IMPROVING WORK SAMPLING ABILITY TO PREDICT CONSTRUCTION LABOR PRODUCTIVITY

BY

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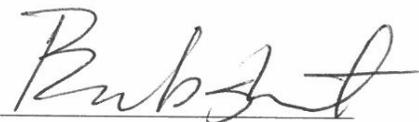
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This thesis is dedicated to my wife, my inspiration, whom I am grateful for, for her tremendous and valuable support, understanding and encouragement throughout. To my adorable sons, Saad, Raad and Faris for their patience. This dedication is extended to my parents, the reason of whom and what I become today. My mother for the special attention. My father, my role model, blessings and mercy of Allah be upon him. This dedication is also extended to N. AlMekhlal for her support.

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ABSTRACT

Full Name   :   Khalid Saad Saleh Al-Najdi

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In construction productivity, work sampling has been used as a technique to evaluate how work time is utilized. Such use has been extended to assess workers' productivity. Less precise techniques such as "Five Minute Rating" and "Head Count" have been used for similar purpose. Various studies were made to assess the ability of work sampling to predict the productivity of construction workers with varying results.

This thesis attempts to improve the prediction ability of work sampling by introducing "worker's pace" as a new variable based on several different field experiments of wall building. Additionally, the thesis will assess the impact of the number of work categories and their weights on predicting labor productivity. Finally, the thesis will assess the accuracy of some related techniques like the Five Minute Rating and the Head Count relative to work sampling. All of which had no previously published research on.

ملخص الرسالة

الاسم الكامل	**:**	**خالد سعد صالح النجدي**
عنوان الرسالة	**:**	**تحسين قدرة عينات العمل على تنبؤ إنتاجية عمال الإنشاء**
التخصص	**:**	**هندسة وإدارة التشييد**

تاريخ الدرجة العلمية: ربيع الأول   1437 هـ

من المعلوم في مجال إنتاجية التشييد، استخدام عينات العمل كأسلوب لتقييم كيفية استغلال أوقات العمل. وقد تم تمديد هذا الاستخدام لتقييم إنتاجية العمال، فيما استخدمت سابقا وسائل أقل دقة مثل "تقييم الخمس دقائق" واسلوب "عد العمال" لنفس الغرض. وفي هذا الصدد فقد تم عمل عدة دراسات مسبقة لتقييم قدرة عينات العمل على التنبؤ بإنتاجية عمال التشييد.

تهدف هذه الرسالة الى محاولة تحسين القدرة التنبؤية لعينات العمل على التنبؤ بإنتاجية عمال التشييد من خلال تقييم "وتيرة العامل" كمتغير جديد بناء على تجارب ميدانيه لبناء عدة جدران مختلفة. بالإضافة إلى ذلك، فإن هذه الرسالة ستقوم بتقييم أثر عدد من فئات العمل وأوزانها على التنبؤ بإنتاجية عمال التشييد. وأخيرا، ستقوم أيضا بتقييم مدى دقة بعض وسائل تقييم استخدام الوقت ذات الصلة مثل اسلوب تقييم الخمس دقائق واسلوب عد العمال بالنسبة لعينات العمل.

ومما هو جدير بالذكر فإن جميع أهداف هذه الرسالة لم تتطرق لها أي بحوث سابقه منشوره، وانما يتم دراستها وطرحها للمرة الأولى.

CHAPTER 1

INTRODUCTION

Construction productivity is an essential and fundamental measure in construction industry. Its vital role originates from the construction industry because it is an essential prerequisite for construction planning, scheduling, estimating and control in addition to obtaining necessary data in order to plan and schedule future projects. Moreover, it continuously improves the construction industry performance in terms of cost and schedule.

Generally, there are three common metrics describing productivity in the construction industry (Gouett et al., 2011):

1. Labor productivity, which can be defined as the ratio of work man-hours to the units of output (Gouett et al., 2011).

2. Unit rate, alternatively called factor productivity, which is defined as "the ratio of labor, materials or equipment costs to the units of output" (Gouett et al., 2011, P 1117).

3. Productivity factor defined as the ratio of the schedule to the actual work man-hours (Gouett et al., 2011).

Although construction productivity is a broad term that covers all kinds of resources including labor, equipment and materials, the first metric, labor productivity, measurement

is the focus of this study. Labor productivity, is usually contemplated when the productivity term is used. In construction industry, labor is considered one of the most unpredictable, variant and costly variables that can affect construction projects success and profits. Due to that reason, labor work time and activities, i.e. labor productivity, have to be identified and quantified in order to achieve the required profit as well as project success (Gouett et al., 2011).

In order to quantify labor productivity, it has to be measured. To measure it, several indirect techniques are employed as summarized below:

1. Cost Method.

2. Work Sampling.

3. Forman Delay Survey (FDS).

4. Craftsman Questionnaire and Interview (CQI).

5. Craftsman Questionnaire and Sampling (CQS).

One important technique to measure labor productivity is the work sampling alternatively called activity sampling. The role of work sampling is essential in labor productivity although indirectly measures it. The basic concept of work sampling is to categorize random observations of work captured at different instants of time into certain activities or tasks, calculate their proportions or percentages, and based on these proportions or percentages, labor productivity can be inferred. Therefore, work sampling can in fact indicate labor productivity. The technique is easy, economical, flexible, less erroneous and has been utilized in the industry for a long period of time (Oglesby et al., 1989). Despite the fact that there are limited statistical supportive studies about work

sampling effectiveness, the accuracy of the technique to measure labor productivity is supported by both professional academic institutions and well experienced construction contractors utilizing the technique, which is well documented in various literature reviews (Gouett et al., 2011).

The literature is to some extent contradictory and inconsistent about work sampling effectiveness. While some confirm that work sampling contributes to improving construction projects, identifies areas of productivity concerns and suggests means to resolve such areas of concern, the other part of the literature considers that no significant productivity improvements could be made out of work sampling. Because the work sampling technique involves controversy regarding its ability to measure labor productivity, it is the objective of this study to investigate the potential of improving the ability of work sampling to predict labor productivity.

1.1   Purpose of The Study

The objectives of this study are three folds. First, it aims to improve the prediction ability of work sampling by incorporating "worker's pace" as a new variable in measuring labor productivity. Second, the study will assess the impact of the number of work categories and their weights on predicting labor productivity. Finally, the study will assess the accuracy of some related techniques like the Five Minute Rating and the Head Count relative to work sampling.

1.2   Significance of The Study

The significance of this study stems from the fact that it will investigate issues related to an important topic of labor productivity which have never been addressed before, specifically:

1.   The introduction of work pace, "speed", in work sampling technique to measure productivity had never been evaluated before, therefore considering it may enhance the technique and improve productivity measurements.

2.   Similar to the point above, consideration of the other aforementioned factors may enhance or improve the prediction of productivity.

3.   Although the techniques used to measure construction workers' effectiveness, such as Five Minute Rating, have been in existence for decades, no previous study on their accuracy has been published. This study will be the first to do so.

Furthermore, this study will help in reducing the controversy around the work sampling abilities for the prediction of construction labor productivity.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a review of the literature on construction productivity generally and work sampling specifically. A special emphasis in this review was given to the validity of work sampling in measuring labor productivity.

2.1   Productivity

2.1.1   Productivity Definition and Measurement

Several definitions exist in the literature for construction productivity. Generally, the literature defines productivity as the relationship between outputs and inputs (Liou and Borcherding, 1986). The inputs include the resources that are associated with labor, materials and equipment while the outputs entail the actual physical constituent injected in the construction projects to achieve the required progress (Gouett et al., 2011).

Generally, productivity could be designated by the following mathematical models:

$$Productivity = \frac{Output}{Input} \tag{1}$$

Or alternatively,

$$Productivity = \frac{Input}{Output} \qquad (2)$$

Both mathematical models, models one and two, have been widely utilized in the construction industry. For Consistency purposes, the first model will be utilized as a reference in this study. Therefore, it is evident from model one above, that productivity will increase if the output increases while the input is kept constant or alternatively by decreasing inputs for the same amount of output.

Similarly, productivity can also be designated as:

$$Productivity = \frac{Goods\ and\ Services}{Productive\ Factor \times Time} \qquad (3)$$

On the other hand, Thomas et al. (1990) identified three models that defined productivity. These models were:

1. The Economical Model,

$$Productivity = \frac{Dollars\ of\ Outputs}{Dollars\ of\ Inputs} \qquad (4)$$

2. The Project Specific Model,

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$$Productivity = \frac{Square\ Feet\ Outputs}{Dollars\ of\ Inputs} \tag{5}$$

3. The Activity Oriented Model,

$$Productivity = \frac{Outputs}{Labor - Cost\ or\ Work - Hours} \tag{6}$$

Productivity is essential as a measure for different crafts and applications considering other industries different from the construction industry. In order to evaluate and quantify the output in the construction industry, labor productivity as a basic metric in this study is measured in actual man-hours per installed quantity (Park et al., 2005). Usually, in the construction industry, a productive process can be achieved by reducing the amount of man-hours per installed quantity or per task. The reduction of man-hours in a completed unit of work is considered an example of an increasing productivity by decreasing inputs (Liou and Borcherding, 1986). This in turn leads to defining labor productivity as "the amount of goods and services produced by a productive factor in a unit of time" (Drewin, 1982, P 3).

Productivity can also be measured with respect to either a single input or a group of inputs. The ratio of the output to the quantity of the production factor for which productivity is to be measured is called partial or factor productivity such as labor productivity. When the quantity in which the factors of production are combined, then this is called total productivity (Oglesby et al., 1989).

In order for the labor productivity to be measured, a reference point has to be established. This reference point could be one of several options, including but not limited to, productivity standards, time and motion studies calculation in addition to internal contractor company's time references. Direct time measurements could also be utilized as a reference. The direct time measurement studies are studies that simply record the time spent to accomplish a task. If the task consists of different subtask, then the total time needed to complete each subtask is also recorded. The total time spent for performing the complete task is then calculated by summing the different subtask timings (Groover, 2007). Consequently, if the time measured to accomplish a task or a subtask is less than or greater than a certain reference point, the labor productivity is deemed to be measured. This kind of measurement will indicate a certain level of satisfaction from a certain level of the achieved productivity. Therefore, determines whether an action to improve the labor productivity is needed, especially in cases where pace is of concern. This is another purpose why labor productivity has to be benchmarked against a certain standard point. A third purpose that could also be considered for setting a reference point to measure labor productivity is to evaluate the effectiveness of the corrective action taken to improve productivity as it is not a one step process, but rather a continuous process (Liou and Borcherding, 1986). As a result, time measurements are of essence. The time variable is considered the sole source of variation for labor productivity in the literature hence the variation in labor productivity as illustrated in Figure 1.
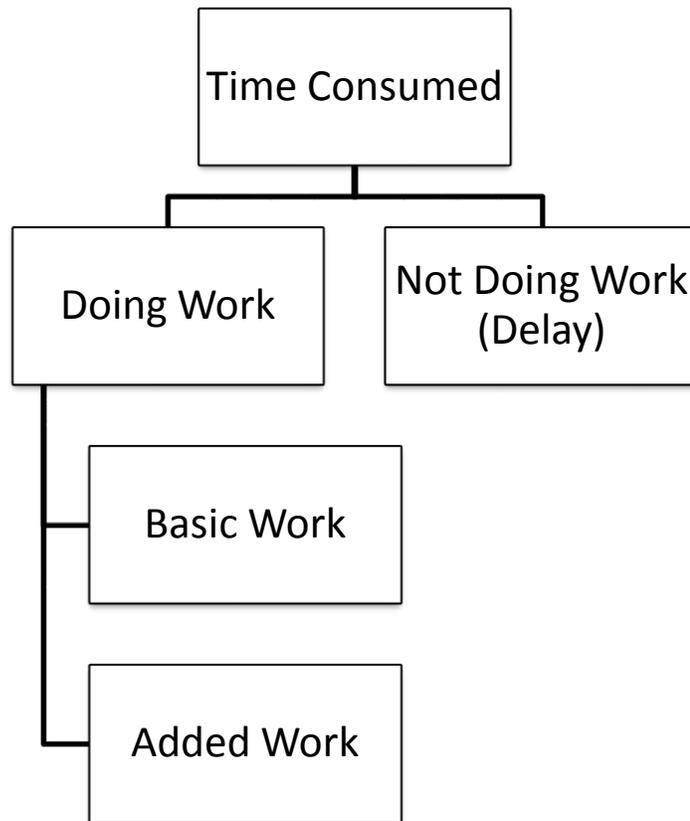
Figure 1 Time Model

Among the several existing techniques to measure productivity such as the Cost Method, Forman Delay Survey, Craftsman Questionnaire and Interview, Craftsman Questionnaire and Sampling, the Five-Minutes Rating and the Head Count techniques, Work Sampling seems to be the most suitably preferred technique to measure labor productivity. This is mainly attributed to the fact that productivity is essential for the construction industry and as a result, it needs to be measured continually, consistently and quickly (Liou and Borcherding, 1986). The work sampling offers such advantages.

2.1.2 Productivity Importance

Productivity holds a great deal of importance. It directly contributes to output growth, competition enhancements as well as cost and profit gains. In the construction industry, productivity is dependent on different factors of which labor constitutes a large variable and costly portion. Moreover, the labor also contributes significantly to the success of the construction projects and specifically its associated quality and profit margins. In view of the above, it is clear that project planning, scheduling, cost estimation, project control and efficient labor utilization are critical to consider from productivity point of view due to their significant impact on the project progress. Since labor productivity influences the construction industry drastically, it is then necessary to improve labor productivity in order to control and improve projects planning, scheduling, increase profit and reduce involved costs. This will lead to better contractor's competitiveness, projects economics and efficient use of labor from size and skills perspectives in addition to labor quality and productivity (Thomas and Mathews, 1986). Hence, the need for continuous productivity improvements shall be considered.

2.2   Work Sampling

In construction productivity, work sampling has been used as a technique to assess workers' productivity because it evaluates how work time is utilized. The work sampling technique has been utilized in the construction industry for a very long period of time. It is well known for identifying productivity problematic areas in the task under observation, however it does not conclude root causes of these identified productivity problematic areas.

The work sampling technique was initially developed by Leonard Tippet, an industrial engineer, in 1927. It was originally called the Snap Reading Method as a work measurement tool to control productivity inputs and was named after the photography concept of snap shot (Tippett, 1934; Groover, 2007; Gouett et al., 2011). The Snap Reading Method was mainly used in the English Textile Industry and was described as a series of instantaneous observations of equipment and operators at random time intervals (Tippett, 1934; Gouett et al., 2011). At that particular period, direct time studies were the popular principal research method to be conducted as work measurement tools. Tippett, recognized that the direct time studies were suitable for setting some time standards, however were not suitable as a work assessment tool because only few workers could be observed at a time.

In 1940, Robert L. Morrow renamed the Snap Reading Method to Ratio-Delay Survey (Heiland and Richardson, 1957; Drewin, 1982). Morrow was recognized and credited to importing the method to America. Morrows' intention was to use this method for establishing delay allowances for time standards. Then in 1952, C. L. Brisley and H. L. Waddell renamed the technique to "Work Sampling" (Heiland and Richardson, 1957). Ever since, the term "Work Sampling" was widely adopted in the construction industry

because it suggested descriptive quantification of work levels. In some other countries, such as Great Britain, work sampling is known as "Activity Sampling" (Gouett et al., 2011).

As stated by Liou and Borcherding (1986, P 92) the use and purpose of work sampling is that "work sampling commonly used in the work measurement and methods engineering area to produce statistically sound estimates of the percentages of time that a work system is in any of a variety of states of work activity. With appropriate procedures, work sampling can produce information from which time standards might be determined".

Few studies have been conducted on the validity of work sampling in measuring construction productivity. Those studies were conducted by Thomas et al. (1984), Liou and Borcherding (1986), Handa and Abdalla (1989) and Al-Ghamdi (1995).

Liou and Borcherding (1986) had deduced that unit rate productivity could be predicted through the direct work rates of work sampling. This position was initially supported by another productivity expert, Thomas (1980), but he later concluded that there is no relation between the direct work rates from work sampling and labor productivity (Thomas, 1991). In fact, Thomas claimed that there is no relation between the actual labor productivity and work sampling categories even though he explored different crafts none of which revealed a significant correlation. In fact, Thomas strongly concluded that direct work category of work sampling cannot be used to predict construction labor productivity (Al-Ghamdi, 1995).

Al-Ghamdi (1995) evaluated the use of work sampling as an indicator in predicting construction labor productivity. The study considered the effect of several factors such as

complexity level, crew size, and skill level on the relationship between productivity and work sampling categories. The study tested three hypotheses: productivity increases as the effective work category increases, productivity increases as the ineffective work category decreases and the effective work category increases as the ineffective work category decreases. Al-Ghamdi utilized a total of 35 field experiments of walls building in his study as the sole source of data collection. These experiments involved two crew sizes, two workers' skill levels and three different wall complexity levels. The results showed that the three hypotheses were true. The study also indicated that the complexity of the walls and the crew skill levels have insignificant effect on the relationships rather, all three relationships were affected by the crew size. In addition, the results indicated that work sampling was not a very strong predictor of construction labor productivity. The study conducted by Al-Ghamdi in 1995 utilizing field experiments also found a moderate correlation between work sampling and productivity. In his study, Al-Ghamdi (1995) did not consider worker's pace influence.

2.2.1 Work Sampling Definition

There are several definitions of work sampling found in the literature. Liou and Borcherding (1986, P 92), define work sampling as "a technique in which a large number of instantaneous observations are made over a period of time of workers, machines, or processes to facilitate quantitative analysis of a task". Oglesby et al. (1989) also define work sampling as a technique that is based on random observations and the theory of probability to determine the relative proportion of time spent on activities associated with the performance of a task. A more comprehensive definition of work sampling is provided

by the Institute of Industrial Engineers as "the application of statistical sampling theory and technique to the study of work systems in order to estimate universe parameters from sample data." (Liou and Borcherding, 1986, P 92).

2.2.2 Work Sampling Rules

As the definitions of work sampling imply, specific conditions must be met in order to obtain accurate results from the technique. These conditions are summarized below:

1. Availability of an adequate sample size. The minimum sample size that had been confirmed to be a representative of the entire population by construction productivity literature is 384 observations. This sample size was substantiated in the construction industry in accordance to a 95% confidence level and an error of 5% (Oglesby et al., 1989) using the following equation:

$$n = \frac{(Z_{\alpha/2})^2 \, p \, (1-p)}{d^2} \qquad (7)$$

Where, n is the sample size, p is the population proportion and d is the error.

Figure 2 below graphically shows the normal sampling distribution of the population proportions for the previously stated statistical parameters.
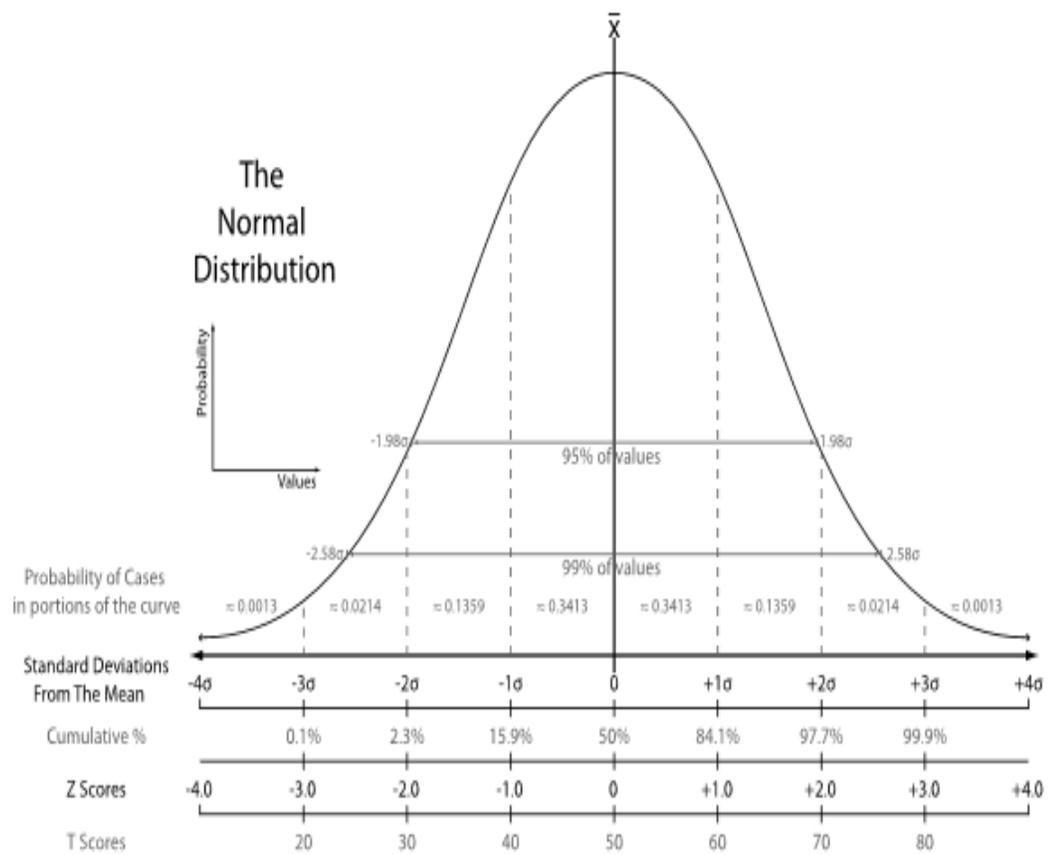
Figure 2 Sampling Distribution of Population Mean, (Investopedia, 2015)

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However, Gouett et al. (2011) argue that equation (7) is based on a binomial distribution and thus would be appropriate to utilize only when sampling two work categories. Where more practical situations involving work sampling with several work categories, a multinomial distribution should be used. Because of the multinomial characteristics that the work sampling technique actually represents, the error would be more than that specified in equation (7) above. Therefore, would not provide the necessary required accuracy that work sampling technique shall maintain. For a more accurate and reliable representation of work sampling of multinomial distribution nature of the population, with the same confidence level of 95% and an error of 5%, the following Thompson Equation should be used:

$$n_0 = max \left[\frac{(Z_{(1-\alpha/2m)})^2 \frac{1}{m} (1-\frac{1}{m})}{d^2} \right] \qquad (8)$$

Where, n_0 is the sample size, m is the work sampling categories and d is the error.

