restricted.

The variables with negative regression coefficients influence decreasing construction labor productivity. These variables are waiting and travel for column formwork, material handling for slab formwork, and preparatory work for slab concreting. On the other hand, variables with positive regression coefficients (material handling) impact increasing construction labor productivity for column formwork activities.

Material handling considerably correlates with construction labor productivity for column formwork activities with regression coefficients of 0.296. This coefficient tells the construction labor productivity to alter for every one-unit change in material handling. For every extra material handling activity segment, construction labor productivity is expected to be enhanced by 0.296 times keeping waiting and travel constantly. Waiting and travel additionally considerably correlate to construction labor productivity with regression coefficients of -1.403 and -3.36 respectively. This tacit that once waiting and personal activity portion enhanced by one unit, construction labor productivity decreases by 0.403 and 3.36, respectively. Therefore, construction labor productivity tends to extend once waiting and travel activity percentage on-site reduces, which may be attributed to an excessive quantity of time being wasted rather than operating (Chandana S.A. and Siriwardana, 2017).

Material handling and preparative work as well considerably correlate for slab formwork and slab concreting activities with a negative coefficient of 3.82 and 5.67 respectively. Therefore, construction labor productivity tends to extend once material handling, and preparative work decrease on-site. This can be because of an excessive amount of time utilized for material handling and preparative work rather than directly putting the material (Chan S.A and Siriwardana, 2017). This result's also fortified by the daily correlation of material handling (R= -0.65 and preparative work (R= -0.278), and direct work.

The nonlinear regression model was tested to envision whether or not non-significant variable quantity (direct work for all activities, preparatory work for formwork, reinforcement activities, tool, and equipment for all activities) suitable nonlinear curve or not. The result proves that solely waiting and travel activity percentage for column formwork activity fitted to a cubic regression line. The relationship between direct work and construction labor productivity was similarly tested. The result shows direct work proportion was not a predictor of construction labor productivity.

Cross-validation, the technique was used to compare the prediction performance of the models by using the coefficient of correlation (R), coefficient of determination ($R^{2),}$ mean absolute percentage error (MAPE), and mean the average accuracy (AA). The result demonstrates that the model performances of column formwork activity were sensible compared with other studies. However, slab formwork and slab concreting activities had a higher mean absolute percentage error (MAPE %) and lower average accuracy percentage (AA %). Hence, the model performance is inadequate as compared to other studies.

Chapter 5 Conclusion and Recommendation

5.1 Introduction

This chapter constitutes a conclusion arrived at and recommendations for future research.

5.2 Conclusion.

This study aimed at developing a construction labor productivity model for formwork, reinforcement, and concreting activities using multiple regression techniques. However, the model for reinforcement and concreting activity were limited to predict construction labor productivity. Even for formwork trade categories, slab and shear wall formwork activity were limited to predict construction labor productivity.

The model for column formwork activity was good predictable with a high degree of accuracy of 95.81%.

In this research, three influential variables (material handling, waiting, and personal) developing construction productivity estimating model for column formwork activity.

Direct work was not significantly correlated with construction labor productivity. Therefore the management should focus not only on direct work but also on other work sampling activities to improve construction labor productivity.

Waiting and finding material, poor site layout, crew failure to follow instructions, insufficient or incomplete drawings, incorrect number and low skill level of crew, waiting for other crews and tools are the main causes of delay in the study area.

5.3 Recommendation for construction firms

Construction is a collaborative activity that integrates the knowledge and experience of many people to meet the needs of today, let alone tomorrow.

The result of field observation and survey revealed that several problems have been observed that affect construction labor productivity. Those are, poor site layout, crew failure to follow instructions, finding materials, insufficient or incomplete drawings, incorrect number and low skill level of crew, unnecessary preparatory work, waiting for materials other crews, and tools. To solve those factors that affect the productivity of laborers in the construction firms, the following recommendation is suggested.

5.3.1 Materials procurement

Construction firms must fix materials supply schedules for the project. The schedule must comprise the period requisite to procure materials and the obtainability of materials in the market place to deliver the necessary materials in a suitable time. Besides, contracting firms have a choice of an appropriate storage location used for procured resources. This storage site would be reachable and nearby construction sites to minimize times for traveling.

5.3.2 Apply Tool and equipment management program

Apply tool management program to allow laborers to leave the workforce, obtain a tool or piece of equipment, and return to the workforce in a short period.

5.3.3 Well designed site layout

Locating store or material backyards at a minimum distance to an actual construction site, reduce the time require for tools and equipment, material-handling, and traveling activity percentages. Concerning to excessive material handling, a poor site layout means labors have to travel long distances to obtain materials. The walk to the material laydown yard is categorized as a travel activity; however, the walk back with the material in hand is categorized as a material-handling activity. Management should consider having material storage areas near the work area. Having materials nearby will greatly reduce the material-handling activity rate. These small storage areas need to be well controlled so that materials can be tracked. The area needs to remain uncluttered and safe.

5.3.4 Provide training to workers.

It is essential to bearing training and conferences in the issues, which increase efficiency in construction projects. Because of lack of training, labors spending extra time to determining which tools, equipment, and materials are required for the job, and too much time planning how to perform the work assignment. Therefore, the management should prepare a detailed work break down that comprise an outline of the work tasks, and the required tools, equipment, and materials. In addition, inexperienced workers often consult with more experienced workers to answer questions regarding the work tasks.

5.3.5 Collaboration stakeholder

According to the project manager, they faced issues of the incompleteness of the design and communication between the contractor and the consultant, most of the buildings have been revised but the consultant did not submit timely the revised drawings. To solve these problems both the contractor and the consultant should have regular meetings either monthly or weekly.

5.3.6 Good Communication

To contribute to the success of a project, a worker must be told properly what tasks are expected from him. Consequently, clear explanations of tasks and expectations are required. Employees must also recognize where their instructions come from, i.e., there must be a visible communication chain on the work. Orders from an unknown source will be disregarded. Furthermore, to be successful, the communications would flow both ways.

5.4 Recommendation for Future Research.

- ✓ Future researchers will be studying labor-intensive activities, such an electrical, mechanical, boilermakers, and piping activities to develop process models for forecasting construction labor productivity.
- ✓ Repeating the same study by using neural network techniques and making a comparison among the outcomes to show which method is more adequate for use in construction management.

BIBLIOGRAPHY

Abdel Razek. R .(2004). "Labor productivity benchmarking and variability in Egyptian projects." International Journal of Project Management. 27 (4), p189-197.

AbouRizk, and M.Song L .(2001). "Measuring and modeling labor productivity using historical data."*J. Constr. Eng. Manage,* p. 786–794.

AbouRizk .(2001). "Estimating labor production rates for industrial construction activities". *J. Constr. Eng. Manage, 127(6), 502–551.*

Agbulos and Abourizk. (2003). "*An application of lean concepts and simulation for drainage operations maintenance crews."*New Orleans, Louisiana, pp, s.n., pp. 1534-1540.

Aggarwal R. (2016). "Common pitfalls in statistical analysis." pp. 7:187-90.

Aiken, L. S. (1991). "*Multiple regression: Testing and interpreting interactions."*

Al–Ghamdi, M.(1995). "Evaluation of work sampling as an indicator of construction labor productivity."*M.Sc. thesis, King Fahd Univ. of Petroleum and Minerals, Dhahran, Saudi Arabia.*

Alinaitwe. (2006). *"Efficiency of craftsmen on building sites – studies in.* uganda."

Allmon. (2000), Jenkins and Orth (2004)."Work sampling studies to direct observation."*j. of construction engineering.*

Allmon, Haas, Borcherding, and Goodrum, P. (2000). "US construction labor productivity trends, 1970-1998."*Journal of Construction Engineering and Management,* pp. 97-104 .

Al-Zwain. (2011). "Using multivariable linear regression technique for modeling productivity construction in iraq."*open journal of civil engineering,* pp. 127-135 .

Al-Zwainy.(2016). "Building a mathematical model for predicting the cost of the communication towers projects using multifactor linear regression technique."*journal of construction engineering and management,*pp. 25-29.

Anon. (2006). "*Workforce view of construction labor productivity."*Texas, US CII (Construction Industry).

Awad S. H. (2005). "Impact of extended overtime on construction labor."*journal of construction engineering and management.*

Campbell D. (1988). "Task complexity a review and analysis."*Acad Manage. Rev,* pp. 13 (1), 40–52.

Choudhry R. M. and Zahoor, H. (2016). "Strengths and weaknesses of safety practices to improve safety performance in construction projects in Pakistan." Journal of Professional Issues in Engineering Education and Practice, vol. 142, no. 4.

Chan P and Scott, D. (2004) "Factors affecting the success of a construction project."*J.,* p. 153–155.

