Construction Labor Productivity Benchmarking: A Comparison Between On-Site Construction and Prefabrication

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CONSTRUCTION LABOR PRODUCTIVITY BENCHMARKING: A COMPARISON BETWEEN ON-SITE CONSTRUCTION AND PREFABRICATION

BY

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ABSTRACT

CONSTRUCTION LABOR PRODUCTIVITY BENCHMARKING: A COMPARISON BETWEEN ON-SITE CONSTRUCTION AND PREFABRICATION

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Marquette University, 2019

Construction labor productivity has been declining over the past sixty years, which has caused a decline in overall construction productivity. The traditional ways of managing construction projects and their delivery have evolved into an inherently inefficient and adversarial process. There was always a need to improve the way construction elements are constructed and delivered to the job site such as adopting lean construction.

One way to achieve this goal is to prefabricate the construction elements off site and then deliver them to the site for installation. Prefabrication is a process of assembling building components in a remote location using a production line in a controlled environment and delivering the parts to the construction site for installation. Several researchers have compared prefabricating construction labor productivity to on-site labor productivity. These comparative studies were conducted at the industrial or project levels but not at the task level. Therefore, the results lack the comparative data analysis identifying the direct, indirect, and idle time that workers spend in both environments. The purpose of this research is to address this gap in the literature by conducting quantitative statistical analysis to determine the effect of prefabrication on construction labor productivity.

A comparison of construction labor productivity (sq. ft/labor hour) between constructing prefabricated stud wall panels and constructing on-site stud wall panels was established. This research project was conducted using field experiments and the data collection procedure consists of observing construction workers assembling steel studs wall panels in a prefabrication shop as well as in a construction site using the work sampling data collection method. The data was collected from five construction projects located in Milwaukee and Madison, Wisconsin. Data analysis was completed by comparing the prefabrication of wall panels to on-site wall panel installation in terms of construction labor productivity.

The results of the research indicated that construction workers spend more direct time and less indirect and idle time in the prefabrication shop than on-site construction. Additionally, Labor productivity increases with stud wall panels size in both...
environments. Also, labor productivity in the prefabrication shop is higher than on-site construction for stud wall panels smaller than 90 sq. ft.

This study provides a better understanding of the factors affecting labor productivity in both environments. The task level comparative analysis presented in this research aims to inform construction firms and contractors of the time allocated by workers in prefabrication and on-site construction, which can help them increase labor productivity and consequently improve construction productivity by identifying deficiencies in the construction process.
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Emad Nadi, PE, MS

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CHAPTER 1: INTRODUCTION

1.1 Background

The construction industry has traditionally been one of the largest industries in the United States. However, construction productivity is not performing well when compared to other sectors. For example, Productivity in manufacturing has doubled between 1994 and 2012 while a slight decline in productivity has occurred in construction sector according to McKinsey Global Institute research organization which can be seen in Figure 1.1

Another report by McKinsey Global Institute research organization indicated that large projects across asset classes are behind schedule by 20% and cost overrun by 30%.
According to the Construction Industry Institute (CII), it has been estimated that 10% of the cost of projects completed in the United States is spent in one rework. Furthermore, between 25% and 50% of construction costs are lost to waste and inefficiencies in labor and materials control. This problem stems from communication difficulties between different operators in the design and construction supply chain.

The customer’s goal is to have the project delivered as planned at the expected quality without exceeding the budget and all the above objectives are accomplished in a safe environment. In other words, the significant elements of a successful project include cost, time, quality, and safety.

The traditional ways of managing a construction project and its delivery have evolved into an inherently inefficient and adversarial process. According to Koskela and Vrijhoef (2000), the management and execution of the process draw out the inherent deficiencies in the current construction process. Koskela and Vrijhoef (2000) suggested that the old way of delivering projects is responsible for all projects’ deficiencies and waste detected in the construction industry. They pointed out the need for a new philosophy in construction management and project delivery that leads to better collaboration, innovation, project delivery, and control.

Between 1948 and 1975, two engineers at Toyota, Taiichi Ohno and Eiji Toyoda, introduced a new approach in the manufacturing sector. This new philosophy, called “lean production,” aims to establish an innovative workflow that maximizes value and eliminates waste in the production line.

Toyota’s production system had two pillar concepts: (1) just-in-time flow (JIT) and (2) autonamation (smart automation) (Aziz et al., 2013). The new approach was
implemented through the company’s unique Toyota Production System (TPS). Womack, Jones, and Roos presented the term “lean” to the business sector in 1990. Then, in 1992, Koskela introduced the lean philosophy to the construction sector, and the term “lean construction” became well known. Since Japanese car makers pioneered this approach in the early years, the lean concept has proven to be significantly successful in improving production. Lean construction, in general, aims to minimize waste and maximize value. Identifying and eliminating waste in the supply chain can have a significantly positive impact on eliminating waste throughout the entire project (Trent, 2008).

Initially, the goal of adopting the new philosophy was to eliminate the deficiencies and inefficiencies resulting from various areas of production waste. These areas involved oversupply based on a push system (delivery based on supply not demand), overproduction downtime/delays, waste inherent in physical construction (also related to estimation), storage on site, inadequate site planning, rework, and quality (Howell, 2008). Overproduction is the main material waste in Construction Supply Chain Management (CSCM); in most cases, this is the reason that the other six types of waste occur (Tapping & Shuker, 2003). Such waste usually results from “push” production leading to unbalanced supply and demand.

To adopt a similar approach of lean philosophy in the construction sector, we must understand that construction is different from manufacturing regarding both the process and final product. Construction tasks are carried out with a great level of complexity and uncertainty (Ballard & Koskela 1998).

While construction is an on-site production field that involves installation and erection, manufacturing consists of line production with fixed manufacturing lines and
moving products. The complexity of construction projects is on a larger scale when compared to manufactured products. In general, manufactured products are standardized and usually assembled in the same controlled environment, while each construction project is unique in its design, site, and surrounding environmental circumstances, and the customer is involved in the final product design. As a result, it is more challenging to apply the lean philosophy to construction projects than to manufacturing.

However, even though construction is not highly repetitive (unlike manufacturing), if projects are broken down, many constituent parts consist of repeated processes and activities. Some projects and activities require a more tailored approach. One of the main elements of lean construction is waste elimination or minimizing.

In construction management, waste refers to any activity that results in no value. There are seven types of waste in construction operations:

1. defects: errors that occur in rework and consequently in increased costs;
2. delays: waiting for upstream activities to finish before another job can begin;
3. over processing: work that is not explicitly asked for by the customer;
4. overproduction: producing something either before it is needed or in too high a quantity;
5. maintaining excess inventory: storing products as a result of overproduction, which leads to costly storage and processing;
6. unnecessary transport of materials: unnecessary movement of a product between processes, such as moving a pile of dirt from one place to another without producing value; and
unnecessary movement of people and equipment: any movement of personnel and equipment that does not add value to the process.

Contractors and project managers adopt lean construction approach in order to eliminate or minimize any of the waste types listed above, which leads to an increase in construction productivity

1.2 Problem Statement

Labor productivity is defined as the ratio of product output to input (labor hours). For example, labor productivity can be expressed as how many square feet of concrete slab are produced per hour of labor input.

Between 1998 and 2013, the US construction labor productivity growth has declined by an annual rate of 0.32% compared to labor productivity in manufacturing sector which has a positive trend over the same period (Teicholz, 2015).

Figure 1-2: Construction vs manufacturing Productivity (1998-2012) - Source McKinsey&Company
Furthermore, according to Matt Stevens’s white paper, which was published in 2014 for Stevens Construction Institute, the labor productivity in the construction industry has declined compared to productivity in 1993.

The industrial construction productivity is affected by two factors: capital productivity (such as machines and new technology input) and manpower productivity, which is labor productivity (Lam, 1987). The focus of this research is on the latter.

Since construction is a labor-intensive industry, the weak growth of construction labor productivity has significantly contributed to the decline of the construction industry. While it is difficult to state the exact causes of declining labor productivity in the construction industry, possible reasons include inadequate training for workers, the age of the labor force, and the increasing number of regulations imposed on the industry (Allman et al., 2000). Also, the quality of the overall construction product relies mainly on the quality level of the labor involved.

Contractors, project managers, and project owners have been seeking ways to improve the overall construction productivity by adopting methods to improve labor productivity. The increase in construction productivity can increase profitability and competitiveness while decreasing construction costs.

Waste related to construction labor productivity could be a significant concern during a construction project. Minimizing or eliminating project waste related to labor is one form of adopting lean thinking, which leads to improving labor productivity. One way to achieve this goal is to prefabricate the construction elements off site and then
deliver them to the site for installation. Construction prefabrication is a process in which construction elements are produced and assembled off site in a controlled environment before being delivered to the construction site for final installation.

This research investigates the significant improvement of labor productivity when adopting a lean construction process of fabrication while defining appropriate procedures for measuring construction labor productivity. To improve labor productivity, we must be able to measure and benchmark it. In this research, on-site construction labor productivity is measured and benchmarked against prefabrication construction labor productivity. The research adopts a procedure to measure construction labor productivity to compare the results, in terms of productivity, of constructing steel stud walls on site and prefabricating steel stud walls.

This research focuses on identifying how prefabrication affect labor productivity in construction sites by comparing the direct, indirect, and idle work times of construction workers while building steel stud walls in a prefabrication shop to the time spent performing the same task on site.

The time that a typical construction worker spends while performing any construction task is divided into three types (Allmon et al., 2000).

1. Direct work time: Time is directly related to the assigned task.
2. Indirect work time: Time is indirectly related to the assigned task.
3. Idle time: Time is not related to the assigned task.
The low rate of labor productivity occurs since construction workers' time spent on site is not fully dedicated to direct productive tasks (Dozzi et al., 1993). On the contrary, workers spend a tremendous amount of time on site engaging in other activities unrelated to work. Some examples of idle time include chatting with other workers, talking on the phone, or taking short cigarettes breaks. Apparently, more idle time results in less productivity in labor time and in construction tasks overall. With the decline in labor productivity of construction tasks performed on site, there is a need to define the factors that affect the performance of labor under traditional construction environments, as well as the problems encountered at a construction site.

1.3 The Significance of the Research

Previous studies, industrial publications, and contractors' reports have highlighted the effectiveness of prefabrication compared to traditional construction. However, these studies were implemented at the project and industrial levels and not the task level. Therefore, the results lack the comparative data analysis identifying the direct, indirect, and idle time that workers spend in both environments. The task level comparative analysis provided in this research aims to inform construction firms and contractors of the time allocated by workers in prefabrication and on-site construction, which will help them increase labor productivity and consequently to improve construction productivity by identifying deficiencies in the construction process.
2.1 Research Objectives

The research objective is to compare the labor productivity in the prefabrication construction process to that of traditional on-site construction. The results provide a better understanding of how prefabrication may improve construction labor productivity. To this end, the author conducted a quantitative analysis of construction labor productivity (based on labor hour per square foot) by comparing the prefabrication of wall panels to on-site wall panel installation. Prefabrication process includes assembling, delivering and installation of wall panels.

Figure 2-1: Steel Stud Wall Panel
The research indicates that the prefabrication of construction elements (e.g., steel stud walls assembled off site) is more productive than constructing the same elements on site. The reason might be that labor productivity during prefabrication is higher than when the task is performed on site.

The variance in labor productivity may be due to the fact that construction workers spend more time in direct work during the prefabrication process than when they construct these elements on site. This research aims to investigate if prefabrication actually yields higher labor productivity than the traditional construction process.

The purpose of this research is to examine labor productivity in the construction sector by comparing construction labor productivity during prefabrication to that measured during on-site construction activities. The study provides a quantitative analysis comparing the labor productivity (based on labor hour per square foot) of prefabricated wall panels to that observed during on-site wall panel construction.

2.2 Research Scope

The research focuses on comparing the labor productivity of steel stud wall prefabrication to on-site steel stud wall installation. Assembling and installing steel stud wall panels are labor-intensive tasks that do not require complex equipment but simple tools, which makes these activities ideal subjects of analysis for the goal of this research. The data were collected from five projects between October 2017 and May 2018 in the Milwaukee and Madison areas covering 228 steel stud wall panels. Based on the
statistical data analysis methods adopted in this research, the amount of data is a sufficient for the purpose of the research within the time available for data collection.

2.3 Research Methodology

The first stage of the research consisted of an extensive literature review conducted to introduce previous studies and findings pertaining to construction productivity, prefabrication, and statistical data analysis. The literature review blends discoveries found in previous research, journals, books, Internet publications, dissertations, and company reports.

Data collection design and data analysis followed the literature review. The data collection stage entailed the observation of both construction sites and a prefabrication shop. During the observations, a stopwatch was used to measure the time it took for a construction worker to assemble a stud wall panel in the prefabrication shop or construct one at a construction site. Data were recorded on a datasheet. Construction plans supplied by a contractor were used during data collection and data analysis. Once the data was collected, the analysis of the data was conducted using computer software, such as Excel spreadsheets and SPSS.

The researcher utilized a quantitative analysis method comparing labor productivity (based on labor hour per square foot) as related to prefabricated wall panels to that observed during on-site wall panel construction.

As mentioned previously, the purpose of this research is to examine labor productivity in the construction sector and to compare construction labor productivity during prefabrication to that measured during on-site construction activities. The results
can help determine the factors that influence labor productivity. To reach this goal, the researcher intends

1. to conduct a comprehensive literature review to establish a background of previous research studies related to construction labor productivity, prefabrication, and data analysis;
2. to conduct on-site data collection regarding labor time while constructing various sizes of wall panels built using the prefabrication process as well as on-site procedures;
3. to establish a comparison of construction labor productivity (sq. ft/labor hour) when constructing prefabricated stud wall panels and on-site stud wall panels;
4. to establish a relationship between stud wall panel size and construction labor productivity and to conduct a regression data analysis of productivity versus wall panel size to identify the "critical" size for cost saving;
5. to determine the significant factors influencing labor productivity by benchmarking the construction labor performance between the two cases and comparing the direct, indirect, and idle time spent by workers in both environments; and
6. to adopt the appropriate performance-measuring technique (e.g., work sampling) to determine the construction labor productivity for both prefabrication and on-site construction activities.

2.4 Dissertation Organization

The dissertation is divided into seven chapters.
1. Chapter 1 provides an introduction to the background of the topic and the statement of the problem.

2. Chapter 2 describes the objective and the scope of the research, as well as the methodology adopted.

3. Chapter 3 consists of a literature review covering the topics of construction productivity, construction labor performance and measurement, prefabrication and its impact on labor productivity, a statistical analysis that includes data collection design, and data analysis.

4. Chapter 4 covers the data collection procedure.

5. Chapter 5 describes how the data collected were analyzed using statistical methods and software, such as spreadsheets and SPSS.

6. Chapter 6 provides a discussion, conclusion, an explanation of this study’s contribution to the literature, and recommendations for future research.

7. References are provided at the end of this paper.
CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

The issue of the decline in construction labor productivity has been a concern for the construction industry for many years (Park et al., 2005). Researchers have conducted numerous studies on the subject and collected data to investigate this issue. Various researchers have measured construction labor productivity at the industrial, project, and task levels.

At the industrial level, national data for construction labor productivity are available in the form of labor productivity indexes. Both government and private organizations have published data on this topic, including the Organization for Economic Cooperation and Development (OECD), the U.S. Department of Labor, the U.S. Bureau of Labor Statistics (BLS), the U.S. Department of Commerce, and the Census of Construction Industries. For example, The BLS publishes two standard measures of productivity: (single-factor) labor productivity and multifactor productivity.

Construction productivity is usually measured at three levels: the industrial, project, and task levels (Huang et al., 2009). Most of the data published are based on total labor hours input versus construction costs output—a price-based or dollar/hr index (Allmon et al. 2000). Also, the trend in changing the available data does not reflect the actual changes in labor costs or an increase in construction costs due to inflation; hence, the data are not always reliable (Goodrum et al., 2002). Additionally, these indexes provide data on labor productivity at the industrial level, but there is a need for construction labor productivity information addressing both the project level and the task level.
At the project level, researchers have conducted numerous studies to collect data through questionnaires and to shed light on labor productivity regarding the total cost per project or total construction output versus labor hours input. However, the issue with this data is the lack of consistency in the definition and the measuring of construction labor productivity (Huang et al., 2009). For example, some studies are based on total workday hours or total labor hours performed per week. However, not all of the 40 hours are spent on work, which means that the research results do not reflect the actual labor productivity (Noor, 1998).

In addition to the studies mentioned above, many construction companies have created their own tracking databases and developed a system measuring construction labor productivity. However, each company has its own definition of labor productivity, which makes it very difficult to define standard productivity (Park et al., 2005). Most companies that conduct such studies use the information to test the performance of construction projects for future reference.

This research concerns the task-level measurement of construction productivity. The measurement was set for a task, such as laying a brick wall or constructing a reinforced concrete slab. The labor work was then monitored and divided into three categories: direct work, indirect work, and idle work. In this research, labor productivity for on-site construction was measured at the task level and then benchmarked against prefabrication construction. Direct work refers to the activities the worker performs that are directly related to the task, such as laying bricks to construct a wall. Indirect work involves activities that indirectly relate to the task, such as receiving instructions, reading a plan, charging tools, or moving equipment. Idle work consists of those unproductive
activities unrelated to the task assigned, such as chatting, smoking, standing idle, waiting, or performing rework. Idle time is considered a “waste” and negatively affects construction productivity. Rework costs account for 5% of total construction costs (Hwang, 2009).

Benchmarking on-site construction labor productivity in relation to prefabrication labor productivity by applying a task-level measurement of labor performance provides a foundation for new research studies that may result in a better understanding of labor productivity measurement at the task level and demonstrate the benefit of applying lean construction thinking in a practical way, such as adopting a prefabrication process.

The productivity of the construction industry has evolved over the past years. Researchers have employed several methodologies to measure labor productivity in the construction industry. In a massive production such as the construction sector, decision making cannot be made easily by a single firm; companies must cooperate with other firms through contracts. Other activities involved include the analysis of transactional costs and the friction of economic processes to achieve efficiency in production and the marketing of goods and products (Forbes & Golomski, 2001).