Thus, above equation results in a sample size of 510 observations, in the worst case scenario, when the work sampling categories "m" is equal to three.

2. Instantaneous identification of observation made (Oglesby et al., 1989).

3. Each of the elements has an equal probability of being selected (Oglesby et al., 1989).

4. No sequential relationship should exist (Oglesby et al., 1989).

5. The basic characteristics of work sampling remain the same during observation

(Drewin, 1982).

2.2.3 Work Sampling Advantages

Work sampling technique is widely used in the construction industry. Its popularity originated from the advantages it possesses. Work sampling key advantages include:

1. Simple and economical (Oglesby et al., 1989).

2. Involves no sophisticated equipment (Oglesby et al., 1989).

3. Does not directly interfere or intervene with the worker (Oglesby et al., 1989).

4. Requires a simple limited training, which can be performed by anyone who has knowledge of the technique (Oglesby et al., 1989).

5. Allows supervisors' and foremens' participation and contribution (Oglesby et al., 1989).

6. Tolerates interruptions of the study at any instant of time with no effect on the study (Oglesby et al., 1989).

7. Quantifies results, which can be readily available (Gouett et al., 2011).

8. Predicts or indicates labor productivity (Liou and Borcherding, 1986).

9. Provides an overall indication about the distribution of activities for different resources particularly the workers (Thomas and Holland, 1980).

10. Possesses an established statistical reliability (Thomas and Holland, 1980).

11. Focusses on the worker as a basic construction unit (Thomas et al., 1990).

12. Can be used to monitor construction crews (Oglesby et al., 1989).

13. Appropriate for the analysis of indirect labor (Richardson, 1976).

14. Identifies productivity inhibitors or barriers (Gouett et al., 2011).

2.2.4 Work Sampling Disadvantages

Irrespective of the advantages the work sampling technique offers, it also has some shortfalls. Some examples of the shortfalls the work sampling has are:

1. Not a direct measure of labor productivity (Richardson, 1976).

2. Can only identify productivity issues but cannot conclude its root causes (Gouett et al., 2011).

3. Does not provide management with work improvements nor the means to plan and implement them (Gouett et al., 2011).

4. Requires very careful and meticulous data analysis (Oglesby et al., 1989).

5. Susceptible for data manipulation (Oglesby et al., 1989).

6. Neither appropriate for short cyclic form of jobs nor economical for the study of single resources, i.e. individual worker and machine (Drewin, 1982, Liou and Borcherding, 1986).

7. Lacks enough statistical validation on its effectiveness (Gouett et al., 2011).

8. Does not consider nor incorporate the workers' pace or workers' speed.

2.2.5 Work Sampling Procedures

Work sampling has a well-defined, sound and established procedure for conducting work sampling studies that is properly documented in the literature. This procedure is described below (Oglesby et al., 1989):

1. Establishing observation categories. To start with, the objective of the study and observer's ability are to be considered at this stage. Observation categories are

considered the most important part when conducting a work sampling study. There are advantages as well as disadvantages that are associated with the number the observation categories the study aims for. The larger the scope and number of observations categories are, the more complicated the study becomes. In general, the observation categories can be classified into three main groups that will be explained in more details in the following Section:

1. Effective Work.

2. Essential Contributory Work.

3. Ineffective Work.

2. Introduction of the work sampling program to the involved people in the construction project or those who are involved in the work sampling study. Explanations of all study aspects to site foremen and consequently workers as well as the project management are crucial at this point. The objective of the study should also be highlighted clearly, indicating that the purpose is to neither measure workers performance nor setting standards but rather identify productivity issues.

3. Collection of data, which maybe in the form of daily summaries. At that stage two approaches could be considered, the Tour Approach and or the Crew Approach.

4. Analysis of the acquired data, where the obtained results should indicate symptoms of low productivity and or any productivity issues.

5. Follow up process, to eliminate identified low productivity issues.

2.2.6 Work Sampling Categories

Regardless of the approach used to collect the sampling data, the prediction of the

sampled data accuracy will heavily depend on the way the observations are made and are categorized (Oglesby et al., 1989). The observations made have to be grouped or classified in a concise and specific certain way. Categorization of the observations is therefore critical for the success of sampling. As a result of categorizing the observations proportions, inferences about labor productivity can be drawn for the overall work activities under the study scope (Richardson, 1976).

For work sampling, there is not a standard way of categorization. Specific work sampling categories have to be developed for the study based on its objectives. Cautious should be seriously considered when developing detailed observation categories based on the study objectives. The extent of level of details related to the categories will complicate the study and will make it very difficult to analyze. However, the following major categories could be first used and exploited to further specify more detailed categories:

1. Effective Work, which is activities that are directly involved in the actual process of performing the unit being constructed (Oglesby et al., 1989; Thomas, 1989).

2. Essential Contributory Work, activities that are not directly involved in the actual process of performing the unit being constructed, however, considered essential to its completion (Oglesby et al., 1989; Thomas, 1989).

3. Ineffective Work, activities that do fall under neither Effective Work nor Essential Contributory Work categories (Oglesby et al., 1989; Thomas, 1989).

From the main categories sated above, work activities could be further categorized in more details and then grouped under either one of the major categories. This highly

depends on the extent of details that the study aims for. Nevertheless, the investigator should pay attention to the difficulties associated to the extent of detailed categorization because the greater the level of details associated with the categories are, the more difficult it becomes to accurately categorize an activity. Further detailed observation categories can also be, but not limited to, direct work, preparatory work, tools and equipment, materials and materials handling, transportation, travelling, delay, personal time and waiting.

2.2.7   Work Sampling Approaches

Basically, there are two main approaches for conducting work sampling studies on the construction site, the Tour and Crew Approaches.

The selection of a proper approach depends on the study objectives. In addition, it is of utmost importance that the investigator recognizes the limitations of either approach in order to accomplish the study objectives. The selection of either approach depends on several factors including site location, layout, labor crews, labor size and environment (Oglesby et al., 1989).

2.2.7.1 The Tour Approach

The Tour Approach is utilized to survey and cover the entire construction site or project. This will assist in quantifying the work and labor levels. The tour had to comply with the work sampling requirements in which the routes have to be randomly chosen throughout the project site. Furthermore, the observation timings should be randomly chosen where the observer also records the findings at the first instance. This approach depends heavily on the observer's abilities and his physical condition as he requires

comprehending the approach, being fit and healthy not to mention has the ability to identify his co-workers (Thomas, 1991). The Tour Approach is not practical for large construction sites. The possibilities of worker's crossover and absenteeism had to be paid attention to by the observer in order not to statistically affect the reliability of the work sampling results, which is very difficult in such a case (Thomas and Holland, 1980).

2.2.7.2 <u>The Crew Approach</u>

Comparably, the Crew Approach, is primarily utilized when the performance and or productivity of a certain craft or crew needs to be monitored. Although this approach may appear to be easy because the investigator is only focused on a crew or a craft, it would require more efforts to collect the required sample size since a limited number of the workers are being observed. Thus, it may not be economical to use. However, the approach makes it easy for the observer to focus on the craft and the critical activities during the project allowing provision of descriptive and quantitative data.

Despite the fact that problems such as worker's crossover or absenteeism are mostly avoided in this approach because the observer will get acquainted with the workers in a relatively short period of time, this approach may cause worker's discomfort and abnormal behavior thus causing the work sampling results to be unreliable or biased (Gouett et al., 2011; Thomas, 1981). The investigator should then emphasize on the program introduction and should clarify the program objective to the workers so that none of that may happen. This approach may be particularly beneficial in studies where field experiments are to be investigated for productivity issues.

In view of the above, the investigator should select that approach that best suites the

type of study to be performed as to whether the entire construction site is to be covered or just a crew where a different greater level of details is to be obtained.

2.2.8   Factors Affecting Work Sampling Accuracy

Several factors can affect the accuracy of the work sampling procedures and its correct implementation, which will consequently affect the accuracy of the resulting proportions or percentages of the work categories and therefore labor productivity. Such factors can be related to either the observer or the construction project. The factors related to the observer limitations could be either proper understanding of the observation work categories or the ability to understand projects' drawings for instance. In addition, other factors could also be observers' bias, knowledge or projects or tasks or even categories variation, crew members' crossover, absenteeism, unusual worker's behavior, construction method, construction time frame, project environment, project layout and complexity, weather and the length of the workday (Oglesby et al., 1989; Thomas, 1989).

2.2.9   Work Sampling Validation

Although work sampling is widely used and principally accepted in the construction industry and its productivity experts, as an early indicator of productivity inhibitors, its use diminished in the previous two decades. This is because the approach was not known to make substantial areas of improvement in measuring labor productivity. This can be attributed to the lack of providing statistical validation of its effectiveness (Gouett et al., 2011). Gouett et al. (2011) also claim that this is due to the absence of easy and accessible guidelines about how to do work sampling. Moreover, the approach only highlights areas

of low and high productivity but does not determine root causes for these high and low productivity areas. This fact made construction contractors hesitant to utilize the work sampling technique since they are interested in the sources, or direct root causes, of the productivity issues. What is more, because the technique does not offer substantial improvements, it made it even more difficult for the construction contractors to plan for any cost and profit benefits such as overall construction cost reductions, which means it is not a continuous process to constantly improve (Gouett et al., 2011). While Thomas and Holland (1980) were of the opinion that it is difficult to measure construction productivity, Liou and Borcherding (1986) showed that work sampling could predict unit rate productivity through direct work rates. However, in order to improve productivity, labor productivity has to be measured against a reference before and after improvements to verify that, the correct action has been taken (Liou and Borcherding, 1986). Subsequently based on the references, productivity can be benchmarked.

Validation of work sampling had been examined and investigated statistically by a limited number of studies which were reported by Thomas et al. (1984), Liou and Borcherding (1986), Handa, and Abdalla (1989) and Al-Ghamdi (1995).

As stated previously, although such validation was not extensive, the previously mentioned studies had commonly concluded that there is a strong positive correlation between direct work activity percentages and labor productivity (Al-Ghamdi, 1995).

Although Thomas, early in 1984, supported the conclusion reached at by Liou and Borcherding (1986), he later opposed it (Thomas, 1991), stating that there is no relationship between work sampling and labor productivity after statistically testing seven case studies

(Gouett et al., 2011).

This was because in 1991, Thomas had conducted a study validating and describing the relationship between direct work reported in several work sampling studies and labor productivity. The driver behind conducting his study (Thomas, 1991) was because the previous studies validating work sampling did not conclusively conclude a common inference about work sampling. In addition, the conclusions for each study were contradictory or not realistic. Furthermore, some studies considered tasks that are not directly related to the working crews (Al-Ghamdi, 1995).

In his study, Thomas (1991) utilized seven different databases collected mainly from thirty projects in nuclear power plant construction projects. Variant databases and large sample size representing very large observations proportions were characteristics of the investigation captured from the existing seven databases in addition to other sources. The thirty project database consisted of 158 work sampling studies from thirty nuclear power plants construction projects with different crafts between 1973 and 1985. Other databases consisted of additional five different subsets of different data sources of which one is performed by Liou and Borcherding (1986) for a similar construction site (Thomas, 1991).

The data investigated by Thomas, had revealed conclusively that direct work is not related to labor productivity. Thomas' hypothesis that direct work percentages obtained by work sampling, can be used to predict labor productivity was based on the following three primary assumptions:

1. "Reducing the amount of time spent waiting leads to more time spent in direct work activities" i.e. better labor productivity is achieved when direct work time increases

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(Thomas, 1991, P 435).

2. "If more time is spent in direct work activities, the productivity will be better." i.e. reduction of the waiting time leads to an increased time for direct work (Thomas, 1991, P 435).

3. "If the first two assumptions are true, it follows that reducing waiting time will lead to improved productivity." i.e. better labor productivity is associated with less waiting time (Thomas, 1991, P 435).

The previously stated assumptions were tested separately using linear regression models. These models showed very poor statistical correlations where the conclusion eventually was that the results of the work sampling studies cannot be used to predict labor productivity (Thomas, 1991). Regardless of the study outcome, the study of Thomas (1991) is significant because it had investigated numerous diverse projects. The study investigated two primary sets of data assembled about ten years ahead of it. Thomas also utilized other sources of databases to support his conclusions. TABLE 1, provides a summary of these databases.

TABLE 1 Thomas's Database Summary

Data Base 1	Number of Data Points 2	Number of Projects 3	Type of Project 4	Type of Data 5	Craft or Activity 6
30 Projects	158	30	Nuclear Power Plants	Biweekly Summary	All major crafts, site wide studies
Rogge and Tucker (1982)	22	1	Nuclear Power Plants	Biweekly Summary	Carpenters, Electricians, Ironworkers, Pipefitters
Logcher and Collins (1978)	5	5	Commercial	2-5 Days Summary	Tile-setting activities
Grand Gulf	14	1	Townhouses	Unknown	9-11 persons framing crew
Handa and Abdalla (1989)	22	1	Nuclear Power Plants	Daily Values	30 Pipefitters installing valves in containment building
Liou (1984)	21	7	Fossil Power Plants	Biweekly Summary	All major crafts, site wide studies
Three- Projects	46	3	Nuclear Power Plants	Biweekly Summary	Carpenters, Electricians, Ironworkers, laborers, Pipefitters

In another study, Al-Ghamdi (1995), tested another three different hypotheses derived from the previously stated three assumptions. These hypotheses were:

1. "The time spent on effective work (EW) is positively related to productivity (Pr)." (Al- Ghamdi, 1995, P 18). This hypothesis was tested using Person's Coefficient of Correlation (r) of effective work and productivity. The null hypothesis was H_0: $r_{EW,Pr} > 0$ (Al- Ghamdi, 1995, P 18).

2. "The time spent in ineffective work (IW) is negatively related to productivity (Pr)." (Al- Ghamdi, 1995, P 19). Similarly, this hypothesis was also tested using Coefficient of Correlation (r) of ineffective work and productivity. The null hypothesis was H_0: $r_{IW,Pr} < 0$ (Al- Ghamdi, 1995, P 19).

3. "The time spent in effective work (EW) is negatively related to that of the ineffective work (IW)." (Al- Ghamdi, 1995, P 19). Person's Coefficient of Correlation (r) was again utilized to test this hypothesis. The null hypothesis in this case was H_0: $r_{EW,IW} < 0$ (Al- Ghamdi, 1995, P 19).

Doubts about the validity of Thomas (1991) conclusion were raised by Al-Ghamdi (1995) who offered several plausible errors that could have led to the above conclusion. These doubts appeared to be realistic for several reasons. First, the databases Thomas (1991) had utilized were gathered from different projects of similar nature but different objectives. Not only that, but also the tasks performed within each project might be different with different crafts and crews and might be completely different with the work sampling data collected by different observers and dissimilar work sampling categories. This introduced a source of variation casting a reasonable doubt on the study conclusion.

Second, since the database considered thirty different projects, the study did not elaborate on the characteristics of the work performed by the different crafts nor the craftsmen performing the work. Though the projects might be similar, there were no guarantees that the tasks or work carried by the working crews were of similar nature with similar characteristics. This again was considered another source of error. Finally, the study adopted the performance factor as a representation of labor productivity. The method of calculation for such representation involved inaccurate estimates of unit rates. Thomas (1991) did not present sufficient evidence in his study concerning the accuracy of unit rate estimates used in the database. Again, with dissimilar projects and the large database considered, the unit rate estimates might not be consistent or accurate for all the data collected from these projects especially when he related the estimated unit rates to the actual ones. This, again, was a major source of error in his study (Thomas, 1991; Al-Ghamdi, 1995).

Thomas (1991) in the same study had also considered additional factors that affect productivity and work sampling relationship. Those factors were project-related which were considered as an additional major source of variation within each case study he considered such as the project complexity and the skill level associated with each project (Al-Ghamdi, 1995).

Thomas's study in 1991 was the last study validating work sampling that was published in the literature after which no other studies were introduced. In an effort to revive validation of work sampling again, some productivity experts started to publish articles on productivity work in 1996 (Gouett et al., 2011). Nevertheless, those articles were not all statistical in nature nor of validating description.

2.2.10 Work Sampling Related Techniques

Work sampling offers other related techniques which had been found to be effective in rating work activities to further explore specific sort of productivity concerns. Those techniques record and analyze field observations to determine what the workers are individually doing at certain particular times. Such field observations provide more insights as to how certain crafts are performing to give a wider coverage about the performance of the construction project and labor workface. Those techniques include Five Minute Rating and Head Count.

2.2.10.1 <u>Five Minute Rating</u>

The Five Minute Rating technique is a work sampling related technique where the activities are quickly recorded for a certain construction crew and for a short period of time. This time should not be less than a length of five minutes or the number of minutes equal to the crew size. It is considered as a quick but effective method to formulate a general assessment of the crew effectiveness. The Five Minute Rating technique, although related to work sampling, is not a true sampling because it does not meet the work sampling requirements. To further clarify, the recorded observations are not recoded randomly, the sample size is not large enough to represent the population proportion and the observations are not recorded at the first instance of occurrence. The technique is based on the total number of observations made during a short duration of the study (Oglesby et al., 1989).

The main objectives of this technique are to determine the crew effectiveness, trigger the attention of the project management to certain areas of delays, particularly its extent, and indicate potential areas of savings resulting from detailed observations and planning of the work activities (Oglesby et al., 1989).

In order to implement the Five Minute Rating on a crew, the observer has to watch each crew member for some amount of time ranging from about thirty seconds to several minutes of the entire duration of time allotted per worker. If the worker appeared to work for more than 50% of the time he was observed for, the worker is then recorded as doing effective work. Otherwise, the worker is recorded as not working, engaged in ineffective work or delayed. Accordingly, the ratio of effective work to the total observation time is then calculated on a man minute basis as an effectiveness ratio.

In order to improve the accuracy of the technique, it is recommended that the observer makes several five minute ratings for the crew and then takes the average (Oglesby et al., 1989).

The effectiveness of a crew can therefore be found by equation (9).

$$Crew\ Effectiveness\ = \frac{Effective\ Man\ Minutes}{Total\ Man\ Minutes\ Observed} \times 100 \qquad (9)$$

It is noteworthy to state that in addition to the Five Minute Rating technique, other rating schemes could attempt to assess the workers' pace or the activity levels if properly designed. To further explain, the categories used for this purpose should in this case reflect the work activities numerically in percentages relative to a standard or average pace selected for the purpose. For example, a fast moving worker, i.e. fast pace, can be shown as a percentage of 120% relative to the standard or average pace that represents a 100%. Similarly, a slow moving worker, i.e. a slow pace, can be shown as 80% relative to the

standard or average pace selected. The aim of this scheme is to extend the activity ratings to reflect the work tone in a more accurate condition (Oglesby et al., 1989).

2.2.10.2 <u>Head Count</u>

Another related technique to work sampling is the Head Count technique called more often as Field Rating technique. This technique mainly classifies workers into two categories, either engaged in doing useful, effective, work activities or not engaged in doing useful, effective, work activities. The Head Count technique basically requires the observations to be recorded for at least 75% of the involved workers at the job site so that reliable and accountable results are obtained. The technique involves recording the workers activities at the first instant of observation, but the observations should be made when the work rhythm is essentially stable. The observer should start watching workers after at least half an hour from the start of the working time and stops before the end of the working time by the same amount of time. In addition, regular breaks should be excluded from being recorded or sampled. Finally, the observations recorded are calculated as a ratio of the total number of observations for the workers observed doing work to the total number of workers observed as per equation (10) below (Oglesby et al., 1989):

$$Field\ Rating\ Index\ (FRI) = \frac{Men\ Observed\ Working}{Total\ Observed\ Men} \times 100 \qquad (10)$$

The technique also provides for the foreman and personal time, for which an additional 10% is normally added to the results in order to cover the instructions supplied

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by the foreman, therefore equation (10) above becomes:

$$Adjusted\ Field\ Rating\ Index\ (FRI) = \frac{Men\ Observed\ Working}{Total\ Observed\ Men} \times 100 + 10\% \qquad (11)$$

The results are then interpreted as productive workers or crew if the obtained result percentage is greater than 60% provided that the sample size complies with work sampling requirements. Otherwise, obtaining less percentage values, than the 60%, are considered unproductive (Oglesby et al., 1989).

2.2.11 Work Sampling Data Analysis

The work sampling data serves a particular purpose, which is mainly assessing the variation of the observation categories percentages or proportions to determine high or low productivity areas. Which will consequently leads to identifying productivity concerns. However, the analysis of work sampling data is specifically subjective to the study objectives.

2.3   Pace of Work

Labor productivity relies primarily on the workers. In addition, it also relies on productivity determinants such as the duration and the intensity of workers' effort. It is thus logical to assume and expect that workers' pace will affect their productivity.

The official definition of pace according to the Institute of Industrial Engineers is the "rate of output or performance compared to an accepted standard. May be expressed quantitatively in terms of units per time or in terms of percent relative to standard." (Institute of Industrial Engineers web site, 2013). There are other terms which are directly related to the pace of work such as "Pace Rating", "Performance Rating" and "Pace Setter". The Pace Rating is "A worker's speed of performance as compared with normal pace." (Institute of Industrial Engineers web site, 2013). The Performance Rating is defined as "Observation of worker performance to determine productivity in terms of standard or normal." (Institute of Industrial Engineers web site, 2013). A Pace Setter is "A worker who is better than average on a particular job, and whose production is used by the employer as a standard for measuring the amount of work which can be done in a given period of time." (Institute of Industrial Engineers web site, 2013). Other than the Pace Setter, the "Average Worker" may also be used as a reference for productivity. Therefore, the "Average Worker" is a representative of all other workers that are normally performing standard work under study (Aft, 2000). A typical average worker is not meant to be the best or the worst worker, but rather a worker who is trained enough and has some experience to perform intended work at hand.