Chandana S.A. and Siriwardana. (2017). "A study to investigate the relationships between work sampling categories and productivity for concrete slab formwork."*8th international conference on structural engineering and construction management.*

Chang, A. (2006). "System model for analyzing design productivity."*J. Manage. Eng.*

Cheng, T. Venugopal, M. Teizer, J. and Vela, P. (2011) "Performance evaluation of ultra-wideband technology for construction resource location tracking in harsh environments," Automation in construction, vol. 20, no. 8, pp. 1173-1184.

Choy and Ruwanpura. (2006). "Predicting construction productivity using a simulation model."*Canadian journal of civil engineering Vol.33 Issue.12,* pp. 1585-1600.

Chromokos and McKee. (1981). "Construction productivity improvement."*journal of the construction division,* pp. 35-47

Construction Industry Institute. (2010). "Activity analysis for work sampling."*Journal of Construction Engineering and Management.*

Construction Industry Institute (2011). "Productivity benchmarking summary report." Austin, Texas: Construction Industry Institute.

Clark and Lorenzoni. (2005). "Estimating or predicting the cost of labor for a given project."

Craney, T. (2002).*"Model-dependent variance inflation factor cutoff values." Quality Engineering.* s.l.:s.n.

Dozzi, S.P, and AbouRizk, S.M. (2003). "*Productivity in construction."*Ottawa, Ontario: National Research Council.

Drewin, F.J. (1982). "*Construction productivity: measurement and improvement through work-study."1st,* s.l.: Elsevier Science Publishing Inc.

Durdyeu, S. (2011). "On-site labor productivity of the New Zealand construction industry Key constraints and improvement measures."*Australasian Journal of construction economics and Building,* pp. 11 (3), p18-33.

El-Gohary. (2014). "Factors influencing construction labor productivity in Egypt."*Journal of Management in Engineering. ,* pp. doi:10.1061/(ASCE)ME.1943-5479.0000168 .

Enshassi. (2011). "Labor productivity measurement in building projects."*The Islamic University Journal,* pp. 19 (1), p103-119.

Ezeldin and Sharara. (2006). "Construction labor productivity prediction models for forms assembly."*J.of construction management.*

Faiq M. (2013). "Using multivariable linear regression technique for modeling productivity construction in Iraq."*Open journal of civil engineering,* pp. 127-135.

Faiq, M. (2016). "Building a mathematical model for predicting the cost of the communication towers projects using multifactor linear regression technique." *international journal of construction engineering and management,* pp. 25-29.

Fayek, A. Robinson, and Oduba, A. (2005). "Predicting industrial construction labor productivity."*J. Constr. Eng. Manage, 131(8),*p. 938–941.

Fayek, A. (2002). "*A pilot study to examine the effective integration."journal of construction engineering and management.*

Flood and ISSA. (2010). "Empirical modeling methodology for construction."*journal of construction engineering and management.*

Frank E and Harrell J. (2001). *" Regression Modeling Strategies."*New York: Springer Science.

Frost, J. (2013). "How Do I Interpret R-squared and Assess the Goodness-of-Fit." Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development Vol. 15, Issue 4, 2015.

Fwu-Shiun Liou1 and John P. Borcherding. (2011). "Work sampling can predict unit rate productivity."*Journal of Construction Engineering and Management.*

Gerk (2014). "Radial basis neural network in modeling the productivity of masonry crews."

Ghoddousi P.and Hosseini, M. R. (2012) “A survey of the factors affecting the productivity of construction projects in Iran,” Technological and Economic Development of Economy, vol. 18, no. 1, pp. 99-116.

Gouett, M. C., Haas, C. T., Goodrum, P. M., and Caldas, C. H. (2011). "Activity analysis for direct-work."*J. Constr. Eng. Manage,* p. 1117–1124.

Gupta. (2019) construction management productivity analysis

Hanna, A. S., Taylor, C. S., and Sullivan, K. T. (2005). "Impact of extended overtime on construction labor". *J. Constr. Eng. Manage,* p. 734–739.

Hanna, A. S.(2010). "Construction labor productivity management and methods improvement." Madison, Wisconsin, US.

Hazati, Ayoub. (2016). "Modeling construction labor productivity."*journal of construction engineering and management.*

Helping, D. W. (2007). “Cyclone Method for Modeling Job Site Processes.” Journal of the Construction Division, 103(3), 489–499."

Hendrickson (2000)."*Project Management for Construction, Fundamental Concepts for Owners, Engineers, Architects and Builder."*

Heravi and Eslamdoost. (2015). "Labor productivity of concreting work for gas, steam."

Herdsman and Ellis. (1990). "Relationship between influencing factors and productivity of steel form erection activity."*j. construction management.*

Horne. (2005). "*Effects of accelerated working, delays and disruptions on labor productivity,* London." Chartered Institute of Building.

H. Randolph Thomas, William F. Maloney, Members, ASCE. (1990). "Modeling construction labor productivity."*Journal of Construction Engineering and Management.*

Huang, Chen and Sun. (2004). "Cyclon modeling methodology to estimate the productivity of formwork operation."

Jarkas, A. M. (2012). "Factors affecting construction labor productivity in Kuwai."*Journal of Construction Engineering and Management,* p. 138(7) 811–820.

Jenkins, J. (2003). "Productivity improvement through work sampling."

Josephson, P., and Björkman, L. (2013). "Why do work sampling studies in construction? The case of plumbing work in Scandinavia." Eng. Construct. Architect. Manage., 20(6), 589–603.

Keith, T. Z. (2015). "Multiple regression and beyond: An introduction to multiple regression and structural equation modeling" 2nd Ed., Routledge, New York, US.

Knowles, R. P. (1997). "Predicting construction labor productivity using neural networks." M.Sc. thesis, Univ. of Alberta, Edmonton, Alberta, CanadaKoch and Moavenzadeh, 2004. productivity improvement in construction labor productivity.

Latzko, W. J., and Saunders, D. M. (1995). "Four days with Dr. Deming": A strategy for modern methods of management. Reading, MA: Addison-Wesley Publishing Co

Liou F and Borcherding, J. D. (1986). "Work sampling can predict unit rate productivity." *Journal of Construction Engineering and Management, 112(1), 90–103.*

Madison, Wisconsin, Hayes. (2013). "*Introduction to mediation, moderation, and conditional process analysis.*

Mao, H. (1999). "Estimating labor productivity using fuzzy set theory." M.Sc. thesis, Univ. of Alberta.

Mendenhall. (2011). "Second Course in Statistics Regression Analysis." Seventh edition, Pearson.

Miguez. (2013). "*Nonlinear Regression Models and Applications in Agricultural Research."* American Society of Agronomy.

Mosehli, O., Assem, I, and El-Rayes, K .(2005). "Change orders impact on labor productivity."*J. Constr,* p. 354–359.

Moselhi, O, and Khan Z. (2012). "Significance ranking of parameters impacting construction labor productivity." J. Cons. Innov.: Info., Proc., Manage., 12(3), 272–296.

Olabosipo. (2011). "Factors affecting the performance of labor in Nigerian construction sites."*Mediterranean Journal of Social Sciences,* pp. 2 (2), p251-257.

Orth and Jenkins. (2003). "Mechanical and general construction productivity results."*AACE International Transactions.*

Pallant J. (2005). "*A step by step guide to data analysis using SPSS for Windows,* Australia"

Panas A. and Pantouvakis.A, (2010). "Simulation-based and statistical analysis of learning effectin floating caisson construction operation."*ASCE Journal of construction engineering and management.*

Panas, A. (2010). "Evaluating research methodology in construction productivity." *The Built and Human Environment Review, 3(1), 63-85.*

Picard, H. E. (2004). "Direct labor productivity measurement: As applied in construction and major maintenance projects." TCM Framework 9.2: Progress and Performance Measurement, AACE International Recommended Practice No. 22R-01. Rome, Italy.

Pinto, A., Nunes, I. L., and Ribeiro, R. A. (2011). "Occupational risk assessment in construction industry-Overview and reflection." Safety Sci., 49(5), 616-624.

Rifat. (1996). "*Construction labor productivity modeling with neural networks and regression analysis"*

Robert, H. (2006). "*Handbook of univariate and multivariate data analysis and interpretation with SPSS."*Rockhampton, Australia: Chapman & Hall/CRC Taylor & Francis Group.

Rogge, D. F., & Tucker, R. L. (2002). "Foreman-delay surveys: Work sampling & output."*Journal of the construction engineering.*

Rojas, E. M. &. A. P. (2004). "Is construction labor productivity declining."*Journal of Construction Engineering and Management,* pp. 129 (1), 41-46.