When comparing the construction industry in the 19th century to current practices, much has changed regarding operations and productivity. During the 19th century, for instance, in London, the industry underwent an internalization process regarding decision making within firms and contractors. During the early years of the century, many contractors used to subcontract work that they could not manage on their own (Forbes & Golomski, 2001). Principal contractors were typically master artisans, such as carpenters or masons, but they could also be architects or surveyors. Artisans used to sign contracts
for work, which involved more than one trade. Later in the century, various firms developed specialized skills to handle construction contracts for various buildings and other works.

The master builders of the 19th century were motivated to conduct risk analyses and to measure productivity through various organizational situations. They began to develop an urge to compete profitably since the market was rapidly changing and becoming more competitive (Motwani, Kumar, & Novakoski, 2015). They sought to increase their productivity through various incentives related to measuring productivity to gauge the profitability of the construction business (Gerald, 1997). Other motivating factors included population growth, developments in the world, advancements in technology, expansion of markets, competition, and the Industrial Revolution. The considerable demand gave them hope that they could benefit from the growing investment in the establishment of all trades of buildings, as well as the increasing demand for workshops.

3.2 Labor Productivity

Generally, the definition of productivity is the ratio of input to output. In the case of labor productivity, the output consists of the number of units produced, and the input refers to the labor hours used to produce these units. Traditionally, the performance measurement of construction projects has been based on the progress and completeness of work within a specific time frame (Haponava, 2010).

On any construction site, the financial gain of the contract is independent of many other aspects. Some of the factors considered include the completion time, the minimum
cost of the project, and labor productivity, which have a direct link to what the project has achieved. Factors that affect labor productivity fall into the following categories:

- the human capacity of work,
- construction site management competence, and
- the motivation of employees.

### 3.2.1 The human capacity of work

An example affecting human capacity work is fatigue. Fatigue has a significant influence, causing a reduction in productivity and poor quality of work; it also increases the risk of accidents in construction (Aryal, 2017).

### 3.2.2 Construction site management competence

Workers at construction sites need to be motivated to produce outputs effectively in a dedicated manner. Various measures can be taken to manage the site effectively. It is mandatory for workers to have confidence and trust in their supervisors. If workers view a site’s management as poorly run, corrupt, unfair, or unruly, their motivation and morale may decrease, leading to poor productivity. Some of the examples of site management that reduce labor efficiency and productivity include

- delayed instructions from the supervisor,
- late delivery of materials,
- unbalanced workgroups,
- use of the wrong management methods,
- poor work allocations, and
- use of poor tools and equipment.
3.2.3 The motivation of employees

Workers are motivated in a couple of ways while at the workplace. The techniques used to encourage workers at the site must ensure the existence of a balance in worker motivation so that all workers can be treated equally. Another approach can involve rewarding the best performing workers so that the rest can also aspire to work at a similarly high level (Motwani, Kumar, & Novakoski, 2015). Furthermore, workers are subject to fear discipline. The fear can include the fear of the site supervisor and the fear of losing their jobs, especially in countries with social security incentives.

The first aspect to consider in a construction site is discipline. Discipline at the site is portrayed via punctuality, lack of absenteeism, ethical standards, and the maintenance of a clean site. When no site discipline exists, productivity and work morale suffer. Supervisors can achieve discipline in the following ways.

➢ Supervisors should explain site rules to every worker and ensure that they understand them.
➢ Supervisors should set an example by establishing and maintaining high discipline standards.
➢ No element of discipline should go unchecked. In this case, retribution should be an inevitable matter.
➢ Supervisors should take personal interest in workers and discuss any problems with them without showing any favoritism.
➢ All infringements of the law should be disciplined instantly.

The other element that supervisors should use to achieve high labor productivity is ensuring job satisfaction. In addition to providing workers with basic site needs (e.g.,
water, food, and shelter), job satisfaction is attained when psychological needs such as personal dignity and self-respect are met. People need to belong to a particular place and feel respected at the site. Job satisfaction is achieved through the attainment of quality output, and such milestones should be rewarded and recognized (Motwani, Kumar, & Novakoski, 2015). Some of the possible factors that cause low self-esteem on the part of workers include poor working conditions and ineffective relationships with supervisors at the construction site.

There are also financial incentives. Incentives of this nature are commonly used in developed countries, but again, they can become sources of conflict and disputes between workers and the management. These incentive schemes enable workers to earn bonuses through their hard work in addition to their regular rates. The rewards are offered to workers who produce more than the usual standards. The only problem is determining what these standards should be.

### 3.2.4 Construction labor productivity

Productivity in the construction industry means the average direct labor input required to install a unit of material. It is believed that perfect productivity can be achieved with 40 hours of work in a week, taking all holidays and vacations into consideration. Construction work requires extensive manual labor, and productivity and human performance relate to one another. Therefore, the most commonly used measure of productivity is the constant contract dollars of new work per work hour.

Scholars have not yet reached a consensus regarding a specific definition of productivity in the construction industry. Therefore, labor productivity relates human labor and the labor cost to the quality of the output produced. In construction,
productivity is regarded as the mean labor productivity—that is, units of labor per hour worked (Motwani, Kumar, & Novakoski, 2015). The inverse of labor productivity is also commonly used, which is personnel hours per unit. A couple of issues, such as the environment, climatic conditions, regulatory policies, and energy costs, have affected productivity in the construction industry.

The construction industry is very complicated. It is a fragmented industry whereby activities are typically complex due to the many tradespeople involved, the material required, as well as the construction methods and machinery needed. These factors make it difficult to gauge and control the costs and efficacy of a project (Robinson, 2014). The construction industry is also fragmented with respect to the various types of professionals working in it, such as project consultants, suppliers, builders, and other engineers who make procurements and contractual arrangements (Motwani, Kumar, & Novakoski, 2015). Construction productivity is affected by internal organization factors, such as the lack of information feedback systems and the ineffective organization of tasks. External factors include social legislation and energy costs.

Benchmarking labor productivity constitutes a difficult undertaking. Many sources, such as historical publications and trade associations, provide guidelines for the benchmarking of trends. Some of the possible sources of such information include the BLS, contractors’ associations, and universities that have conducted similar research. Every year, construction companies, operators, engineers, and procurement companies are hit by huge billion-dollar construction claims due to inefficient elements affecting labor productivity (Robinson, 2014). Effective construction planning must take into consideration various aspects of labor to effectively monitor conditions used to estimate
project costs. Also, the plan should try to eliminate the effect of productivity, which directly affects construction expenses. Available technologies, such as Intergraph and SmartPlant Construction, can be used to help work planners control labor impacts by enabling users to adjust and regulate the labor aspects of a project (Motwani, Kumar, & Novakoski, 2015). These technologies also assist users in visualizing work packages and manipulate them to eliminate labor factoring. Intergraph also helps in the creation of work package documentation to support construction claims resulting from labor factoring.

3.2.5 Productivity trends in the United States

Construction productivity trends significantly impact the economy of any nation. According to the BLS, in the past 40 years, the productivity of non-farm businesses has increased by more than 100%, whereas that of construction has remained constant. However, construction costs have escalated to higher levels. The cost of raw materials, such as steel, cement, and other major equipment, has increased as well. Labor is very crucial in any industry, and yet construction sites are experiencing less labor productivity (Oberlender, 2000). The following graph displays the total construction productivity trend from 1966 to 2003.
3.2.6 Factors affecting construction productivity

Several factors have typically affected the construction productivity. These factors continue to influence productivity, as well as the adoption and implementation of quality initiatives. The following are some of the factors affecting construction productivity.

According to results of previous research, poor site management contributes to time wastage at construction sites. Active management is necessary for profitability and project success. Lack of proper control has been cited as the primary cause of reduced productivity due to the unmotivated and less skilled workforce (Oberlender, 2000). Four fundamental ways to increase productivity through management practices include planning, control, the supply of resources, and the selection of the right people to control specific project functions.

Figure 3-1: Construction productivity—1966 to 2003.
The code enforcement of the government administration conducts construction inspections. The work involves inspecting critical elements of the construction process by analyzing some factors without focusing on the artistry aspect.

Architectural contracts are said to be ambiguous regarding professional standards of performance; this situation results in low and unmet expectations. Construction proprietors feel that the architect/engineer (A/E) contracts protect the engineers at the expense of the owner. For instance, current contracts defend the designer from any liability in case of lawsuits between the servicer and the owner of the structure (Pekuri, Haapasalo, & Herrala, 2011).

Benchmarking helps improve employees’ performances through a systematic and logical manner by comparing an individual’s performance with that of others. Occasionally, benchmarking has played a critical role in the construction industry as firms seek to improve their general performance. For instance, benchmarking helps managers to identify specific performance goals that the firm would like to achieve on both a short- and long-term basis. However, despite the increased performance of benchmarking within the construction industry, firms may fail to implement the strategy when discharging their duties for various reasons.

Firstly, firms are limited in their use of benchmarking since most of the models used in the construction industry are specific to the project. Most companies in the construction industry use a single performance metric; thus, it is not possible to translate the details into an improvement in overall firm performance. Additionally, the benchmarking model is also limited in the construction industry since it does not allow firms to measure the impact of using a particular technology and its effects on overall
performance (Huang et al., 2009). Furthermore, most of the benchmarking models used in the construction industry do not assist managers in understanding various performance metrics trade-offs. Lastly, the benchmarking models do not demonstrate the relationship between performance and the expansion of the metrics. Therefore, the firm can hardly measure their return on investment after using a specific benchmarking model. In conclusion, the construction industry is highly competitive; therefore, it requires continuous performance improvements by continuously gaining new knowledge. However, the existing benchmarking models have various limitations that prevent managers from ensuring superior firm performance.

There is a common descending pattern in the accessibility of a skilled workforce in the business. The common wellsprings of specialists—professional school projects and apprenticeships—have not remained aware of the interest. In the territory of experts and gear administrators alone, there is an anticipated shortage. Certain areas in various U.S. states have additionally reported a shortage of skilled workers, and government-funded instruction frameworks or association-based projects cannot fill the need. In the so-called building boom (2000–2006), a significant part of the demand for workers in the United States was met with vagrant work from Central and South America (Huang, Chapman, & Butry, 2009). Even though the end of the first decade of millennium was characterized by monetary compression, a lack of skilled workers is probably going to become an issue again once the economic situation improves.

Ventures in construction are never planned or approached in the same way. Natural factors (e.g., climate and physical area) make each venture one of a kind. Though most workers view this uniqueness as an alluring component of professional
development, it can adversely affect development profitability (Koskela & Howell, 2002). Project uniqueness requires changes in how a project is developed. Specialists have to absorb information in the early phases to adapt to during each step of the process.

There is an absence of formal preparation in construction compared to any significant part of the economy. This absence of training is because of pragmatic concerns, such as businesses finishing the expanded level of non-association work. All in all, the workforce of temporary employees is profoundly versatile (Huang, Chapman, & Butry, 2009). Thus, companies are frequently hesitant to invest in preparing individuals who may, before long, be working for another organization. This situation might result in a decline in the development of the workforce. It remains unclear how this influences profitability.

Progressively increased use of highly skilled workers may even lead to higher profitability in a few activities (Pekuri, Haapasalo, & Herrala, 2011). Broadly educating the workforce in different areas can decrease unit work costs. Contracts that allow for adaptable work at the work site guarantee profitability as well.

3.2.7 Construction productivity and lean construction

There is a significant and valid relationship between lean construction and construction productivity. Lean construction is a collaboration-based system based on accountability and commitments during a construction project. In this scenario, the construction stakeholders must trust one another. The relationship between contractors and the design teams must be valid and trustworthy. In most of the projects where lean construction principles are applied, teams come together through collaborative tools and look for ways to eliminate waste in the construction project (Motwani, Kumar, &
Novakoski, 2015). The groups plan how they can improve through reflections. The lean processes are developed to remove and improve a project’s predictability, and they actively promote respect for all people involved.

Productivity in construction constitutes a measure of how well a company’s resources are harnessed to facilitate the objectives of a project in place. Productivity has reached the highest level when the costs are minimized and when the performance achieved is high. Productivity is measured as the ratio of inputs to the rate of outputs in construction productivity, and it is expressed as the constant in-pace value divided by the data, such as the labor and materials used. Productivity measurements allow managers to assess the importance of work, the supervision of a project, equipment, and the elements in the production of a structure at the lowest feasible cost. Therefore, productivity is directly linked with lean construction, which aims to coordinate all the stakeholders to reduce any waste in a project.

Over 7.6 million individuals were employed in the U.S. construction sector in 2007. Positions in the industry relate to planning, new construction, remodeling development, hardware and materials assembly, and supply, thus making the structure and building industry the largest assembling industry in the United States (Pekuri, Haapasalo, & Herrala, 2011). In this way, the industry dramatically affects the condition of the economy.

Productivity is an essential part of the general idea of performance. Even though people disagree about what comprises an execution, a few definitions allude to it as a blend of efficiency, quality, auspiciousness, spending adherence, and well-being. Productivity is fundamentally estimated by expenses. Tasteful profitability refers to work
achieved at a reasonable cost to the proprietor and with generous profits for the project contractor. The other factors include quality, timeliness, budget adherence, and safety.

Traditional construction project management tools do not address the issue of productivity sufficiently; they only include the cost overruns and schedule slippages. The construction industry as a whole measures productivity in terms of the time taken for completion, if completion is within the budget, and if the construction codes are met. Quality is assumed to be sufficient if all the construction codes are followed. Many contractors believe that is it difficult to fulfill all four requirements simultaneously, and they assume that there is a zero-sum relationship between the elements. In simpler terms, these contractors mean that any accelerated project time results in increased project costs, less safety at work, and poor quality. At the same time, higher quality requires a higher price and a relatively longer time span while security remains constant.

Construction profitability is a noteworthy concern, particularly when compared among different enterprises. Broadly, profitability in the development area has not kept pace with various businesses. At the firm level, it directly affects profitability. As revealed by the U.S. Bureau of Commerce, development efficiency has been increasing at a much slower rate than in different sectors; between 1990 and 2000, it climbed by around 0.8%, in contrast with over 2% for all U.S. industries (Motwani, Kumar, & Novakoski, 2015). In any case, profitability in the construction business remains unmeasured to a great extent, and those measures that do exist are conflicting and contradictory. The BLS does not keep an official productivity list for the construction business; it is the only exception among the industries the agency follows.
Lean construction and productivity are two inseparable aspects. When lean construction is implemented appropriately, it leads to improved efficiency and reduced waste. When incorporated with the productivity aspect, timeliness, quality, and budget adherence are attained. The benefits of applying lean construction principles are explained in the following section.

Lean principles and integrated delivery depend solely on the trust and respect of all involved. The more people work together, the higher performance becomes due to effective communication. When people are working together in a team, unlike the traditional adversarial manner, each stakeholder feels empowered and motivated to produce high-quality work. Additionally, the alignment of objectives and goals and the heavy focus on coordination result in decreased chances of having to redo the job and other issues during project execution.

Lean construction relies on the collaboration of a team during construction. Managing a lean construction project empowers all team members to contribute to the continuous advancement process through close and collaborative problem-solving techniques. To achieve the best collaboration, teams should use modern technological tools and software that can facilitate problem-solving strategies and effective communication. For instance, construction productivity software can allow for cross-functional teams and collaboration for solving issues.

In order to take full advantage of lean development, the board depends on everybody understanding and adjusting to the proprietor's objectives and destinations. Knowing which parts of a task are viewed as the most profitable to the proprietor and end clients enables groups to make the best, fastest choices, without imperiling the result.
At the point when proprietors realize that their interests are at the center of each choice made during the project, the speed with which issues are settled fundamentally increases. Essential leadership and commitments are decentralized, thus enabling the task to progress more quickly. A team that can immediately resolve any problems has a greater chance of remaining on schedule and within budget. These elements lead to extremely satisfied proprietors, as well as more contracts, work, and benefits for everybody involved.

Organizations have reported increased productivity through the utilization of lean construction management strategies. This approach translates into an increased return on investment. Production rates are important measurement units that a contractor uses based on the calculations of estimates. Apart from wastage reduction, the overall project efficiency is improved. Other factors that may result in losses in productivity include efficiency lost in waiting for materials, equipment, or some crucial information, as well as inefficient processes and energy lost due to poor scheduling of employees (Griffis, Farr, & Morris, 2000). Since lean development uses prefabrication wherever possible, a decrease in material waste is additionally an extraordinary open door for increases in productivity. Limiting the requirement for stock and surplus materials yields reserve funds that can then be reinvested in the business. Without the effective use and implementation of lean construction, labor productivity tends to decline terribly.

### 3.3 Measuring Labor Productivity

The fragmentation of a construction site makes it very difficult to measure its performance. A typical site consists of six or more trades or disciplines (Ahmad, 2016). According to Dozzi, 1993) monitoring and measuring productivity can be performed at
micro- and macro-levels. At the macro-level, an individual deals with contracting methods, labor legislation, and the organization of labor. At the micro-level, one deals with the management of the project and mainly the operations happening at the construction site (Dozzi & AbouRizk, 1993). To improve construction productivity, we must measure it. Moreover, the changes adopted in methods, efforts, and systems are measured. The measured values are then compared with the production standards or the estimates.

Several factors can affect construction productivity on a site. The Construction Industry Development Council task force developed a questionnaire for evaluating the factors affecting productivity. The list contains seven categories and more than 90 factors (Dozzi & AbouRizk, 1993). Figure 3-2 displays the most significant factors in the seven categories.

![Table 1.1 factors seriously impairing construction productivity](image)

**Figure 3-2: Factors impacting construction productivity (Dozzi, 1993)**
3.3.1 Measuring performance

Labor productivity enhances the living standards of people. With the growth of labor productivity, the production of many goods and services has been made possible for increasing the output and availability of products and services.

1. The advancement in labor productivity is attributed to the variations in the human and physical capital along with the new technology. The development of labor productivity is generally due to the growth of the three factors. The physical capital is the total money that individuals accumulate in investments along with savings. New technologies are improvements in technology, such as the assembly line and robots (Malcolm Baldrige National Quality Award, 2007). In terms of human capital, both the specialization and education of the workforce have increased, and the measure of labor productivity provides an understanding of the fundamental trends.

2. Labor productivity serves as a vital measure of cyclical changes and short-term development changes. The high labor productivity is a mix of both the labor time used and the total output. The measuring of labor productivity allows scholars to estimate the reform on the output in connection to the different labor time (Malcolm Baldrige National Quality Award, 2007).

3. If the output increases when the labor time is constant, the economy may improve in terms of technology, which is a highly desirable outcome.