When the workers' pace is considered, certain characteristics related to it should be addressed. These characteristics are performance, performance speed, consistency, and the pace rating (Aft, 2000).

Normal pace, which is also referred to as average pace, could be identified or designated by an activity of a normal, and typical averaged type rhythm, better yet, rate. Because normal or average terms are subjective measures that are dependent on the worker,

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there are certain requirements that should be met in order to exactly define them. First, the normal pace utilized to evaluate one type of work within an organization should be the basis for evaluating other types of work within the same organization. In this case, the average pace, that is monitored, should be used in the same way to evaluate other field experiments. Second, the normal pace should be the pace that an average typical worker can work with for the entire working time without resulting in unnecessary physical fatigue, in other words it should be neither fast nor slow but rather consistent. Third, a normal pace should be related to what should be done rather than what is actually being done. To further clarify, this means that the normal pace does not essentially indicate average pace or average productivity for a certain organization performing the work. Finally, the normal pace must not be changed once it has been established if considered as a reference (Aft, 2000).

The pace of the worker can be measured through a Direct Time Study of Intensive Sampling (DTSIS). It is "a procedure in which the performance of a task is observed directly and continuously for a limited period of time" (Mundel, 1978, P 324). The evaluation of the workers' performance in comparison to an average pace worker is carried out together for the activities time and activities count. The Direct Time of Intensive Sampling Study is best implemented for manual as well as repetitive or cyclic work activities (Mundel, 1978).

For a Direct Time Study of Intensive Sampling to be implemented, the following procedure needs to be followed (Mundel, 1978):

1. Defining the measurement standard which means setting a pace rating for the

workers.

2. Recording the standard practice.

3. Observing and recording the work activities time consumed by a worker in addition to the work activities count.

4. Rating the performance in comparison to the measured standard or reference.

5. Determining allowances and applying an adjustment factor to the measurements.

Amongst the above procedure, steps one, two and four are of direct reference to this study. In a Direct Time Study of Intensive Sampling, the basic mechanics of the human motion are monitored. Acceleration of the human parts such as the hands for a constant travelling distance with a certain velocity is what is considered as the pace. Consequently, the pace or rate of activities could be defined as "the rate at which muscular force is applied to the creation of body, arm, hand or finger movements, disregarding the effect of job difficulty (mass constant), and hence as the observed rate of acceleration of the body member doing the work." (Mundel, 1978, P 361).

In order to rate the worker's pace, the average velocity or speed for a body part is not the appropriate component to use for the rating as the definition implied above, but rather the rate of movement at the beginning of the activity and the rate of deceleration at the end of movement (Mundel, 1978). It is crucial to make a referenced average pace rating. Several ways to set a reference rating exist. First, the pace rating may be set or determined by the crew itself as one way. The crew can make its own average pace rating by performing the activities normally at hand in a normal way where the observer then records this crew performance as an average pace reference. Second, the use of a professional crew to set an average standard pace rating. Third, the use of construction standards to determine

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a pace rating. Finally, by benchmarking of different companies' standards to determine an average pace rating (Mundel, 1978).

Measurement units vary according to the study objectives. Physical quantities such as actual man-hours per installed quantity, volume or installed quantity per unit of time such as completed number of meters per minute, number of installed blocks per minute and or number of transported blocks per minute are all considered possible units of measure. The first method for setting an average pace rating is adopted throughout this study.

2.4   Theoretical Framework

The theoretical framework considered in this study is based on Maloneys' Model (Maloney, 1981) of the workers' productivity determinants that includes:

1. Duration of the workers' effort.

2. Intensity of the workers' effort.

3. Effectiveness with which the worker's effort is combined with technology and other resources.

4. Efficiency of the workers' effort.

Out of the four aforementioned productivity determinants, the first two are related to work sampling, hence, will be utilized as a basis in this study.

CHAPTER 3

RESEARCH METHEDOLOGY

3.1   Objectives of The Study

This study aims to improve the prediction ability of work sampling by introducing "workers' pace" as a new variable. The study key objective is to investigate the first two productivity determinants of Maloneys' Model, which are the duration, and the intensity of workers' effort. Additionally, the study will assess the impact of the number of work categories and their weights on predicting labor productivity. Finally, this study will assess the accuracy of some related techniques like Head Count and Five Minute Rating relative to work sampling. This chapter will further elaborate on the methodology, state the hypotheses involved, the influencing variables associated with the hypotheses and the study design related to the objective of the study.

3.2   Hypotheses Testing Criterion

Prior to the discussion of the study hypotheses, it may be helpful to clarify how these hypotheses will be tested first. This is mainly to aid in understanding the discussed hypotheses.

The study hypotheses will be tested using the Multiple Regression Model. As a result, this

dictates that all the hypotheses will utilize the Coefficient of Determination "R^2" as a criterion to operationalize the theoretical hypotheses. In other words, the Coefficient of Determination "R^2" will be examined and compared for statistical variation or statistically significant difference. In addition, the Correlation Coefficient "R", or multiple R, will be used to determine the strength of the relationship. It indicates how strong the relationship is. A value of one indicates a perfect positive relationship, while a value of zero indicates no relationship. The "R", multiple R or Correlation Coefficient, is the square root of the Coefficient of Determination.

The Coefficient of Determination "R^2" is a statistical measure, its main purpose is to explain the variation between the dependent variable and the tested independent variable(s) and how well such data fit the model. It is a measure that determines how certain one can be in making predictions from particular data or models. Simply, it is the ratio of explained variation to the total variation. It is useful because it provides the proportion of variance for a variable that may be predictable from another variable. Statistically, it has a value such that zero < R^2 < one, or alternatively 0%< R^2 <100%. Both values denote the relative strength of association between the two variables X and Y. Where, the zero indicates that the model does not explain the variability of data, one or 100% indicate that the model completely explains all the variability of associated with data or model. In general, the higher the R^2 is, the better the model fits the presented data.

Another way to look at the Coefficient of Determination "R^2" is that it equals to one minus the ratio of the sum of squared estimated errors, which is the deviation of the actual value of the dependent variable from the regression model line, to the sum of squared deviations about the mean of the dependent variable. Hence, the R^2 is a measure of the

extent to which the total variation of the dependent variable is explained by the regression.

In addition to the Coefficient of Determination, the literature uses the Correlation Coefficient, R, to assess the relative strength of association between variables and based on its value, a linguistic description is provided. The following are typical ranges of the correlation coefficient and their association description, which will be used in this study:

Zero $\leq$ R $\leq$ 0.35   : Weak Correlation

0.36 $\leq$ R $\leq$ 0.59   : Moderate Correlation

0.60 $\leq$ R $\leq$ 0.90   : Strong Correlation

0.91 $\leq$ R $\leq$ One   : Perfect Correlation

In testing the hypotheses in this study, some regression equations involve multiple independent variables. As a result, instead of using the Coefficient of Determination in this case, the adjusted R^2 will be used as shown in equation (12).

$$R^2 = 1 - (1 - R^2)\frac{(n-1)}{n-p-1} \qquad\qquad (12)$$

Where,

R^2 is the sample Coefficient of Determination

n is the sample size

p is the total number of independent variables or predictors in the regression model

The adjusted R^2 will adjust for the number of independent variables used in the hypotheses represented by the regression model. A need to compare two Coefficient of Determination, R^2, for statistically significant difference will also happen, however, one potential statistical problem that may arise during testing, particularly the second hypothesis using the regression model, is autocorrelation, i.e. high correlation between certain work categories. The study will then employ the method of hierarchical decomposition, which specifies and tests the order of variable inclusion in the regression model, to further scrutinize the impact of the independent variables.

3.3   Hypotheses

Stemming from the study objectives, two hypotheses will be tested, which were not previously explored by any published research. In presenting the research hypotheses, the following notations will be utilized throughout the study:

1. P   : Productivity.

2. E   : Effective Work Proportion.

3. Ep   : Effective Work Pace.

4. E.Ep : Weighted Pace Effective Work Category.

5. C   : Essential Contributory Work Proportion.

6. Cp   : Essential Contributory Work Pace.

7. C.Cp : Weighted Pace Essential Contributory Work category.

8. I   : Ineffective Work Proportion.

9. B   : Slope

The research hypotheses can then be stated as:

1. The predictive ability of work sampling will improve when work pace is included.

   Considering the workers' pace while performing effective work may result in better productivity predictability for the work sampling technique. The inclusion of workers' pace in this hypothesis will be done in two different ways. The first way can be represented mathematically as:

$$P = A + B_1 E + B_2 Ep + \varepsilon \qquad (13)$$

   While the second way can be represented mathematically as:

$$P = A + B_1 (E.Ep) + \varepsilon \qquad (14)$$

   Where,

   P is productivity, the dependent variable.

   E is effective work, an independent variable.

   Ep is effective work pace, an independent variable.

E.Ep is weighted pace effective work category, an independent variable.

A is constant.

B_1 is coefficient of variability of effective work, hypothesized to be positive and significant.

B_2 is coefficient of variability of effective work pace, hypothesized to be positive and significant.

ε is the error, a constant amount reflecting other factors influential to productivity.

Equation (14) will be considered as the main representation for the inclusion of pace in the first hypothesis, since it makes more sense to have the workers' pace integrated with the effective work category rather than separately include both variables. This hypothesis will be tested using the multiple regression model where three pairs of R^2 shall be considered for different work categories. The first pair is R^2 of:

$$P = A + B_1 E + \varepsilon \qquad (15)$$

Compared to R^2 of equation (14) above.

This study is designed to provide control over different examination or testing scenarios. The attained experimental data will allow representation of various results simulations. Of which, the second pair of R^2 will consider

incorporating the essential contributory work category into the hypothesis to verify its overall contribution to the work sampling ability and the productivity relationship. Hence, assessing its impact as:

$$P = A + B_1 E + B_2 C + \varepsilon \qquad (16)$$

Compared to the R^2:

$$P = A + B_1 (E.Ep) + B_2 (C.Cp) + \varepsilon \qquad (17)$$

Where,

C.Cp is weighted pace essential contributory work category, an independent variable.

B_1 is coefficient of variability of weighted pace effective work category, hypothesized to be positive and significant.

B_2 is coefficient of variability of weighted pace essential contributory work category, hypothesized to be positive and significant.

Similarly, the third pair of R^2 will consider including ineffective work category in addition to the workers' pace to evaluate its contribution to improve the

work sampling ability to predict construction labor productivity, where $(R^2_2 - R^2_1) >$ 0 or $R^2_2 > R^2_1$. The third pair of equations can be represented mathematically as:

$$P = A + B_1 E + B_2 C + B_3 I + \varepsilon \tag{18}$$

Compared to the R^2 of:

$$P = A + B_1 (E.Ep) + B_2 (C.Cp) + B_3 I + \varepsilon \tag{19}$$

Where,

B_3 is coefficient of variability of ineffective work category, hypothesized to be positive.

Any of the aforementioned R^2 pairs of the equations, will be compared to a reference R^2 of the equation which is a basic one of the workers' productivity excluding the explanatory independent variable(s) of a designated weighted pace work category, in order to measure the variation in the Coefficient of Determination R^2:

To operationalize the previous hypothesis, this means that the Coefficient of Determination for equations (14), (17) and (19), will be compared for statistically

significant difference, or variation, with the Coefficient of Determination for equations (15), (16) and (18). To further clarify, if the difference between compared Coefficients of Determination (R^2_2 - R^2_1) is found statistically significant, then the first hypothesis, null hypothesis, is true.

The second hypothesis this study will test is:

2. The predictive ability of work sampling will improve when more work categories are considered.

The study performed by Al-Ghamdi (1995) showed that there was a strong negative correlation between productivity and ineffective work, about -0.675 with a significance level of less than 0.005. It was found that the Coefficient of Correlation of ineffective work and productivity was greater than the Coefficient of Correlation of effective work and productivity when their absolute values were compared against each other. This result was found to be logical since the study of Al-Ghamdi (1995) found ineffective work a better predictor of productivity than effective work category. This was mainly because ineffective work certainly resulted in no productivity while effective work was not always fully productive. Although this hypothesis was partially tested by Al-Ghamdi using the Coefficient of Correlation, this study will utilize multiple regression model to make a more comprehensive assessment of all possible combinations of the independent variables, which are effective work, essential contributory work and ineffective work categories, in predicting productivity. Such variables can be represented mathematically in this hypothesis as previously represented by equations (15)

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and (14) as a first set of equations, where the R^2_1 of this set will be compared to the R^2_2 for the second set represented by equations (16) and (17), i.e. $R^2_2 > R^2_1$. Similarly, the third set of equations will involve comparing the R^2_3 of equations (18) and (19) to R^2_2 of the second set.

All previous sets of equations for the second hypothesis include evaluating the effect of workers' pace for improved productivity.

To further clarify the operationalization of the second hypothesis above, this means that the Coefficients of Determination for all the considered sets will be compared for statistically significant difference in each stage. If the differences between compared Coefficients of Determination $R^2_3 > R^2_2 > R^2_1$ are found statistically significant between the three sets including most of the work categories compared to ones with less work categories, then the second hypothesis, null hypothesis, is true. Similarly for the weighted pace work categories.

One potential statistical problem that may arise during testing the second hypothesis using multiple regression model is autocorrelation since effective work and ineffective work are highly correlated. This concern will be ruled out using either the standard regression or hierarchal regression methodologies to distinctly distinguish relative contribution of each variable considered in the hypothesis.

3.4   Study Design

The study methodology is based on field experiments that were conducted by Al-

Ghamdi (1995) in his study thesis. Twenty eight of the 35 filmed field experiments, recorded by Al-Ghamdi (1995), of constructing block walls are utilized. The remaining seven experiments were excluded from this study because they involved low skill workers, which is a variable of no interest to this study. In fact, excluding these low skill workers eliminate the variation in the skill level and thus provides a better experimental control over this variable, which enhances the reliability of this study.

Though the filmed field experiments were already done, the entire data extracted from these films, used for this study, are original. The filmed field experiments offer credible data, provides full control on such data, specifically the pace is accurately rated, in addition to reliable and precise means to better achieve this study objectives. The twenty eight field experiments were made by conducting seven experiments for 4 different sets of groups of different influencing variables according to TABLE 2.

TABLE 2 Distribution of Field Experiments

Group Number	Crew Size (Men)	Complexity Level	Skill Level	Number of Experiments
1	2	Simple	High	7
2	2	Moderate	High	7
3	2	High	High	7
4	4	Simple	High	7

For every experiment, the observations, including the workers' pace, are sampled randomly and labeled according to different work sampling categories consistent with this study objectives. The availability of an adequate sample size is considered crucial for a better model representation. The minimum sample size for sampling construction activities is 384 observations with 95% confidence level and an error of 5% (Oglesby et al., 1989). However, since this study considers more than two work categories, Thompson multinomial distribution sample size is more appropriate to use for this study (Gouett et al., 2011). Therefore, 510 observations per experiment are used mainly for better representation of population proportions and to offer further accurate results. This sample size is used with the same confidence level of 95% and an error of 5%.

The implementation of Thompson's sample size results in a total number of 35700 observations for the entire study. This is due to the fact that all crew members per experiment had been observed. This means that there are 510 observations per crew member shown in TABLE 2. The initial work sampling observations taken are also repeated twice, over the course of this study, to ascertain the reliability of the workers' pace ratings. In different occasions, these observations have also been repeatedly ascertained mainly for the verification of the recorded activity types in the field experiments. Therefore, the recorded observations maintains very high degree of reliability and accuracy.

Since labor productivity relies mainly on workers in addition to productivity determinants such as the duration and the intensity of workers' effort, it is thus logical to expect workers' pace to affect their productivity. In order to rate the worker's pace, the average velocity or speed for a body part is not the appropriate component to use for the

rating as the pace rate definition implies. Rather the rate of movement at the beginning of the activity and the rate of deceleration at the end of movement. It is then important to make a referenced average pace rating.

Among the several ways to set a reference pace rating stated previously, this study focuses on the crew for setting its own average pace reference. To further explain, the crew can set its own average pace by performing the usual activities at hand in a normal way without external influences. The observer then records this crew performance as an average pace reference. The selection of average pace reference for the crew performance was carefully established through random but purposive viewing of several field experiments periods in the films that meets carefully designed conditions for this study. Among which, the selected pace reference shall first reflect workers' performing work activities in an averaged condition. Second, shall include the highest number of different crew work activities that can be attained from a reference film, to set pace rate for. Finally, incorporates repetitive or cyclic operations execution for different work activities to consider as a reference pace. Therefore, the best reference period that is found representative of the crew average performance is chosen from the first field experiment. The reference crew performance is of seven minutes and nine seconds period and is allocated between the time period of 65:45 to 72:54.

Figure 3 illustrates a standard example of the crew performing one of the field experiments constructing a block wall. The crew demonstrates working in a typical way with no external interference or influence.

Figure 3 Working Crew Pace and Performance Example

The study design also considers sound and detailed assumptions to accurately calculate the pace rate. Such assumptions include the wall dimensions 3.2m X 1.4m, block dimensions (20cm X 20cm X 40cm) and average stride length of about 68cm. These elements will be explored in greater details later in chapter four.

3.4.1 Observation Categories

The basic concept of work sampling is to categorize random observations of work captured at different instances of time into certain activities or tasks, calculate their percentages or proportions, and based on these percentages and or proportions the labor utilization and or effectiveness can be determined. Regardless of the approach used to collect the sampling data, the prediction of the sampled data accuracy will heavily depend on the way the observations are made and categorized (Oglesby et al., 1989). The observations made have to be grouped or classified in a certain systematic way. Categorization of the observations is therefore critical for the success of sampling. As a result of categorizing the observations percentages or proportions, inferences about labor utilization or effectiveness can be drawn for the overall work activities under the study scope (Richardson, 1976).

As stated earlier, there is not a standard way of categorization for work sampling. Every study has its own categories depending on its objectives. Therefore, specific work sampling categories are developed for this study based on its objectives. The following major work categories are utilized to classify the observations in this study:

1. Effective Work.

2. Essential Contributory Work.

3. Ineffective Work.

The construction of the walls in this study 50 activities. These activities are classified into the above three major categories as shown in TABLE 3.

Activity Number	Activity Description	Activity Categorization
1	Assisting / helping to align the wall / or a concrete block	Contributory
2	Breaking a concrete block to the required size	Effective
3	Carrying materials	Contributory
4	Chatting	Ineffective
5	Chipping the edges of the concrete block	Effective
6	Filling wall voids with mortar	Effective
7	Finishing of the wall	Effective
8	Laying / positioning a concrete block on the wall	Effective
9	Leveling the mortar on the wall location	Effective
10	Lifting concrete blocks in preparations for moving them	Contributory
11	Lifting concrete blocks in preparations to position on the wall	Contributory
12	Lifting mortar bucket	Contributory
13	Listening to coworkers instructions	Contributory
14	Mixing / preparing mortar	Effective
15	Mixing mortar in the bucket	Contributory
16	Moving concrete blocks from the original location to the wall construction location	Effective
17	Moving mortar bucket from the mixing place to the wall construction location	Contributory
18	Moving the mortar bucket closer to work location	Contributory
19	Out of sight. (worker cannot be observed)	Ineffective
20	Performing horizontal wall alignment with a straight metal bar	Effective
21	Performing horizontal wall alignment with a string	Effective
22	Performing vertical wall alignment with a straight metal bar	Effective
23	Performing vertical wall alignment with a string.	Effective
24	Picking up a string for alignment	Contributory
25	Picking up tools such as alignment string, alignment metal bar, bucket or a shovel	Contributory

Activity Number	Activity Description	Activity Categorization
26	Preparing to lift a concrete block (leaning down towards the concrete block)	Contributory
27	Positioning a concrete block on the wall	Effective
28	Putting a tool in mortar bucket	Ineffective
29	Putting tools away from work location	Ineffective
30	Reloading Mortar from the bucket	Effective
31	Removing a concrete block from the wall	Effective
32	Repositioning a concrete block on the wall	Effective
33	Resting	Ineffective
34	Scraping the ground from excess mortar	Contributory
35	Scraping the wall from excess mortar	Contributory
36	Searching for a tool	Contributory
37	Spreading mortar on the concrete block / its location	Effective
38	Staying Idle (delaying or engaged in ineffective work)	Ineffective
39	Taking mortar from the bucket	Contributory
40	Travelling around the wall from wall construction location to perform an activity	Contributory
41	Travelling back around the wall to perform an activity	Contributory
42	Travelling back with a tool from the wall construction location	Contributory
43	Travelling empty handed (not performing any activity)	Ineffective
44	Travelling empty handed to perform an activity	Contributory
45	Travelling to the concrete blocks location	Contributory
46	Travelling with a tool to the wall construction location	Contributory
47	Travelling with mortar bucket from wall construction location to the mixing area	Contributory
48	Waiting	Ineffective
49	Watching	Ineffective
50	Wearing gloves	Contributory

3.4.1.1 <u>Effective Work Category</u>

The effective work category considered in this study under these field experiment films is defined as any activity that is deemed necessary to construct or build the block wall as designed and within specifications. Engaging in any active physical or mental activity was considered as performing effective work. Therefore, the work activities that qualified classifying the observations as working or performing effective work are classified to 17 activities according to TABLE 3 above.

3.4.1.2 <u>Essential Contributory Work Category</u>

Essential contributory work is defined as those activities that are performed to support construction of the field experiment block wall as designed and within specifications. Twenty four work activities qualified as essential contributory work category are identified in TABLE 3 above.

3.4.1.3 <u>Ineffective Work Category</u>

While ineffective work is defined as performing or involving in any activity that is not necessary nor related to the construction of the field experiment, block wall or support of it. Nine activities are classified as ineffective work summarized in TABLE 3.