Sanders, S. R., and Thomas, H. R. (1993). "Masonry productivity forecasting model." J. Constr. Eng. Manage., 119(1), 163–179.

Shahtaheri, C. T. (2014). "Setting baseline rates for on-site work categories in the construction industry."*J. Constr. Eng. Manage,* pp. 141(5), 04014097.

Soekiman, A., Pribadi, A. & Soemardi, B. (2009). "Factors relating to labor productivity affecting the project schedule performance in Indonesia."*Journal of Construction Engineering and Management,* pp. 3 (2), p1-8.

Song L. and Liang, D. (2011) "Lean construction implementation and its implication on sustainability: A contractor's case study," Canadian Journal of Civil Engineering, vol. 38, no. 3, pp. 350-359

Sonmens and Rowings. (2007). "labor productivity models for concrete pouring, formwork, and concrete finishing."*j. construction engineering.*

Stevens, J. (1996). "*Applied multivariate statistics for the social sciences (3rd edn)." Mahway, .,* s.l.: NJ: Lawrence Erlbaum.

Strandberg and Josephson. (2005). "*What do construction workers do? Direct observations in housing projects.*"

Tabachnick, B. &. F. L. (2013). "*Using multivariate statistics." 6th edition. Pearson Education, Inc.,* Northridge:: California State University,.

Tam C M, Thomas K.L Tong, and Sharon L Tse. (2002). "Artificial neural networks."*Engineering Construction and,* pp. 446-452.

Tangen. (2005). "Demystifying productivity and performance." *International Journal of Productivity and Performance Management,* pp. 54(1), 34-46.The U.S. Bureau of Labor Statistics (BLS, 2012).

Thomas, and Yiakoumis. (1987). "Factor Model of Construction."*Journal of Construction Engineering and Management 113 (4,* p. 623–639.

Thomas, H. R. (2004). "Crew performance measurement via activity sampling."*Journal of construction.*

Thomas, H. R., and Mathews, C. T. (1986). “Learning curve models of construction productivity” J. Constr. Eng. Manage., 112 (2), 245–258.

Tsehayae, Fayek, and Aminah Robinson. (2015). "Developing and Optimizing Context-Specific and Universal Construction Labour Productivity Models."*A Research Framework for Work Sampling and its Application in Developing Comparative Direct and Support Activity Proportions for Different Trades,* p. 348.

Tsehayae, A. A., and Fayek, A. Robinson. (2012). “A research framework for work sampling and its application in developing comparative direct and support activity proportions for different trades,” Proc., Construction Research Congress, ASCE, West Lafayette, Indiana,

Vilasini, N. Neitzert, T. R. and Gamage, J. (2011) “Lean methodology to reduce waste in a construction environment,” in 15th Pacific Association of Quantity Surveyors Congress, Colombo, Sri Lanka.

Yi, W., and Chan, A. (2014). "Critical Review of Labor Productivity Research in Construction Journals." J. Manage. Eng., 30(2), 214–225.

APPENDIX

Appendix A. Summary of Case Study Data

Activity Percentage of an Activities

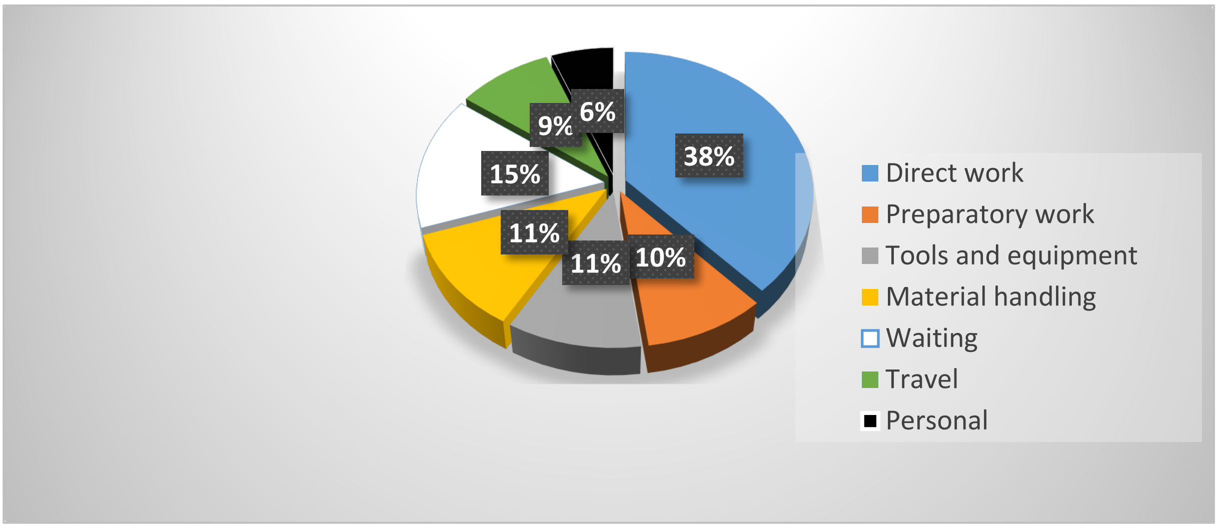

Figure A.1. Column Formwork Activity Percentage

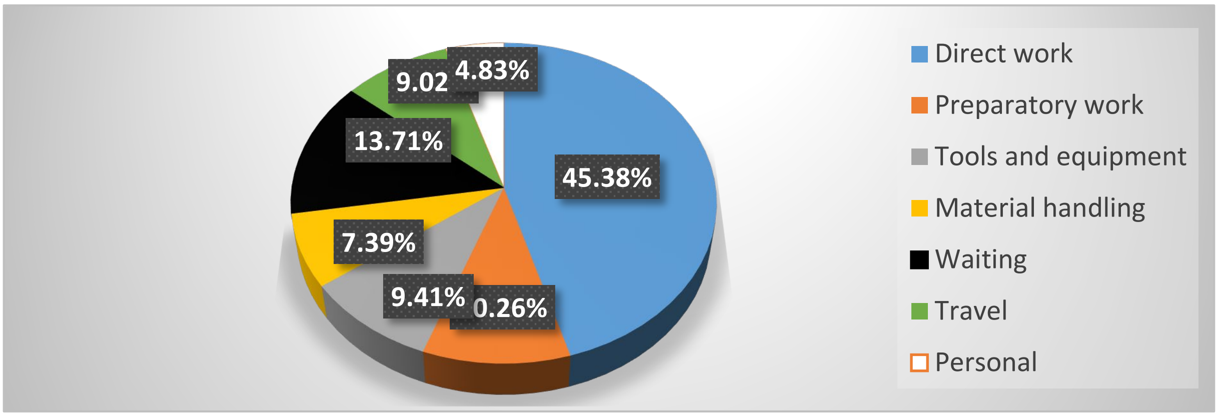

Figure A.2. Slab Concreting Activity Percentage

Table A.1 Result of Construction Labor Productivity for Column Formwork

Day	Crew Size	Production	CLP(M2/Hr)	Day	Crew Size	Production	CLP(M2/Hr)
1	8	34.56	0.54	38	4	20.8	0.65
2	4	27.2	0.85	39	4	26.56	0.83
3	12	50.88	0.53	40	5	35.2	0.88
4	12	84.48	0.88	41	6	42.24	0.88
5	5	19.2	0.48	42	6	42.24	0.88
6	6	38.88	0.81	43	6	42.24	0.88
7	5	39.6	0.99	44	4	23.04	0.72
8	4	16.32	0.51	45	4	23.68	0.74
9	5	21.6	0.54	46	5	22.4	0.56
10	5	25.2	0.63	47	4	30.72	0.96
11	5	23.6	0.59	48	8	56.96	0.89
12	3	16.8	0.7	49	7	36.96	0.66
13	10	59.2	0.74	50	6	34.08	0.71
14	10	59.2	0.74	51	4	28.16	0.88
15	10	50.4	0.63	52	6	27.84	0.58
16	8	47.36	0.74	53	5	29.6	0.74
17	5	29.6	0.74	54	5	42.8	1.07
18	5	35.2	0.88	55	4	19.2	0.6
19	6	24.48	0.51	56	3	13.2	0.55
20	6	28.32	0.59	57	5	22	0.55
21	5	28	0.7	58	4	23.68	0.74
22	4	28.16	0.88	59	6	30.24	0.63
23	5	26.4	0.66	60	5	28	0.7
24	5	35.6	0.89	61	4	28.16	0.88
25	14	73.92	0.66	62	5	18.8	0.47
26	15	86.4	0.72	63	4	18.88	0.59
27	9	42.48	0.59	64	4	14.72	0.46
28	10	70.4	0.88	65	6	33.6	0.7
29	10	56	0.7	66	5	35.6	0.89
30	14	60.48	0.54	67	5	26.4	0.66
31	10	58.4	0.73	68	5	28.4	0.71
32	10	70.4	0.88	69	4	28.16	0.88
33	5	38.8	0.97	70	6	27.84	0.58
34	1	5.6	0.7	71	6	31.2	0.65
35	5	28.8	0.72	72	4	26.56	0.83