4. On the other hand, if there is an increase in the labor hours in relation to a constant output, it indicates that the economy requires more financing in the learning sector for organizations to realize increases in human capital.
3.3.2 Framework for productivity improvement in construction

Productivity advancement in the construction industry is well comprehended when the construction process is recognized as an entire system. The construction process is diverse and contains many different trades. The whole system consists of the equipment, management, materials, personnel, and money as the significant inputs. The system consumes these resources as companies produce the construction unit. Total control of the system is attained by collecting and processing data about the rate at which production is achieved. To measure output or input, the parameter defined as productivity, two types of input are used (i.e., person-per hour and cost per unit).

To improve labor effectiveness, various factors can be addressed, such as job safety, environmental factors, motivation, and physical limitations. Management practices include data collection, planning, scheduling, control, and job analysis (Dozzi & AbouRizk, 1993). Material timeliness is ensured by implementing site layout, procurement scheduling, and other crucial site aspects.

3.3.3 Types, levels, and dimensions of construction productivity measurement

The nature of the construction industry calls for the three aspects of construction productivity. The three dimensions include 1) task, 2) project, and 3) industry. Task refers to specific construction activities, such as steel erection, plastering, roofing, and concrete placement. Projects consist of the collections of activities undertaken in the process of the construction of a new facility (e.g., the construction of a new office building). Industry measures (the third dimension) are implemented from the codes
established by the North American Industrial Classification System (NAICS). Industry reflects the total portfolio of projects.

Generating measures of construction productivity at each of the three levels involves the establishment of two metrics: the appropriate parameters and tools. Therefore, construction industry shareholders can perform the calculations for the selected metrics. Once generated, these metrics and tools will aid the construction industry to make more cost-effective measures in productivity-enhancing technologies and evaluation capabilities (Huang, Chapman, & Butry, 2009). The main concepts underlying the construction industry in terms of the output are project, task, and production. The inputs and outputs, therefore, contribute significantly to the primary measurement of productivity. An example of this type of measure is output per work hour. If all the inputs are utilized, the ratio is a multifactor productivity metric.

Organizations use the measures of workers' performance to identify their productivity even though this process is not straightforward. Most occupations include some measures of performance. Measuring workers' productivity is crucial for the private sector and public policy in decision making (O'Connor, 2017). Due to insufficient reliable methods to evaluate workers' level of productivity, many organizations often use limited performance measures, such as how various incentives have an impact on employees' character (Thomas et al., 1990). Public sector organizations additionally use these types of measures to evaluate and monitor their personnel. Performance measures are generally available for high- and low-skilled jobs—even for jobs in the public and private sectors.
Task-level productivity metrics

Task are activities related to construction, such as steel erection and concrete placement in a structure. Task-level measures are widely used in the construction industry. Most of these measures only focus on labor productivity since they are single-factor measures (Huang, Chapman, & Butry, 2009). For instance, single-factor, task-level metrics published by R.S Means estimate how much a particular output is typically produced in a typical eight-hour day. In this scenario, the denominator becomes the working hours per particular crew (Huang, Chapman, & Butry, 2009). Therefore, for a specific day of work, higher output is better. In this case, higher outputs equate to higher task labor productivity. For some tasks, equipment may be involved; in such cases, the output estimate is calculated for a designated crew in eight-hour days along with the equipment they use.

The other metric used is the CII Benchmarking and Metrics Program. This program uses a different parameter to calculate task labor productivity. It fixes the output (e.g., the cubic yards of concrete put in place) and measures the labor hours required to generate that production; the denominator is a fixed output, and the numerator is the hours worked (Huang, Chapman, & Butry, 2009). Therefore, for a given amount of production, lower labor hours are best. In this scenario, lower labor equates to higher task labor productivity.

Field rating

Field rating aims to arrive at an estimate of the amount of activity in a construction site. The technique classifies workers as either working or non-working; thus, the management uses the working ratio as workers’ efficiency. For the collection of
a sample, the observer has to be placed on site to check all the activities occurring in the section together with the workers (Merriam & Tisdell, 2015).

During the collection of the sample, the field rankings are counted as full investigations in the "hard workers" section. The total number of views, plus 10% to account for supervisory activities and supervisors, then divides the working part. The calculation is as follows:

The field ratings = full investigation of the hard-working employees/the full amount of research + 10%. The number found is supposed to be approximately more than 60% for the task (Robinson, 2014). This type of method does not reveal the inefficiencies or the kinds of problems faced. The technique only suggests there is something wrong or amiss.

**The work sampling**

Work sampling is an indirect method of measuring productivity (Dozzi & AbouRizk, 1993). It is an analytical investigative theory; moreover, work sampling is a practical technique (Robinson, 2014). Work sampling’s main aim is to observe an operation for a specific period. This method has been widely used in the construction sector since the construction process lacks repetitive cycles and consists of a wide range of activities. The method allows the observer to record spontaneous direct and indirect activities within a specific process or task (Loera, 2013). The research determined the effectiveness of productivity. Since it is impossible to observe all workers performing all tasks all the time, the workers observed are a small sample from the entire population of the investigations; each glimpse of the employees offers a different view, and hence, each sample of work can result in many observations (Alarcon & Serpell, 2004).
Rather than having to deal with the entire population, the method allows the researcher to collect only a section, assess the observations thoroughly, and finally create a confidence limit around the sample. The work sampling method consists of the following steps.

1. Select a random worker or a crew member to perform the research observation.
2. Categorize the workers’ time to perform construction work from the three modes of operation: idle, indirect, and direct work.
3. Each observation consists of a number of time slots or cycles, usually in minutes.
4. The total number of observations, which is typically large, is then recorded, and the observations are classified into a category (i.e., direct, indirect, and idle).
5. Tally all the findings from each mode and estimate a ratio.
6. The observations and the ratio are used in the statistical analysis based on a confidence interval and a level of error accepted.
Table 3-1: Work Sampling Typical Data Form

Table 3-1 displays eight observations (two minutes for each observation) for all three categories: direct, indirect, and idle. Each category can also be divided into a sub-category. For example, if the construction task is to build a brick wall, then the direct task can be divided into subtasks, such as placing the mortar, laying the brick, and so forth. The total time allotted is 16 minutes to complete a certain task. The observer can count six observations for direct work, one observation for indirect work, and one observation for idle work. The total observations are 8 or 16 minutes.

**Five-minute rating**

This non-statistical sampling technique provides simple but vital information regarding the effectiveness of a construction group.

The technique provides quick and fair approximation of data of work activities (Oglesby, 1989). The observation is divided into five-minutes cycles, and all crew members are observed during each cycle.
### Table 3-2: Five-Minute Rating Example

If the entire group is involved in more than three minutes out of the five-minute cycle performing a task, then a check mark is made; otherwise, the five-minute slot is left blank. In the end, the researcher counts the percentage of the counted slots compared to the total time, and the effectiveness is calculated. The recorded five-minute slots are called “the effective,” and the researcher calculates “the effective percent” out of the total observation.

The example in Table 3-2 indicates the existence of 40 observations in total, each with a five-minute cycle. The effective total cycles, 21 (52%) in total, are the ones with check marks.

### Field survey and foreman delay survey

These two methods depend on questionnaire forms sent to project managers, foremen, superintendents, and field crew to identify the sources of project delays and factors affecting project productivity. The difference between both methods is the fact
that the foreman delay survey is a survey questionnaire that a project foreman fills out at the end of a construction day or week (Dozzi & AbouRizk, 1993).

**The method productivity delay model (MPDM)**

The method productivity delay model (MPDM) combines both productivity measurement and time study; the MPDM demands that the observer collects data in a particular form that pertains to the cycle time of a leading resource on the operation (Adrian & Boyer, 1976). The observer then notes the delay time in operation. Then, a set of computations are done indicating the major source of the delay (Halpin & Riggs, 1992). This is an effective measure of on-site productivity and the delays that undermine the project. This method is less confusing when implemented on an electronic spreadsheet such as Microsoft Excel (Halpin & Riggs, 1992). The MPDM provides more data than other sampling methods. In addition to providing measures, it can also provide sources of delays and how the they affect productivity, as seen below.

<table>
<thead>
<tr>
<th>Environmental</th>
<th>Equipment</th>
<th>Labour</th>
<th>Material</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in soil conditions</td>
<td>Equipment being positioned</td>
<td>Personal break</td>
<td>Not available when needed</td>
<td>Poor planning</td>
</tr>
<tr>
<td>Change in wall section</td>
<td>Temporary breakdown</td>
<td>Finding materials or tools</td>
<td>Defective and has to be replaced</td>
<td>Undecided as to what should be done</td>
</tr>
<tr>
<td>Unscheduled maintenance</td>
<td>Getting instructions</td>
<td>Improperly located on site</td>
<td>Unavailable for instructions</td>
<td>Interfering with other operations</td>
</tr>
</tbody>
</table>

*Figure 3-3: MPDM data collection*

**Project-level productivity measures**

As mentioned earlier, a project is a collection of tasks required in a construction project. Hence, measuring a project is more complex than measuring each task. The
performance of the entire project is a function of the performance of all tasks making up the project. Each task performs differently. Therefore, it is not possible to accumulate and calculate the task in general since the inputs and outputs differ from one task to another (Huang, Chapman, & Butry, 2009). Thus, adjustments must be made before measuring project level productivity.

A data set referenced to calculate baseline values for every task is used to make these adjustments. Since some tasks are completed in parallel, the composition of task flows can affect the overall project productivity. In this case, each component of the project metric has the hard task productivity baseline value as a denominator, the task weight, the task productivity value for that project serving as a numerator and a measure of the task mix (Huang, Chapman, & Butry, 2009). The project productivity index, in this case, is the function of individual components. Companies use an index at the project level to control or monitor productivity over time. In this scenario, the reference data set equates to zero. For each index, the task weight values and task baseline values are compared to values calculated in the data set (Alarcon & Serpell, 2004). The numerator in this case now becomes the averaged value of the corresponding task productivity in the future data set. Each construction project is unique. Therefore, the mix of projects differs each year, posing a fundamental challenge in the construction industry regarding productivity analysis (Huang, Chapman, & Butry, 2009).

**Industry-level productivity measures**

At this level, productivity is the amount of output generated per unit input. This also provides a measure of industrial efficiency. The BLS published two common
standards: single- and multifactor. In the production of multiple outputs, a Tornqvist index is used in chaining various output indices together to form an output measure. Increased labor productivity may be due to increased labor efforts or labor quality (Robinson, 2014). Also, productivity can increase due to technological advancements or even increased capital utilization.

The BLS measures multifaceted productivity utilizing output, work, capital, and middle-of-the-road buys input. A Tornqvist index list is used to consolidate the contributions to a solitary proportion of generation (Huang, Chapman, & Butry, 2009). Multifaceted efficiency captures development in yield that is not clarified by growth in these quantifiable sources of info. In the development bookkeeping system, multifaceted efficiency is determined as a leftover. Multifaceted profitability development can be credited to variables, such as the executives rehearsals, best practices in the generation procedure, and so on (Koskela & Howell, 2002). Since multifactor efficiency is the piece of yield development not clarified by information development, work hours in multifaceted profitability should be quality balanced. For example, work hours worked by specialists with various aptitude levels should be recognized in multidimensional productivity results. At the point when information quality expands, the info can be considered to have developed at the first quality dimension (Huang, Chapman, & Butry, 2009). Conversely, work hours utilized in labor productivity counts consist of the raw number of hours worked.

Multifactor productivity is preferable to labor productivity because labor productivity measures are usually misinterpreted. An increase in labor productivity can reflect an increase in the capital-to-labor ratio rather than an increase in labor quality
(Thomas et al., 1990). Additionally, a unit of production may attain higher levels of labor productivity but result in the overall productivity being compromised due to the capital-to-labor ratio, which is not optimal. Finally, measuring labor productivity does not require as much data as a multifactor calculation.

**Difficulty in measuring an output**

Organizations measure their output in terms of either value (dollars) or volume (units) (Robinson, 2014). It is challenging in combining both value and volume. If by chance the output is similar, then volume will be the most effective factor to use in measuring productivity. Also, if the output is not identical, it is appropriate to measure productivity regarding value. Nevertheless, if some of the units are similar and others are not, then the organization has a high chance of facing hardships in the measure of productivity.

Unlike manufacturing, the construction process does not involve repetitive cycle, which makes it difficult to measure (Espinosa, 2017). Furthermore, it is not easy to know whether the work in progress together with the by-products should be added or not in the output. If the output is included, then it becomes difficult to find the appropriate value.

Many organizations do not have legal records of the inputs of labor, capital, machines, and land. Even if the documents are accessible, calculating the hours of a person working (e.g., trying to figure the input of labor) can sometimes pose problems.

**Factorial productivity**

Factorial productivity is when different factors (e.g., labor, material, and equipment) contribute to the overall productivity. The majority of management experts state that it is rare for only one factor to be responsible for the overall of construction
productivity (Robinson, 2014). It is only possible to have productivity when one factor of production is included with the elements of production.

As time goes by, there are significant changes every other day in the price of both the outputs and the inputs, the required tools and machines, the quality of labor, and the variety of raw materials. All of the above make measuring productivity difficult.

**The service sectors**

It is incredibly exhausting to measure the productivity of service sectors (e.g., education, banking, insurance, etc.) since the service sector is insubstantial.

**Various types of periods**

It is next to impossible to make a comparison in the productivity of two homogenous periods, such as trying to compare the productivity of a peaceful period and a war period.

**The difficulty of measuring staff hours**

Attempting to determine the accurate number of hours of productive person hours is a challenging task since the employees' wages also include idle time costs.

**Technological changes**

The measurement of productivity may be difficult because the different types of changes in technology can cause a difference in the quality and nature of the output. For example, the integration of building information modeling (BIM) with project data can lead to an improvement in labor productivity (Lee, 2017). The transformation of data allows workers to monitor and track the progress of work activities, and the clash detection provided by a 3D model helps construction managers of different trades to avoid rework. Investing in technology is a major step toward improving labor
productivity; however, this investment is a high risk since the future is very uncertain (Jaejin Jang, 1993).

### 3.4 Lean Construction and Prefabrication

Information regarding prefabrication in the construction industry has been well documented. For example, the precast concrete market share in Europe is 18% of the overall concrete construction compared to 6% in the United States (Chen, 2010). In Hong Kong, prefabrication and modularization have been adopted in the private and public sectors since the 1980s (Jaillon, 2008). Several research projects have been conducted to address prefabrication as a means of increasing construction productivity. Research studies have been conducted comparing precast concrete to the conventional poured-in-place method (Bhosale, 2017). There is an increase in adopting prefabrication in the construction industry and an increase in research interest. Numerous research studies have been conducted, but they lack a systematic theoretical framework to measure the performance of prefabrication projects. In other words, the systematic analysis of these studies remains still insufficient (Li, 2014).

#### 3.4.1 Definition and history of prefabrication in building

The Modular building Institute defines prefabrication as the process of manufacturing and assembling the major components of a building at a remote offsite location, while the subsequent installation is carried out at the construction site (Shahzad et al., 2014). In its operational form, prefabrication is a construction innovation aimed at taking as many construction activities as possible away from the site of the project to the factory, which ensures quality and safer production of the components. Shahzad et al.
(2014) argued that there has been very little differentiation between the traditional types and the componentized types of fabrication, as conventional buildings take into account the panelized and the componentized prefabrication types. A building can be classified as belonging to the prefabrication of the component if the prefabrication portion is more than 50% of the total building value, and the differentiation is made by determining the value or proportion of the prefabrication and the components manufactured on site. The term has been used in the construction site to differentiate this practice from more conventional practices such as the transportation of the basic materials to the site of construction where all the assembly happens. Prefabrication can also be applied when it comes to the manufacturing of items differ from those made at a fixed site (Hanafi et al., 2010).

Azman et al. (2012) carried out a comparative study of the prefabrication construction process by analyzing the historical context of prefabrication and the possible challenges faced in the UK, Australia, and Malaysia. The research indicates that the concept of constructability begun in the late 1960s to integrate the optimal application of construction knowledge and experience in the course of development of a conceptual plan, detail engineering, and procurement. This concept of constructability has been in the development process in the UK, Australia, and Malaysia, where it has been known to save costs and time in the course of executing a construction project from its inception. The management has the responsibility to determine ways to expedite the project schedule and increase project productivity during the design phase. Modularization, standardization, and prefabrication are considered at that time. The Smart Market Report indicates that, even though market research on prefabrication only began in 2011, the
construction process and modularization have been used for centuries. The report reveals that everything about prefabrication and modularization is new again, while its reemergence in the construction industry as a new trend is tied to the rise of the BIM and the push for green building trends (Construction, 2011).

3.4.2 How prefabrication is related to lean construction

The strong increase in the productivity offered by the application of prefabrication and modularization in the building process fits squarely into the lean model of construction (Construction, 2011). The appeal of lean construction methods and practices increases during difficult economic times. Lean construction is defined as the process of combining the operational research and practical development in the design and construction with the consequent adoption of lean manufacturing principles and practices (Aldridge et al., 2001). Construction (2011) discovered that prefabrication construction is related to the lean construction model in that it also considers the combination of operational research and practical development in the design and construction of the components of the building. Just like lean production, prefabrication provides organizations with benefits that enhance the process of lean manufacturing because it is less expensive, has greater flexibility, reduces site disruption and construction time, and improves quality.

Björnfot and Sardén (2006) demonstrated that prefabrication can provide a means of responding to value stream fluctuations, especially in traditional construction projects that pose difficulties in terms of defining the value accurately. Björnfot and Sardén (2006) also addressed the prefabrication decision and strategies that can meet the customer demand from three producers of fabricated timber in Sweden, which can help to
define prefabrication’s relationship to lean production. The results indicate that the construction industry in Sweden is slowly shifting toward the adoption of fabrication construction based on the generation of customer value. Prefabrication is regarded as a lean manufacturing process because the process involves a strategy where a well-defined and tested product offered to the customer results in the redistribution of resources from the process of design to the value stream. The key principle of lean manufacturing is continuous improvement, which involves the identification of opportunities for improvement during the project process as well as future projects (Björnfot & Sardén, 2006).