3.4.2 Study Preparations

The study preparations are done well ahead of time. It involved several steps, of which some are lengthy. The first step involves conversion of the field experiments films, which were of the old Video Cassette Tapes, to a Compact Disc to be able to view the experiments in addition to ease of use and unavailability of a suitable Video Cassette

Recorder. The second step involves researcher acquaintance with the site conditions that appears in the filmed field experiments to identify how the crew is working, interacting and whether there are any associated abnormal conditions interfering with the actual work being performed or any unusual conditions that hinders taking the observations. Third, familiarization with the site and block wall dimensions in preparation to calculate the pace. Fourth, familiarization with the crew members and how they react towards the filming to identify any biased reaction jeopardizing the observations accuracy. Fifth, the identification of a suitable and appropriate reference film footage to rate the pace. Sixth, identification of each activity that is performed in the reference filmed field experiment in addition to its reference pace. Seventh, preparation of all activities pace tables. Eighth, development of a random time selection program instead of the lengthy and typical method utilizing random time tables. Ninth, actual assessment of the market for a pace rating software that may be available to help rate the pace of the workers' in a concise way for ease of use and reliable results. Finally, calculation of the pace for all the activities included under the scope of this study.

3.5   Influencing Variables

The influencing factor that the study will primarily consider is pace. Effect of this influencing variable on the predictive ability of the work sampling is statistically tested. Other factors such as constructed wall type, its complexity level, the crew skill level and its size are not to be investigated for the following reason:

1. The work activities involved in constructing the different types of walls are

basically similar. Therefore, the complexity level is also similar.

2. The skill level is expected to influence productivity but this study controls this variable by considering only one skill level. Consequently, this study excludes the seven experiments involving different skill levels and focuses on 28 field experiments involving same skill level for better experimental control over the results.

3. As for the crew size, four workers are not practically too many to cause congestion or interference, therefore it is not considered as an influencing variable. This observation is consistent with the conclusion made by Al-Ghamdi (1995) that in his experiments the crew size did not affect the productivity relationships, hence is not influential to this study.

3.6   Data Collection

Data collection involves primarily three tasks, selecting random observation times, categorizing sampled activities into work categories and rating the pace of the work activities.

3.6.1 Selecting Random Observation Times

One of the important work sampling rules is to record the observations randomly. The data is collected randomly from the field experiments films. In order to guarantee random selectivity, the use of Microsoft Office Excel Program is employed. Distinctively, the use of the analysis Microsoft Excel's ToolPak Program package to perform complex

data analysis, to generate random timings from a certain population, is specifically developed for this study. The tool uses appropriate statistical and engineering macro functions together with the statistical function "Rand between ( )" available in Excel to calculate and display the results in an output table. The essential parameters required to generate random timings for this study are the experiment duration, the time format and determining the number of the sample size required. These parameters per field experiment require to be entered in the developed Excel Program. Then, the Random Number Generation Analysis Tool deliver independent random timings that are drawn from one of several distributions. A problem is noticed to occur with this method every time this tool is used, which is duplications or repetition of the generated random timings in every experiment table. In order to ensure eliminating duplications of the generated random timings from the offered results, the use of Visual Basic Programming Language Functions, including user-defined arrays written for Excel, is applied. The program is then tested several times with different possibilities and the required sample size with unique observational results are generated without duplications. The duplications of the randomly generated timings before noticing the repetition pattern consumed huge amount of time while recording or viewing the sampled observations. This is why it was important to eliminate such duplications.

In so doing, the generation of random timings tables to have the observations recorded is performed promptly allowing more focus to the observations rather than generating traditional time tables or being concerned to consume unnecessary time.

Although the design of this random timing Excel Program is difficult, it is provided with a user friendly interface that allows entry of the required data easily. This interface in

the Excel Program depends mainly on both the duration of the field experiments and the time format. The duration of the field experiments is entered in the duration field in the program to generate a predetermined set of possible random timings in a stopwatch format, particularly 510 unique observations for this study. Therefore, for each specific field experiment, there are completely unique and randomly generated observation timings. It may be worth to mention that the randomly generated timings in this study are very close, i.e. seconds away between times. This fact is attributed to the large sample size required under this study that exceeds the overall field experiments durations in minutes. Therefore, to represent the proper population proportion, randomly generated timings that were seconds away from each are provided. Figure 4 shows the Excel Program used in this study, while a sample of the randomly generated times are shown in TABLE 4.
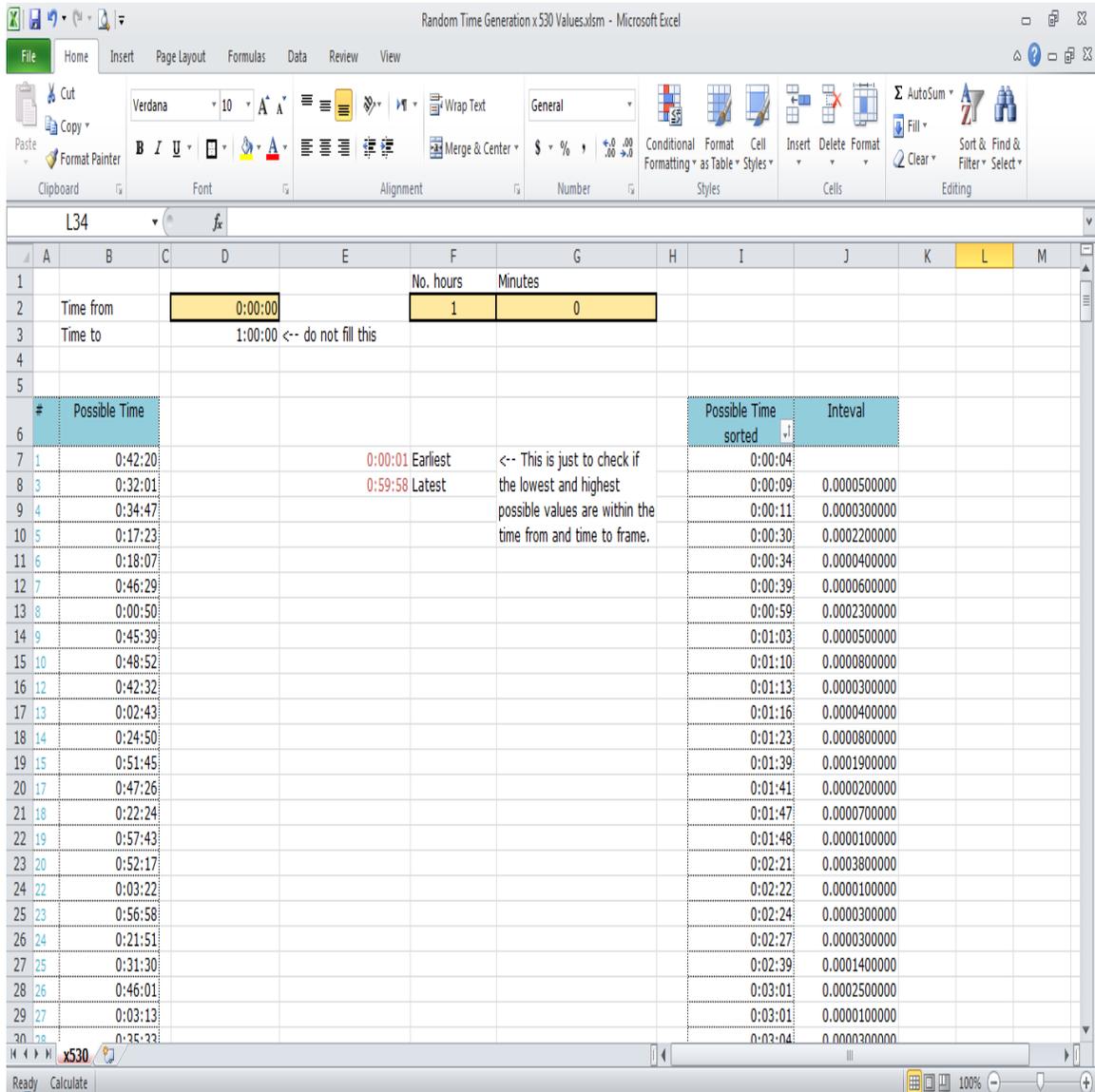
Figure 4 Excel Random Time Generator Program

TABLE 4 Generated Random Timings

S.N.	Random Observation Time HH:MM:SS
1	0:00:51
2	0:03:24
3	0:03:58
4	0:04:11
5	0:04:21
6	0:04:29
7	0:04:32
8	0:05:27
9	0:05:36
10	0:06:12
11	0:07:02
12	0:07:53
13	0:08:00
14	0:08:42
15	0:08:50

3.6.2 Categorization of Work Activities

Work activities are categorized as described in Section 3.4.1. To ascertain the accuracy of the categorization, it has been extensively repeated and verified during documenting and recording all the observations.

3.6.3 Rating The Pace of Work Activities

In addition to classifying the sampled work activities into the three major categories described in Section 3.4.1, pace related categories is specifically developed and used in this study in order to assess and categorize the worker's pace at the instance the observations are recorded. These categories are slow pace, average (normal) pace and fast pace.

To determine a pace rate for the sampled work activities, a reference or average pace rate is first established. Using this as a reference, the pace rate of all sampled work activities are rated. Detailed approach to determine the average pace rate is described below:

3.6.3.1 Determining Average Pace Rate

As previously mentioned, a film footage of about seven minutes duration to represent a worker average pace is selected, this section of the film footage is considered the reference standard for the average normal pace for all the field experiments in the entire study. The reference standard section of the film footage is chosen through purposive selection, i.e. by watching several experiments to reflect an average pace performance for the workers that contain as many work activities under the scope of this study as possible. The selection of the reference film footage excludes the first and last fifteen minutes of the

film to eliminate any typical performance issues associated to starting or finishing of the task. The way the pace rate is set is by the working crew itself utilizing its own normal pace where the researcher monitors a duration of the film footage that is representative of the average workers performance.

Although the use of motion analysis softwares to rate the pace for the workers in the field experiments films is considered an option, however, a proper software could not be found for this kind of analysis due to several reasons. The majority of time or motion analysis softwares are designated for either sports or medical use. In addition, such softwares require licensing and are very expensive to use for such a study. Another reason why such softwares are not adopted in this study, is that those are difficult to incorporate in the specifically recoded field experiments compact disc player format. Finally, the extent of detailed time and motion analysis required for this study is exhaustive and as a result is difficult to find a software that combines and simulates such details. Additionally, there are no complex mathematical formulas involved in this study to measure, calculate or rate the pace.

This study mainly depends on time and distance dimensions, measured by carefully detailed approximations, to determine the "pace" using equation (20):

$$Speed = \left[\frac{Movement\ Distance}{Time}\right] \tag{20}$$

The movement distance was used in equation (20) instead of the generic distance

term to specifically refer to the work activities that do not involve travel.

These speed or "pace" calculations are performed for every observed activity in this study and are used as references for all other repeatedly iterated activities in all the field experiments. The pace is set as such and does not follow time and motion studies approach either.

The controlled approximations or assumptions that are associated with the calculation of pace of workers are summarized hereafter:

1. Specifying a standard step length for a worker. The American College of Sports Medicine reports that there are approximately two thousand steps in one mile, approximately 1.6km, (American College of Sports and Medicine, 2013). Therefore, the average step length is about 2.6 feet or about thirty one inches, which is around 78.74cm. This means that for an average person, the approximate distance between the initial point of contacts of left and right heels is about 78.74cm. For convenience and ease of reference, the researcher utilizes an approximations based on an average step length of about 68cm as a conservative number. This approximation is commonly used in different walking, sports and medical programs.

2. Determining the duration required to conduct each activity. For every observed activity in the field experiments, the duration to perform this activity is monitored several times on different occasions in the reference film footage until an average duration is concluded for each activity.

3. Utilizing the concrete block and block wall dimensions for calculating the

distances required to measure the pace. To further explain, the wall dimensions used in Al-Ghamdi (1995) study are considered, where the dimensions are used as the distance or movement measurements in addition to the time consumed for the activities, both of which are necessary to calculate a workers' pace. Figure 5 reveals the details of one type of the block walls dimensions, which is similar in dimensions to the others two wall types.
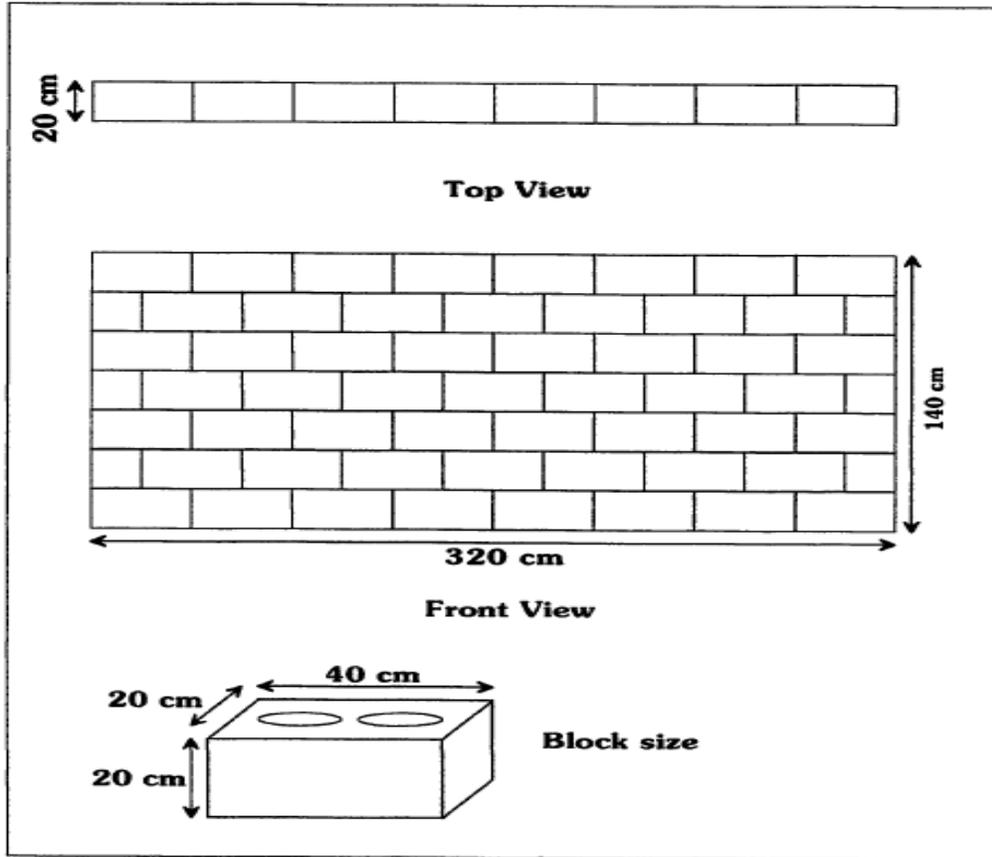
Figure 5 Concrete Wall Overall Dimensions

Therefore, for each observed activity in the reference film footage a detailed second by second time motion analysis has been conducted in order to provide a concise approach for the identification of the sampled observation categories, the calculation of the pace rate and the rating of the pace. Figure 6 shows a sample of the aggregate timings of groups of observed activities for the first six minutes period of the reference film, noting that the timing for each element within the shown groups of activities was also recorded.
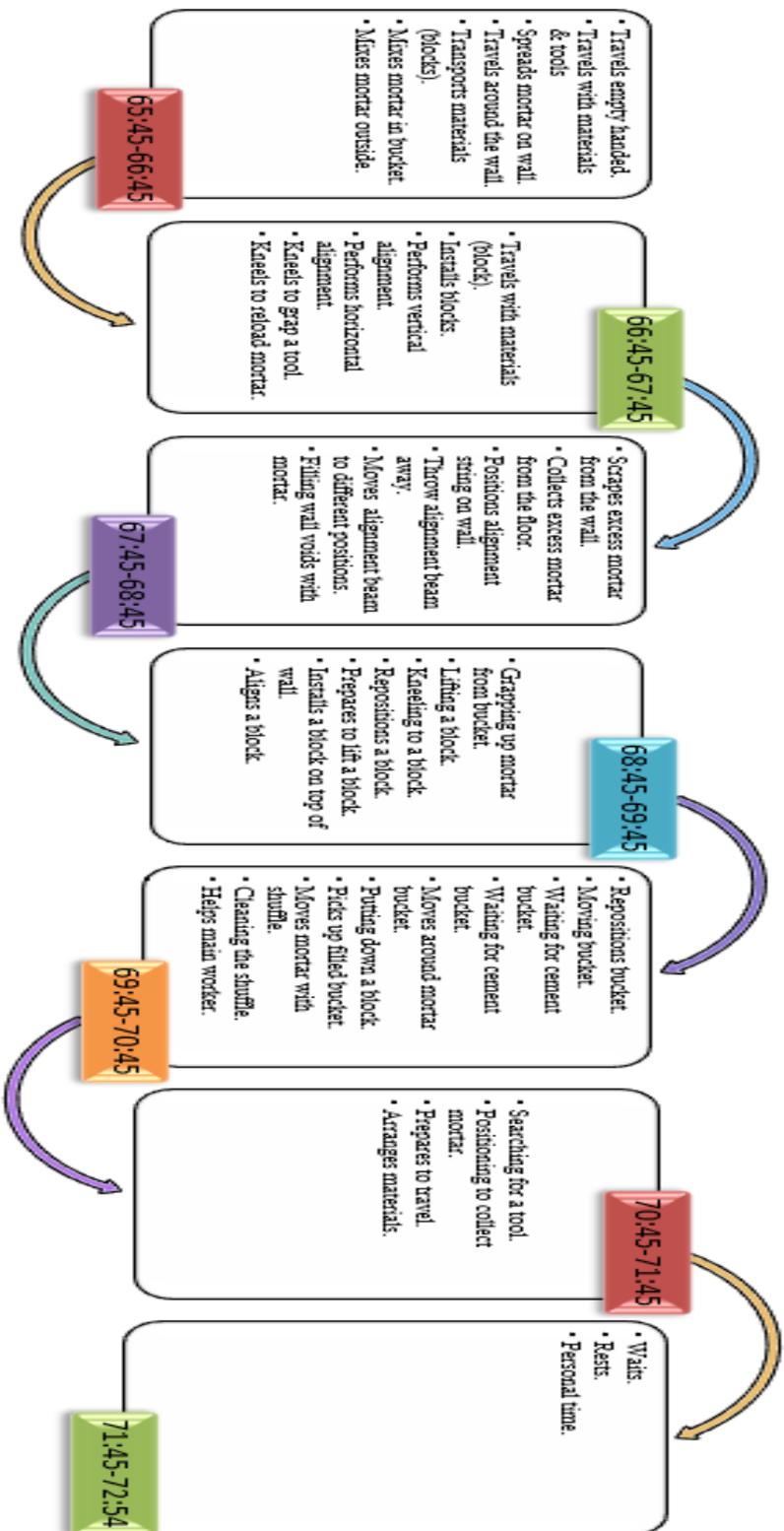
Figure 6 Identified Reference Sampled Activities From The reference Field Experiment

65:45-66:45
- Travels empty handed.
- Travels with materials & tools
- Spreads mortar on wall.
- Travels around the wall.
- Transports materials (blocks).
- Mixes mortar in bucket.
- Mixes mortar outside.

66:45-67:45
- Travels with materials (block).
- Installs blocks.
- Performs vertical alignment.
- Performs horizontal alignment.
- Kneels to grap a tool.
- Kneels to reload mortar.

67:45-68:45
- Scrapes excess mortar from the wall.
- Collects excess mortar from the floor.
- Positions alignment string on wall.
- Throw alignment beam away.
- Moves alignment beam to different positions.
- Filling wall voids with mortar.

68:45-69:45
- Grapping up mortar from bucket.
- Lifting a block.
- Kneeling to a block.
- Repositions a block.
- Prepares to lift a block.
- Installs a block on top of wall.
- Aligns a block.

69:45-70:45
- Repositions bucket.
- Moving bucket.
- Waiting for cement bucket.
- Moves around mortar bucket.
- Putting down a block.
- Picks up filled bucket.
- Moves mortar with shuffle.
- Cleaning the shuffle.
- Helps main worker.

70:45-71:45
- Searching for a tool.
- Positioning to collect mortar.
- Prepares to travel.
- Arranges materials.

71:45-72:54
- Waits.
- Rests.
- Personal time.

70

Furthermore, TABLE 5 and TABLE 6 are examples of average pace calculations for travelling and spreading mortar respectively. The calculation of the average pace of the remaining activities are in Appendix B. These established average paces are subsequently used to rate the pace of all sampled observations. TBALE 7 lists all the activities and their average reference pace rate.