Table A.2 Result of Construction Labor Productivity for Slab Concreting

Day	Crew Size	Production	CLP(M2/Hr)	Day	Crew Size	Production	CLP(M2/Hr)
1	13	16.38	0.14	19	11	37.95	0.69
2	13	15.6	0.15	20	9	26.1	0.58
3	14	17.64	0.18	21	11	13.2	0.24
4	10	36.5	0.73	22	8	7.2	0.18
5	17	50.15	0.59	23	13	62.4	0.96
6	13	39.65	0.61	24	14	50.4	0.72
7	18	32.4	0.36	25	10	24.5	0.49
8	14	10.5	0.15	26	14	12.6	0.18
9	13	14.3	0.22	27	13	16.9	0.26
10	13	33.8	0.52	28	11	33	0.6
11	10	29.5	0.59	29	10	25.5	0.51
12	9	26.1	0.58	30	14	32.2	0.46
13	11	25.3	0.46	31	12	57.6	0.96
14	14	42.7	0.61	32	9	7.65	0.17
15	14	35.7	0.51	33	21	51.45	0.49
16	14	51.8	0.74	34	8	16.4	0.41
17	12	18	0.3	35	14	17.64	0.14
18	15	54	0.72	36	8	15.68	0.28

Table A.3 Data matrix for column formwork activities

Average hourly Ws							
Direct work	Preparatory work	Tools and equipm	Material handling	Waiting	Travel	Personal	CLP
0.34	0.08	0.11	0.10	0.19	0.12	0.09	0.54
0.41	0.13	0.03	0.15	0.14	0.07	-	0.85
0.33	0.11	0.08	0.13	0.19	0.13	0.10	0.53
0.41	0.07	0.08	0.15	0.13	0.07	0.02	0.88
0.33	0.05	0.11	0.12	0.20	0.15	0.13	0.48
0.34	0.07	0.06	0.13	0.14	0.07	0.08	0.81
0.43	0.14	0.10	0.10	0.08	0.05	-	0.99
0.33	0.10	0.03	0.13	0.19	0.13	0.10	0.51
0.33	0.09	0.09	0.13	0.19	0.13	0.10	0.54
0.38	0.10	0.09	0.15	0.17	0.11	0.07	0.63
0.35	0.10	0.11	0.17	0.18	0.11	0.08	0.59
0.39	0.06	0.13	0.14	0.16	0.10	0.05	0.70
0.33	0.11	0.12	0.17	0.23	0.17	0.16	0.42
0.42	0.02	0.13	0.08	0.15	0.08	0.01	0.74
0.39	0.08	0.06	0.10	0.08	0.04	0.06	1.02
0.56	0.13	0.10	0.09	0.15	0.08	0.01	0.74
0.38	0.05	0.06	0.11	0.17	0.11	0.06	0.63
0.44	0.17	0.09	0.10	0.15	0.08	0.02	0.74
0.43	0.09	0.13	0.07	0.15	0.08	0.03	0.74
0.39	0.09	0.08	0.09	0.13	0.06	0.02	0.88
0.33	0.11	0.18	0.08	0.19	0.14	0.10	0.51
0.37	0.13	0.10	0.13	0.18	0.11	0.08	0.59
0.40	0.11	0.08	0.05	0.16	0.09	0.04	0.70
0.31	0.07	0.12	0.15	0.11	0.05	0.06	0.88
0.39	0.05	0.08	0.11	0.17	0.10	0.06	0.66
0.41	0.13	0.11	0.07	0.11	0.05	0.07	0.89
0.39	0.13	0.13	0.09	0.17	0.10	0.05	0.66
0.41	0.10	0.13	0.14	0.16	0.09	0.03	0.72
0.37	0.06	0.05	0.10	0.18	0.11	0.08	0.59
0.35	0.07	0.14	0.11	0.14	0.07	0.04	0.81
0.37	0.13	0.09	0.12	0.11	0.05	0.08	0.88
0.39	0.07	0.16	0.11	0.17	0.10	0.05	0.70
0.33	0.06	0.11	0.11	0.19	0.12	0.10	0.54
0.42	0.09	0.11	0.07	0.16	0.09	0.03	0.73
0.44	0.15	0.09	0.10	0.13	0.06	0.05	0.88
0.34	0.12	0.06	0.15	0.08	0.05	0.05	0.97
0.40	0.07	0.15	0.15	0.16	0.10	0.05	0.70
0.41	0.12	0.08	0.15	0.16	0.09	0.04	0.72
0.38	0.06	0.03	0.11	0.17	0.10	0.06	0.65
0.43	0.11	0.17	0.15	0.15	0.09	0.03	0.73
0.32	0.15	0.13	0.15	0.14	0.07	-	0.83
0.36	0.08	0.08	0.13	0.13	0.06	0.08	0.88
0.38	0.10	0.12	0.15	0.13	0.07	0.05	0.88
0.36	0.08	0.11	0.10	0.13	0.06	0.10	0.88
0.38	0.11	0.12	0.15	0.12	0.06	0.03	0.88
0.41	0.13	0.14	0.07	0.16	0.09	0.03	0.72
0.34	0.12	0.09	0.09	0.14	0.08	0.03	0.74
0.34	0.12	0.05	0.08	0.18	0.11	0.09	0.56
0.43	0.13	0.12	0.06	0.09	0.05	0.02	0.96
0.44	0.07	0.10	0.10	0.03	0.04	0.04	1.05
0.42	0.11	0.10	0.07	0.11	0.05	0.08	0.89
0.39	0.10	0.03	0.15	0.17	0.10	0.06	0.66
0.41	0.10	0.13	0.13	0.16	0.09	0.04	0.71
0.47	0.05	0.05	0.07	0.13	0.06	0.04	0.88
0.40	0.13	0.12	0.16	0.14	0.07	0.05	0.85
0.34	0.05	0.10	0.11	0.18	0.11	0.08	0.58
0.50	0.12	0.07	0.08	0.15	0.08	0.02	0.74
0.34	0.12	0.16	0.09	0.01	0.03	0.03	1.07
0.37	0.05	0.12	0.15	0.18	0.11	0.07	0.60
0.34	0.08	0.17	0.10	0.18	0.12	0.09	0.55
0.38	0.13	0.13	0.11	0.13	0.06	0.08	0.88
0.26	0.12	0.17	0.07	0.18	0.15	0.09	1.07
0.34	0.10	0.22	0.15	0.18	0.12	0.09	0.55
0.50	0.08	0.11	0.09	0.14	0.08	0.04	0.76
0.41	0.11	0.17	0.05	0.15	0.08	-	0.74
0.38	0.13	0.08	0.11	0.17	0.11	0.07	0.63
0.40	0.13	0.10	0.11	0.16	0.10	0.05	0.70
0.31	0.05	0.11	0.07	0.13	0.06	0.06	0.88
0.33	0.08	0.07	0.14	0.20	0.16	0.14	0.47
0.36	0.07	0.16	0.13	0.18	0.11	0.08	0.59
0.33	0.10	0.14	0.17	0.23	0.17	0.15	0.46
0.40	0.12	0.09	0.18	0.16	0.10	0.05	0.70