The prefabrication process is also related to lean manufacturing because it enhances quality improvement during the production process (Björnfot & Sardén, 2006). Factories with prefabricated production lines are usually expected to comply with some strict regulations. The processes that enhance the improvement of quality in the prefabrication process consist of the testing and quality procedures required to ensure that each component is of high quality and can meet customers’ requirements. Prefabrication ensures that there is a high level of screening and quality present in the production process, and contractors depend on individual suppliers to deliver the quality demanded. The lean process is therefore associated with the prefabrication process, as it recognizes the value of the customers by understanding their point of view after building a high level of trust that is established in the planning phases of the project (Pasquire et al., 2005). Just like the prefabrication technique in the building, lean construction involves bringing all the stakeholders—including the owners, engineers, contractors, and suppliers—
together to ensure that they not only deliver what the client requires, as well as offering advice and assistance to shape the actors’ expectations throughout the project.

Prefabrication is also related to lean manufacturing because it enhances the elimination of waste during the production process (Construction, 2011). A primary principle of lean construction is the elimination and minimization of waste at every opportunity. Some of the approaches that lean production applies in the elimination of waste include avoiding overproduction, ensuring that all the workers use their talents effectively, and avoiding the waste associated with transport, inventory, and processing (Björnfot & Sardén, 2006). In this regard, the prefabrication approach ensures that the raw materials used are unaffected by weather conditions, thus eliminating waste. The prefabricated building components are usually created in a factory to avoid exposure to the elements. As a result, the final quality of the products is usually high, and the measurements and sizes are rarely distorted. In contrast, traditional on-site construction is associated with the exposure of the materials such as bricks, cement mix, and steel at a construction site for months or weeks during the production process (Pasquire et al., 2005).

3.4.3 Effects of prefabrication on construction costs

The Smart Market Report indicates that firms currently using prefabrication or modularization are aware of the potential of these construction methods in terms of the overall project budget. It is evident that more than 66% of these firms expect the application of the fabrication construction model to have a medium to very high impact on the cost of the project. Only 5% of these firms were found to expect that prefabrication would have no impact at all. This implies that the industry has currently
developed optimistic expectations regarding the direct savings associated with prefabrication (Cutting, 2011). The research result indicate that the cost of a project depends on other inputs, including the time and schedule, where a project completed with a model that reduces the time requirements is likely to offer cost benefits. A correlational study on the impact of the project schedule on the eventual cost of the project reveals that projects completed within extended deadlines tend to be costly. As a time-saving construction process, prefabrication is likely to offer benefits (e.g., saving on the costs because it limits the time requirements).

Shahzad et al. (2015) carried out a study on marginal cost savings by computing the difference between the final cost of a building under prefabrication and the corresponding cost of a similar building erected using traditional system in New Zealand. The researchers discovered that the marginal cost savings offered by the use of prefabrication as a construction method over the traditional method of construction were 19% on average. In addition, the highest cost savings amounted to 24%, which were achieved when computing the marginal cost savings for community buildings perhaps because they had a relatively simpler design nature compared to other buildings with complex designs.

On the other hand, the researchers found that on-site production requires highly skilled manpower compared to prefabrication production. Overall, 83% of the firms that had not considered the prefabrication construction model expected that there would be a medium to very high impact of reducing skilled manpower and equipment compared to prefabrication, where the effect of the lack of skilled manpower is much less. On-site resources are known to impact the total cost of construction projects, and Shahzad et al.
have shown that reducing on-site resources has a potential impact in terms of reducing the cumulative costs of a project. Essentially, the construction industry has demonstrated that the use of prefabrication as a construction method eliminates possible increases in the overall costs of the project and promotes reduction in the time, on-site resources, and on-site manpower, which also have a fundamental impact on costs.

3.4.4 Impacts of prefabrication on construction scheduling

A shorter project schedule is the most common product and benefit of using prefabrication as a construction method (Shahzad et al., 2015). Three-quarters of firms using prefabrication have reported reductions in the project schedule, while more than 30% have experienced a decrease of one month in the time required to complete projects (Hanafi et al., 2010). Prefabrication has been found to yield time savings since employees can work on site and off site simultaneously. Moreover, this approach allows for better coordination among different trades. Moreover, prefabrication requires less on-site setting up and staging (e.g., scaffolding), thus saving time (Pasquire et al., 2005).

Regionally, the ability to evade adverse weather conditions can help in the reduction of the time required to complete construction projects. Site condition factors can also significantly impact construction schedules, which can be controlled by the application of prefabrication as a modern construction method (Aldridge et al., 2001). According to Motwani (1995), adverse site conditions ranked as the top reason affecting productivity.

On the other hand, more time may be spent in the design phase when dealing with complex projects such as the coordination of prefabrication (Hanafi et al., 2010). However, the time saved on site typically reduces the overall project schedule. Construction on site is regarded as a labor-intensive, expensive affair, while the time-
saving component can compensate for the costs because this is a cost-saving module (Björnfot & Sardén, 2006). Prefabrication is known to provide critical assistance in terms of scheduling in sectors such as higher education, where project deadlines are frequently inflexible. On the other hand, projects on active sites may be impacted by time factors, as the construction may influence companies’ entire operations (Shahzad et al., 2015). For instance, the construction of a new building in a healthcare facility may affect the operations, which may require shorter timelines. Prefabrication offers a solution to such problems, as it reduces the overall schedule for construction (Pasquire et al., 2005).

Prefabrication is known to reduce both the coordination time and the construction time, which positively impacts the overall schedule (Aldridge et al., 2001). The coordination time is defined as the time spent by people when coordinating the construction process (Hanafi et al., 2010). Coordination is regarded as one of the most complex factors in the implementation of projects and may be difficult to quantify as well (Björnfot & Sardén, 2006). Prefabrication considers technological tools for the coordination of work, which in turn reduces the coordination time.

3.4.5 Impacts of prefabrication on quality

Prefabricated construction usually occurs in a controlled environment and follows some set of quality standards and procedures to ensure that the structures are built to a uniform quality (Aldridge et al., 2001). Structures built on site depend on the various skills and experiences of contractors, who are encouraged to work on their areas of specialization to enhance the production of quality products (Shahzad et al., 2015). With prefabrication, all the sub-assemblies are constructed by an experienced crew in a weather-resistant factory accompanied by various quality checks throughout the entire
process (Hanafi et al., 2010). Besides, multiple components of prefabricated buildings are built through the use of precise machine equipment to ensure adherence to building codes. The quality is also enhanced by ensuring that the work process flows through clear communication among the contractors. Through this approach, when one part of the project lags behind or ahead of schedule, everyone is informed regarding how to avoid waste related waiting and excess inventory that can interfere with the quality of the production (Björnfot & Sardén, 2006).

Prefabrication also renders high-quality products because of the testing and quality procedures carried out to confirm that each component meets the customers’ requirements (Aldridge et al., 2001). Furthermore, the use of effective raw materials during the production process ensures that the final products are of the highest quality (Hanafi et al., 2010). Another way that the prefabrication approach enhances quality is by verifying that the raw materials are not exposed to weather conditions that may affect the outputs. Since all the processes related to materials happen within the factory, the materials are not exposed to the adverse weather conditions that can otherwise interfere with their quality (Björnfot & Sardén, 2006). Moreover, through the reduction of site disruptions, prefabrication enhances the production of quality products, especially through the creation of a safe environment for workers.

### 3.4.6 Impacts of prefabrication on safety and waste reduction

Unlike traditional construction practices that require extra materials, prefabricated buildings have an advantage when it comes to safety and waste reduction since they are manufactured in factories where the sub-assemblies are constructed within the factory, and most of the extra materials are recycled in house (Aldridge et al., 2001). Through this
approach, the prefabrication process reduces waste instead of sending these by-products directly to a landfill from the construction site. The prefabrication process also minimizes waste by ensuring that the factory allows for a more accurate construction process, tighter joints, and better air filtration, which then allows for proper wall insulation and increased energy efficiency (Aldridge et al., 2001). This approach minimizes waste products but also reduces air pollution that can otherwise be unsafe for the workers and the surrounding community.

Apart from the construction materials, prefabrication also minimizes financial waste and results in financial savings, a major benefit because prefabrication usually targets all budgets and price points, hence creating affordable options (Björnfot & Sardén, 2006). Prefabrication also reduces waste by recycling used materials (Hanafi et al., 2010), thus minimizing the chances of overproduction. The efforts of human resources are also not wasted through delays since all the materials used in the production process are available on the site once they have been manufactured (Aldridge et al., 2001). All workers are encouraged to use their talents during the construction process by specializing in their specific areas to ensure that their skills, knowledge, and experiences are not wasted (Hanafi et al., 2010). The waste associated with transport is also reduced through verifying that the materials, equipment, and workers are always at the job site and that avoiding unnecessary transport costs. Besides, the factories where prefabrication is carried out are associated with strict regulations and rules to ensure that the materials are used effectively and that the products meet the quality required by the customers to avoid wastage (Pasquire et al., 2005).
The prefabrication process enhances safety because of the reduced number of accidents, pollution, and other common irritants that can be unsafe for workers (Björnfot & Sardén, 2006). As a result, the problems related to traditional job sites, such as noise, pollution, waste, and other common irritants, are highly reduced (Aldridge et al., 2001). The production process enhances the elimination of disruptions that are typical in construction sites by providing a more efficient atmosphere of productivity.

The prefabrication approach also enhances safety through the use of dry materials in the creation of the sub-assemblies in the factory-controlled environment. As a result, workers are at less risk of exposure to the problems associated with moisture, dirt, and other environmental hazards (Björnfot & Sardén, 2006). Therefore, people working at construction sites and the eventual tenants of the project are less likely to experience weather-related health risks (Pasquire et al., 2005). Besides, the provision of an indoor construction site reduces the risks of accidents and other liabilities that can be associated with external operations. The approach also enhances safety by ensuring that there are strict factory processes and procedures protecting workers from job-related injuries. Prefabrication has a positive impact on the environment by reducing resource depletion and energy consumption (Cao, 2015).

3.4.7 Impact of prefabrication on productivity

Shahzad et al. (2014) conducted a study on the marginal productivity gained through prefabrication and documented the objective and quantifiable benefits of the construction model from a statistical point of view across building types in New Zealand. The researchers computed the marginal productivity outcomes for each building as a product of other benefits, including cost and time savings. They found that the use of
prefabrication as compared to the traditional building system resulted in 34% and 19% average reductions in both the time and costs, respectively. In addition, they discovered that there was an improvement in the productivity outcomes when the prefabrication was used as compared to traditional methods. The impact of prefabrication in architecture has been lauded for its potential of increasing the efficiency of production without sacrificing quality. Countries such as New Zealand rely heavily on prefabrication due to a potential advantage of quickly producing affordable housing.

Aldridge et al. (2001) described and classified the benefits of pre-assembly and standardization while outlining the tools and techniques available in the construction and other industries, including the impact of prefabrication on productivity. The researchers analyzed reports including the “Rethinking Construction” (1998) that instigated a discussion on the need for improvement of performance in the UK construction industry. The authors identified factors such as supply chain partnerships, standardization, and pre-assembly as playing critical roles in improving the construction process. Moreover, these factors are correlated with the implementation of prefabrication construction systems.

Research conducted at Loughborough University on the development of the methodology for measuring the benefits of standardization and pre-assembly for construction uncovered the fact that there are high levels of feasibility spanning from the process of design, construction, handover, and decommissioning. The impact of prefabrication is thus defined in terms of efficiency, effectiveness, and performance. The effectiveness looks at the measurable benefits—not only in monetary terms but also regarding the greater certainty of the cost and time estimates. On the other hand, fabrication is known to improve the efficiency of productivity, which includes measurable financial benefits,
including the cost records and time sheets. Moreover, the construction method is known to improve the levels of performance, which comes with benefits that have an influence on the outcomes of the project or the business enterprise and are not easily measurable in quantitative terms, including improved working relationships and worker safety.

The controlled working conditions of prefabrication plants significantly increase product quality, where quality is viewed in terms of the overall quality and that of the components (Björnfot & Sardén, 2006). Moreover, Aldridge et al. (2001) discovered that prefabrication improves efficiency by reducing the total project costs, transaction costs, overheads, and other miscellaneous expenses, which improves overall productivity. Productivity is also measured in terms of time required to complete a project, and there are reductions in the overall project time, as well as the time required for designing, completing construction, and commissioning projects by applying the prefabrication process. Moreover, prefabrication impacts productivity in terms of the measure of the quality of health and safety parameters. The method is efficient since it leads to fewer defects and accidents. Consequently, productivity is improved by the realization of minimal risks, as the model reduces financial risks because of the greater certainty of the costs and time estimates in the course of determining the completion date and the application of established solutions.

3.5 Study Design

Study design begins with a claim or hypothesis to be tested using research methodologies such as data collection and analysis. This process consists of activities or experiments with the aim of comparing different variables under different conditions by manipulating certain independent variables to test their effect on dependent variables.
After the hypothesis is set, and the objective is determined, the variables are defined. The design of the experiment consists of utilizing a means to measure and test the variables in question. Data collection is a major part of the experimental design. There are five different types of data: count, categorical, ordered, interval, and ratio. Once the data are collected, statistical analysis is carried out (Heiberger, 2009). The outcome of the analysis is discussed, and conclusions are reached. The researcher may provide a recommendation for further research to either enhance or focus on certain aspects of the research.

### 3.6 Statistical Data Analysis

Statistical data analysis is the backbone of any quantitative research. Typically, it is conducted as part of the research design after the data are collected and organized. The statistical analysis begins with general descriptive statistics, specifying the hypothesis of the test, setting the level of significance, determining the type of statistical test required based on normality conditions and sample size, running the statistical analysis, and specifying results and conclusions (Lind, 20015). The statistical analysis in this research covers the following topics: descriptive statistics, normal distribution, level of confidence and significance, hypothesis, inference about the population’s central value, inferences comparing two population central values, categorical data analysis, correlation, and regression analysis. Details of these topics are provided in Appendix A of this report.
CHAPTER 4: STUDY DESIGN AND DATA COLLECTION

4.1 Study Design

The researcher adopted a quantitative experimental design approach. The purpose of this research is to conduct a comparative study examining labor productivity as a dependent variable affected by two different environments (independent variables or factors). The quantitative research design plan, requiring a numerical assessment of the dependent variable, was conducted through data collection and data analysis. The collected data were analyzed through statistical tests; then, the statistical inference was developed. Two groups of construction workers were observed in two different environments:

1. Group one consists of workers installing steel stud walls using a conventional procedure on site (control group).
2. Group two consists of workers assembling the steel stud walls in a prefabrication shop, and the prefabricated stud walls were then loaded on a truck, transported to the job site, unloaded, and then installed (experimental group).

This research aims to measure the effect of the prefabrication environment on labor productivity. A hypothesis test was conducted with the idea that labor productivity would be improved under a prefabrication environment. Labor productivity was quantified as a square foot of stud wall produced per labor hour. The hypothesis of the study claims that the workers can produce more square feet of stud walls per labor hour utilizing the prefabrication procedure than adopting the conventional on-site process.

To conduct an accurate comparison between the two cases, a conceptual framework was created. The ideal way to ensure comparable groups is through a
completely random assignment to either the treatment group (prefabrication) or the conventional installation (control) group. The conceptual framework below shows the comparative cycle of stud wall production in both environments.

![Figure 4-1: On-site stud wall installation cycle](image)

![Figure 4-2: Prefabrication stud wall assembly and installation](image)

The comparative study excluded the transportation part from the prefabrication cycle since the purpose of the research is to focus on the labor productive only.

To achieve this goal, observations of randomly selected workers assembling, loading, unloading, and installing stud wall panels were conducted.

The data collection was carried out according to the following procedures.
1. The research data collection involved observing construction workers assembling steel stud wall panels in a prefabrication shop as well as in a construction site using the work sampling data collection method.

2. The time observed was divided into three categories: direct work, indirect work, and idle time.

3. The panels constructed were of different sizes. Therefore, the collected data were synthesized based on labor hour *per square foot*, installed for prefabricated wall panels and conventional wall panels from two different projects.

4. Wall panels were grouped into three or four major groups based on size (e.g., wall panels less than 4’ wide, 4–6’ wide, more than 6’ wide).

5. Savings in labor hours were compared based on wall panel size.

6. A regression analysis was conducted: wall panel size versus labor hours utilized.

### 4.2 Data Collection Procedure

Data were collected from four projects in the Milwaukee and Madison areas. The four projects are as follows:

1. Marquette University New Residence Hall—(The Commons) -Milwaukee, WI;
2. Summit Credit Union New Headquarter—Madison, WI;
3. Marouf Educational Center—Milwaukee, WI; and
4. St. Anthony Apartment Building—Milwaukee, WI.

The prefabrication procedure was conducted for the Marquette University New Residence Hall and the Summit Credit Union, while on-site installation was conducted for the Marouf Educational Center and St. Anthony Apartment Building projects.
The prefabrication data were collected from the Findorff Construction prefabrication shop located in Madison, WI. The data cycles for comparative analysis purposes for both procedures were reduced as follows:

4.3 Data Collection at the Prefabrication Shop

Data were collected at a prefabrication shop located near Madison, WI, to be used for two projects in this research: The Marquette University Residence Hall (The Commons) and the Summit Credit Union Headquarters.

1. Marquette University New Residence Hall.

The 292,000-square-foot project located in the Marquette campus with a $108 million price tag was completed in the summer of 2018. The project consists of three connected towers with 11 residential floors each. The project was 30% complete when the research data collection took place in September 2017. The project is reinforced concrete with brick, glass cladding, exterior insulation and finish system (EIFS).

![Figure 4-3: Marquette University New Residence Hall](image)
2. **Summit Credit Union Project:**

The six-story, 152,000-square-foot project in Cottage Grove, WI, was completed in the summer of 2018. The project was designed to host the headquarters for the Summit Credit Union, the largest credit union in Wisconsin. The structure was constructed using different textures of brick, glass cladding, and EIFS material.

### 4.1.1 Data Collection Procedure

![Summit Credit Union Headquarters](Madison.com)

*Figure 4-4: Summit Credit Union Headquarters (Madison.com)*

*Marquette University Residence Hall:* Data were collected at the prefabrication shop and the site over a three-week period covering two floors of the New Residence

*Figure 4-5: Marquette University New Residence Hall—October 2017*
Hall project. The process of stud wall panel installation was observed, and data were gathered between September 26th and October 18th, 2017.

*Summit Credit Union Headquarters:* Data were collected at the prefabrication shop and at the construction site between May 3rd and May 18th, 2018.