TABLE 5 Determining Average Pace Rate for Traveling Speed (Empty Handed) By Laborer 1

	Traveled Distance (Meters)	Time (Seconds)	Pace Rate "Speed" (Meters/Second)
	0.6	1	0.6
	0.6	1	0.6
	2	2	1
	2.6	4	0.65
Total	2.6	4	0.65
Counts	2.6	4	0.65
	4.2	4	1.05
12	4.2	4	1.05
	4.2	5	1.125
	4.4	5	0.84
	4.5	4	0.88
	4.5	6	0.75
Total	37	44	9.845
Average	3.08	3.67	0.84

TABLE 6 Determining Average Pace Rate for Spreading Mortar on The Wall By Laborer 1

	Traveled Distance (Meters)	Time (Seconds)	Pace Rate "Speed" (Meters/Second)
	0.1	1	0.1
	0.1	1	0.1
	0.1	1	0.1
	0.2	1	0.2
	0.2	1	0.2
	0.2	1	0.2
	0.2	1	0.2
	0.2	1	0.2
	0.2	2	0.1
	0.2	2	0.1
Total Counts 24	0.2	2	0.1
	0.2	2	0.1
	0.2	2	0.1
	0.2	3	0.07
	0.2	3	0.07
	0.2	3	0.07
	0.2	4	0.05
	0.4	3	0.13
	0.4	3	0.13
	0.4	3	0.13
	0.4	3	0.13
	0.8	4	0.2
	0.8	5	0.16
	0.8	5	0.16
Total	7.1	57	3.1
Average	0.3	2.4	0.125

TABLE 7 Reference Pace Rating For All Work Activities

Activity Number	Reference Pace Rating	Activity Description
1	0.05 m/s	Aligning a concrete block on the wall
2	0.06 m/s	Assisting / helping to align the wall / or a concrete block
3	0.13 m/s	Breaking a concrete block to the required size
4	0.8 m/s	Carrying materials
5	15 s	Chatting
6	0.03 m/s	Chipping the edges of the concrete block
7	0.04 m/s	Filling wall voids with mortar
8	0.3 m/s	Finishing of the wall
9	0.2 m/s	Laying / positioning a concrete block on the wall
10	0.13 m/s	Leveling the mortar on the wall location
11	0.35 m/s	Lifting concrete blocks in preparations for moving them
12	0.4 m/s	Lifting concrete blocks in preparations to position on the wall
13	0.6 m/s	Lifting mortar bucket
14	9 s	Listening to coworkers instructions
15	0.03 m/s	Mixing / preparing mortar
16	0.06 m/s	Mixing mortar in the bucket
17	0.8 m/s	Moving concrete blocks from the original location to the wall construction location
18	0.8 m/s	Moving mortar bucket from the mixing place to the wall construction location
19	0.6 m/s	Moving the mortar bucket closer to work location
20	40 s	Out of sight. (worker cannot be observed)
21	0.07 m/s	Performing horizontal wall alignment with a straight metal bar
22	0.16 m/s	Performing horizontal wall alignment with a string
23	0.09 m/s	Performing vertical wall alignment with a straight metal bar
24	0.6 m/s	Performing vertical wall alignment with a string.
25	1 m/s	Picking up a string for alignment

Activity Number	Reference Pace Rating	Activity Description
26	0.8 m/s	Picking up tools such as alignment string, alignment metal bar, bucket or a shovel
27	0.2 m/s	Preparing to lift a concrete block (leaning down towards the concrete block)
28	0.2 m/s	Putting a tool in mortar bucket
29	0.33 m/s	Putting tools away from work location
30	1.1 m/s	Reloading Mortar from the bucket
31	0.13 m/s	Removing a concrete block from the wall
32	0.2 m/s	Repositioning a concrete block on the wall
33	0.06 m/s	Resting
34	0.13 m/s	Scraping the ground from excess mortar
35	0.3 m/s	Scraping the wall from excess mortar
36	0.3 m/s	Searching for a tool
37	0.13 m/s	Spreading mortar on the concrete block / its location
38	0.03 m/s	Staying Idle (delaying or engaged in ineffective work)
39	0.9 m/s	Taking mortar from the bucket
40	0.5 m/s	Travelling around the wall from wall construction location to perform an activity
41	0.5 m/s	Travelling back around the wall to perform an activity
42	0.5 m/s	Travelling back with a tool from the wall construction location
43	0.7 m/s	Travelling empty handed (not performing any activity)
44	0.8 m/s	Travelling empty handed to perform an activity
45	0.7 m/s	Travelling to the concrete blocks location
46	0.8 m/s	Travelling with a tool to the wall construction location
47	0.8 m/s	Travelling with mortar bucket from wall construction location to the mixing area
48	0.03 m/s	Waiting
49	0.03 m/s	Watching
50	0.1 m/s	Wearing gloves

3.6.3.2 <u>Determining Pace Rate of Sampled Activities</u>

For each sampling observation in the field experiment films, the researcher views closely and repeatedly one minute of duration before and after the observation is made to compare the pace to the normal or average pace established, as described in Section 3.5.3.1. The researcher then rates the observation as slow, average (normal) and fast pace.

In order to improve the reliability of the pace ratings, each rating is performed at least twice for each of the randomly selected timing. The second set of ratings is done after the first set of ratings, for the entire experiment, was completed. This is to ensure that the pace ratings were consistent. If the two pace rating of each observation are identical, then the rating is accepted and used. On the other hand, if two ratings of the same observation are different, then a third rating is done, after at least two days from the first rating. This is done again to compare the previous two ratings. The most frequent rating in that case is used. If in case all three ratings are different, then a fourth rating is done and the two identical ratings are used.

During the course of rating the observations, it is worth to mention that almost all the second ratings are found consistent with the first ratings. This is primarily attributed to the detailed approach described above in rating the observations. The number of rating errors noticed while the observations are taken was extremely low averaging two errors per experiment, which is less than 0.4% of the total sample size. The error in most cases is not related to the pace ratings, but to the activity being performed. To further explain, the error originating mainly from identifying a workers' certain orientation, at the time the activity is sampled because it is difficult to distinguish a workers' pose at the first instance. To give an example, if the worker is leaning or rising during a particular activity at a particular

instant of time. A second example of the error sources noticed while rating the activities, is if the worker is posing empty handed at a random particular timing, which means that the worker is either putting down or taking a tool in or from a certain location. A summary of the filmed field experiments details are summed up in TABLE 8.

TABLE 8 Filmed Field Experiments Details

Experiment Number	Wall Number	Experiment Starting Time	Experiment Duration (Hours)
1	1	8:32	1.600
2	2	10:38	1.142
3	3	13:08	1.103
4	4	14:37	0.923
5	5	7:16	1.105
6	6	8:46	0.973
7	7	10:18	0.885
8	8	12:37	1.404
9	9	14:34	1.088
10	10	7:32	1.295
11	11	9:10	1.332
12	12	10:59	1.279
13	13	12:50	1.367
14	14	7:19	1.291
15	15	9:05	1.588
16	16	11:33	1.471
17	17	13:20	1.454
18	18	7:27	1.441
19	19	9:25	1.504
20	20	12:04	1.540
21	21	14:11	1.334
22	22	7:27	1.383
23	23	9:07	0.883
24	24	10:19	0.914
25	25	11:20	0.817
26	26	12:46	0.923
27	27	13:54	0.645
28	28	14:46	0.529

The sampled observations collected from all the field experiments are then recorded in a work sampling form designed for this study objectives as in Figure 7.

Work Sampling Data Collection Form

Experiment Time Length		Tape/Experiment Number	7
Viewing Date*	21/08/2013	Referenced Tape Number	1
Verification Date**		Observer	Khalid S. Al-Najdi
Notes	*Experiment starting time:	· **Duration:	·

S.N.	Observation Time (HH:MM:SS)	Original Viewing and Verification Dates	Worker 1	Worker 2	Worker 3

Worker columns subdivided into: Fast, Slow, Same, Working, Delay, Travel, Tools & Equip., Materials, Transportation, Waiting, Personal Time

S.N.	Observation Time
1	10:18:07 AM
2	10:18:11 AM
3	10:18:14 AM
4	10:18:29 AM
5	10:18:38 AM
6	10:18:46 AM
7	10:18:48 AM
8	10:18:50 AM

Figure 7 Work Sampling Form

3.6.4 Five Minute Rating

The Five Minute rating technique data is collected by observing the effective work activities of the working crews in each of the field experiments to obtain their effectiveness as described by Oglesby et al. (1989). The selection of random timings is generated by the Excel Tool to observe the working crews. Then, the effective man minutes for the working crews for five minutes in every field experiment is observed. The crew effectiveness is then obtained for each field experiment using equation (21).

$$Effectiveness = \frac{Effective\ Man\ Minutes}{Total\ Man\ Minutes} \times 100 \qquad (21)$$

To assess the accuracy of Five Minute Rating, its resulting effectiveness is compared with the combined proportions of work sampling effective and essential contributory work categories. Since both effectiveness and work proportions are in terms of percentages, the comparison is done between these two sets of percentages in terms of their difference and correlation. If the difference between the two sets of percentages is found small and the correlation between the two sets is found strong, then the technique of Five Minute Rating will be considered accurate.

3.6.5 Assessment of The Labor Utilization Factor

Another investigation that can be assessed in relation to work sampling is the evaluation of the labor utilization factor weights represented by equation (22).

$$Labor\ Utilization\ Factor = \frac{Effective\ Work + {^1/_4}\ Essential\ Contributory\ Work}{Total\ Observed} \quad (22)$$

Where,

$$Total\ Observed = Effective\ Work + Essential\ Contributory\ Work +$$

$$Ineffective\ Work \quad\quad\quad (23)$$

This can be investigated by inspecting the standardized regression coefficients, B_1 and B_2, of the equations used in testing the hypotheses particularly equations (16) and (22). This is done in order to ascertain the weights used in equation (22) related to the accuracy of labor utilization, i.e. ascertain the ration of four to one.

Currently in the literature, the only weight found is the 25% related to the contributory work. However, it is found that a more realistic utilization is obtained when the 25% weight factor is removed because it is a very conservative weight factor (Oglesby et al., 1989). In addition, the investigation of introducing a more realistic factor or even removing it, is carried out by this study.

3.6.6 Head Count Rating

The accuracy of the Head Count technique relative to work sampling is examined using bivariate correlations. The researcher chooses random timings generated by the Excel

tool to rate the workers, excluding the start and end of every field experiment. The researcher then observes every worker in the crews for performing useful work. The Head Count Rating percentage is then calculated and compared with the work sampling effective and essential contributory work categories percentages to assess the accuracy of the technique. If the correlation between the two sets of percentages is found high and the difference between the two sets of percentages is small then, the technique is considered accurate.

3.7 Measurements of Variables

The variables involved in this study include productivity, effective work, essential contributory work, ineffective work and pace. The measurement of the pace rate, due to its uniqueness, was discussed in details in Section 3.6.3. The measurements of the other variables are described as follows:

$$P = \frac{Output}{Input} = \frac{Number\ of\ Wall\ Blocks}{Number\ of\ Men\ X\ Entire\ Duration\ to\ build\ entire\ wall} \qquad (24)$$

The effective work proportion, which is the independent variable (E), is calculated according to equation (25) below.

$$Effective\ Work\ Proportion = \frac{Number\ of\ Effective\ Work\ Observations}{Total\ Number\ of\ Observations} \qquad (25)$$

E_i (Effective Work Proportion) is the proportion of effective work category for wall (experiment) i.

For the effective work category, the average pace rating (Ep), for each wall or experiment, is calculated using equation (26) as follows:

$$Ep_i = \frac{3 \sum EF_i + 2 \sum EA_i + 1 \sum ES_i}{3 \sum EO_i} \tag{26}$$

Where,

Ep_i is pace of effective work proportion for wall i

EF_i is number of effective work observations rated as fast for wall i.

EA_i is number of effective work observations rated as average for wall i.

ES_i is number of effective work observations rated as slow for wall i.

EO_i is the total number of effective work observations for wall i.

Constants 1, 2 and 3 represent slow, average and fast pace rates.

While for the ineffective work proportion, which is the dependent variable (I), is calculated according to equation (27) stated below:

$$Ineffective\ Work\ Proportion\ = \frac{Number\ of\ Ineffective\ Work\ Observations}{Total\ Number\ of\ Observation} \quad (27)$$

I_i (Ineffective Work Proportion) is the proportion of ineffective work category for wall (experiment) i.

The ineffective work category does not have a pace rating.

The essential contributory work proportion, which is the independent variable (C), is also calculated using equation (28).

$$Essential\ Contributory\ Work\ Proportion =$$

$$\frac{Number\ of\ Essential\ Work\ Observations}{Total\ Number\ of\ Observations} \quad (28)$$

C_i (Essential Contributory Work) is the proportion of essential Contributory work category for wall (experiment) i.

For the essential contributory work category, the average pace rating (Cp), for each wall or experiment, is calculated using equation (29) as follows:

$$Cp_i = \frac{3\sum CF_i + 2\sum CA_i + 1\sum CS_i}{3\sum CO_i} \quad (29)$$

Where,

Cp_i is pace of essential contributory work proportion for wall i

CF_i is number of essential contributory work observations rated as fast for wall i.

CA_i is number of essential contributory work observations rated as average for wall i.

CS_i is number of essential contributory work observations rated as slow for wall i.

CO_i is the total number of essential contributory work observations for wall i.

Constants 1, 2 and 3 represent slow, average and fast pace rates.

It is important to mention that in equations (26) and (29), the constants of 1, 2 and 3 used for the three pace rates are in an ordinal scale. The use of ordinal scale is the only sure way to represent these three rates logically. The two other higher level scales, i.e. interval and ratio scales require to show equal distances between measures (in the case of interval scale), or even meaningful ratios between the measures (in the case of ratio scale). Both of these measurements properties cannot be ascertained the way the pace is estimated in this study. Although it is true that the use of an ordinal scale vis-a-vis interval or ratio scale may attenuate the true correlation, the impact of pace in an ordinal scale can be still captured.

Furthermore, equations (26) and (29) calculate the pace of a particular work category as the ratio of pace weighted observations of that work category to the total observations of the work category but assuming all were fast pace.

To illustrate the calculations of the above variables, the following example is for wall or experiment 15:

TABLE 9 Collection Data for Wall (Experiment) 15

Work Category	Pace Rate	Worker's Number		Total	Work Category Proportion %
		Worker #1	Worker #2		
Effective Work	F	77	34	111	47.5
	A	39	7	46	
	S	238	90	328	
	Total	**354**	**131**	**485**	
Essential Contributory Work	F	32	64	96	26.4
	A	39	32	71	
	S	76	26	102	
	Total	**147**	**122**	**269**	
Ineffective Work	**Total**	**9**	**257**	**266**	26.1
Total	**Total**	**510**	**510**	**1020**	**100**

E_{15} : Effective work proportion (substitute in equation (25)):

$$E_{15} = \frac{485}{1020} = 0.475 = 47.5\%$$

C_{15} : Essential contributory work proportion (substitute in equation (28)):

$$C_{15} = \frac{269}{1020} = 0.264 = 26.4\%$$

I_{15} : Ineffective work proportion (substitute in equation (27)):

$$I_{15} = \frac{266}{1020} = 0.261 = 26.1\%$$

Ep_{15} : Effective work proportion average pace rating (substitute in equation (26)):

$$Ep_{15} = \frac{(3X111)+(2X46)+(1X328)}{3\ X\ 485} = \frac{753}{1455} = 0.52$$

Cp_{15} : Essential contributory work proportion average pace rating (substitute in

equation (29)):

$$Cp_{15} = \frac{(3X96)+(2X71)+(1X102)}{3\ X\ 269} = \frac{532}{807} = 0.66$$

To further elaborate, the way the pace rate is obtained, or rated, is that after rating of all the study observations, every pace rating within the major study categories is the multiplied by its weight corresponding to an ordinal scale to statistically quantify its rating, categorize pace ratings and measure the degree of its variability. The total is then divided by the total number of observations multiplied by the best scale rating, which is three for the fast pace. The ordinal scale is chosen for its simplicity compared to other types of data measurement scales. The ordinal scale weight values assigned for the pace ratings in this

study are one for slow pace, two for average or normal pace and three for fast pace.

The resulting calculations and the regression model of all the variables which will be used in testing the hypotheses of this study are presented in TABLE 10 below:

TABLE 10 Overall Regression Model And Study Data Summary

Total Number of Observations	Wall No.	Productivity (Blocks/Man-Hours)	Effective Work Proportion (E)	Effective Work Pace Ratings			Effective Work Average Pace (Ep)	Essential Contributory Work Proportion (C)	Essential Contributory Work Pace Ratings			Essential Contributory Work Average Pace (Cp)	Ineffective Work Proportion (I)	Pace Weighted Effective Work (E.Ep)	Pace Weighted Essential Contributory Work (C.Cp)
				S	A	F			S	A	F				
1020	1	17.5	0.412	284	40	96	0.5175	0.294	110	64	126	0.6844	0.294	0.2132	0.2012
1020	2	24.5	0.494	302	80	122	0.5476	0.226	139	50	42	0.5267	0.280	0.2705	0.1190
1020	3	25.4	0.461	300	46	124	0.5418	0.239	156	46	42	0.5109	0.300	0.2498	0.1221
1020	4	30.3	0.479	314	48	127	0.5392	0.251	144	40	52	0.5367	0.289	0.2583	0.1240
1020	5	25.3	0.470	298	57	124	0.5456	0.255	132	45	83	0.6038	0.275	0.2564	0.1540
1020	6	28.8	0.494	305	73	126	0.5483	0.209	142	48	23	0.4804	0.297	0.2709	0.1004
1020	7	31.6	0.464	318	43	112	0.5215	0.269	136	56	82	0.6010	0.268	0.2420	0.1617
1020	8	22.4	0.447	299	41	116	0.5329	0.251	143	39	74	0.5768	0.302	0.2382	0.1448
1020	9	29	0.511	331	71	119	0.5310	0.225	102	58	69	0.6186	0.265	0.2714	0.1392
1020	10	24.3	0.477	324	47	116	0.5243	0.241	121	64	61	0.5854	0.281	0.2501	0.1411
1020	11	23.6	0.466	317	42	116	0.5256	0.283	147	52	90	0.6009	0.251	0.2449	0.1701
1020	12	24.6	0.483	294	81	118	0.5477	0.254	126	38	95	0.6268	0.263	0.2645	0.1592
1020	13	23	0.501	324	76	111	0.5277	0.218	124	49	49	0.5541	0.281	0.2644	0.1208
1020	14	24.4	0.469	297	51	130	0.5502	0.236	111	67	63	0.6003	0.295	0.2580	0.1417
1020	15	22	0.475	328	46	111	0.5175	0.264	102	71	96	0.6592	0.261	0.2458	0.1740
1020	16	23.8	0.498	328	78	102	0.5184	0.232	145	65	27	0.5007	0.270	0.2581	0.1162
1020	17	24.1	0.437	286	43	117	0.5404	0.272	136	68	73	0.5909	0.291	0.2361	0.1607
1020	18	24.3	0.441	295	42	113	0.5319	0.270	117	80	78	0.6194	0.289	0.2345	0.1672
1020	19	23.3	0.489	319	47	133	0.5424	0.249	153	51	50	0.5315	0.262	0.2652	0.1323
1020	20	22.7	0.495	312	56	137	0.5512	0.239	148	44	52	0.5355	0.266	0.2728	0.1280
1020	21	26.2	0.492	319	61	122	0.5359	0.257	139	51	72	0.5814	0.251	0.2636	0.1494
2040	22	10.1	0.415	576	107	164	0.5045	0.274	352	109	98	0.5152	0.311	0.2094	0.1412
2040	23	15.8	0.421	541	123	195	0.5324	0.247	315	92	97	0.5225	0.332	0.2241	0.1291
2040	24	15.3	0.412	527	114	199	0.5365	0.268	331	132	84	0.5161	0.320	0.2210	0.1383
2040	25	17.1	0.433	562	98	223	0.5387	0.257	303	120	102	0.5390	0.310	0.2333	0.1385
2040	26	15.2	0.428	509	105	259	0.5712	0.266	326	119	98	0.5267	0.306	0.2445	0.1401
2040	27	21.7	0.410	538	129	169	0.5195	0.309	336	143	152	0.5695	0.281	0.2130	0.1760
2040	28	26.5	0.427	584	77	210	0.5235	0.297	341	147	118	0.5440	0.276	0.2235	0.1616

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3.8   Methods of Analysis

3.8.1   Regression Analysis Method

Multiple regression is a powerful technique. The purpose of using multiple regression is to study the relationship between a criterion, called the dependent variable, and several other independent variables, alternatively called predictor variables and their contribution to the relationship.

In this study, regression analysis is used to evaluate the effect of workers' pace as an additional predictor variable of work sampling productivity. Specifically, it involves a comparison of several Coefficients of Determination "R^2" for statistical variations to conclude inferences. This is explained in greater details in Section 3.2. The regression variables and values are those listed in TABLE 10.

3.8.2   Regression Analysis Software

Microsoft Office Excel Regression Data Analysis Package is used as the primary regression software for this study. Excel has been long used as a powerful and proven regression tool by the statisticians' community mainly due to its simplicity and availability.

3.8.3   Relationship Between Productivity And Observed Work Sampling Categories

As mentioned previously, the study investigates "R^2", the Coefficient of Determination as a result of multiple regression analysis detailed in Sections 3.2 and 3.3 to

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determine the relationship between productivity and the work sampling categories predictors including the pace. The results of testing the hypotheses of this study are presented in details in Chapter Four.

3.8.4 Experimental Control

This study is designed in a way to specifically test each hypothesis and conclude an inference because of the carefully chosen work sampling observed categories, the independent variables. This resulted in an increased, level of experiment control over the data acquired for the independent variables. The experimental control referred to in this study is controlling other variables which are not relevant to it. This was done in this study by keeping these variables fixed such as the skill level, the complexity of design level, variation quality, work environment, and reaction to observations.

3.8.5 Statistical Control

Using regression in hypotheses testing, potential statistical autocorrelation maybe present. This is additionally investigated by this study through the hierarchical decomposition technique. This technique tests the order of variable inclusion, to further scrutinize the correlation between the variables. This test is theoretically evaluated by the F ratio, F distribution test according to the following equations for the case of three independent variables (Kim and Kohout, 1975):

$$F = \frac{r_{y1}^2 / 1}{(1 - R_{y.12,\ldots k}^2)/(N-k-1)} \qquad (30)$$

$$F = \frac{r_{y(2.1)}^2 / 1}{(1 - R_{y.12,\ldots k}^2)/(N-k-1)} \qquad (31)$$

$$F = \frac{r_{y(3.12)}^2 / 1}{(1 - R_{y.12,\ldots k}^2)/(N-k-1)} \qquad (32)$$

Where,

r^2 is the Coefficient of Determination, bivariate correlation.

R^2 is the Coefficient of Determination, multiple correlation.

N is the sample size.

N-k is degree of freedom.

k is number of independent variables.

This test is also done even if autocorrelation is not present. It is done in order to find out the contribution of an independent variable while controlling, keeping constant, the effect of other independent variables. The results are presented in Chapter Four in greater details.