Table A.4 Data matrix for slab concreting activities

Average Hourly Result							
Direct Work	Preparatory Work	Tool &Equipment	Material Handling	Wating	Personal	Travel	CLP(M2/hr)
0.47	0.09	0.12	0.08	0.13	0.07	0.04	0.14
0.44	0.12	0.08	0.1	0.15	0.09	0.06	0.15
0.42	0.08	0.12	0.11	0.17	0.11	0.07	0.18
0.45	0.07	0.06	0.07	0.14	0.09	0.04	0.73
0.39	0.08	0.09	0.13	0.04	0.15	0.06	0.59
0.39	0.08	0.09	0.11	0.16	0.09	0.11	0.61
0.43	0.12	0.1	0.08	0.17	0.1	0.04	0.36
0.57	0.1	0.08	0.05	0.09	0.06	0.02	0.15
0.42	0.12	0.07	0.17	0.11	0.11	0.07	0.22
0.45	0.09	0.06	0.13	0.15	0.08	0.04	0.52
0.49	0.08	0.07	0.06	0.12	0.06	0.03	0.59
0.45	0.1	0.08	0.11	0.15	0.07	0.04	0.58
0.43	0.1	0.13	0.1	0.16	0.1	0.05	0.46
0.47	0.11	0.07	0.11	0.13	0.07	0.04	0.61
0.4	0.11	0.06	0.09	0.14	0.12	0.07	0.51
0.45	0.06	0.09	0.08	0.15	0.08	0.05	0.74
0.57	0.19	0.05	0.07	0.06	0.05	0.01	0.3
0.39	0.08	0.07	0.06	0.2	0.06	0.04	0.72
0.57	0.07	0.05	0.08	0.09	0.05	0.02	0.69
0.47	0.09	0.06	0.12	0.13	0.07	0.04	0.58
0.41	0.12	0.1	0.13	0.12	0.13	0.04	0.24
0.48	0.15	0.11	0.05	0.13	0.07	0.03	0.18
0.45	0.05	0.11	0.08	0.21	0.08	0.07	0.96
0.54	0.07	0.09	0.07	0.11	0.06	0.02	0.72
0.41	0.1	0.13	0.09	0.15	0.15	0.04	0.49
0.42	0.13	0.11	0.07	0.14	0.1	0.02	0.18
0.45	0.11	0.08	0.11	0.15	0.08	0.04	0.26
0.34	0.08	0.15	0.07	0.14	0.09	0.04	0.6
0.44	0.09	0.11	0.13	0.19	0.09	0.06	0.51
0.49	0.1	0.06	0.13	0.12	0.07	0.03	0.46
0.42	0.1	0.1	0.1	0.15	0.1	0.04	0.96
0.51	0.12	0.06	0.08	0.11	0.06	0.03	0.17
0.42	0.09	0.01	0.19	0.12	0.12	0.09	0.49
0.46	0.12	0.07	0.1	0.12	0.06	0.06	0.41
0.39	0.14	0.09	0.1	0.09	0.11	0.07	0.14
0.44	0.13	0.11	0.09	0.1	0.08	0.06	0.28

Appendix B. Sample calculation for validation of Data

Calculating Actual Errors for Activity Percentage for Column Formwork

With the activity percentages calculated, the actual error of each percentage may be calculated using the binomial distribution.

$$d = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} \ldots\ldots\ldots\ldots\ldots\ldots (5.1)$$

where d is the error, Zα/2 = 1.96 corresponding to a confidence level of 95%, p is the activity percentage being considered, and n is the total number of observations. For this particular case, the total number of observations is 1271.

The error for each activity percentage is calculated as follows

$$d(direct\ work) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.38(1-.38)}}{1271^{1/2}} = 2.66\%$$

$$d(Preparatory\ work) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.1(1-.1)}}{1271^{1/2}} = 1.65\%$$

$$d(Tool\ and\ Equipment) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.11(1-.11)}}{1271^{1/2}} = 1.16\%$$

$$d(Material\ Handling) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.11(1-.11)}}{1271^{1/2}} = 1.16\%$$

$$d(Waiting) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.15(1-.15)}}{1271^{1/2}} = 1.96\%$$

$$d(Travel) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.09(1-.09)}}{1271^{1/2}} = 1.57\%$$

$$d(Personal) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.06(1-.06)}}{1271^{1/2}} = 1.3\%$$

Calculating Actual Errors for Activity Percentage for Slab Concreting Activities

$$d(direct\ work) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.45(1-.45)}}{2265^{1/2}} = 2.04\%$$

$$d(Preparatory\ work) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.1(1-.1)}}{2265^{1/2}} = 1.65\%$$

$$d(Tool\ and\ Equipment) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.09(1-.09)}}{2265^{1/2}} = 1.17\%$$

$$d(Material\ Handling) = \frac{\sqrt{z^2 p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2 x 0.07(1-.07)}}{2265^{1/2}} = 1.05\%$$

$$d(Waiting) = \frac{\sqrt{z^2p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2x0.13(1-.13)}}{2265^{1/2}} = 1.38\%$$

$$d(Travel) = \frac{\sqrt{z^2p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2x0.09(1-.09)}}{2265^{1/2}} = 1.17\%$$

$$d(Personal) = \frac{\sqrt{z^2p(1-p)}}{n^{1/2}} = \frac{\sqrt{1.96^2x0.0483(1-.0483)}}{2265^{1/2}} = 0.28\%$$

Appendix C: Descriptive Statistics Table

Table C.1. Descriptive Statistic: Column Formwork

Work sampling	N	Minimum	Maximum	Mean	Std. Deviation
Direct work	72	.26	.52	.3790	.04925
Preparatory	72	.02	.17	.0996	.02933
Tool and Equipment	72	.03	.17	.1042	.03266
Material	72	.05	.18	.1160	.03397
Waiting	72	.01	.23	.1429	.04716
Travel	72	.03	.18	.0921	.03596
Personal	72	.01	.16	.0624	.03363
Productivity	72	.46	1.10	.7435	.15495

Table C.2 Descriptive Statistics: Formwork Shear wall

	N	Minimum	Maximum	Mean	Std. Deviation
Direct Work	21	.23	.43	.3433	.04913
Preparatory Work	21	.07	.20	.1233	.03812
Tool and Equipment	21	.04	.21	.1124	.04437
Material Handling	21	.06	.17	.1148	.02943
Waiting	21	.03	.27	.1543	.05688
Travel	21	.04	.17	.0924	.03477
Personal	20	.01	.14	.0635	.03514
Productivity	21	.60	1.18	.7819	.17174

Table C.3. Descriptive Statistics: Slab Concreting

	N	Minimum	Maximum	Mean	Std. Deviation
Direct Work	30	.30	.57	.4488	.06089
Preparatory Work	30	.05	.16	.0982	.02528
Tool and Equipment	30	.04	.15	.0869	.02717
Material Handling	30	.05	.14	.0934	.02598
Waiting	30	.04	.21	.1366	.03552
Travel	30	.05	.15	.0863	.02600
Personal	30	.01	.17	.0569	.04468
Productivity	30	.14	.96	.4694	.23338

Table C.4. Descriptive Statistics: Column Concreting

	N	Minimum	Maximum	Mean	Std. Deviation
Direct Work	32	.30	.58	.4359	.06445
Preparatory Work	32	.05	.17	.1047	.02771
Tool and Equipment	32	.03	.14	.0891	.02595
Material Handling	32	.03	.20	.1003	.03914
Waiting	32	.07	.20	.1325	.03121
Travel	32	.05	.15	.0916	.02273
Personal	31	.01	.08	.0481	.01815
Productivity	32	.12	.94	.3966	.23102

Table C.5. Descriptive Statistics: Column Reinforcement

	N	Minimum	Maximum	Mean	Std. Deviation
Direct Work	75	.17	.49	.3369	.06424
Preparatory Work	75	.02	.16	.0896	.03248
Tool and Equipment	75	.04	.19	.0985	.03021
Material Handling	75	.06	.33	.1644	.06966
Waiting	75	.02	.22	.1292	.03506
Travel	75	.05	.21	.1156	.03728
Personal	75	.04	.18	.0728	.03034
Productivity	75	.29	30.83	25.9	4.10841

Table C.6. Descriptive Statistics: Slab Reinforcement

	N	Minimum	Maximum	Mean	Std. Deviation
Direct Work	52	.17	.49	.3335	.06299
Preparatory Work	49	.02	.14	.0855	.02799
Tool and Equipment	49	.04	.19	.1018	.03283
Material Handling	49	.06	.29	.1578	.05363
Waiting	49	.06	.21	.1273	.02914
Travel	49	.07	.19	.1131	.03144
Personal	48	.04	.18	.0763	.03119
Productivity	49	11.03	30.83	26.04	4.97359

Table C.7. Descriptive Statistics: Beam Reinforcement

	N	Minimum	Maximum	Mean	Std. Deviation
Direct Work	18	.29	.54	.3939	.07421
Preparatory Work	18	.04	.13	.0844	.02382
Tool and Equipment	18	.04	.16	.1006	.04412
Material Handling	18	.06	.28	.1706	.06102
Waiting	18	.02	.17	.1161	.04258
Travel	18	.08	.23	.1394	.04556
Personal	17	.01	.18	.0771	.03965
Productivity	18	10.68	30.29	22.5356	6.28621

Appendix D: Pearson Correlation Analysis: Work Sampling Proportions with CLP

Table D.1. Correlation: Work Sampling Proportion with CLP for Slab Formwork Activity

		X1	X2	X3	X4	X5	X6	X7	K
X1	Pearson Correlation	1							
	Sig. (2-tailed)								
X2	Pearson Correlation	-.065	1						
	Sig. (2-tailed)	.697							
X3	Pearson Correlation	-.026	-.034	1					
	Sig. (2-tailed)	.876	.841						
X4	Pearson Correlation	-.113	-.005	-.268	1				
	Sig. (2-tailed)	.501	.976	.104					
X5	Pearson Correlation	-.226	.111	-.096	-.288	1			
	Sig. (2-tailed)	.172	.509	.567	.079				
X6	Pearson Correlation	-.303	-.095	-.247	.095	-.244	1		
	Sig. (2-tailed)	.064	.570	.136	.569	.140			
X7	Pearson Correlation	-.288	-.446**	-.158	-.123	-.084	.001	1	
	Sig. (2-tailed)	.079	.005	.343	.463	.617	.998		
K	Pearson Correlation	.352*	-.166	.192	-.450**	.149	-.139	-.178	1
	Sig. (2-tailed)	.030	.319	.248	.005	.372	.404	.285	
*. Correlation is significant at the 0.05 level (2-tailed).									