The data collection was conducted through site observations of the assembly of stud wall panels at the prefabrication shop using the work sampling data method. The process started by meeting with the prefabrication shop manager to conduct the research. Safety protocols were carefully followed, including wearing hardhats and safety glasses:

The 10,000 sq. ft, one-floor prefabrication shop building consists of an office, a bathroom, and an assembling area. The assembly area is divided into two sections for the assembly of small and large panels. In the small panel assembly area, sizeable wooden jog tables (Figure 4-10) have been set up, and small panels are assembled on the jog tables. Small panels typically range from 2’ x 3’ to 4’ x 8’. One construction worker assembles smaller ones, while the larger ones require two workers.

The other assembling zone consists of large assembling steel stands (Figure 4-9). Each stand can hold four large panels, and usually, it takes three to four workers to complete the assembly of the steel stud panels using these stands.

The research observation was conducted by adopting the work sampling method, in which assembling time was measured using a stopwatch and recorded on a data sheet (see Appendix A). The observation time started at the beginning of each panel’s assembly and stopped when the panel was completed. A time increment of one minute was recorded. The data were collected using two comparative data analysis types:
1. the time it takes to assemble one panel, which was converted into square-foot-per-labor hour; and

2. the categorical comparative analysis, in which the time observed was divided into three categories: direct work, indirect work, and idle time.

Once the stud wall panels were assembled at the prefabrication shop, they were bundled, loaded on a truck, and shipped to the project site for installation. When the stud wall panels arrived at the construction site, they were unloaded and installed. The data collection continued at the construction site to complete the cycle of steel stud wall panel assembly and installation.

A typical stud wall panel consists of vertical studs spaced at 16” On Center (O.C), braced using lateral bracing channels, the base, and top tracks (Figure 4-8). All these components are connected using bolts and brackets.

![Figure 4-6: Stud wall panel details](image)
Figure 4-7: Large stud wall panels assembly

Figure 4-8: Small stud wall panels assemblies
Figure 4-9: Raw Studs delivered to prefabrication shop

Figure 4-10: Assembled stud wall panel ready for shipping
Figure 4-11: loaded and ready for shipping to construction site

Figure 4-12: Unloading stud wall panels using a crane
4.4 Data Collection at the Construction Site (On-Site)

Collecting data using on-site steel stud wall panel installation followed the same procedure and work sampling method used for the prefabrication wall panels. However, the data cycle was shorter, as it consisted of installing the stud steel stud panels directly. The data were collected during three projects:

*St Anthony Apartment, located downtown Milwaukee:* Data were collected from January 28\(^{th}\) until March 4\(^{th}\), 2018;

*Marouf Educational Center, located north of Milwaukee:* Data were collected from January 17\(^{th}\) until January 26\(^{th}\), 2018; and

*Summit Credit Union (First Floor):* Data were collected from May 3\(^{rd}\) until May 11\(^{th}\), 2018. Usually, two or three workers place the top and bottom track plates, followed by the installation of the vertical steel studs spaced 16” O.C. For large walls, U-channels are installed horizontally to function as a bracing element of the stud wall. The observation took place at the site using the work sampling method, and data were recorded.

*Figure 4-13: On-site stud wall panel installation (Sticks)*
Figure 4-14: Cantilever loading area
CHAPTER 5: DATA ANALYSES

5.1 Introduction

The primary purpose of this research is to investigate the effect of construction prefabrication (independent variable) on labor productivity (dependent variable) while identifying the factors that affect the labor productivity by conducting quantitative research through a series of statistical analyses, which are divided into three parts:

1. correlation and regression analysis: conducted on labor productivity and various sizes of the steel stud panels constructed in using prefabrication and on-site construction procedures;
2. statistical test utilizing inferences: conducted comparing two populations; and
3. categorial statistical: inferences about the difference between two population proportions (i.e., \( \pi_1 = \) direct work and \( \pi_2 = \) all other types).

5.1.1 Estimating sample size for inference comparing population central values:

\[
n = \frac{2(z_{a/2})^2 \sigma^2}{\Delta^2}
\]

According to the equation above, to determine the sample size required to conduct the statistical inference, the researcher needed to decide on the level of confidence and tolerable error acceptable for this type of research, as well as an estimation of the standard deviation of the data collected.
It has been widely accepted to use a level of confidence of 95% in quantitative statistical research studies. When adopting this level of confidence, the researcher wanted to conduct research with a 95% confidence rate for the accurate representation of the population on which the study was performed. As described in Chapter 3, the coefficient of the 95% confidence level is $z_{\alpha/2} = 1.96$.

The standard deviation could be estimated with previous studies or if an observational pilot study could be conducted to determine the typical range of the data observations. Using the range of observations, the standard deviation was estimated by using the following equation:

$$\sigma = \frac{\text{range}}{4}$$

To estimate the range of the data and the possible tolerable error “$E$,” the researcher conducted a pilot data collection round and interviewed several construction project managers, workers, as well as prefabrication shop manager and workers.

According to the pilot data collected and the interviews, the labor productivity range in the prefabrication shop was estimated between 16 sq. ft/labor hour as minimum and 24 sq. ft/labor hour as a maximum, which included the loading and unloading of prefabricated stud wall panels. Thus, the standard deviation was estimated to be 2. If an acceptable error margin of 5% is selected for the data mean (Mundel, 1978; Niebel, 2001), then the sample size required to conduct the research is near 16 small units. It is well known that this would provide enough data as long as the data collected has a normal distribution, which can be tested by different means, such as a boxplot. However, since the normality distribution is not guaranteed, a large sample of at least 30 panels was
needed. Additionally, to avoid the normality condition, a non-parametric hypothesis test, the Wilcoxon signed-rank test, which does not require normality distribution, was adopted.

5.1.2 Estimating sample size for inference on categorical data:

The data were analyzed at a level of confidence of 95%, which required a reasonable enough sample size. Previous studies have indicated that direct times involved in traditional construction vary between 60% and 70% of the total time involved. As a result, a data sample size of can be estimated to be around 350 observations of one minute each while accepting an error of 0.05. In the most severe case, a very conservative 50% of direct time can be assumed, and the sample size needed would be near 385 time observations of one minute each. The data size estimate was based on the following equation (Ott et al., 2010):

$$n = \frac{z_{\alpha}^2 / 2 \pi (1 - \pi)}{E^2}$$

5.2 Data Analysis

The rest of this chapter is divided into three major sections.

1. The first section concerns data analysis of the data set in the prefabrication process addressing:
   a. descriptive frequencies, normality check;
   b. correlation between labor productivity and panel size; and
   c. categorical data analysis.
2. The next section involves data analysis of the data set collected in the construction sites addressing:
   a. descriptive frequencies, normality check;
   b. correlation between labor productivity and panel size; and
   c. categorial data analysis.

3. The final section is related to the comparative analysis between data set in the prefabrication shop and on-site.

5.3 Descriptive Statistical Analysis of Data Set in the Prefabrication Process

Prefabrication data were collected from two projects of a total of 104 stud wall panels of different sizes. Assembly in the shop was observed, and the time it took to assemble the panels was recorded. For the categorical statistical analysis, the time required to assemble each panel was divided into three categories: direct time, indirect time, and idle time. With the purpose of learning if there was a difference in the categorial times' types between the work performed in the prefabrication shop and the construction site.

The table below displays examples of the types of time involved during the prefabrication assembly:
<table>
<thead>
<tr>
<th>TYPE</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Work</td>
<td>D1</td>
<td>Placing STUDS—measuring, placing, aligning, and bolting</td>
</tr>
<tr>
<td></td>
<td>D2</td>
<td>Placing TOP PLATE—fixing and bolting</td>
</tr>
<tr>
<td></td>
<td>D3</td>
<td>Placing SOLE PLATE—fixing and bolting</td>
</tr>
<tr>
<td></td>
<td>D4</td>
<td>LOADING AND UNLOADING</td>
</tr>
<tr>
<td>Indirect Work</td>
<td>I1</td>
<td>Talking to a supervisor (discussion) only if between paneling phase</td>
</tr>
<tr>
<td></td>
<td>I2</td>
<td>Moving equipment, tools, and materials</td>
</tr>
<tr>
<td></td>
<td>I3</td>
<td>Read and discuss blueprint/instructions</td>
</tr>
<tr>
<td>Idle</td>
<td>ID1</td>
<td>Doing nothing—chatting, smoking, waiting, and so forth</td>
</tr>
<tr>
<td></td>
<td>ID2</td>
<td>An activity that involves rework</td>
</tr>
</tbody>
</table>

*Table 5-1: Categorial Work Type for Prefabrication of Stud Wall Panels*

Each assembled panel was placed with a group of panels on a ballet, and all panels were bundled together and then loaded on the truck to be transported to the job site. Loading and unloading data were also collected, and the total time was added to the installation cycle shown in Figure 4 of Chapter 4.

The prefabrication data collection was conducted through observing the assembling and the installation of 104 stud wall panels. A total of 5,926 observation cycles were recorded, with each observation consisting of one minute for a total of 98.73 hours. Many panels required more than one labor hour to perform the assembling, loading, unloading, and installation. As a result, the total labor time involved was factored into the data collected and analyzed, as shown in Table 5-5.

As mentioned in Chapter 4, the complete production of a stud panel goes through one cycle, which consists of three stages:

1. assembling panels in the prefabrication shop,
2. loading and unloading the panels, and
3 installing the assembled panels in the project site.

The total observations of one-minute data excluding loading/unloading were 4,947 minutes or 82.45 hours in the prefab shop and 13.11 hours installing the prefabricated panels at the project site. Observations of loading the assembled panels at the prefabrication shop and unloading the same panels at the project site were conducted separately, and 764 observations, or 12.73 hours, were recorded. The loading/unloading time was then added to the total cycle.

**Descriptive statistical analysis of frequency**

According to the descriptive statistical analysis performed, the size range of the 104 installed panels was between 3.09 sq. ft and 166.23 sq. ft with a mean of 47.92 sq. ft. The lowest productivity was 5.73 sq. ft/hr, while the highest productivity was 80.69 sq. ft/hr.

<table>
<thead>
<tr>
<th>N</th>
<th>Panel Area sq. ft</th>
<th>Productivity sq. ft/hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td>Missing</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mean</td>
<td>47.92</td>
<td>32.51</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>45.06</td>
<td>19.3</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.09</td>
<td>5.73</td>
</tr>
<tr>
<td>Maximum</td>
<td>166.23</td>
<td>80.69</td>
</tr>
<tr>
<td>Percentiles</td>
<td>25</td>
<td>10.26</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>26.61</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>74.67</td>
</tr>
</tbody>
</table>

*Table 5-2: Descriptive Statistics—Prefabrication Stud Wall Panels*
The labor productivity mean was near 32.51 sq. ft/hour. It was noted that lower labor productivity was observed for smaller stud wall panels, whereas higher labor productivity was observed for larger stud wall panels. These facts and findings are discussed and analyzed in detail later in this chapter.

**Normality check**

As discussed in Chapter 3, the normality distribution of a data set is a significant factor in identifying the type of hypothesis test required. In addition, the SPSS software was used to determine if the dependent variable (labor productivity) data have a normal distribution. To test the data normality distribution, the Shapiro–Wilk hypothesis test was employed. Additionally, the visual histogram, Q-Q, and boxplot were also created using the SPSS software.

The Shapiro–Wilk test \((p < 0.05)\) (Shapiro & Wilk, 1965; Razali & Wah, 2011) indicated that labor productivity (dependent factor) is not normally distributed. The significance is less than 0.05, which tends to reject the null hypothesis and confirm that there is a difference between the data distribution and the normal distribution.

<table>
<thead>
<tr>
<th>Kolmogorov–Smirnova</th>
<th>Shapiro–Wilk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistic</td>
<td>df</td>
</tr>
<tr>
<td>sq. ft/hr</td>
<td>0.13</td>
</tr>
<tr>
<td>a. Lilliefors Significance Correction</td>
<td></td>
</tr>
</tbody>
</table>

*Table 5-3: Shapiro–Wilk Normality Test*
The histogram in Figure 5-1 below demonstrates that the labor productivity data distribution is skewed slightly to the left and therefore is not normally distributed. These results concur with the Shapiro–Wilk hypothesis test above.

![Normal Q-Q Plot](image)

*Figure 5-2: Normal Q-Q Plot*

Additionally, the Q-Q test was conducted, revealing that many points do not fall on the normality line. It can be concluded that the labor productivity distribution is not normal.

The boxplot of the labor productivity data counts is displayed in Figure 5-3. From the plot, we can observe that the data for the labor productivity taken in the prefabrication shop are not symmetric but slightly skewed to the left with outlines.
As discussed in Chapter 3, when the data set distribution is not normal, the parametric \( t \) test for comparing the population central values to investigate the differences between the prefabrication and the on-site data becomes unappropriated and may lead to inaccurate results unless the data count is large.

**Correlation between labor productivity and stud panel size**

It was necessary to determine if there was a correlation between labor productivity and the size of the stud wall panels assembled and installed. The SPSS software output table below suggests a strong positive correlation between the size of the stud wall panel and labor productivity. The high Pearson correlation coefficient of 0.942 with a significance of less than 0.01 indicates a strong positive relationship between the stud panel size and labor productivity, \( r (104) = 0.942, \ p < .01 \).

*Figure 5-3: Boxplot of Labor Productivity sq. ft/hr*
**Table 5-4: Correlations Between Panel Size and Labor Productivity for the Prefabrication Shop**

The correlation scatter fit line in Figure 5-4 below indicates a positive effect of the panel area size on labor productivity. The graph clearly shows that labor productivity rises with the increase of panel size.

**Figure 5-4: Correlations Between Panel Size and Labor Productivity for Prefabrication**

<table>
<thead>
<tr>
<th></th>
<th>Panel Area—sq. ft</th>
<th>Productivity sq. ft/hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel Area sq. ft</td>
<td>Pearson correlation: 1</td>
<td>.942**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>104</td>
</tr>
<tr>
<td>Productivity sq. ft/hr.</td>
<td>Pearson correlation: .942**</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>104</td>
</tr>
</tbody>
</table>

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

The data collected in the prefabrication shop were organized using an Excel spreadsheet and later analyzed using the SPSS software. The data were categorized as direct, indirect, and idle times in terms of minutes and hours. Many panels required more than one labor hour to perform the assembling, loading, unloading, and installation. As a result, the total labor time involved was factored into the data collected and analyzed.

Table 5-4 below illustrates the categorial time of each observation type in percentage of minutes and hours.

<table>
<thead>
<tr>
<th>Type of Work</th>
<th>In minutes</th>
<th>In hours</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Work</td>
<td>7,085</td>
<td>118.08</td>
<td>92.75%</td>
</tr>
<tr>
<td>Indirect Work</td>
<td>491</td>
<td>8.18</td>
<td>6.43%</td>
</tr>
<tr>
<td>Idle Work</td>
<td>63</td>
<td>1.05</td>
<td>0.82%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7,639</strong>*</td>
<td><strong>127.31</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>

*Table 5-5: Categorial Data Set for Prefabrication Work*
Table 5-4 and Figure 5-4 indicate that the direct time involved in the prefabrication of stud wall panels is 92.75% of the total time. As seen in the table, 6.43% of the time was allocated for indirect work activities, such as measuring, marking, or receiving instructions from a supervisor, while less than 1% was wasted on idle time, such as rework, waiting, or talking with no purpose. One panel installation involved a rework type that falls in the idle category.

5.4 Descriptive Statistical Analysis of Data Set—On-Site Process

On-site data were collected from three different projects with a total of 114 stud wall panels of different sizes. Installation at all three construction sites was observed, and the time it took to install the panels was recorded. The time required to install each panel was divided into three categories: direct time, indirect time, and idle time. These time categories were used for the categorial statistical analysis presented later in this paper with the purpose of learning if there was a distinction in the categorial time types between the work performed in the prefabrication shop and the construction site.
A total of 3,424 observation cycles were recorded, with each observation consisting of one minute for a total of 57.1 hours. The table below displays examples of types of time involved during the installation of steel stud wall panels.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Work</td>
<td>D1</td>
<td>Placing STUDS—placing, aligning, and bolting</td>
</tr>
<tr>
<td></td>
<td>D2</td>
<td>Placing TOP PLATE—fixing and bolting</td>
</tr>
<tr>
<td></td>
<td>D3</td>
<td>Placing SOLE PLATE—fixing and bolting</td>
</tr>
<tr>
<td></td>
<td>D4</td>
<td>Measuring and marking</td>
</tr>
<tr>
<td>Indirect Work</td>
<td>I1</td>
<td>Talking to a supervisor (discussion) only if between paneling phase</td>
</tr>
<tr>
<td></td>
<td>I2</td>
<td>Moving equipment, tools, and materials</td>
</tr>
<tr>
<td></td>
<td>I3</td>
<td>Read and discuss blueprint/instructions</td>
</tr>
<tr>
<td>Idle</td>
<td>ID1</td>
<td>Doing nothing—chatting, smoking, waiting, and so forth</td>
</tr>
<tr>
<td></td>
<td>ID2</td>
<td>An activity that involves rework</td>
</tr>
</tbody>
</table>

Table 5-6: Categorial Work Type for On-Site of Stud Wall Panels Installation

Raw steel studs arrived at the site in standard size. The installation was performed through what is known as “stick” procedure, in which the base plate is installed on the bottom floor followed by the top plate, which is fixed to the top floor, and then vertical stud pieces are installed at 16” O.C.

Many panels required more than one labor hour to perform the assembling, loading, unloading, and installation. As a result, the total labor time involved was factored into the data collected and analyzed.
Descriptive statistical analysis of frequency

According to the descriptive statistical analysis performed, the size of the installed panels ranged between 6.10 sq. ft to 152.2 sq. ft. The lowest labor productivity was 9.00 sq. ft/hr., while the largest productivity was 71.43 sq. ft/hr. The table below summarizes this finding.