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CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter starts by providing an overview of the variables used in this study in terms of their descriptive statistics. This is followed by presenting the results of testing the two hypotheses stated in this study. For each of these hypotheses, a discussion of the results is provided. Additionally, this chapter presents and discusses the results emanating from investigating the relative weights of work categories and the relative accuracy of the Five Minute Rating and Head Count techniques.

4.1   Descriptive Statistics

4.1.1   Productivity (P) - The Dependent Variable

Equation (24) is used to calculate labor productivity, P, in this study. Productivity calculations depend mainly on the entire duration of each field experiment, its crew size and their physical output in terms of the number of blocks used to construct the wall. The resultant productivity calculations are presented in TABLE 11 below.

TABLE 11 Productivity Results of the Field Experiments

Field Experiment or Wall Number	Number of Blocks	Crew Size (Men)	Experiment Duration (Hours)	Productivity (P) (Blocks/Man-hour)
1	56	2	1.600	17.5
2	56	2	1.142	24.5
3	56	2	1.103	25.4
4	56	2	0.923	30.3
5	56	2	1.105	25.3
6	56	2	0.973	28.8
7	56	2	0.885	31.6
8	63	2	1.404	22.4
9	63	2	1.088	29
10	63	2	1.295	24.3
11	63	2	1.332	23.6
12	63	2	1.279	24.6
13	63	2	1.367	23
14	63	2	1.291	24.4
15	70	2	1.588	22
16	70	2	1.471	23.8
17	70	2	1.454	24.1
18	70	2	1.441	24.3
19	70	2	1.504	23.3
20	70	2	1.540	22.7
21	70	2	1.334	26.2
22	56	4	1.383	10.1
23	56	4	0.883	15.8
24	56	4	0.914	15.3
25	56	4	0.817	17.1
26	56	4	0.923	15.2
27	56	4	0.645	21.7
28	56	4	0.529	26.5

TABLE 11 shows that the field experiments labor productivity ranges from 10.1 blocks/man-hour to 31.6 blocks/man-hour with a mean and a standard deviation of 22.96 and 4.9 blocks/man-hour respectively.

4.1.2 Work Categories And Pace - The Independent Variables

This study involves evaluating several independent variables in the multiple regression model. These include:

1. E   : Proportion of Effective Work Category.

2. C   : Proportion of Essential Contributory Work Category.

3. I   : Proportion of Ineffective Work Category.

4. Ep   : Pace Effective Work Category.

5. Cp   : Pace Essential Contributory Work Category.

6. E.Ep : Weighted Pace Effective Work category.

7. C.Cp: Weighted Pace Essential Contributory Work Category.

The values of the above variables along with their averages and standard deviations are presented in TABLE 12.

TABLE 12 Data Summary of All Variables

Total Number of Observations	Wall No.	Productivity (Blocks/Man-Hours)	Effective Work Proportion (E)	Effective Work Pace Ratings			Total (E)	Effective Work Average Pace (Ep)	Essential Contributory Work Proportion (C)	Essential Contributory Work Pace Ratings			Total (C)	Essential Contributory Work Average Pace (Cp)	Total (I)	Ineffective Work Proportion (I)	Pace Weighted Effective Work (E.Ep)	Pace Weighted Essential Contributory Work (C.Cp)
				S	A	F				S	A	F						
1020	1	17.5	0.412	284	40	96	420	0.5175	0.294	110	64	126	300	0.6844	300	0.294	0.2132	0.2012
1020	2	24.5	0.494	302	80	122	504	0.5476	0.226	139	50	42	231	0.5267	285	0.280	0.2705	0.1190
1020	3	25.4	0.461	300	46	124	470	0.5418	0.239	156	46	42	244	0.5109	306	0.300	0.2498	0.1221
1020	4	30.3	0.479	314	48	127	489	0.5392	0.251	144	40	52	236	0.5367	295	0.289	0.2583	0.1240
1020	5	25.3	0.470	298	57	124	479	0.5456	0.255	132	45	83	260	0.6038	281	0.275	0.2564	0.1540
1020	6	28.8	0.494	305	73	126	504	0.5483	0.209	142	48	23	213	0.4804	303	0.297	0.2709	0.1004
1020	7	31.6	0.464	318	43	112	473	0.5215	0.269	136	56	82	274	0.6010	273	0.268	0.2420	0.1617
1020	8	22.4	0.447	299	41	116	456	0.5329	0.251	143	39	74	256	0.5768	308	0.302	0.2382	0.1448
1020	9	29	0.511	331	71	119	521	0.5310	0.225	102	58	69	229	0.6186	270	0.265	0.2714	0.1392
1020	10	24.3	0.477	324	47	116	487	0.5243	0.241	121	64	61	246	0.5854	287	0.281	0.2501	0.1411
1020	11	23.6	0.466	317	42	116	475	0.5256	0.283	147	52	90	289	0.6009	256	0.251	0.2449	0.1701
1020	12	24.6	0.483	294	81	118	493	0.5477	0.254	126	38	95	259	0.6268	268	0.263	0.2645	0.1592
1020	13	23	0.501	324	76	111	511	0.5277	0.218	124	49	49	222	0.5541	287	0.281	0.2644	0.1208
1020	14	24.4	0.469	297	51	130	478	0.5502	0.236	111	67	63	241	0.6003	301	0.295	0.2580	0.1417
1020	15	22	0.475	328	46	111	485	0.5175	0.264	102	71	96	269	0.6592	266	0.261	0.2458	0.1740
1020	16	23.8	0.498	328	78	102	508	0.5184	0.232	145	65	27	237	0.5007	275	0.270	0.2581	0.1162
1020	17	24.1	0.437	286	43	117	446	0.5404	0.272	136	68	73	277	0.5909	297	0.291	0.2361	0.1607
1020	18	24.3	0.441	295	42	113	450	0.5319	0.270	117	80	78	275	0.6194	295	0.289	0.2345	0.1672
1020	19	23.3	0.489	319	47	133	499	0.5424	0.249	153	51	50	254	0.5315	267	0.262	0.2652	0.1323
1020	20	22.7	0.495	312	56	137	505	0.5512	0.239	148	44	52	244	0.5355	271	0.266	0.2728	0.1280
1020	21	26.2	0.492	319	61	122	502	0.5359	0.257	139	51	72	262	0.5814	256	0.251	0.2636	0.1494
2040	22	10.1	0.415	576	107	164	847	0.5045	0.274	352	109	98	559	0.5152	634	0.311	0.2094	0.1412
2040	23	15.8	0.421	541	123	195	859	0.5324	0.247	315	92	97	504	0.5225	677	0.332	0.2241	0.1291
2040	24	15.3	0.412	527	114	199	840	0.5365	0.268	331	132	84	547	0.5161	653	0.320	0.2210	0.1383
2040	25	17.1	0.433	562	98	223	883	0.5387	0.257	303	120	102	525	0.5390	632	0.310	0.2333	0.1385
2040	26	15.2	0.428	509	105	259	873	0.5712	0.266	326	119	98	543	0.5267	624	0.306	0.2445	0.1401
2040	27	21.7	0.410	538	129	169	836	0.5195	0.309	336	143	152	631	0.5695	573	0.281	0.2130	0.1760
2040	28	26.5	0.427	584	77	210	871	0.5235	0.297	341	147	118	606	0.5440	563	0.276	0.2235	0.1616
Average		22.957	0.461	368.96	68.643	139.679	577.286	0.534	0.255	181.321	71.714	76.714	329.750	0.566	367.964	0.285	0.246	0.145
Average Deviation		3.555	0.028	89.589	22.832	31.518	140.571	0.011	0.019	73.911	26.306	23.214	114.768	0.042	127.161	0.017	0.016	0.017
Standard Deviation		4.904	0.032	106.832	27.353	40.965	166.909	0.014	0.024	88.377	33.116	29.672	137.931	0.050	151.436	0.021	0.019	0.022

4.1.3 Discussion of The Descriptive Statistics

As shown in TABLE 12, the effective work category has the highest average proportion of 46%, followed by the average proportions of ineffective and essential contributory with 29% and 26% respectively. As such, this may be attributed to the fact that there is always one worker, the one who is building the block wall, who is always engaged in doing useful or effective work almost all times, obviously because he is the main worker constructing the wall. The assistant worker in this case only assists in the construction process mainly engaged in either contributory or ineffective works. Thus, the representation by the statistics demonstrated previously. Both workers did not show any signs of any sources of variations associated with their performance, building the wall, and the recording of the field experiments via a video camera. That means that both workers were normally executing required tasks intended and necessary to complete the block wall. This remark can authenticate that the reference film footage was actually representative of the overall average workers' pace validating this study reference. This is specifically exhibited for the ineffective work category because the assistant worker(s) did not mind the video camera.

Concerning the pace rate, TABLE 12 shows that the dominant pace rating of the effective work category is slow with average observations of 369, followed by fast and average paces with average observations of 140 and 69 respectively.

Similarly, the dominant pace rating of the essential contributory work category is again the slow pace, followed by fast and average paces with average observations of 181, 77 and 72 respectively.

Needless to say that the ineffective work category has no pace rating because it is meaningless to have a pace rating for any sort of delays or simply when being inactive.

4.2   Results of Testing Hypothesis One

For testing hypothesis one, and hypothesis two as well, multiple regression is utilized. The test results are obtained in statistical tables' format. Namely, the regression statistics summary output and the ANOVA results. These tables measure the goodness of fit, explaining how well the calculated equations fits the collected data. Such tables include the following information:

1. Multiple R: is the correlation coefficient. Provides information about how strong the linear relationship is. A value of one indicates a perfect positive relationship, while a value of zero indicates no relationship. The multiple R is obtain as the square root of R square.

2. R square: is namely the Coefficient of Determination, "R^2". The purpose is to explain the variation between the dependent variable and the independent variable tested and how well such data fit the model.

3. Adjusted R square: This measure adjusts for the number of independent variables used in the regression model, it is only used if there are more than one independent variable to be explained.

4. Significance F: The associated P-Value.

The interpretation of the regression test results are always determined using the

regression statistics summary output table more frequently compared to the ANOVA results table. The ANOVA table comes to use during multiple regression to signify the significance of the relationship. As a result, the regression model is then used to assess both study hypotheses where their results are introduced in the next sections separately.

In the following presentation of results and to avoid repetition of previously stated equations, only the equation number will be indicated to describe its Coefficient of Determination and its contribution in each set.

The first hypothesis states that the predictive ability of work sampling will improve when work pace is included. Theoretically, when the workers' pace is incorporated in the effective or the essential work categories, the work sampling predictive ability for construction labor productivity will be improved. Since the emphasis is centered all around pace, the inclusion of the workers' pace to work sampling categories is done in two ways. The first way is when the workers pace is treated as an independent variable in the regression equation, as for example (13). The second way which has a more logical appeal is to include the pace rate as a weighting factor for its corresponding work category. This representation is referred to as the weighted pace for a specific work category such as the representation in equation (14). Therefore, this study will assess both ways to evaluate the contribution of each variable to the productivity relationship.

Testing this hypothesis will involve comparison of the Coefficients of Determination, R^2, between three different sets of equations. Each set consists of three equations, the first equation will exclude the pace, only assessing the contribution of the work sampling work categories, while the other two equations will include the pace in two forms as stated above.

In addition, each set will also compare every equations' Coefficient of Determination to assess its contribution to work sampling predictive ability.

Specifically, the difference between the compared Coefficients of Determination for each equation, $(R^2_2 - R^2_1)$ and $(R^2_3 - R^2_1)$, are compared for statistically significant difference for the relative contribution to productivity. Similarly, the same will also be done for each set. If the difference is found to be statistically significant for a particular set, then the first hypothesis is true.

Prior to testing this hypothesis, it will be informative to provide a summary of the overall bivariate correlations among all the variables, the inter-correlation matrix as shown in TABLE 13. In addition, it directly shows the association of differently investigated work categories compared to each other.

TABLE 13 Correlation Coefficients Matrix (Inter-Correlation Matrix)

Description	P	E	Ep	E.Ep	C	Cp	C.Cp	I
P	1	-	-	-	-	-	-	-
E	0.654^*	1	-	-	-	-	-	-
Ep	0.124	0.229	1	-	-	-	-	-
E.Ep	0.613^*	0.949^*	0.523^{**}	1	-	-	-	-
C	-0.346	-0.759^*	$-0.390^{\#}$	-0.790^*	1	-	-	-
Cp	0.162	0.025	-0.251	-0.104	$0.378^{\#}$	1	-	-
C.Cp	-0.116	$-0.485^{\#}$	$-0.392^{\#}$	-0.552^{**}	0.838^*	0.819^*	1	-
I	-0.598^{**}	-0.646^*	0.106	-0.531^{**}	-0.007	$-0.403^{\#}$	-0.237	1

* : Significance Level ≤ 0.0005

**: Significance Level ≤ 0.005

: Significance Level ≤ 0.05

The highest correlation with P is with E, E.Ep and I where all are of about same level of 0.6, suggesting that these independent variables have equal predictive power of productivity. Also, one can see that the correlation of $R_{P,E.Ep}$ is higher than it with $R_{P,E}$, i.e. $R_{P,E.Ep} < R_{P,E}$. TABLE 13 also shows that there is a high correlation between E and E.Ep

in addition to C and C.Cp which is expected because both work categories are common in each case. One can also notice that there is a strong correlation between effective, E, and essential contributory, C, work categories, which may indicate the potential of auto correlation in regression models.

4.2.1 Impact of Pace and Effective Work Category on Productivity

The first set of equations involves only the effective work category and its impact, or contribution, to the productivity. It is represented as follows:

$$P = A + B_1 E + \varepsilon \tag{15}$$

$$P = A + B_1 E + B_2 Ep + \varepsilon \tag{13}$$

$$P = A + B_1 (E.Ep) + \varepsilon \tag{14}$$

The impact of the first set effective work category to productivity is revealed by the regression analysis summarized in TABLE 14 below:

TABLE 14 First Set Results Summary – Hypothesis One

Set	Set Equations	Equation Number	R	Adjusted R^2	Significance
1	$P = A + B_1 E + \varepsilon$	15	0.654	0.428	< 0.001
	$P = A + B_1 E + B_2 Ep + \varepsilon$	13	0.655	0.383	< 0.001
	$P = A + B_1 (E.Ep) + \varepsilon$	14	0.613	0.375	< 0.001

The regression statistical output and part of the ANOVA results are shown in TABLE 14. The strength of each regression equation representing the effective work category and or its related pace is found to be moderate. From a statistical point of view, the regression analysis indicates that all regression equations have a positive strong relationship between the effective work category, its pace and productivity. However, the strongest relationship is found when the effective work and its pace are regressed independently as individual variables with $R=0.655$. This is followed by the weighted pace factor for the effective work with $R= 0.613$ compared to the base equation excluding the workers' pace. Both equations Coefficients of Determination are found to be $R^2= 0.383$ and $R^2=0.375$ consecutively compared to $R^2=0.428$ for the base equation excluding the workers' pace. That means that around 38% of the total variation in the productivity variable can be explained by the variation of the effective work observations and its pace in either of the forms. Therefore, the other 62% of the total variation in productivity remains unexplained. Evidently, this indicates that there are other factors that influence the productivity since 62% of the variability is left unexplained. The two variables, effective work category and its weighted pace are directly correlated to productivity with a significance level less than 0.005, which means that the possibility that R for the regression equations is equal to zero is less than 0.5% merely obtained randomly. The first set regression results indicate a significant relation with less than 5%.

4.2.2   Impact of Pace, Effective And Essential Contributory Work Categories on Productivity

The second set of equations incorporates the essential contributory work category in

addition to the effective work category into the first hypothesis. Mainly to assess its overall contribution to the work sampling ability and the productivity relationship hence, assessing its impact. The second set is represented as:

$$P = A + B_1\,E + B_2\,C + \varepsilon \tag{16}$$

$$P = A + B_1\,E + B_2\,C + B_3\,Ep + B_4\,Cp + \varepsilon \tag{33}$$

$$P = A + B_1\,(E.Ep) + B_2\,(C.Cp) + \varepsilon \tag{17}$$

The impact of the second set of equations including effective and essential work categories in addition to their paces to productivity is revealed by the regression analysis summarized in TABLE 15, where the adjusted Coefficient of Determination is used to adjust for the number of variables involved in the regression equations. By applying this approach, the researcher is able to judge on the prevalent variables that are considered as work sampling predictors for labor productivity. Further assumptions are evaluated accordingly to scrutinize the effect of pace on the productivity relationship, therefore verifying the first null hypothesis.

TABLE 15 Second Set Results Summary – Hypothesis One

Set	Set Equations	Equation Number	R	Adjusted R^2	Significance
	$P = A + B_1\,E + B_2\,C + \varepsilon$	16	0.694	0.440	< 0.005
2	$P = A + B_1\,E + B_2\,C + B_3\,Ep + B_4\,Cp + \varepsilon$	33	0.699	0.400	< 0.005
	$P = A + B_1\,(E.Ep) + B_2\,(C.Cp) + \varepsilon$	17	0.668	0.402	< 0.005

The regression output results are shown in TABLE 15. The strength of each regression equation representing the effective work, essential contributory work categories and or their related pace is found to be strong. From a statistical point of view, the regression analysis indicates that all regression equations have a positive strong relationship between the effective work, essential contributory work categories and their pace and productivity. One can see that the strongest relationship is found when all the independent variables including the pace are regressed independently as individual variables with R=0.699. Again, the strength of the weighted pace for both the effective and essential contributory work categories is ranked second for this set of equation with R= 0.668. The base equation for the second set of equations excluding the pace variable has a Correlation Coefficient of about 0.694. Both equations Coefficients of Determination are found to be 0.400 and 0.402 consecutively compared to R^2=0.440 for the base equation. That means that only around 40% of the total variation in the productivity variable can be explained by the variance of the effective, essential contributory work observations and their related pace in either of the forms similar to the first set. Therefore, the other 60% of the total variation in productivity remains unexplained which clearly suggests that there are other factors that affect the productivity. All three variables, effective, essential contributory work categories and their pace in either forms are directly correlated with a significance level less than 0.005. To further clarify, this means that the possibility of R for the regression equations being equal to zero is less than 0.3% that is also obtained randomly. The second set regression results indicate a significant relation with less than 5% also.

4.2.3 Impact of Pace, Effective, Essential Contributory And Ineffective Work Categories on Productivity

The third set of equations examined to test the first hypothesis will consider including ineffective work category to the other two work categories and their paces. This will allow evaluating the contribution of all related work categories included in this study objectives and to improve the work sampling ability to predict construction labor productivity. The third set of equations is represented as:

$$P = A + B_1\,E + B_2\,C + B_3\,I + \varepsilon \qquad\qquad (18)$$

$$P = A + B_1\,E + B_2\,C + B_3\,Ep + B_4\,Cp + B_5\,I + \varepsilon \qquad\qquad (34)$$

$$P = A + B_1\,(E.Ep) + B_2\,(C.Cp) + B_3\,I + \varepsilon \qquad\qquad (19)$$

The impact of the last set of equations including the ineffective work category in addition to the other ones on the productivity relationship is shown by the regression analysis output in TABLE 16.

TABLE 16 Third Set Results Summary – Hypothesis One

Set	Set Equations	Equation Number	R	Adjusted R^2	Significance
	$P = A + B_1 E + B_2 C + B_3 I + \varepsilon$	18	0.695	0.418	< 0.05
3	$P = A + B_1 E + B_2 C + B_3 Ep + B_4 Cp + B_5 I + \varepsilon$	34	0.700	0.374	< 0.05
	$P = A + B_1 (E.Ep) + B_2 (C.Cp) + B_3 I + \varepsilon$	19	0.693	0.416	< 0.05

The regression statistical output are shown in TABLE 16. The strength of each regression equation representing the ineffective work category in addition to the other two work categories and their related paces involved is again found to be rather strong. The strongest relationship is found when all the independent variables including the pace are regressed independently with R=0.700. Also, the strength of the weighted pace for both the effective and essential contributory work categories is ranked second for this set of equation with R=0.693 when ineffective work category is specifically introduced. The base equation for the third set of equations excluding the pace variable has a Correlation Coefficient of about 0.695. The Coefficients of Determination for equation (34) in the third set, where the independent variables are represented separately, is found to be positive and statistically representing a good relationship with productivity of about 0.374. While the Coefficient of Determination for equation (19) is found around 0.416 compared to a positive Coefficient of Determination for the third set base equation of about 0.418. That implies that only around 37.4% to 42% of the total variation in the productivity variable can be explained by the variance of all work sampling major work categories also incorporating each category pace in any form. Therefore, the remaining 58% to 62.6% of the total variation in productivity remains unexplained which obviously suggests that there are other factors that affect the productivity. The third set regression results indicate a significant relation with less than 5%.

4.3　Discussion of Results of Testing Hypothesis One

TABLE 17 provides a summary comparison of all the three sets of equations utilized to test the first hypothesis. The results obtained from all the three sets of equations clearly indicate that the null hypothesis is not true , i.e. the predictive ability of work sampling, in terms of R^2, did not improve when work pace is included. Actually there was a small reduction in R^2 when pace is included. Generally speaking, the difference in R^2 in all the regression models in TABLE 17 are so small that performing a test for statistical significance of the differences is not justifiable.

TABLE 17 Equations And Results For Hypothesis One

Set	Set Equations	Equation	R	Adjusted R^2	Significance
1	$P = A + B_1 E + \varepsilon$	15	0.654	0.428	< 0.001
	$P = A + B_1 E + B_2 Ep + \varepsilon$	13	0.655	0.383	< 0.001
	$P = A + B_1 (E.Ep) + \varepsilon$	14	0.613	0.375	< 0.001
2	$P = A + B_1 E + B_2 C + \varepsilon$	16	0.694	0.440	< 0.005
	$P = A + B_1 E + B_2 C + B_3 Ep + B_4 Cp + \varepsilon$	33	0.699	0.400	< 0.005
	$P = A + B_1 (E.Ep) + B_2 (C.Cp) + \varepsilon$	17	0.668	0.402	< 0.005
3	$P = A + B_1 E + B_2 C + B_3 I + \varepsilon$	18	0.695	0.418	< 0.01
	$P = A + B_1 E + B_2 C + B_3 Ep + B_4 Cp + B_5 I + \varepsilon$	34	0.700	0.374	< 0.01
	$P = A + B_1 (E.Ep) + B_2 (C.Cp) + B_3 I + \varepsilon$	19	0.693	0.416	< 0.01

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4.3.1 Discussion Impact of Pace and Effective Work Category on Productivity

As shown in TABLE 17, set one of equations, the inclusion of pace in proportions of effective work category did not improve the prediction of productivity. The results also prove that there are other influential productivity predictors, other than the effective work and its average pace. Consequently, the introduction of the workers' pace of effective work category does not improve the predictive ability of work sampling thus far. This means that a worker engaging in effective work, or alternatively the time spent performing effective work activities, is proportional to productivity.