Table D.2. Correlation: Work Sampling Proportion with CLP for shear wall Formwork Activity

		X1	X2	X3	X4	X5	X6	X7	K
X1	Pearson Correlation	1							
	Sig. (2-tailed)								
X2	Pearson Correlation	-.259*	1						
	Sig. (2-tailed)	.028							
X3	Pearson Correlation	-.125	.041	1					
	Sig. (2-tailed)	.297	.731						
X4	Pearson Correlation	-.286*	-.010	-.044	1				
	Sig. (2-tailed)	.015	.930	.714					
X5	Pearson Correlation	-.236*	-.010	.001	-.093	1			
	Sig. (2-tailed)	.046	.932	.995	.439				
X6	Pearson Correlation	-.34**	.119	-.041	.076	-.282*	1		
	Sig. (2-tailed)	.004	.320	.732	.524	.016			
X7	Pearson Correlation	-.062	-.251*	-.173	-.172	-.174	.034	1	
	Sig. (2-tailed)	.606	.033	.146	.150	.144	.778		
K	Pearson Correlation	.109	-.034	-.93	.015	.066	-.027	.128	1
	Sig. (2-tailed)	.361	.775	.06	.903	.584	.822	.284	
*. Correlation is significant at the 0.05 level (2-tailed).									

Table D.3. Correlation: Work Sampling Proportion Slab Concreting Activity

		X1	X2	X3	X4	X5	X6	X7	K
X1	Pearson Correlation	1							
X2	Pearson Correlation	-.278	1						
	Sig. (2-tailed)	.101							
X3	Pearson Correlation	-.396*	.099	1					
	Sig. (2-tailed)	.017	.567						
X4	Pearson Correlation	-.325	-.279	-.326	1				
	Sig. (2-tailed)	.053	.100	.053					
X5	Pearson Correlation	-.267	-.086	.201	-.100	1			
	Sig. (2-tailed)	.116	.618	.239	.563				
X6	Pearson Correlation	-.326	-.140	-.022	.118	.37*	1		
	Sig. (2-tailed)	.052	.416	.899	.494	.025			
X7	Pearson Correlation	-.533**	-.208	-.063	.513**	.115	.134	1	
	Sig. (2-tailed)	.001	.224	.715	.001	.504	.437		
K	Pearson Correlation	.045	-.326	.057	.492**	-.127	.010	.112	1
	Sig. (2-tailed)	.793	.052	.742	.002	.462	.955	.516	

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

Table D.4. Correlation: Work Sampling Proportion Column Concreting Activity

		X1	X2	X3	X4	X5	X6	X7	K
X1	Pearson Correlation	1							
X2	Pearson Correlation	-.232	1						
	Sig. (2-tailed)	.173							
X3	Pearson Correlation	-.283	.014	1					
	Sig. (2-tailed)	.094	.937						
X4	Pearson Correlation	-.636**	-.252	-.180	1				
	Sig. (2-tailed)	.000	.138	.294					
X5	Pearson Correlation	-.414*	-.193	-.021	.209	1			
	Sig. (2-tailed)	.012	.259	.901	.221				
X6	Pearson Correlation	-.112	-.497**	.115	.209	-.099	1		
	Sig. (2-tailed)	.514	.002	.503	.222	.568			
X7	Pearson Correlation	-.245	.066	-.194	.161	-.064	-.217	1	
	Sig. (2-tailed)	.156	.705	.263	.357	.717	.210		
K	Pearson Correlation	-.070	-.005	.188	.203	-.160	.096	-.348*	1
	Sig. (2-tailed)	.686	.979	.273	.235	.351	.579	.041	
*. Correlation is significant at the 0.05 level (2-tailed).									

Table D.5. Correlation: Work Sampling Proportion Slab Reinforcement Activity

		X1	X2	X3	X4	X5	X6	X7	K
X1	Pearson Correlation	1							
X2	Pearson Correlation	-.277*	1						
	Sig. (2-tailed)	.047							
X3	Pearson Correlation	.007	-.134	1					
	Sig. (2-tailed)	.959	.343						
X4	Pearson Correlation	-.409**	-.082	-.176	1				
	Sig. (2-tailed)	.003	.563	.211					
X5	Pearson Correlation	.031	-.065	-.186	-.292*	1			
	Sig. (2-tailed)	.826	.649	.186	.035				
X6	Pearson Correlation	-.178	-.011	-.369**	-.108	.204	1		
	Sig. (2-tailed)	.206	.939	.007	.448	.148			
X7	Pearson Correlation	-.141	-.181	-.050	-.117	-.197	.185	1	
	Sig. (2-tailed)	.323	.203	.726	.414	.165	.195		
K	Pearson Correlation	.459**	-.121	-.028	-.321*	.177	-.027	-.070	1
	Sig. (2-tailed)	.001	.395	.841	.020	.211	.848	.627	
*. Correlation is significant at the 0.05 level (2-tailed).									

Table D.6. Correlation: Work Sampling Proportion Column Reinforcement Activity

		X1	X2	X3	X4	X5	X6	X7	K
X1	Pearson Correlation	1							
	Sig. (2-tailed)								
X2	Pearson Correlation	.152	1						
	Sig. (2-tailed)	.303							
X3	Pearson Correlation	-.010	-.168	1					
	Sig. (2-tailed)	.947	.254						
X4	Pearson Correlation	-.051	-.036	-.037	1				
	Sig. (2-tailed)	.728	.806	.804					
X5	Pearson Correlation	-.264	.084	-.201	-.371**	1			
	Sig. (2-tailed)	.070	.573	.170	.009				
X6	Pearson Correlation	.215	-.004	-.41**	-.104	.182	1		
	Sig. (2-tailed)	.143	.979	.004	.481	.215			
X7	Pearson Correlation	.325*	-.107	-.069	-.126	-.190	.195	1	
	Sig. (2-tailed)	.024	.468	.640	.392	.197	.184		
K	Pearson Correlation	.131	-.161	-.276	-.207	.012	.081	-.012	1
	Sig. (2-tailed)	.375	.275	.057	.158	.936	.584	.933	
*. Correlation is significant at the 0.05 level (2-tailed).									

Table D.7. Correlation: Work Sampling Proportion Beam Reinforcement Activity

		X1	X2	X3	X4	X5	X6	X7	K
X1	Pearson Correlation	1							
	Sig. (2-tailed)								
X2	Pearson Correlation	.063							
	Sig. (2-tailed)	.804							
X3	Pearson Correlation	.147	-.042	1					
	Sig. (2-tailed)	.562	.870						
X4	Pearson Correlation	.592**	.083	.312	1				
	Sig. (2-tailed)	.010	.743	.207					
X5	Pearson Correlation	.014	-.260	-.158	-.223	1			
	Sig. (2-tailed)	.955	.297	.530	.373				
X6	Pearson Correlation	.260	.002	.120	.265	.538	1		
	Sig. (2-tailed)	.298	.992	.635	.289	.021			
X7	Pearson Correlation	-.294	.251	-.528	-.50	.298	-.207	1	-.
	Sig. (2-tailed)	.252	.331	.029	.041	.245	.426		.
K	Pearson Correlation	.111	.199	.222	.176	.007	.364	-.299	1
	Sig. (2-tailed)	.660	.429	.375	.484	.979	.138	.244	