<table>
<thead>
<tr>
<th>N</th>
<th>Panel Area—sq. ft</th>
<th>Productivity sq. ft/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid</td>
<td>114</td>
<td>114</td>
</tr>
<tr>
<td>Missing</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mean</td>
<td>41.55</td>
<td>37.83</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>42.57</td>
<td>19.51</td>
</tr>
<tr>
<td>Minimum</td>
<td>6.1</td>
<td>9.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>152.5</td>
<td>71.43</td>
</tr>
<tr>
<td>Percentiles</td>
<td>25</td>
<td>12.92</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>50.83</td>
</tr>
</tbody>
</table>

*Table 5-7: Descriptive Statistics—Prefabrication Stud Wall Panels*

The average of all panel sizes installed was 41.55 sq. ft, while the labor productivity mean was 37.83 sq. ft/hour. It was noted that lower labor productivity was observed for smaller stud wall panels, whereas higher labor productivity was recorded for larger stud wall panels. These facts and findings are discussed in detail later in this chapter.
Normality check

As discussed in Chapter 3, the normality distribution of a data set is a significant factor in identifying the type of hypothesis test required. The SPSS software was used to determine if the dependent variable (labor productivity) data have a normal distribution. To test the data normality distribution, the Shapiro–Wilk hypothesis test was conducted. Additionally, the visual histogram, Q-Q, and boxplot were also performed using the SPSS software.

The Shapiro–Wilk test ($p < 0.05$) (Shapiro & Wilk, 1965; Razali & Wah, 2011) indicated that labor productivity (dependent factor) is not normally distributed. The significance is less than 0.05, which tends to reject the null hypothesis and confirm that there is a difference between the data distribution and the normal distribution.

<table>
<thead>
<tr>
<th></th>
<th>Kolmogorov–Smirnov$^a$</th>
<th>Shapiro–Wilk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Statistic</td>
<td>df</td>
</tr>
<tr>
<td>Productivity sq. ft/hr</td>
<td>0.139</td>
<td>114</td>
</tr>
<tr>
<td>a. Lilliefors Significance Correction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5-8: Shapiro–Wilk Normality Test of Normality*
The histogram in Figure 5-6 demonstrates that the labor productivity data distribution is not normally distributed. These results concur with the Shapiro–Wilk hypothesis test above.

*Figure 5-6: Normality Test—Histogram*
Additionally, the Q-Q test was conducted, revealing that many points do not fall on the normality line. Therefore, the labor productivity distribution is not normal.

![Normal Q-Q Plot](image)

*Figure 5-7: Normal Q-Q Plot*

The boxplot of the labor productivity data counts is displayed in Figure 5-8. From the plot, we can see that the data for the labor productivity taken in the prefabrication shop are not symmetric but slightly skewed to the left with outlines.

![Boxplot of On-Site Labor Productivity sq.ft/hr](image)

*Figure 5-8: Boxplot of On-Site Labor Productivity sq.ft/hr*
As discussed in Chapter 3, when the data set distribution is not normal, the parametric \( t \) test for comparing the population central values to investigate the differences between the prefabrication and the on-site data becomes unappropriated and may lead to inaccurate results unless the data count is large.

**Correlation between labor productivity and stud panel size**

Like the data set collected in the prefabrication shop, it was necessary to determine if there was a correlation between labor productivity and the size of the stud wall panels installed. The SPSS software output table below suggests a strong positive correlation between the size of the stud wall panel and labor productivity. The high Pearson correlation coefficient of 0.6 with a significance of less than 0.01 indicates a strong positive relationship between the stud panel size and the labor productivity, \( r (114) = 0.625, p < .01 \).

<table>
<thead>
<tr>
<th>Panel Area—sq. ft</th>
<th>Panel Area sq. ft</th>
<th>Productivity sq. ft/hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson correlation</td>
<td>1</td>
<td>.625**</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>114</td>
<td>114</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Productivity sq. ft/hr.</th>
<th>Pearson correlation</th>
<th>0.625**</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sig. (2-tailed)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>114</td>
<td>114</td>
<td></td>
</tr>
</tbody>
</table>

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

*Table 5-9: Correlations Between Panel Size and Labor Productivity for the Prefabrication Shop*
The correlation scatter fit line in Figure 5-9 below indicates a positive effect of the panel area size on labor productivity. The graph clearly shows that labor productivity rises with the increase of panel size.

![Figure 5-9: Correlations Between Panel Size and Labor Productivity—On site](image)

**Categorical data analysis:**

The data collected in the three construction sites were organized using an Excel spreadsheet and later analyzed using the SPSS software. The data were categorized as direct, indirect, and idle times in terms of minutes and hours. Many panels required more than one labor hour to perform the assembling, loading, unloading, and installation. As a result, the total labor time involved was factored into the data collected and analyzed.
Table 5-10 below illustrates the categorial time of each observation type in percentage of minutes and hours.

<table>
<thead>
<tr>
<th>Type of Work</th>
<th>In minutes</th>
<th>In hours</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Work</td>
<td>4,936</td>
<td>82.27</td>
<td>72.27%</td>
</tr>
<tr>
<td>Indirect Work</td>
<td>1,680</td>
<td>28</td>
<td>24.60%</td>
</tr>
<tr>
<td>Idle Work</td>
<td>214</td>
<td>3.57</td>
<td>3.13%</td>
</tr>
<tr>
<td></td>
<td>5,331</td>
<td>99.41</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

*Table 5-10: Categorial Data Set for Prefabrication Work*

Table 5-10 and Figure 5-10 indicate that the direct time involved in the prefabrication of stud wall panels is 72.27% of the total time. As seen in the table, 24.6% of the time was allocated for indirect work activities, such as measuring, marking, or receiving instructions from a supervisor, while 3.13% was wasted on idle time such as rework, waiting, or talking around with no purpose. Six panel installation incidents involved a rework type which falls in the idle category.

*Figure 5-10: Pie Chart of Categorial Data Set for Prefabrication Work*
5.5 Comparative Analysis Between Prefabrication and On-Site Labor Productivity

This section of Chapter 5 is divided into three parts:

1. comparative correlation between prefabrication and on-site labor productivity,
2. inferences comparing two population central values, and
3. categorial statistical analysis.

5.5.1 Comparative correlation between prefabrication and on-site labor productivity

It was determined earlier in this chapter that there is a strong positive correlation between the stud wall panel size and labor productivity for both prefabrication assembly and on-site construction installation. In the prefabrication process, the correlation between the panel size and the productivity is stronger than the correlation on-site. Based on the observations during the data collection, workers in the prefabrication shop repeat the same exact process of assembly over and over while the on-site installation is performed at a different location which creates variation in the time it takes to install the panels of similar sizes.
However, when comparing these two correlations in Figure 5-11, we can conclude that the labor productivity in the prefabrication shop for panels sizes smaller than 90 sq. ft is lower than the labor productivity for on-site wall panel installation, but it is higher for all panels of 90 sq. ft or larger. To statistically investigate this fact, a statistical hypothesis test was conducted. The details of this test are presented in the next section.

To further investigate the correlation and regression between the panel size and the productivity affected by both environments as shown in Figure 5-11, and in order to
test if there is an interaction between the two affecting factors (prefabrication and on-site), a General Linear Model (GLM) analysis were conducted using SPSS.

The purpose of the GLM is to examine if there is a different effect between the prefabrication and onsite environments on the productivity as the panel size changes. The graph shows that the prefab slope is steeper.

In other words, does the difference between the prefabrication and onsite depends on the panel size?

The GLM model can be described by:

\[
Productivity = \text{Panel size} + \text{Type} + \text{Panel size} \times \text{Type} + \text{Error}
\]

A statistical significance of the interaction effect \(\text{Panel size} \times \text{Type}\) would indicate that the difference between the prefabrication and on-site depends on the panel size. The assumption of this model is that the errors (i.e. residuals) are normally distributed and the \(\text{Var} (\text{Error}) = \text{Constant}\)

Table 5-11 below which shows “Between – Subjects effects “, indicates that the p-value of significance is < 0.001. This indicates that interaction exists between the fixed factors which are the environments types (prefabrication and on-site). There is an effect of the type of installation on the labor productivity within different sizes. In other words, the relationship between the productivity and panel size is greatly affected by the work type (on-site or prefabrication).
<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>71559.686*</td>
<td>3</td>
<td>23853.229</td>
<td>175.088</td>
<td>0.000</td>
</tr>
<tr>
<td>Intercept</td>
<td>40161.358</td>
<td>1</td>
<td>40161.358</td>
<td>294.792</td>
<td>0.000</td>
</tr>
<tr>
<td>type</td>
<td>4887.535</td>
<td>1</td>
<td>4887.535</td>
<td>35.875</td>
<td>0.000</td>
</tr>
<tr>
<td>panel size</td>
<td>62255.526</td>
<td>1</td>
<td>62255.526</td>
<td>456.968</td>
<td>0.000</td>
</tr>
<tr>
<td>type * panel size</td>
<td>2567.322</td>
<td>1</td>
<td>2567.322</td>
<td>18.845</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>30516.873</td>
<td>224</td>
<td>136.236</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>419881.713</td>
<td>228</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>102076.559</td>
<td>227</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. R Squared = .701 (Adjusted R Squared = .697)

Table 5-11: GLM - Tests of Between-Subjects Effects

The assumptions for adopting the GLM are: the residuals are homoscedastic, independent, and are normally distributed.

To check for homoscedasticity, a plot of residuals vs predicted value was performed. Figure 5-12 below, shows no outliers as the score values are between -3.00 and +3.00.
A normality test was conducted. Figures 5-13 and 5-14 show that the distribution of the residuals is normal which satisfies the condition which indicates that the regression model is linear if the error terms are normally distributed.

Figure 5-12: Residuals vs Predicted values

Figure 5-13: Residuals Normal Distribution
5.5.2 Inferences comparing two population central values—All panel sizes

For this section, a hypothesis about the difference between the two population means of the prefabrication labor productivity and the on-site labor productivity were tested. The procedure served to specify a research hypothesis for the difference in population means.

Null Hypothesis $H_0: \mu_1 \leq \mu_2$

Alternative Hypothesis $H_a: \mu_1 > \mu_2$

where:

$\mu_1$: prefabrication labor productivity population mean
\( \mu_2: \) on-site labor productivity population mean

The statistical test serves to investigate the claim that prefabrication is more productive than on-site construction. The inferences about \( \mu_1 > \mu_2 \) are based on random samples independently selected from two populations. A parametric \( t \) test can be conducted between two independent samples if normality or large sample size conditions are met. Otherwise, a non-parametric statistical test would be required where the test statistics (T.S.):

\[
T.S: t = \frac{\bar{y}_1 - \bar{y}_2}{Sp \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}
\]

As tested previously in this chapter, the data distributions for both data sets are not normal. However, the sample sizes for the data collected in the prefabrication shop and on-site, \((n_1 = 104, n_2 = 114)\) are considered large enough to conduct either a parametric \( t \) test or a non-parametric, namely the Wilcoxon rank sum test. The test statistics (T.S.) are expressed as follows:

\[
T.S: Z = \frac{T - \mu_t}{\sigma_T}
\]

The researcher conducted both a parametric \( t \) test and a non-parametric Wilcoxon test to evaluate if there is a significant difference in the labor productivity between the prefabrication and on-site construction. The independent factor is the location where the work is performed, while labor productivity is the dependent factor.
Parametric $t$ test for the independent sample

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor Productivity sq. ft/hr.</td>
<td>ON_SITE</td>
<td>114</td>
<td>38.848</td>
<td>21.03</td>
</tr>
<tr>
<td></td>
<td>PREFAB</td>
<td>104</td>
<td>33.084</td>
<td>20.218</td>
</tr>
</tbody>
</table>

Table 5-12: Group Statistics for Comparing Independent Sample Means

<table>
<thead>
<tr>
<th>Labor Productivity sq. ft/hr</th>
<th>$t$ test for Equality of Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$t$</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td></td>
<td>2.06</td>
</tr>
</tbody>
</table>

Table 5-13: Independent Samples, $t$ Test

According to Tables 5-12 and 5-13, which display the parametric $t$ test results, the prefab labor productivity ($M = 33.084$, $SD = 20.218$) was statistically significantly lower than the on-site labor productivity, ($M = 38.848$, $SD = 210.30$); $p = 0.041$, with a 95% confidence interval [1.139, 10.389]. This result reflects all sizes of stud wall panels.

**Non-Parametric Wilcoxon rank test (Mann–Whitney U test)**

A non-parametric Wilcoxon rank test was also performed to check and compare the results obtained from the parametric $t$ test. The non-parametric test confirmed the $t$ test, indicating that the on-site labor productivity was significantly higher than the prefabrication labor productivity ($N_1 = 114$, $N_2 = 104$, $p = 0.035$) as shown in Table 5-14 below.
| \text{Labor Productivity sq. ft/hr—Rank} | \text{Mann–Whitney U} | 4,945.50 |
| Wilcoxon W | 10,405.50 |
| \text{Z} | -2.112 |
| \text{Sig. (2-tailed)} | 0.035 |
| \text{Grouping Variable: LOCATION} |

\textit{Table 5-14: Wilcoxon Rank Test (Mann–Whitney U Test)—Ranks}

| \text{LOCATION} | \text{N} | \text{Mean Rank} | \text{Sum of Ranks} |
|\text{Labor Productivity sq. ft/hr.} | \text{ON_SITE} | 114 | 118.1 | 13,465.50 |
| \text{PREFAB} | 104 | 100.1 | 10,405.50 |
| Total | 218 |

\textit{Table 5-15: Wilcoxon Rank Test (Mann–Whitney U Test)—Test Statistics}

\textbf{5.5.3 Inferences comparing two population central values—Panel Size < 90 sq. ft}

As explained in the previous section, the labor productivity for smaller stud panels is higher in the construction site than in the prefabrication shop. The cut-off size was determined to be 90 sq. ft, as shown in Figure 5-11.

Stud wall panels smaller than 90 sq. ft were installed at higher labor productivity in the construction site than in the prefabrication shop. For this section, the researcher has conducted a statistical investigation to determine if there is a significant difference in labor productivity for panels sizes smaller than 90 sq. ft. A similar statistical investigation was conducted for panel sizes larger than 90 sq. ft, as shown in the next section.
To determine if the data set for labor productivity when installing panel sizes smaller than 90 sq. ft is normally distributed or not, the Shapiro–Wilk test for normality was conducted. The Shapiro–Wilk test \( p < 0.05 \) results in Table 5-16 illustrate that labor productivity is not normally distributed for both data set locations. The significance is less than 0.05 for both locations, which tends to reject the null hypothesis and confirm that there is a difference between the data distribution and the normal distribution.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Kolmogorov–Smirnov(^a)</th>
<th>Shapiro–Wilk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Statistic</td>
<td>df</td>
</tr>
<tr>
<td>On-Site</td>
<td>Labor Productivity sq. ft/hr</td>
<td>0.155</td>
</tr>
<tr>
<td>Prefabrication</td>
<td>Labor Productivity sq. ft/hr</td>
<td>0.134</td>
</tr>
</tbody>
</table>

*Table 5-16: Shapiro–Wilk Normality Test—Panels Size < 90 sq. ft*

Due to the lack of normality in the statistical data distribution, a non-parametric hypothesis test was conducted. The Wilcoxon rank test purpose is to determine if there is a significant difference between the two population central values of prefabrication labor productivity and on-site labor productivity. The procedure is to specify a research hypothesis for the inferences about \( \mu_1 - \mu_2 \): (Independent Samples)

\[
\mu_1: \text{On-site labor productivity population mean}
\]

\[
\mu_2: \text{Prefabrication labor productivity population mean}
\]
For samples sizes larger than 10, \( n_1 > 10 \) and \( n_2 > 10 \)

\( H_0 \): The two populations are identical.

\( H_a \): Population 1 is shifted to the right of population 2.

\[ T.S: z = \frac{T - \mu_T}{\sigma_T} \]

T.S.: where \( T \) denotes the sum of the ranks in sample 1.

R.R.: For a specified value of \( \alpha \),

Reject \( H_0 \) if \( Z > Z\alpha \)

The statistical test was conducted to investigate the claim that prefabrication is less productive than onsite construction for panel sizes smaller than 90 sq. ft. The inferences about \( \mu_1 > \mu_2 \) were based on random samples independently selected from two populations.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Mean</th>
<th>( N )</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Site</td>
<td>35.37</td>
<td>97</td>
<td>20.27</td>
</tr>
<tr>
<td>Prefabrication</td>
<td>26.25</td>
<td>87</td>
<td>13.42</td>
</tr>
<tr>
<td>Total</td>
<td>31.06</td>
<td>184</td>
<td>17.92</td>
</tr>
</tbody>
</table>

*Table 5-17: Descriptive Statistics—Panel Size < 90 sq. ft*

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>( N )</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor Productivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sq. ft/hr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-Site</td>
<td>97</td>
<td>103.1</td>
<td>10,000.50</td>
</tr>
<tr>
<td>Prefabrication</td>
<td>87</td>
<td>80.68</td>
<td>7,019.50</td>
</tr>
<tr>
<td>Total</td>
<td>184</td>
<td>103.1</td>
<td>10,000.50</td>
</tr>
</tbody>
</table>

*Table 5-18: Wilcoxon Rank Test (Mann–Whitney U test)—Ranks < 90 sq. ft*
Table 5-19: Wilcoxon Rank Test (Mann–Whitney U Test)—Test Statistics Panel Size < 90 sq. ft

<table>
<thead>
<tr>
<th>Labor Productivity sq. ft/hr</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann–Whitney U</td>
<td>3,191.50</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>7,019.50</td>
</tr>
<tr>
<td>Z</td>
<td>-2.85</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.004</td>
</tr>
</tbody>
</table>

a Grouping Variable: LOCATION

Table 5-17 contains descriptive statistics of the data collected for panels with sizes smaller than 90 sq. ft produced on site, and the mean of labor productivity is higher than for prefabrication. However, this difference is not sufficient to statistically determine that the labor productivity was significantly higher on site than for prefabrication. Tables 5-18 and 5-19 present results from the Wilcoxon rank non-parametric test, which indicates that the mean rank of on-site labor productivity is higher than for prefabrication, which confirms that the on-site labor productivity was significantly higher than the prefabrication labor productivity for all stud wall panels smaller than 90 sq. ft ($N_1 = 97, N_2 = 87, p = 0.004$).