Figures 8, 9 and 10 show the scatter plots of each independent variable and productivity and how well the multiple regression equations for the first set fit the data.

Effective Work Proportion (E) Line Fit Plot

Legend:
+ Productivity (Blocks/Man-Hours) (P)
—— Linear (Predicted Productivity (Blocks/Man-Hours) (P))

R=0.654
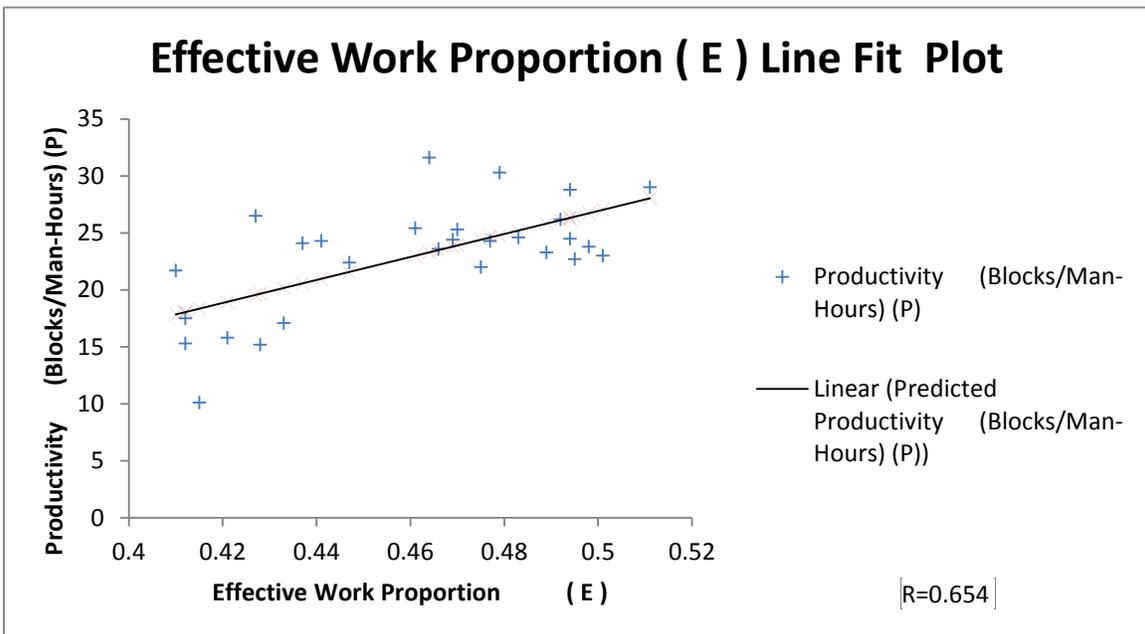
Figure 8 Relationship Between Effective Work Category And Productivity
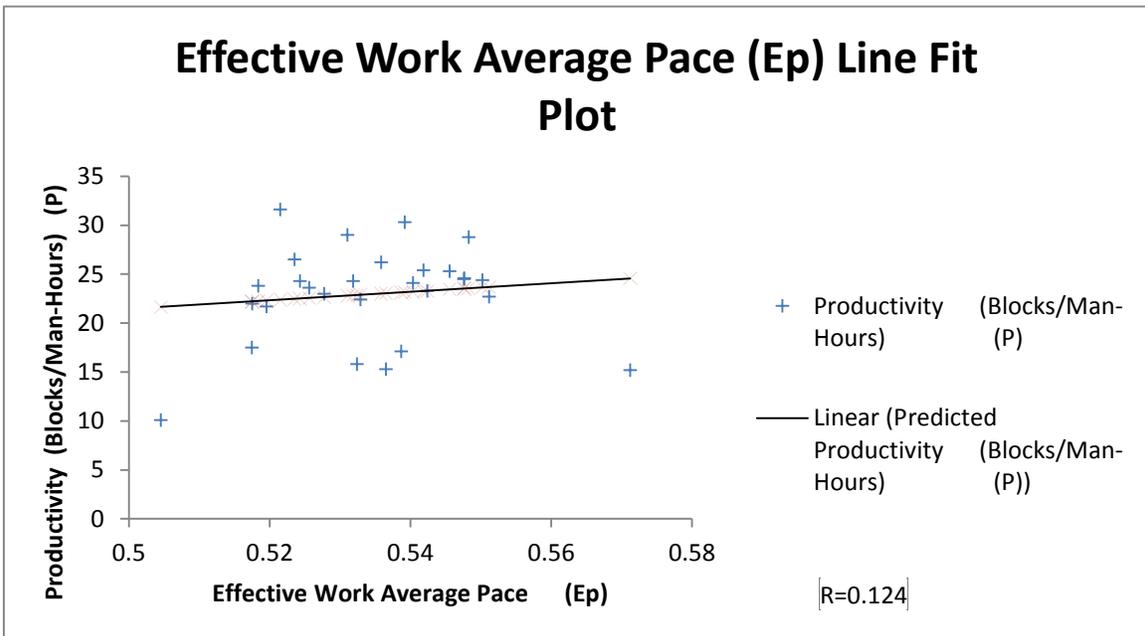
Figure 9 Relationship Between Pace Effective Work Category And Productivity
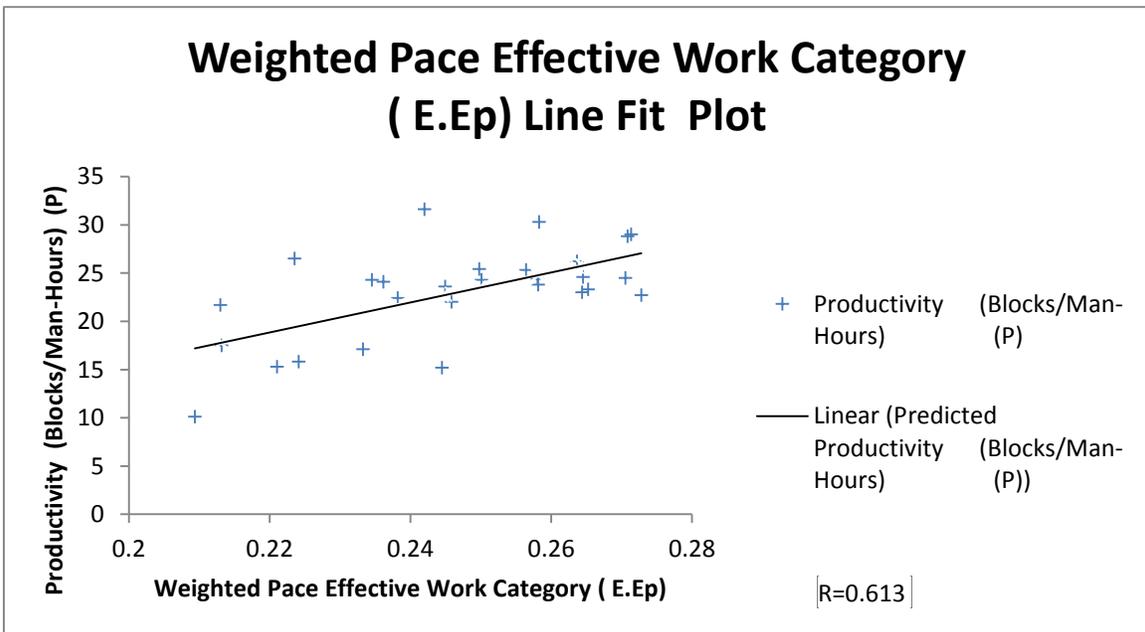
Figure 10 Relationship Between Weighted Pace Effective Work Category And Productivity

4.3.2 Discussion Impact of Pace, Effective And Essential Contributory Work Categories on Productivity

Set two of equations shown in TABLE 17 also shows that the inclusion of pace in the proportions of effective and essential contributory work categories did not improve the predictive ability of work sampling for productivity. Again, the statistical significance test of the differences is not justified because it is so small. The result also indicates that the null hypothesis for the second set is not true.

Figures 11, 12 and 13 illustrate the scatter plots of each independent variable and productivity and how well the multiple regression equations for the second set fit the data.
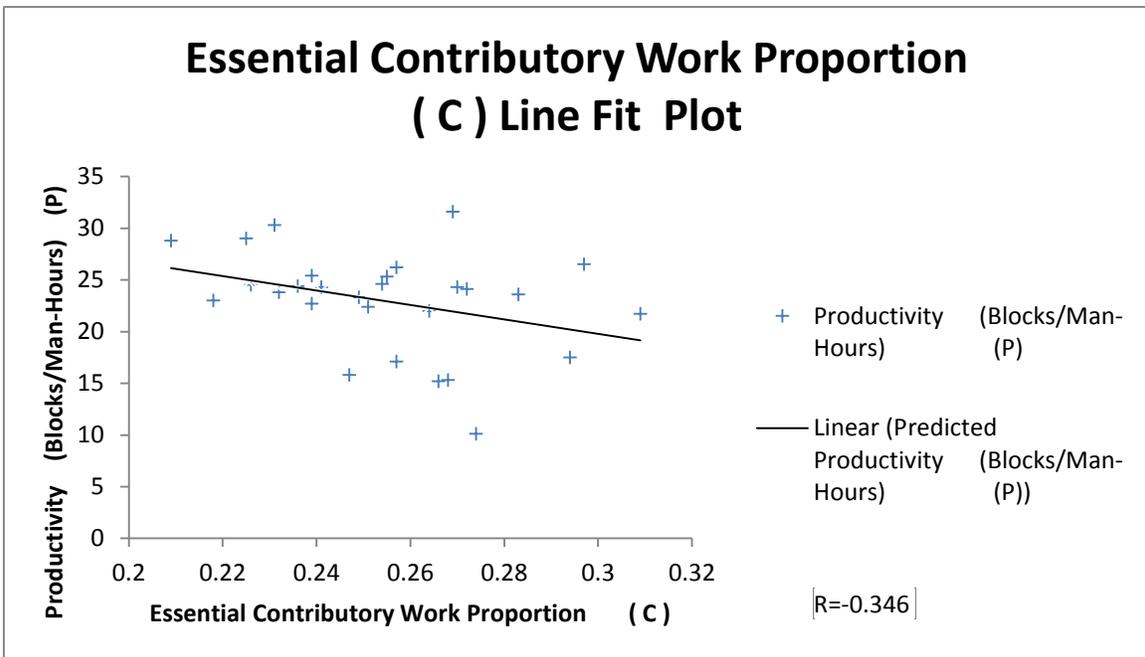
Figure 11 Relationship Between Essential Contributory Work Category And Productivity
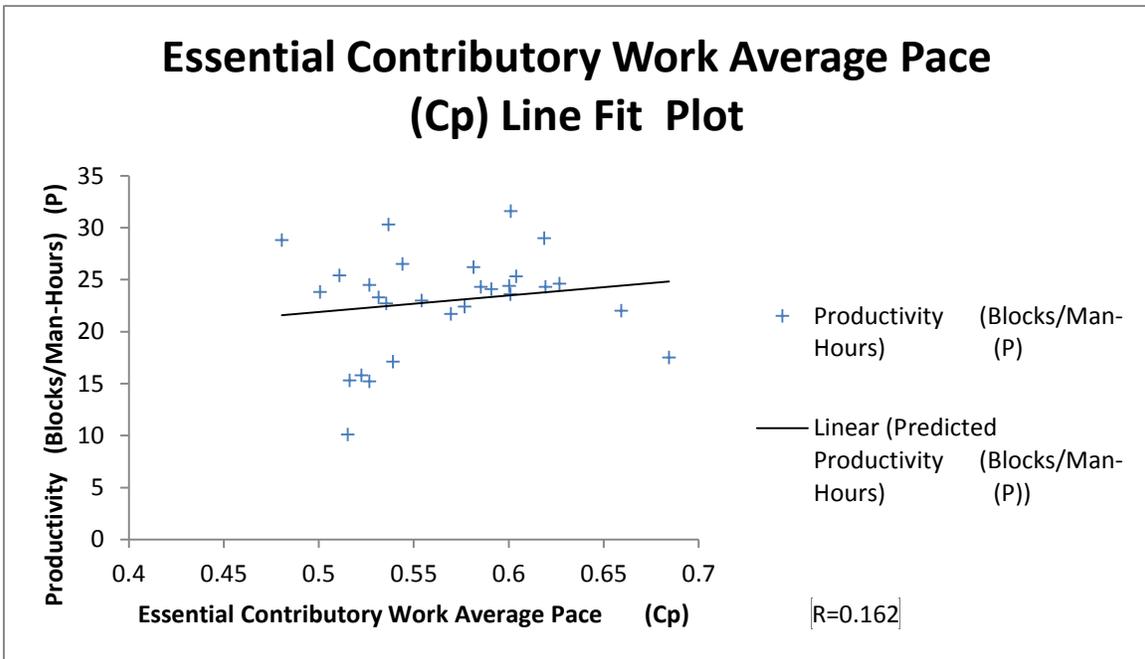
Figure 12 Relationship Between Weighted Pace Essential Contributory Work Category And Productivity
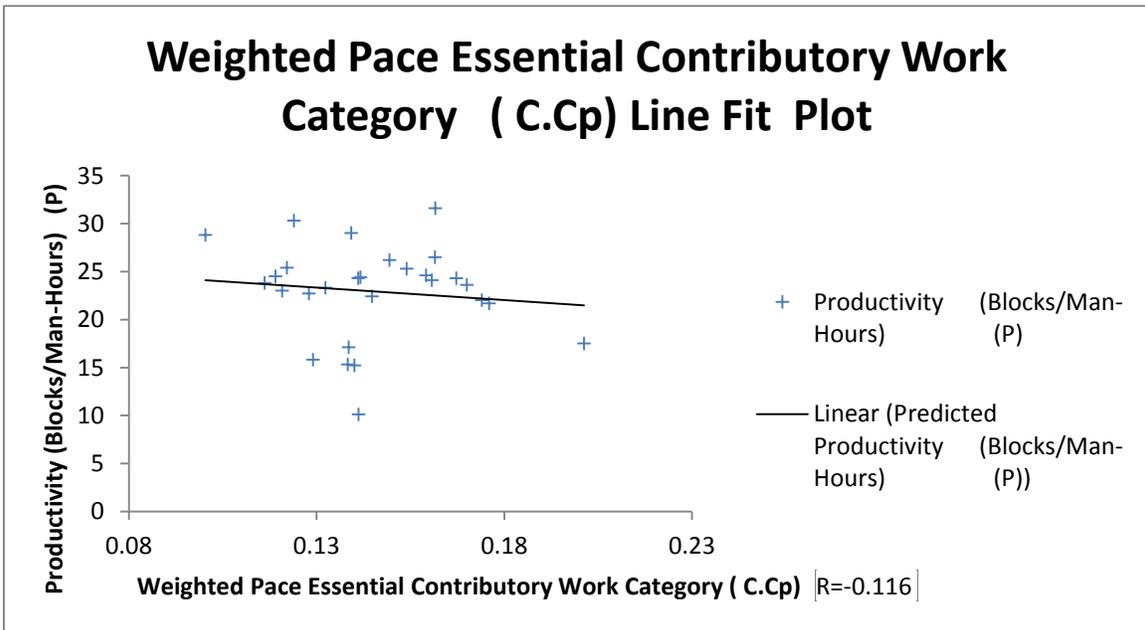
Figure 13 Relationship Between Weighted Pace Essential Contributory Work Category And Productivity

4.3.3 Discussion Impact of Pace, Effective, Essential Contributory And Ineffective Work Categories on Productivity

In reference to TABLE 17, set three of equations, the inclusion of pace in the proportions of effective, essential contributory and ineffective work categories also did not improve the work sampling prediction of productivity. In fact, TABLE 13 clearly shows that the effective wok category is the best predictor for construction labor productivity as it has the highest correlation among the independent variables with productivity. This result actually contradicts with the finding of Al-Ghamdi (1995) which concluded that the ineffective work category is a better predictor for construction labor productivity than effective work category. This is because being engaged in effective work activities surely aids and contributes to completing the intended work activities, therefore improves overall labor productivity. On the other hand, this does not essentially mean that being engaged in effective work will always improve productivity or even result in productivity, because a worker could always pretend doing effective work while he actually is not. In this case, being engaged in ineffective work activities, although not crucial for productivity measurement on actual basis, necessitates that a worker is not actually productive. As shown in Figure 14, the relationship between productivity and ineffective work category is negative but moderately correlated with 0.598. This finding is consistent with the result of Al-Ghamdi (1995) where he found a negative correlation of about 0.675.
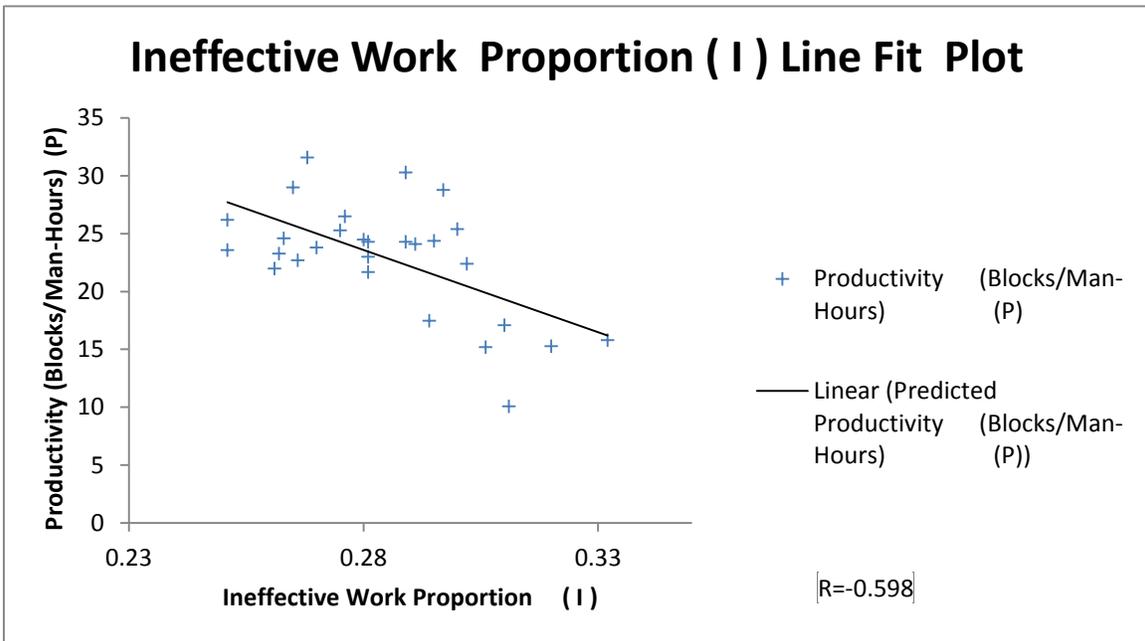
Figure 14 Relationship Between Ineffective Work Category And Productivity

4.4   Results of Testing Hypothesis Two

The second hypothesis asserts that the predictive ability of work sampling will improve when more work categories are considered. This study utilizes multiple regression to assess all possible combinations of the work sampling categories as independent variables including effective, essential contributory, ineffective work categories, pace for different wok categories in addition to the weighted pace variable. Therefore, the second hypothesis is evaluated against two different sets of equations. Each set consists of a number of equations. The first set involves testing the hypothesis for the effective, essential contributory and ineffective work categories for different numbers of work categories combinations, i.e. evaluate the impact of more work categories considering single, dual and three possible work category combinations. Similar to the first set, the second will involve testing weighted pace work categories for different number of work category combinations. The effect of workers pace is assessed in the second set based on each set criterion to verify their relative contribution to the predictive ability of work sampling for productivity.

The second hypothesis also makes use of the difference between the Coefficients of Determination of the two sets where the difference will be compared for statistically significant difference. If the difference between compared Coefficients of Determination (R^2_1 - R^2_2) is found statistically significant for the sets including most of the work categories compared to ones with less categories, then the second hypothesis is considered true.

TABLES 18 and 19 summarize the results of important regression parameters for the different combination of work categories for the first and second sets of hypothesis two consecutively.

TABLE 18 First Set Results Summary for Hypothesis Two

Set	Set Equations	Equation Number	R	Adjusted R^2	Significance
	$P = A + B_1 E + \varepsilon$	15	0.654	0.428	< 0.001
1	$P = A + B_1 E + B_2 C + \varepsilon$	16	0.694	0.440	< 0.001
	$P = A + B_1 E + B_2 C + B_3 I + \varepsilon$	18	0.695	0.418	0.001

TABLE 19 Second Set Results Summary for Hypothesis Two

Set	Set Equations	Equation Number	R	Adjusted R^2	Significance
2	$P = A + B_1 (E.Ep) + \varepsilon$	14	0.613	0.375	< 0.001
	$P = A + B_1 (E.Ep) + B_2 (C.Cp) + \varepsilon$	17	0.668	0.402	< 0.001
	$P = A + B_1 (E.Ep) + B_2 (C.Cp) + B_3 I + \varepsilon$	19	0.693	0.416	0.001

The first set of equations for the second hypothesis involves a combination of different numbers of work categories excluding pace, i.e. the first set compromises of single, dual and three work categories as represented by equations (15), (16) and (18) respectively summarized in TABLE 18 above. While the second set of equations for hypothesis two involves a different combination of different numbers of pace weighted work categories considering single, dual and three work categories as represented by equations (14), (17) and (19) and shown in TABLE 19.