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

Appendix E: Histogram, Scatter plot

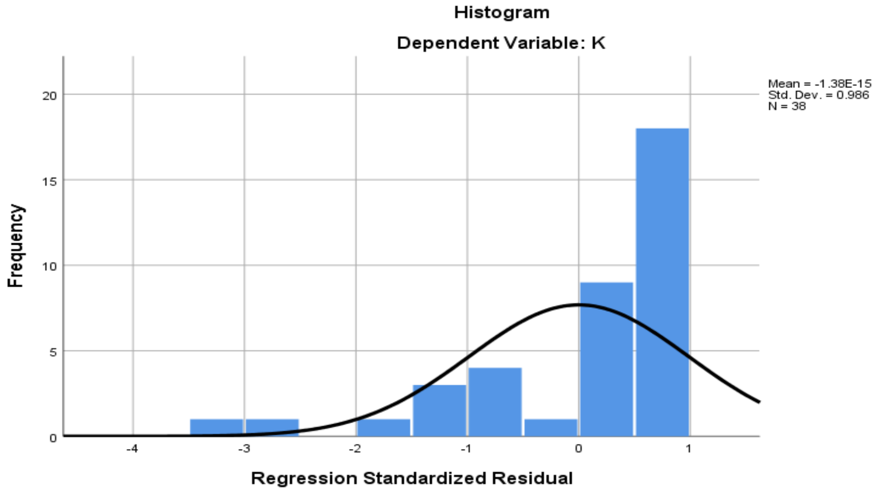

Figure E.1. Histogram of Residuals with Normal Curve for Slab Formwork Activities

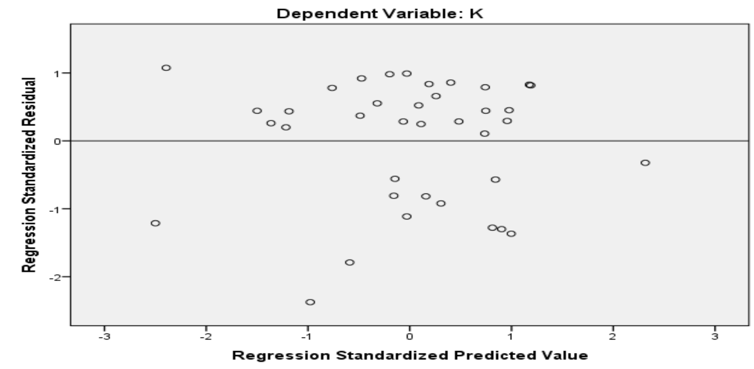

Figure E.2. Scatter plot of Predicted Values vs. Residuals for Slab Formwork activities

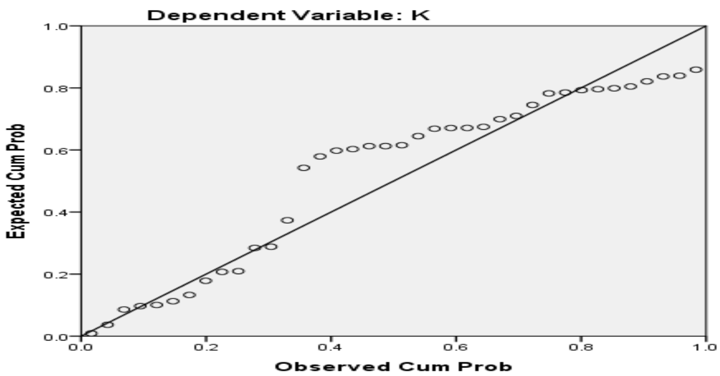

Figure E.3. Normal Probability Plots Regression standard Residual for Slab Formwork Activities

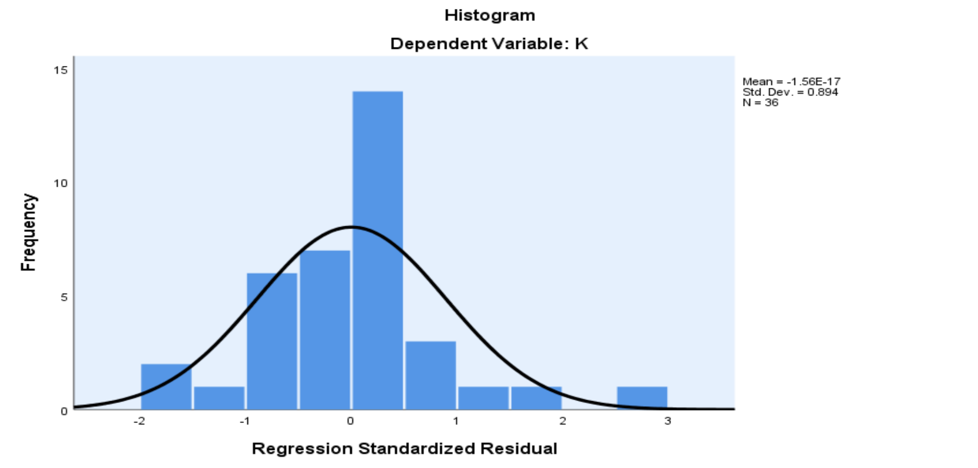

Figure E.4. Histogram of Residuals with Normal curve for Slab Concreting Activities

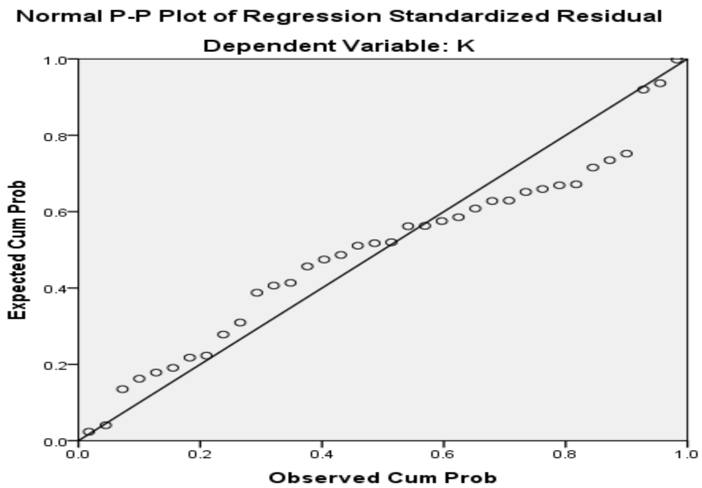

Figure E.5. Normal Probability Plots Regression standard Residual for Slab Concreting Activities

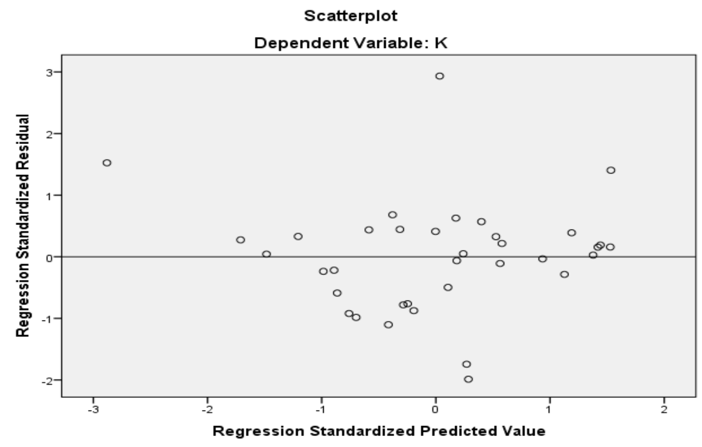

Figure E.6. Scatter Plot of Predicted Values vs. Residuals Slab for Concreting Activities

Appendix F: Work Sampling Proportion versus construction labor productivity

F1: CLP as Function of Direct Work Proportion: Scatter Plots

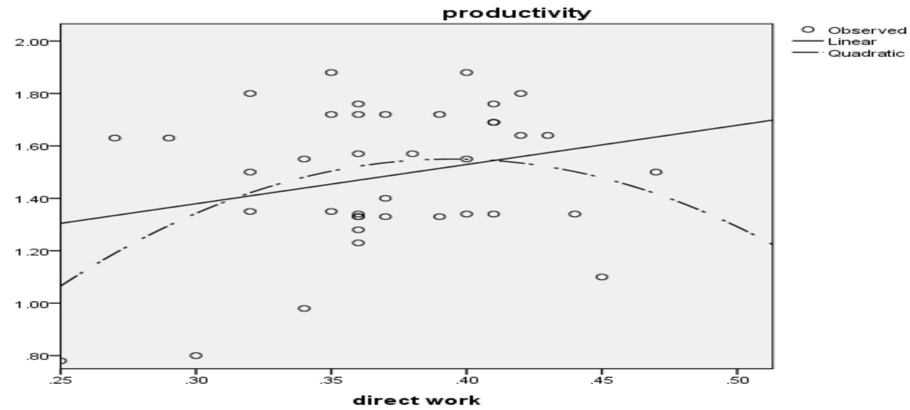

Figure F.1. Productivity as Function of Direct Work Proportion for Slab Formwork Activity