5.5.4 Inferences comparing two population central values—Panel size > 90 sq. ft

In the previous section, a non-parametric test was conducted to compare the population central values of labor productivity for all data sets covering panel sizes smaller than 90 sq. ft. Based on the hypothesis test, the labor productivity for smaller stud panels was found to be higher in the construction site than in the prefabrication shop. For
this section, a similar statistical investigation was conducted for panel sizes larger than 90 sq. ft. To determine the appropriate statistical inference test to be conducted, the normality of the data set distribution was investigated using the Shapiro–Wilk test.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Statistic</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LABOR PRODUCTIVITY</td>
<td>Kolmogorov–Smirnov</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-Site</td>
<td>0.177</td>
<td>17</td>
<td>0.163</td>
</tr>
<tr>
<td>Prefabrication</td>
<td>0.231</td>
<td>27</td>
<td>0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Statistic</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LABOR PRODUCTIVITY</td>
<td>Shapiro–Wilk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-Site</td>
<td>0.929</td>
<td>17</td>
<td>0.209</td>
</tr>
<tr>
<td>Prefabrication</td>
<td>0.852</td>
<td>27</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Table 5-20: Shapiro–Wilk Normality Test—Panels Size > 90 sq. ft*

The Shapiro–Wilk test ($p < 0.05$) in Table 5-20 indicates that labor productivity is NOT normally distributed for both data set locations. The significance is less than 0.05 for both locations, which tends to reject the null hypothesis and confirm that there is a difference between the data distribution and the normal distribution. Due to the lack of normality in the statistical data distribution, a non-parametric hypothesis test was conducted. The Wilcoxon rank test purpose serves to determine if there is a significant difference between the two population means of prefabrication labor productivity and on-site labor productivity. The procedure can specify a research hypothesis for the inferences about $\mu_1 - \mu_2$: (Independent Samples).

$\mu_1$: On-site labor productivity population mean

$\mu_2$: Prefabrication labor productivity population mean

For samples sizes larger than 10, $n1 > 10$ and $n2 > 10$
$H_0$: The two populations are identical.

$Ha$: Population 1 is shifted to the left of population 2.

\[ T.S.: z = \frac{T - \mu_T}{\sigma_T} \]

T.S.: where $T$ denotes the sum of the ranks in sample 1.

R.R.: For a specified value of $\alpha$,

Reject $H_0$ if $Z > Z_\alpha$

The statistical test serves to investigate the claim that prefabrication is less productive than onsite construction for panel sizes smaller than 90 sq. ft. The inferences about $\mu_1 > \mu_2$ were based on random samples independently selected from two populations.

<table>
<thead>
<tr>
<th>LABOR PRODUCTIVITY</th>
<th>LOCATION</th>
<th>$N$</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Site</td>
<td>17</td>
<td>14.71</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Prefabrication</td>
<td>27</td>
<td>27.41</td>
<td>740</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5-21: Descriptive Statistics—Panel Size > 90 sq. ft*
<table>
<thead>
<tr>
<th>Labor Productivity sq. ft/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann–Whitney U</td>
</tr>
<tr>
<td>Wilcoxon W</td>
</tr>
<tr>
<td>Z</td>
</tr>
<tr>
<td>Sig. (1-tailed)</td>
</tr>
<tr>
<td>Grouping Variable: LOCATION</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann–Whitney U</td>
<td>97</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>250</td>
</tr>
<tr>
<td>Z</td>
<td>-3.197</td>
</tr>
<tr>
<td>Sig. (1-tailed)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 5-22: Wilcoxon Rank Test (Mann–Whitney U Test)—Ranks > 90 sq. ft

<table>
<thead>
<tr>
<th>LABOR PRODUCTIVITY</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION</td>
<td>Mean</td>
<td>N</td>
</tr>
<tr>
<td>On-Site</td>
<td>58.67</td>
<td>17</td>
</tr>
<tr>
<td>Prefabrication</td>
<td>70.97</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td>66.22</td>
<td>44</td>
</tr>
</tbody>
</table>

Table 5-23: Wilcoxon Rank Test (Mann–Whitney U Test)—Test Statistics Panel Size > 90 sq. ft

Table 5-21 displays descriptive statistics of the data collected for panels with sizes larger than 90 sq. ft produced on site, and the mean of labor productivity is lower for prefabrication. However, this difference is not sufficient to statistically determine that the labor productivity was significantly lower on site than for prefabrication. Tables 5-22 and 5-23 present results from the Wilcoxon rank non-parametric test, indicating that the mean rank of on-site labor productivity is lower than for prefabrication; therefore, the on-site
labor productivity was significantly lower than prefabrication labor productivity for all stud wall panels larger than 90 sq. ft \((N_1 = 17, N_2 = 27, p = 0.001)\).

### 5.5.5 Categorial statistical analysis

<table>
<thead>
<tr>
<th>Type of Work</th>
<th>On-site</th>
<th>Prefabrication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours</td>
<td>Percent</td>
</tr>
<tr>
<td>Direct Work</td>
<td>82.27</td>
<td>72.27%</td>
</tr>
<tr>
<td>Indirect Work</td>
<td>28</td>
<td>24.60%</td>
</tr>
<tr>
<td>Idle Work</td>
<td>3.57</td>
<td>3.13%</td>
</tr>
</tbody>
</table>

**Table 5-24: Categorial Comparative of Prefabrication Versus On-site Work Type**

Table 5-24 above compares different work categories between prefabrication and on-site stud wall panel installation. As the table illustrates, direct work makes up 92.75\% of the total prefabrication labor hours and 72.27\% of the total on-site labor hours. This means that the construction labors spent 7.25\% of the total time doing activities not directly related to work during the prefabrication process versus 27.73\% during on-site construction work. The difference seems significant. This section presents the results of a categorial statistical test used to investigate the significant difference in labor productivity in categorial work types between the two locations.

In this section, the research analysis is focused on the direct, indirect, and idle work conducted by workers in the prefabrication shop as well as the construction on site.
In each category, time was divided into one-minute time slots, and the time for each category was recorded on the datasheet.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>PREFAB</th>
<th>Category</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>7,085</td>
<td>491</td>
</tr>
<tr>
<td>Expected Count</td>
<td>6,346.60</td>
<td>1,146.20</td>
<td>146.2</td>
</tr>
<tr>
<td>% within LOCATION</td>
<td>92.70%</td>
<td>6.40%</td>
<td>0.80%</td>
</tr>
<tr>
<td>ON-SITE</td>
<td>Count</td>
<td>4,936</td>
<td>1,680</td>
</tr>
<tr>
<td>Expected Count</td>
<td>5,674.40</td>
<td>1,024.80</td>
<td>130.8</td>
</tr>
<tr>
<td>% within LOCATION</td>
<td>72.30%</td>
<td>24.60%</td>
<td>3.10%</td>
</tr>
<tr>
<td>Total</td>
<td>Count</td>
<td>12,021</td>
<td>2171</td>
</tr>
<tr>
<td>Expected Count</td>
<td>12,021.00</td>
<td>2,171.00</td>
<td>277</td>
</tr>
<tr>
<td>% within LOCATION</td>
<td>83.10%</td>
<td>15.00%</td>
<td>1.90%</td>
</tr>
</tbody>
</table>

*Table 5-25: Location versus Category Crosstabulation*

The statistical inference for this type of study falls in the categorial statistical analysis, which requires inferences about either the difference between two population proportions ($\pi_1 =$ direct work, and $\pi_2 =$ all other types), assuming two binomial
populations or inferences about several proportions by applying the Chi-Square test ($\pi_1 =$ direct work, $\pi_2 =$ indirect work, and $\pi_3 =$ idle time).

$$\text{Chi-Square distribution test} = \sum_i \left( \frac{(n_i - E_i)^2}{E_i} \right)$$

Table 5-25 indicates that the prefabrication direct work count of 7,085 is higher than the expected value of 6,346.6, while the on-site direct work count of 4,936 is less than the expected value of 5,674.4. This can be interpreted as meaning that the direct work in the prefabrication shop was significantly higher than the direct work on-site.

Similarly, the prefabrication indirect work count of 491 is lower than the expected value of 1,146.2, while the on-site indirect work count of 1,630 is higher than the expected value of 1,024.8. This can be interpreted as meaning that the indirect work in the prefabrication shop was significantly lower than the indirect work on-site. The idle work category for prefabrication count is 63, which is lower than the expected count of 146.2 compared to the on-site location, which rendered a count of 214—higher than the expected count of 130.8. This indicates that the idle work category on-site was significantly higher than the idle work category for prefabrication.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymptotic Significance (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>1,075.806*</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>14,469</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5-26: Chi-Square Test for Categorical Data Set*
The Pearson Chi-Square test results, as shown in Table 5-26, indicate that there is a significant relationship between the location where the stud wall panel is installed and the work category. $\chi^2(2, N = 14469,) = 1075.8, p < .001$.

According to the Chi-Square test, construction workers spent more time on-site than in prefabrication doing activities unrelated to direct work.

5.5.6 Statistical inference of labor productivity—A comparison to RS means data

This section provides a comparison between the results obtained from the data collected in both environments (prefabrication and on site) and the data used in the industry, which is provided by the RSMeans Building Construction Cost Data book.

RSMeans Building Construction Cost Data describes labor productivity in a daily crew output based on the 8 daily hours of work a crew worker takes to produce a certain number of units of a task. RSMeans publishes this information and updates it yearly based on the geographic area. The labor productivity is then calculated by dividing the total labor hours by the total units produced in one day (daily output). The 2014 RSMeans Building Construction Cost Data labels the labor productivity as a “labor-hour” for one linear foot stud with wall heights ranging between 8’ and 20’. These data is listed under the “Framing Stud Walls” category for various stud thicknesses and stud spacing on center (O.C.)

The RSMeans Building Construction Cost Data book provides information about labor productivity for various stud wall sizes (i.e. 4”, 6”, 8”, etc.). In order to conduct an
accurate comparison, 6” steel studs spaced at 16” O.C were used from *RSMeans Building Construction Cost Data* since this is the stud size used in all previous research studies. According to *RSMeans Building Construction Cost Data*, labor productivity is described in terms of labor hours required to produce one linear foot of stud wall of various heights. For example, it requires 0.219 labor hours to produce a wall 1’ wide and 8’ tall described as 18 gauge, 6” wide, and spaced at 16” O.C, which means the labor productivity is 36.53 sq. ft/labor hour. Since the research projects used stud walls of various heights, the comparison analysis was conducted on the average labor productivity for different heights.

The table below displays the labor hours and labor productivity for stud wall heights of 8-, 10-, 12-, 16-, and 20-feet high stud walls.

<table>
<thead>
<tr>
<th>wall height (feet)</th>
<th>Labor hour</th>
<th>Labor productivity (sq. ft/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0.219</td>
<td>36.53</td>
</tr>
<tr>
<td>10</td>
<td>0.219</td>
<td>45.66</td>
</tr>
<tr>
<td>12</td>
<td>0.276</td>
<td>43.48</td>
</tr>
<tr>
<td>16</td>
<td>0.333</td>
<td>48.05</td>
</tr>
<tr>
<td>20</td>
<td>0.381</td>
<td>52.49</td>
</tr>
</tbody>
</table>

*Table 5-27: RSMeans Building Construction Cost Data—Metal Stud Framing Labor Hour*

The table indicates that average labor productivity to install steel stud walls is 45.24 sq. ft/hr. To compare this value with the results obtained from prefabrication and on-site data, a non-parametric hypothesis test with inferences about population central
value was conducted. The inference testing was conducted twice with two separate hypothesis tests for each environment.

The first statistical hypothesis test determined whether the mean of the on-site labor productivity was different from the mean obtained from the 2014 *RSMMeans Databook* (i.e., 45.24 sq. ft/hr). The two-tailed hypothesis test is described below:

Null Hypothesis $H_0$: $\mu_1 = \mu_o$

Alternative Hypothesis $H_a$: $\mu_1 \neq \mu_o$

where:

$\mu_1$: On-site labor productivity population mean

$\mu_o$: RSMMeans labor productivity population mean = 45.24 sq. ft/hr

with a 95% confidence level ($\alpha = 0.05$).

As previously determined, the on-site labor productivity mean was calculated as 38.35 sq. ft/hr. The alternative hypothesis claims that the data collected on site differ from the data published in the *RSMMeans Cost Databook* regarding labor productivity of installing stud walls.

A Z test was used even though the data distribution was not normal. The central limit theorem allows for the use of the Z test if the sample size $n \geq 30$; $\sigma$ can be replaced with the sample standard deviation $s$. 
The hypothesis test was conducted using the SPSS software. The Z value calculated was -3.24, which is less than $Z = 1.96$ for 95% confidence, and $P = .0018$, which is less than $\sigma = .05$. We can thus reject the null hypothesis and conclude that the on-site labor productivity mean is significantly different from the mean calculated from the RSMeans Databook.

The second statistical test research hypothesis helped determine whether the mean of the prefabrication labor productivity ($33.08$ sq. ft/hr.) was less than the mean obtained from the 2014 RSMeans Databook ($45.24$ sq. ft/hr). The one-tailed hypothesis test is described below.

Null Hypothesis $H_0$: $\mu_1 \leq \mu_o$

Alternative Hypothesis $H_a$: $\mu_1 > \mu_o$

where:

$\mu_1$: Prefabrication labor productivity population mean

$\mu_o$: RSMeans labor productivity population mean = 45.24 sq. ft/hr

with a 95% confidence level ($\alpha = 0.05$).
The Z value calculated was -6.14 which is less than Z = 1.96 for 95% confidence, and \( P < 0.001 \), which is less than \( \sigma = 0.05 \). So, the null hypothesis is rejected, and it is concluded the prefabrication labor productivity mean is significantly less than the mean calculated from the *RSMeans Building Construction Cost Data* book.

Similar inferences testing was conducted for wall panels larger than 90 sq. ft. The sample size \( n \) was less than 30, and the data were not normally distributed. As a result, one sample Z test could not be conducted. Alternatively, a bootstrap technique was used with a statistical \( t \) test. The test results indicate that the on-site labor productivity for the data set collected for this research is significantly higher than the central mean value of 45.24 sq. ft published in the *RSMeans Building Construction Cost Data* book. \( t(16) = 4.274, p = .001 \)

<table>
<thead>
<tr>
<th>Test Value = 45.24</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t )</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>On-Site Labor Productivity</td>
</tr>
</tbody>
</table>

*Table 5-28: Bootstrap t Test Comparing On-site to RSMeans Mean of Labor Productivity*

The similar bootstrap technique was used with a statistical \( t \) test, revealing that the prefabrication labor productivity for the data set collected for this research is significantly
higher than the central mean value of 45.24 sq. ft published in the *RSMeans Databook*.

\[ t(26) = 14.23, p < .001 \]

<table>
<thead>
<tr>
<th>PREFABRICATION</th>
<th>( t )</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>26</td>
<td>0</td>
<td>25.73</td>
<td>Lower: 22.01, Upper: 29.45</td>
</tr>
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</table>

*Table 5-29: Bootstrap t Test Comparing Prefabrication to RSMeans Mean of Labor Productivity*

The results confirm that prefabrication labor productivity for panels larger than 90 sq. ft was higher, and prefabrication labor work can be more productive than on-site stud wall installation, as published in the industry in *RSMeans Building Construction Cost Data*, and vice versa if the panel size is smaller than 90 sq. ft. This conforms with the results obtained comparing on-site and prefabrication labor productivity, which was obtained from the data collected and analyzed for this study.
CHAPTER 6: SUMMARY, CONCLUSIONS, RECOMMENDATIONS, AND CONTRIBUTIONS

6.1 Summary

This research aimed at investigating the impact of prefabrication on labor productivity in the construction sector by examining the production of steel stud wall panels. Observations of assembling and constructing the stud wall panels took place at the prefabrication shop as well as on site. The data were analyzed using mathematical and statistical inferences for the data collected in order to compare the labor productivity in both environments. The labor productivity was presented in term of square foot of wall panel produced per one labor hour. The researcher also investigated the categorical data in which time spent by construction laborer was divided into three categories: direct, indirect and idle in both environments and a study comparing these categorical data was conducted.

6.2 Conclusions

The results of the research analyses indicate that there is a strong positive correlation between the labor productivity and the stud wall panel sizes assembled in both environments (prefabrication and on site). In other words, the labor productivity is higher when installing larger panels than when installing smaller ones.

To statistically investigate these facts, statistical hypothesis testing was conducted using both parametric and non-parametric tests. The results are summarized as follows:

1. The overall on-site mean of labor productivity was determined to be 38.84 sq. ft/hr compared prefabrication mean of labor productivity of 33.08 sq. ft/hr. The
hypothesis test shows that there is a significant evidence that labor productivity for work done on site is higher than labor productivity in prefabrication for all panel sizes (smaller and larger than 90 sq. ft).

2. A similar hypothesis testing process was conducted for stud wall panels smaller than 90 sq. ft and larger than 90 sq. ft, respectively. It uncovers significant evidence that on-site labor productivity (35.37 sq. ft/hr.) for smaller panels (less than 90 sq. ft) is higher than prefabrication labor productivity (26.25 sq. ft/hr).

3. Prefabrication labor productivity (70.97 sq. ft/hr) for large panels (larger than 90 sq. ft) is higher than on-site labor productivity (58.67 sq. ft/hr), despite the fact that the longer prefabrication process, which consists of handling, loading, and unloading large prefabricated panels, is still more labor productive than installing the wall panels on site. This is a very important finding for contractors who wish to adopt the prefabrication process to consider the prefabrication process for large panels only and install small panels on-site.

Categorical data analyses were conducted comparing direct, indirect and idle times spent by construction labor in the prefabrication shop and on-site. Results show the following:

1. Construction workers in the prefabrication process spend more direct time on the job than on-site workers. Workers in the prefabrication shop spend 92.75% of their total time performing activities directly related to the task assigned versus 72.27% for their on-site counterparts. This means that on-site workers spend near 28% of total work time doing activities that are not directly related to the assigned task. Examples of these indirect activities include moving or looking for tools, as
well as taking instructions from the supervisor. The reason for this higher percentage is that workers are very familiar with the prefabrication shop. The process is very similar to the manufacturing process where workers come back to the same line every day and perform similar tasks, so they need fewer instructions. Additionally, tools and prefabrication lines are typically located at the same places in the shop. On the contrary, construction workers arrive at construction sites that are very unfamiliar to them. They constantly need instructions from their supervisors. Additionally, they need to set up areas to place their tools and equipment, and they must constantly relocate them as they move from one area or floor to another.