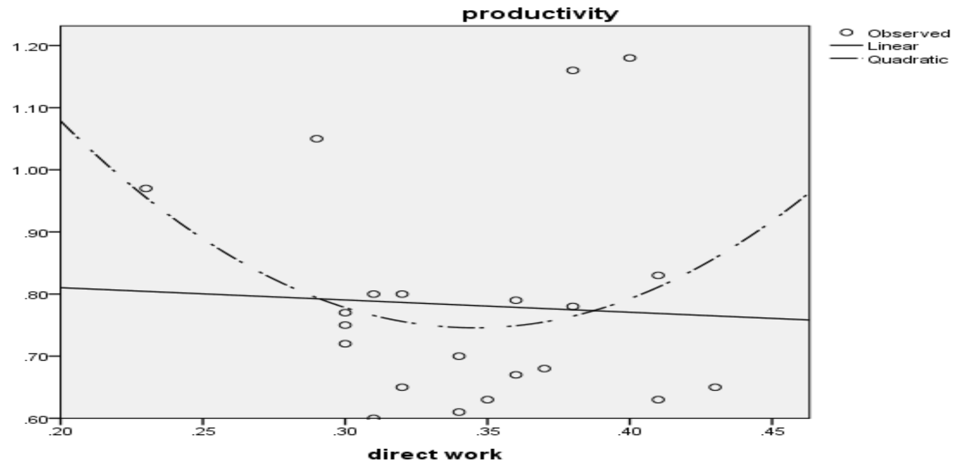

Figure F.2. Productivity as Function of Direct Work Proportion for Shear wall Formwork Activity

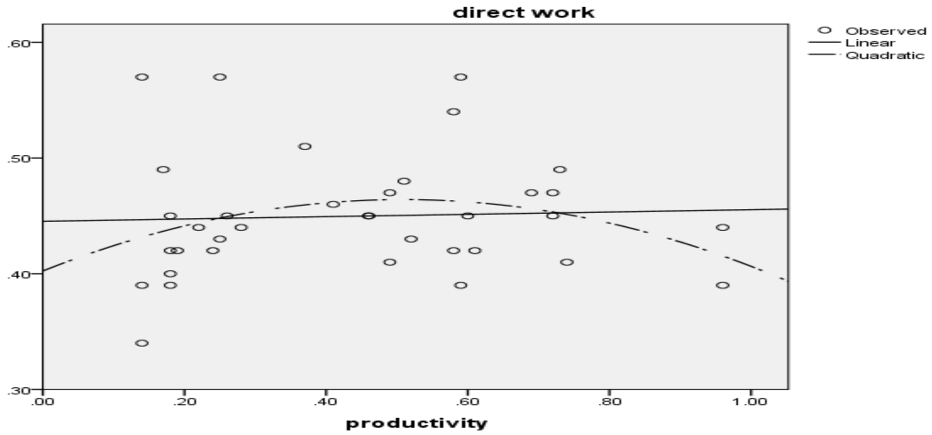

Figure F.3. Productivity as Function of Direct Work Proportion for Slab Concreting Activity

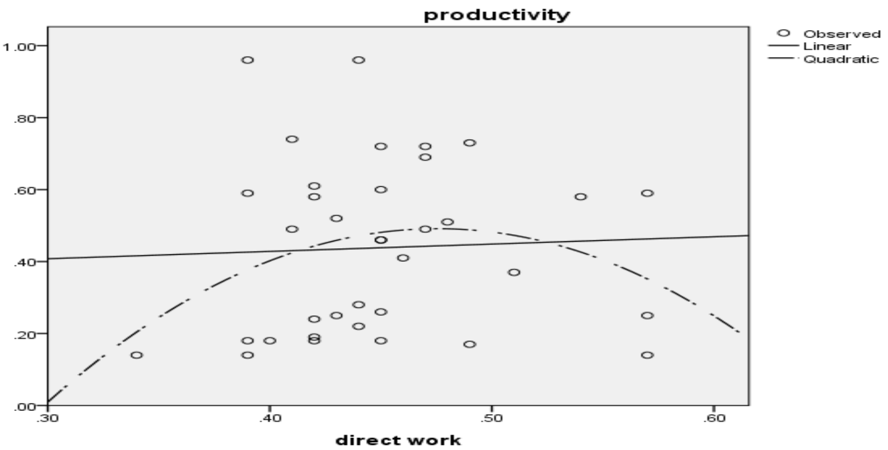

Figure F.4. Productivity as Function of Direct Work Proportion for Column Concreting Activity

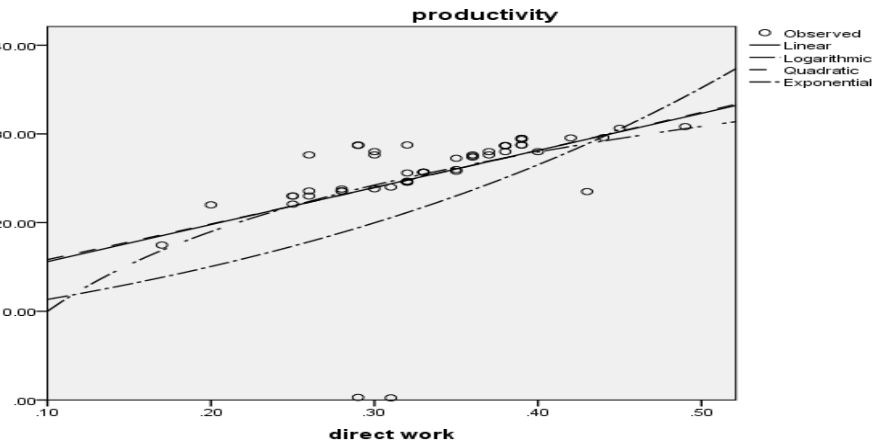

Figure F.5. Productivity as Function of Direct Work Proportion for Slab Reinforcement Activity

Figure F.6. Productivity as Function of Direct Work Proportion for Column Reinforcement Activity

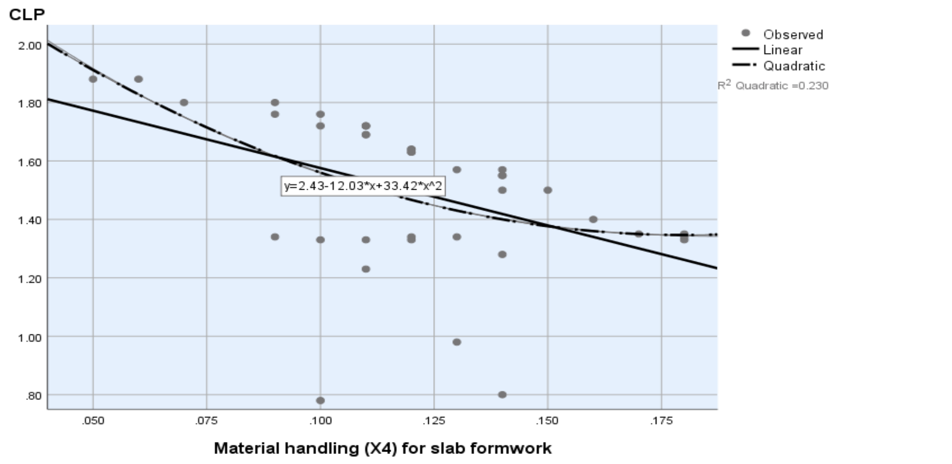

Figure F.7. Productivity as Function of Material Handling Proportion for Slab Formwork Activity

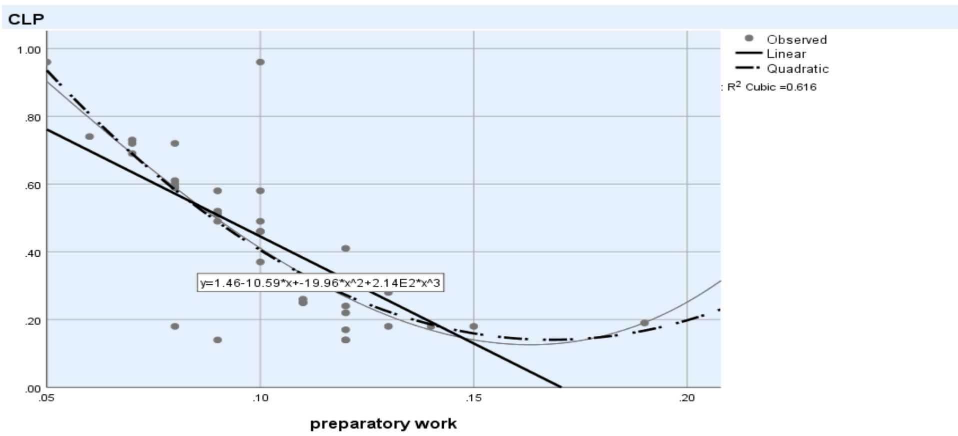

Figure F.8. Productivity as Function of Preparatory Work Proportion for Slab Formwork Activity