2. The research indicates that the idle time in the prefabrication process is near 0.8% versus 3.1% on site. Even though both percentages are small compared to the total time allocated to complete a construction task, the on-site idle time is almost four times more than the prefabrication idle time. The idle time category refers to when a worker spends time unrelated to work, such as chatting, smoking, or being idle while waiting for instructions or even performing rework. It was noted that on-site construction workers are subject to more distractions than those who perform a similar task in a prefabrication shop. The interaction with other trade workers, such as plumbers, electricians, and so forth, contributes significantly to the workers’ distraction and a consequent increase in the idle time percentage. Rework falls in the idle work category. Six incidents of rework activities were detected on site, in which workers had to uninstall and reinstall construction elements. However, there were not enough observations to conduct a study on the
total rework activities for all projects observed. Previous studies have indicated that rework typically makes up near 5% of total construction costs (Hwang, 2009).

The last part of this research involved conducting a statistical analysis of inference comparing the labor productivity data published in the *RSMeans Building Construction Cost Databook* to the labor productivity determined by the data collected at the prefabrication shop and on site. The results indicate the following:

1. Generally, there is a difference between the labor productivity mean (45.24 sq. ft/hr) for installing stud walls published in the *RSMeans Building Construction Cost Databook* and the labor productivity mean determined from the data collected on site (38.84 sq. ft/hr) for all stud wall panel sizes (i.e., small and large).

2. This research results show that prefabrication labor productivity (70.97 sq. ft/hr) for large panel sizes (> 90 sq. ft/hr.) is higher than the labor productivity published in *RSMeans Building Construction Cost Databook*, which concurs with the fact that there is a significant improvement in labor productivity when applying the prefabrication process for large stud walls.

Since it is not clear if the data published in in *RSMeans Building Construction Cost Databook* included a prefabrication process or it represented only on-site installation, caution needs to be taken when considering the results in this research.
6.3 Recommendations

The purpose of this research was to investigate how prefabrication can improve construction labor productivity for the installation of steel stud wall panels. The researcher adopted steel wall panel installation as a construction element since the construction of steel stud walls is labor intensive and does not involve the use of construction equipment. Consequently, labor is the main factor influencing construction productivity.

Future research that targets construction productivity addressing additional factors, such as equipment, material, and transportation, will find that this research contains valuable information regarding construction labor productivity. The researcher recommends the followings:

1. Conduct more in-depth study targeting the rework category in both prefabrication and on site.
2. Conduct similar research selecting different labor-intensive construction components such as prefabricated brick walls.
3. Conduct research studying the factors affecting the construction workers’ behavior during indirect work and idle time in both environments.
4. Conduct research comparing labor productivity when workers perform work in an isolated environment versus being surrounded by other trades.
5. Conduct similar research in other states that are subject to different weather, work cultures, and environments.
6. Conduct research comparing the work sampling method adopted in this research with other types of methods, such as survey and questionnaires.
6.4 Contributions

Contractors can use the findings in this research to improve the work environment, increase labor productivity, and reduce construction costs if they adopt the following approaches.

1. Adopt prefabrication process for panel sizes larger than 90 sq. ft while considering on-site process if panel sizes are smaller than 90 sq. ft

2. Apply measures that lead to reducing the bundling time in the prefabrication shop, which contributes significantly to the reduction in overall labor productivity.

3. Create an on-site work environment similar to the prefabrication process that serves as a hybrid construction environment, benefiting from both prefabrication and on-site advantages. An example is to designate a prefabrication area on or near the construction site (if space permits). This approach can reduce the time and costs involved in transporting and handling the assembled construction elements.
REFERENCES


Livonia, MI: Sharpe, Inc.


APPENDIX A: STATISTICAL ANALYSIS LITERATURE

7.1 Statistical Data Analysis

Statistical data analysis is the backbone of any quantitative research. Typically, it is conducted as part of the research design after the data are collected and organized. The statistical analysis begins with general descriptive statistics, specifying the hypothesis of the test, setting the level of significance, determining the type of statistical test required based on normality conditions and sample size, running the statistical analysis, and specifying results and conclusions (Lind, 20015). This section addresses the following topics: descriptive statistics, normal distribution, level of confidence and significance, hypothesis, inference about the population’s central value, inferences comparing two population central values, categorical data analysis, correlation, and regression analysis.

7.1.1 Descriptive statistics

Quantitative research typically begins with data collection after an experimental design is set. It addresses a problem that can be described and analyzed using variables and measured numbers, and the hypotheses can be verified through hypothesis testing (Creswell, 1994). Once the sample size is estimated, and the data is collected and organized, descriptive statistics are usually analyzed first. A typical descriptive statistic consists of frequency distribution, a measure of central tendency, and the standard deviation. A reporting summary can be derived from quantitative analyses (Dudová, 2014).
The descriptive statistics process is simple; however, it provides overall information regarding the data collected (Naoum, 1998). Information can be presented in the form of a percentage or real numbers depending on the population size; it can be presented in several formats, such as tables, bar charts, or graphs. This information provides the reader with a visual presentation of how the data is distributed, categorized, and how frequently it occurred.

A measure of central tendency provides valuable information regarding certain statistics, such as the mean, median, and mode. The mean is the average of the data, such as the class score average. The median is the score that falls in the middle when the data is classified from the lowest to the highest score, and the mode is the number or score that most frequently occurs or is repeated.

The mean of data may not provide a complete picture of how the data are distributed. Another statistical measure that provides information on how the data are clustered around the mean is the standard deviation. Once the data distribution is known, the standard deviation provides valuable information regarding the inference of the data collected. The standard deviation is known as SD or σ and can be determined using the following formula:

\[
SD = \sqrt{\frac{\sum(x - \bar{x})^2}{N}}
\]

where \( N \) is the sample size, \( x \) represents the individual observed data, and \( \bar{x} \) denotes the mean of the data.
7.1.2 Normal distribution

Once the data are presented on the graph, we can check if the distribution is “normal” or not. A normally distributed graph looks like a bell shape, as seen in Figure 3-4 below:

![Normal Distribution](image)

*Figure 7-1: Example of normal distribution curve*

The normality distribution of a data set is extremely important when we conduct inference of the research population. It allows us to use certain hypothesis testing methods on a small sample size with a very high confidence level. The graph illustrates that the variables are symmetrically distributed around the central value on both sides, while the tails of the graph have infinite values. The standard deviation measures how variables are spread in both directions around the mean. When reading the normal distribution, we are interested in the percentage of the variables under the curve. If normally distributed, then 68% of the area is bound by a value \( x = \mu \pm \sigma \), where \( \sigma \) is the standard deviation, and \( \mu \) is the sample or population mean. Similarly, 95% of the area is bound by a value \( x = \mu \pm 2\sigma \) (Fellows et al., 2015). This is called the confidence interval,
which plays a significant role in conducting inferential research hypothesis testing. The 95% level of confidence, or a level of significance of 0.05, provides the extent of probability regarding the inference of certain population values. In other words, 95% of the data variables are within an interval of $\mu \pm 2\sigma / \sqrt{n}$.

### 7.1.3 Confidence interval and level of significance

The level of significance is defined as how likely a value of the test statistic can be obtained, which is as likely or more likely to reject a null hypothesis (known as $H_0$) as the actual observed value of the test statistic if the null hypothesis is true (Ott, 2010). In other words, if the value of the significance is small, then we cannot support the null hypothesis and tend to reject it. The question is how small the significance value is. The answer depends on the level of confidence pre-set by the researchers. Most research studies published use a level of confidence of 95%, so the value of the level of confidence is 0.05. This value is well known as a $p$ value.

### 7.1.4 Null and alternative hypotheses

The null hypothesis is an “assumption or prediction” of a value tested against an opposite value called the alternate hypothesis, known as $H_a$ (Fellows, 2015). For example, the null hypothesis assumes or speculates that there is no difference between the sample mean and the predefined, previously known population mean. The hypothesis test is conducted at a level of significance $p = \alpha$. Usually, accepting or rejecting a null hypothesis is decided according to the following rules:

If the $p$ value $\leq \alpha$, then reject $H_0$. 
If the $p$ value $\geq \alpha$, then do not reject $H_0$.

As mentioned earlier, most research studies adopt a value of $\alpha = 0.05$ for $\alpha$ or a 95% level of confidence. In other words, the researcher is 95% confident in rejecting the null hypothesis and accepting the alternative hypothesis.

The hypothesis test is conducted in the following format:

Alternative hypothesis $H_a$: $\mu_1 \neq \mu_o$

Null hypothesis $H_0$: $\mu_1 = \mu_o$

where $\mu_1$ denotes the sample mean, and $\mu_o$ refers to the known value published by research studies or industrial and government publications, with a 95% confidence level ($\alpha = 0.05$).

### 7.1.5 Inference about population central value

The average or the mean of a certain population has been one of the most important parameters of interest that researchers have always conducted inference about. Typically, a researcher either estimates the mean of a population or runs a hypothesis test. The latter method has been very popular with accurate results. The researcher sets the level of confidence typically acceptable by the academic or industrial sectors (typically 95%), which determines the type of statistical test needed, and estimates the minimum sample size for the data collection. The inference about the central value is a parametric or non-parametric statistical test that aims at comparing the mean obtained from a sample to a certain population mean value.
Several hypothesis tests methods can be employed; however, many need to meet certain conditions. For example, the $z$ test is a very popular test provided that the data variables are either normally distributed or that the sample size is large.

$$TS : Z = \frac{\bar{y} - \mu_0}{\sigma / \sqrt{n}}$$

The term $\bar{y}$ is the test statistics or the mean of the sampled data. The test is used to investigate if the sampled mean differs from the population mean $\mu_0$.

If the population distribution is normal, and the standard deviation is known, or if the sample size is fairly large, then we can be confident that the sampling distribution is approximately normal with a mean $\mu_0$ and standard deviation $\sigma / \sqrt{n}$ (Ott, 2010). The term “fairly large” for a $z$ test is if $N \geq 30$.

Once the $z$ value is calculated, we can compare it against a tabulated value based on the level of significance or level of confidence. Since 95% of the data variables are within an interval of $\mu \pm 1.96\sigma / \sqrt{n}$, the 95% level of confidence tabulated value is approximately $\pm 1.96\sigma / \sqrt{n}$, which bound the shaded area in Fig 3-4 below. All $z$ values that fall outside this area are considered in the “rejection region.” In other words, if the calculated $z$ value is larger than $1.96\sigma / \sqrt{n}$ or smaller than $-1.96\sigma / \sqrt{n}$, we can reject the null hypothesis and accept the alternative. The $z$ test can be conducted for a two-tailed test or a one-tailed test.
If the sample data is normally distributed, but the population standard deviation is unknown, and the sample size $N$ is less than 30, then the $z$ test will be replaced by a $t$ test, which has a $t$ distribution. This method allows us to replace the value $\sigma / \sqrt{n}$ with $s / \sqrt{n}$. The $t$ statistics distribution is given by the following formula:

$$TS: \quad t = \frac{\bar{y} - \mu_0}{s / \sqrt{n}}$$

$df = n-1$, and a specific value of $\alpha$ typically $= 0.05$

where df is a parameter called the degree of freedom, which specifies which $t$ distribution to be used for this inference. If the data distribution is not known or is not normal, and the sample size $N < 30$, then the $z$ test and $t$ test above cannot be used for hypothesis testing of the inferential of the central value. Alternatively, a bootstrap technique can be applied. The bootstrap (Efron, 1979) is a re-sampling technique of the original sample that provides a fair approximation of the $t$ distribution when the sample size is small, and the normality condition is not met. Most of the statistical analysis software, such as SPSS, can bootstrap and re-sample the data. Figure 3-6 below provides an example:
Inference comparing two central values

In the previous section, we discussed the inference comparing the sample mean to a common value that was known or published previously. The inference comparing two central values is used when we compare the means of two sets of data. In this research, the inference compares the mean of prefabrication labor productivity to the mean of on-site labor productivity. The inference is to investigate if the mean of the first data set is larger or smaller than the mean of the second data set, or to investigate if the two means are equal or not. The hypothesis test is about the inference of $\mu_1 - \mu_2$. The samples must be randomly selected from two different populations, and the two data sets collected are independent of each other. Two types of testing are conducted for this inference: a parametric test or a non-parametric test.

7.1.6.1 Parametric $t$ test

A parametric $t$ test is applied when both populations distributions are normally distributed with both standard deviations nearly equal or if the sample sizes are large.
regardless. A non-parametric test is applied when both sample sizes are small, and the population distributions are non-normal.

When the data samples are large enough \((n_1 > 10 \text{ and } n_2 > 10)\) with both samples’ standard deviations being near equal, a parametric \(t\) test is conducted.

The \(t\) test is calculated as:

\[
t = \frac{\bar{y}_1 - \bar{y}_2}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}
\]

With a degree of freedom \(df = n_1 + n_2 - 1\)

where \(n_1\) and \(n_2\) denote the sample sizes, and \(s_p\) = represents the common standard deviation.

The hypothesis for the \(t\) test is conducted in the following format:

Alternative hypothesis \(H_a: \mu_1 \neq \mu_2\)

Null hypothesis \(H_o: \mu_1 = \mu_o\)

\(\mu_1\): Sample mean taken from population 1

\(\mu_2\): Sample mean taken from population 2

with a 95% confidence level \((\alpha = 0.05)\).

7.1.6.2 Non-parametric \(t\) test—Wilcoxon rank sum test:

The parametric test is useful when normality conditions and equal variance conditions are met or if the sample size is larger than 10. When the samples taken from
both populations are small, and the data variables are not normally distributed, a non-parametric test is conducted. The hypothesis test is formulated as follows:

For \((n_1 \leq 10 \text{ and } n_2 \leq 10)\), with two independent samples

Alternative hypothesis \(H_a: \mu_1 \neq \mu_2\). Both populations are NOT identical.

Null hypothesis \(H_0: \mu_1 = \mu_o\). Both populations are identical.

\(\mu_1\): Sample mean taken from population 1

\(\mu_2\): Sample mean taken from population 2

with a 95% confidence level \((\alpha = 0.05)\).

7.1.7 Categorial data analysis

When data is classified in categories such as best, better, good and poor, it is called categorical data. Statistical inference about categorical data has been very popular in many fields of science. For this research, the construction work was categorized into three types: direct, indirect, and idle. The categorial statistical analysis, which requires inferences about either the difference between two population proportions, \((\pi_1 = \text{direct work, and } \pi_2 = \text{all other types})\) assuming two binomial populations or inferences about several proportions by applying the Chi-square test \((\pi_1 = \text{direct work, } \pi_2 = \text{indirect work, and } \pi_3 = \text{idle time})\).

\[
\text{Chi-square distribution test} = \Sigma_i \left[ \frac{(n_i - E_i)^2}{E_i} \right]
\]

where \(n_i\) denotes the number of observations in cell \(i\), and \(Ei\) is the expected number in cell \(i\).
### 7.1.8 Regression and correlation

Regression and correlation are defined as statistical techniques describing the relationship between a dependent variable and an independent variable. These techniques provide information on the effect of independent variables on the dependent ones. The main purpose is to investigate the strength of the relationship between the dependent and independent variables. Regression and correlation only describe whether a relationship exists but do not establish any causality of this relationship (Fellows, 2015). Typically, the data is plotted on a scatterplot graph with the independent variable on the x-axis and the dependent variable on the y-axis. A simple regression relationship is represented by a single straight line, which is either positively or negatively sloped. The linear regression relationship is set by a standard formula:

\[ y = a + bx \]

The linear regression line which “best fits” the scattered points can reveal an approximate relationship, allowing us to predict the dependent variable for a certain set of independent variables. It is rare that all data points fall exactly on the regression line. The line is created using the least squares method, which determines the values of “a” and “b” in the formula above as follows:

\[ b = \frac{\sum xy - n \bar{x} \bar{y}}{\sum x^2 - n \bar{x}^2} \]

\[ a = \bar{x} - b \bar{y} \]

where \( \bar{x} \) and \( \bar{y} \) are means for the dependent and independent variables, respectively and “b” is a constant. Certain data set scatter plots require a curve line for the best fit, so not all
data sets have straight lines as the best regression fit line. The observation of scattered points suggests a linear or non-linear regression fit line.

Correlation is a statistical method that examines the strength of the relationship between the dependent and independent variables. It utilizes the coefficient of correlation “r” to determine the significance of the relationship between both variables. The correlation coefficient, $r$, which is known as the Pearson coefficient, varies from -1 to 1, where 1 suggests a strong positive relationship, whereas -1 suggests a strong negative relationship. A coefficient value of 0 suggests a weak relationship between the independent and dependent variables; in other words, it is an indication that there is an insignificant effect of the independent variable on the dependent one. The Pearson correlation is a parametric test that can be conducted using several computer software programs, such as SPSS, MINITAB, or Excel.

7.2 Sample Size Determination

The first step needed to conduct data collection is to determine the sample size required to carry on this research. The sample size is crucial in providing accurate data results and must be adequately selected to give a close representation of the population being researched. Small sample size may not provide an accurate inference about the population. On the other hand, if the sample size is too large, then it would be a waste of resources, time and cost. There are two factors to be considered when selecting the sample size: tolerable error and confidence interval.

As mentioned before, in this research, we are conducting two types of statistical inferences:
1. Inference comparing the population central values (Difference in the means of two populations)

2. Inferences about categorial data in which the time data is classified into three categories: direct, indirect and idle times.

Each type requires an appropriate sample size that meets the minimum confidence level and the smallest accepted marginal error. The following two equations can be used to determine the sample size required to conduct the statistical inferences based on the level of confidence, marginal error, and estimated standard deviation of the sample reading.

A. The difference in the means of two populations:

\[
n = \frac{\left(z_{\alpha/2}\right)^2 \sigma^2}{E^2}
\]

B. Categorial data inference:

\[
n = \frac{z_{\alpha/2}^2 \pi (1 - \pi)}{E^2}
\]
# APPENDIX B: DATA COLLECTION FORM

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<thead>
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<th>Observation No</th>
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<th>Indirect Work</th>
<th>Idle</th>
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<td>D2</td>
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Form No. 17

Date: 10/2/2017

Starting Time: 8:10 Panel D1

Finishing Time: 8:32 D2

Total Time: 22 min

Observation Interval (min): 1

No. of Crew 2

Notes

Location

Key:

D1 Placing STUDS—placing, aligning, and bolting
D2 Placing TOP PLATE—fixing and bolting
D3 Placing SIDE PLATE—fixing and bolting
D4 Measuring and marking
I1 Talking to a supervisor
I2 Moving equipment, tools, and materials
I3 Read and discuss blueprint/instructions
I4 Doing nothing
I5 Rework