4.4.1 Impact of Single Work Category Combinations on Productivity

As shown in TABLE 18, the regression statistical output indicates that the strength of different combinations of each regression equation in the first set of hypothesis two involving single, dual and three work categories is found positively strong, with Coefficients of Determination at a significant level of less than 0.001. Comparing the Coefficients of Determination, R^2, results in 0.428, 0.440 and 0.418 for single, dual and three work categories respectively. That means that around 42.8% of the total variation in the productivity variable can be explained by the variance of the effective work category. The remaining 57.2% of the total variation in productivity remains unexplained. Similarly, TABLE 19 shows the same regression statistical output for pace weighted single work category in the second set of hypothesis two which indicates a strong positive relationship with productivity. However, at a lower R^2 of 0.375 and a significant level of less than 0.001 which means that only around 37.5% of the total variation in the productivity variable can be explained by the variance of pace weighted effective work category.

4.4.2   Impact of Dual Work Categories Combinations on Productivity

Similarly, the second hypothesis involves evaluating dual work categories within the first set of equations for hypothesis two to assess the predictive ability of work sampling for productivity, hence prove the null hypothesis. As indicated in TABLE 18 above, the second equation also contains dual work sampling categories particularly the effective and essential contributory work categories represented by equation (16). The regression statistical output for a combination of dual work categories indicates a positive and moderate relationship at a significant level. The resultant Coefficients of Determination for dual work categories is found to be at 0.440. That means that around 44% of the total variation in the productivity variable can be explained by the variance of dual work categories consisting of effective work and essential contributory work categories. The remaining 56% of the total variation in productivity remains unexplained. Also, it is evident from TABLE 18 that the dual work categories has a stronger relationship with productivity than the other combinations. Comparably, TABLE 19 shows the same regression output for pace weighted dual work categories of the second set which also indicates a strong positive relationship with productivity. However, at a lower R^2 of 0.402 and a significant level of less than 0.001 which means that only around 40% of the total variation in the productivity variable can be explained by the variance of dual pace weighted effective and essential work categories combination.

4.4.3 Impact of Including All Three Work Categories Combinations on Productivity

Because of the study design offered by the field experiments, the three work categories in both sets of the second hypothesis are tested considering the evaluation of all possible three work categories combination. The researcher aims to assess the ability of work sampling to predict productivity when more work categories are considered. Hence, proves the null hypothesis. TABLE 18 above, shows all possible three work categories including effective, essential contributory and ineffective work categories represented by equation (18). By comparing the Coefficients of Determination for all possible three work categories in both sets of equations for hypothesis two, the researcher can assess the null hypothesis. If the Coefficients of Determination for the three work categories demonstrate a statistical significance compared to the single and dual work categories within the same set, the null hypothesis will then be considered true. As a result, the predictive ability of work sampling to predict construction labor productivity improves when more work categories are considered. The regression output for the three work categories of the first set shown in TABLE 18, indicate an increased strength of about 0.695 with R^2 of 0.418 in relation to productivity at a significant level compared to single and dual work categories, the strongest relationship between all three possible combinations of independent variables or work categories. This means that around 41.8% of the total variation in the productivity can be explained by the variance of the three work categories combination considered in this study while the 58.2% of the total variation in productivity remains unexplained. Also, it is evident from TABLE 18 that the three work categories combination has the weakest relationship with productivity among the other two combinations. On the other hand,

TABLE 19 shows the same regression output for pace weighted three work categories of the second set which also indicates a strong positive relationship with productivity however with a lower R^2 of 0.416 and a significant level of 0.001 which means that only around 41.6% of the total variation in the productivity variable can be explained by the variance of the three pace weighted effective, essential work categories and ineffective work categories combination.

Comparing the Coefficients of Determination of the three work categories in both sets of hypothesis two compared to the other two combinations, does not indicate a general increase in the goodness of fit therefore cannot accept the null hypothesis.

4.5   Discussion of Results of Testing Hypothesis Two

In reference to TABLES 18 and 19, the results obtained from both sets of equations clearly indicate that the null hypothesis is not supported, which implies that the predictive ability of work sampling does not clearly improve when more work categories are considered. This is evident when all the three Coefficients of Determination within both sets are compared to each other.

4.5.1 Discussion of The Impact of Single Work Category Combinations on Productivity

From a statistical standpoint TABLES 18 and 19 indicate the strength of work sampling ability in predicting productivity considering a single work category, particularly the effective work category in set one and the pace weighted effective work category in set two, which result in a strong relationship with Correlation Coefficients of 0.654 and 0.613

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respectively. In general, considering a combination of different single work categories does not necessarily results in a strong relationship with productivity such as the case when only the essential contributory work category is used as single combination, where the Coefficient of Correlation is determined to be weak with a value of -0.346 as shown in TABLE 13. The researcher finds that when a single work sampling category is used to predict productivity, the effective work category is the strongest predictor in this case because it is known to make progress with the task at hand contributing to the project useful work activities, therefore accomplishing the task. Similarly, TABLES 13 and 18 indicate that this is followed by the pace weighted effective work category then the ineffective work category with 0.613 and -0.598 Coefficients of Correlation respectively. Because in the case of pace weighted effective work, this is still a combination of useful work incorporating the workers' pace, while in the case of ineffective work category it is a clear waste or delay of productivity hence strictly affecting it. However, the obtained results also show that there are other single work categories that are influential productivity variables other than the effective work and its pace weighted categories. Consequently, considering only a single work category to predict construction labor productivity does not certainly improve the predictive ability of work sampling thus far. In addition, such results also support the findings of Al-Ghamdi (1995) where he found a moderately positive relationship between productivity and effective work category. This means that a worker engaging in effective work, or alternatively the time spent performing effective work activities, is proportional to productivity. However, in order to prove that the second hypothesis is true, a comparison between various orders of variables inclusions is necessary.

4.5.2 Discussion of The Impact of Dual Work Categories Combinations on Productivity

In reference to the discussions made in the previous Section, incorporating a dual combination of work sampling categories in either sets of the regression equations for the second hypothesis, had definitely improved the situation in predicting construction labor productivity. The strength of the dual work categories, specifically the effective work, essential contributory work and their pace weighted work categories, Correlation Coefficients are consistent and found to be stronger than a single work category combination with Coefficients of Determination of 0.440 and 0.402 consecutively compared to the Coefficients of Determination for the single work category of 0.428 and 0.375 respectively. This relationship is found to be statistically significant for the dual work categories combinations considered in both sets of hypothesis two. Considering dual work sampling categories in the productivity relationship certainly had improved the null hypothesis up to this stage. So far, the more work sampling categories introduced to both sets of the regression equations of productivity relationship, the better the results appear to be at a significant level. This finding seems logical because in reality, one has to have proper work categorization, that is more work sampling independent variables for the task at hand in order to know the overall relative contribution of each independent variable to productivity in a better way. In addition, this also means that one can identify in a logical and systematic approach, to some extent, the predictors that may contribute to losing productivity.

The impact of the pace weighted work on dual categories although considered moderate but did not improve the work sampling prediction ability of productivity. Since

only about 40% to 44% of the total variation in the productivity variable can be explained by the variance of dual work sampling categories as shown in both sets in TABLES 18 and 19. Although considering dual work categories to predict construction labor productivity leads to improved predictive ability of work sampling in comparison to single work sampling categories nevertheless, hypothesis two requires additional investigation to evaluate the impact of including more work sampling categories i.e. independent variables.

4.5.3 Discussion of The Impact of Including All Three Work Categories Combinations on Productivity

In relation to the two previous discussion Sections, the inclusion of more than dual work sampling categories in both sets of the regression equations for the productivity makes a distinctive difference in accepting the null hypothesis. TABLES 18 and 19 again indicate a strong relationship with productivity of about 0.695 and 0.693 with Coefficients of Determination 0.418 and 0.416 for a combination of three work categories, the effective, essential contributory and ineffective work categories compared to a combination of three pace weighted effective and essential contributory work and ineffective work categories. In comparison to dual work sampling categories within both sets of hypothesis two, one can notice that the Coefficient of Determination decreased in the first set while it increased in the second set considering the pace weighted work categories. Hence, the null hypothesis cannot be fully accepted. In fact, TABLES 18 and 19 clearly indicate that the highest Coefficient of Determination of 0.440, is obtained when dual work sampling categories of effective and essential contributory work activities are considered followed by a Coefficient of Determination of 0.428 for the effective work category. Therefore, the inclusion of all the three work sampling categories in a non-paced form does not improve

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the work sampling predictive ability of productivity while, the inclusion of all the three pace weighted categories improves the predictive ability of work sampling in this case. The results also show that, although such combination is not sufficient to completely identify necessary productivity predictors, it is not the best combination among the two sets of regression equations. This is possibly because the impact of ineffective work category on productivity is limited basically because it introduces more delays impacting the progress of the job activities. Therefore, probably, introducing more detailed and specifically chosen work sampling categories related to scope of study, the project critical activities in general, may help improve productivity. Therefore, considering the Coefficients of Determination for both sets of hypothesis two, the predictive ability of work sampling to predict construction labor productivity is not conclusively improved when more work categories are considered.

4.6   Effect of Excluding The Influence of Crew Size Inefficiency

The previously reported Coefficients of Determination, R^2, were generally lower than expected. To further look into plausible reasons for such results, the researcher considered the effect of crew size inefficiency. To further clarify, it is noticed during the observation of the field experiments that the effective work category proportion is about 0.461 on average compared to 0.255 essential contributory category proportion and 0.285 ineffective work category proportion. The researcher, during the examination of the study hypotheses, believed that this might be due to the fact that the proportion of the effective work category performed and the combined essential contributory and ineffective work

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categories proportions are practically equal to each other. Of which both are in the vicinity of 0.5 average proportion. That actually meant that almost for every worker engaged in performing effective work, there is another worker who is not, but rather engaged in ineffective or essential contributory work activities. This effect is found to be more in the field experiments where the crew size is four workers, of which only one worker is actually always engaged in building the block wall, while the other three are almost engaged in ineffective or contributory work activities, if not effectively assisting the main worker building the block wall. The researcher assessed the influence of this crew efficiency by excluding those field experiments with a crew of four workers, since the other three workers are mostly engaged in ineffective work.

The same regression model is used for the analysis after excluding the last 7 field experiments which involved crew size of four workers. The results of this analysis was a significant drop in the Coefficients of Determination ranging from zero, meaning no relationship, for productivity and ineffective work category to as high as 0.2 for the relationships of other work sampling categories and productivity. A possible reason for such unexpected results is the restriction of range of the dependent variable, i.e. productivity. That is, by excluding these 7 field experiments, with low productivity, the variation in productivity, the dependent variable, dropped dramatically which will automatically cause R^2 to drop.

The previously obtained results, although clearly show that the crew size actually affects the productivity, nevertheless, showed a clear consistency with the conclusions Al-Ghamdi (1995) obtained in his study with respect to crew size. Though, this may be an evidence that the crew size is crucial for productivity, the researcher by performing this

study, ascertains the findings Al-Ghamdi (1995) concluded about the adequacy of the sample size to signify the crew size productivity relationship, therefore, work sampling predictive ability to predict labor productivity.

4.7   Weights of Work Categories on Labor Utilization Factor

The study considers evaluating the accuracy of the weights of the effective and essential contributory work categories represented in equation (16) in addition to assessing the appropriateness of the Labor Utilization Factor represented in equation (22). In order to evaluate the techniques' relative accuracy and its weight for any of the working categories, the results of the regression analysis for equation (16) from the regression output as per below unstandardized form:

$$P = - 60.9 + 142.4 \, E + 71.6 \, C$$

The previous form can also be represented in a standardized form using the Z score where the standardized Coefficients of effective and essential contributory work categories are found to be 0.93 and 0.35 respectively. Hence, equation (16) can be represented as:

$$P = 0.93 \, Z_E + 0.35 \, Z_C$$

This means that if the effective work category increases by one standard deviation, then one would expect 0.93 standard deviation increase in productivity holding the effect of the essential contributory work category constant. This finding is consistent with the finding of the unstandardized regression equation also, where one can notice that the ratio of the effective work category to the essential contributory work category is two to one. Assuming Labor Utilization Factor is a surrogate of productivity, it appears that the coefficients of variability, weights, for the independent variables of the effective and essential contributory work categories are 142.4 and 71.6 respectively. For a long time, the ratio adopted for the Labor Utilization Factor was four to one for effective and essential contributory work categories. The results obtained from this study shows a different, but more appropriate ratio of two to one as shown in both forms above. As a result, equation (22) seems to be a very conservative measure for the Labor Utilization Factor. In fact, the researcher compared both weights, 25% and the newly suggested 50% factors, on Labor Utilization Factor to assess their appropriateness using the Coefficient of Correlation relative to productivity. The more appropriate weight is the one leading to a higher Correlation Coefficient. A comparison of the calculated Labor Utilization Factors together with the productivity correlations are shown in TABLE 20 below.

TABLE 20 Comparison Between Calculated Labor Utilization Factors Using The Old and New Weights

Productivity (Blocks/Man-Hours) (P)	Effective Work Proportion (E)	Essential Contributory Work Proportion (C)	LUF 25% Factor	LUF 50% Factor
17.5	420	300	48.53	55.88
24.5	504	231	55.07	60.74
25.4	470	244	52.06	58.04
30.3	489	236	53.73	59.51
25.3	479	260	53.33	59.71
28.8	504	213	54.63	59.85
31.6	473	274	53.09	59.80
22.4	456	256	50.98	57.25
29	521	229	56.69	62.30
24.3	487	246	53.77	59.80
23.6	475	289	53.65	60.74
24.6	493	259	54.68	61.03
23	511	222	55.54	60.98
24.4	478	241	52.77	58.68
22	485	269	54.14	60.74
23.8	508	237	55.61	61.42
24.1	446	277	50.51	57.30
24.3	450	275	50.86	57.60
23.3	499	254	55.15	61.37
22.7	505	244	55.49	61.47
26.2	502	262	55.64	62.06
10.1	847	559	48.37	55.22
15.8	859	504	48.28	54.46
15.3	840	547	47.88	54.58
17.1	883	525	49.72	56.15
15.2	873	543	49.45	56.10
21.7	836	631	48.71	56.45
26.5	871	606	50.12	57.55
Productivity Correlation			0.6795	0.6922

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As shown in TABLE 20, the strength of association is higher, 0.6922, in the case of the newly suggested weight than the old traditional one which is 0.6795, though the difference is minimal, probably due to the moderate ability of work sampling to predict productivity as reported in the previous Sections. Therefore, the newly suggested weight is more appropriate to use as a realistic measure. Besides, the reviewed literature provided no justification or basis for using the factor of 0.25 for the essential contributory work category. Therefore, the conclusion that a more realistic utilization factor is obtained when the 25% weight factor is replaced with 50% because the 25% factor is a very conservative weight factor. As a result, the researcher suggests utilizing the 50% factor in equation (35) rather than equation (22).

$$Labor\ Utilization\ Factor = \frac{Effective\ Work + \frac{1}{2}\ Essential\ Contributory\ Work}{Total\ Observed} \quad (35)$$

This conclusion supports the results found by Al-Ghamdi (1995) where his model recommended using a different weight than that of 0.25.

4.8   Results of Five Minute Rating

Since the overall objective of the Five Minutes Rating technique is to estimate the crew effectiveness, the study evaluates the accuracy of this technique compared to work proportions produced by the work sampling.

Basically, all 28 field experiments involved two crews only. A crew of two workers and another of four, referred to hereafter as crew one and two respectively. To have an accurate evaluation of this technique, the timings used to assess the technique were selected randomly by the Excel tool. For each experiment, the crew members were observed for five minute period and each member was rated for every minute. If the worker was found to be working in the majority of the minute, i.e. more than 30 seconds, the worker is determined as effective in the observed minute otherwise he is rated as ineffective. At the end of the five minute observation period, the number effective or working man minutes is counted and is then divided over the total number of man minutes for all the crew members being observed and the effectiveness percentage is obtained. TABLE 21 shows a summary of all field experiments Five Minute Rating technique effectiveness outcome.

TABLE 21 Five Minute Rating Technique Effectiveness Outcome

Field Experiment or Wall Number	Crew	Total Man Units	Effective Man Units	Overall Crew Effectiveness (Percentage)
1	1	10	7	70.00
2	1	10	7	70.00
3	1	10	7	70.00
4	1	10	10	100.0
5	1	10	8	80.00
6	1	10	6	60.00
7	1	10	5	50.00
8	1	10	8	80.00
9	1	10	5	50.00
10	1	10	7	70.00
11	1	10	10	100.00
12	1	10	10	100.00
13	1	10	6	60.00
14	1	10	9	90.00
15	1	10	8	80.00
16	1	10	7	70.00
17	1	10	7	70.00
18	1	10	7	70.00
19	1	10	8	80.00
20	1	10	9	90.00
21	1	10	9	90.00
22	2	20	12	60.00
23	2	20	14	70.00
24	2	20	8	40.00
25	2	20	10	50.00
26	2	20	8	40.00
27	2	20	16	80.00
28	2	20	12	60.00
TOTAL		350	240	68.57

To assess the accuracy of the Five Minute Rating technique in comparison to work sampling, the crew effectiveness in each experiment is compared to the combined proportions of effective and essential contributory work categories in the same experiment as obtained from work sampling. The rationale for combining the proportion of effective work with the proportion of essential contributory work is that activities in both types of categories are classified as effective in the Five Minute Rating. TABLE 22 presents the results of above comparison.

TABLE 22 Comparison of Results Between Five Minute Rating Technique And Work Sampling

Field Experiment	Five-Minute Crew Effectiveness (Percentage)	Work Sampling Effective Work (Percentage)	Work Sampling Essential Contributory Work (Percentage)	Work Sampling Effective and Essential Contributory Work (Percentage)	Effectiveness Difference Work Sampling and Five Minute Effectiveness (Percentage)
1	70	41.2	29.4	70.6	0.6
2	70	49.4	22.6	72	2
3	70	46.1	23.9	70	0
4	100	47.9	23.1	71	-29
5	80	47	25.5	72.5	-7.5
6	60	49.4	20.9	70.3	10.3
7	50	46.4	26.9	73.3	23.3
8	80	44.7	25.1	69.8	-10.2
9	50	51.1	22.5	73.6	23.6
10	70	47.7	24.1	71.8	1.8
11	100	46.6	28.3	74.9	-25.1
12	100	48.3	25.4	73.7	-26.3
13	60	50.1	21.8	71.9	11.9
14	90	46.9	23.6	70.5	-19.5
15	80	47.5	26.4	73.9	-6.1
16	70	49.8	23.2	73	3
17	70	43.7	27.2	70.9	0.9
18	70	44.1	27	71.1	1.1
19	80	48.9	24.9	73.8	-6.2
20	90	49.5	23.9	73.4	-16.6
21	90	49.2	25.7	74.9	-15.1
22	60	41.5	27.4	68.9	8.9
23	70	42.1	24.7	66.8	-3.2
24	40	41.2	26.8	68	28
25	50	43.3	25.7	69	19
26	40	42.8	26.6	69.4	29.4
27	80	41	30.9	71.9	-8.1
28	60	42.7	29.7	72.4	12.4
Average	71.43	46.08	25.47	71.55	0.12
Standard Deviation	16.93	3.18	2.43	2.07	14.86

As shown in TABLE 22, the results indicate the following:

1. An overall crew effectiveness average of 71.4 which is impressively close to the 71.6 average of the work sampling proportions of effective and essential contributory work categories.

2. The range of difference between the effectiveness difference work sampling and the Five Minute effectiveness is -29 to 29.4 percentage points.

3. The average absolute difference is 58.4%.

4. In nine of the experiments, the difference did not exceed 5 percentage points.

5. In sixteen of the experiments the difference is within 10 percentage points.

6. The standard deviation of effectiveness is much higher than the standard deviation of work sampling effective and essential contributory work categories with 16.9 vs. 2.07 percentage.

7. The calculated strength of association i.e. the Correlation Coefficient is found positively moderate at 0.471.

4.9   Discussion of Results of Five Minute Rating

The comparison between the Five Minute Rating technique and work sampling revealed a positively moderate correlation between the two, specifically between the Five Minute Rating and work sampling, effective and essential contributory work categories. This moderate correlation can be partially attributed to the fact that crew one only comprises two workers of which one, main worker, is always doing effective work while the other is assisting doing both effective and essential contributory works. The main

worker is rarely engaged in ineffective work during the course of the field experiments. Therefore, when the crew was observed, the majority of the man units were always effective compared to work sampling where the assisting worker is additionally engaged in the different types of work categories.

As also reported in the previous Section, the large absolute average difference of 58.4% can be explained mainly from the composition of both crews. The majority of the crew workers, especially in crew two, are engaged in doing essential contributory work and mainly a large proportion of ineffective work categories, hence efficiently contributing to the delay of the job completion. It may be suggested that if all the crew members were also mostly engaged in doing effective work, then the difference in absolute average would have gone additionally smaller. On the other hand, the standard deviation of the overall crew effectiveness is much higher than the work sampling effective and essential work categories mainly because of the Five Minute procedure, in which the observer judgment is used to determine effectiveness of the crew while the work sampling procedure is more stringent when registering the observation at the first instance of the observed period in addition to the sample size used in both procedures, where it is bigger in case of work sampling resulting in a less standard deviation.

A more significant observation is the almost identical overall average of both the Five Minute Rating and work sampling, 71.43% vs 71.55%, which indicates that the Five Minute Rating is much more accurate than traditionally thought.

4.10 Results of Head Count

The other related technique to work sampling is the Head Count technique or the Field Rating technique. This technique mainly classifies workers into two categories, working or not. This technique is not considered true sampling because mainly the observations are not taken randomly. In this study, the timings for the Five Minute Rating technique were used to perform the Head Count avoiding either the start or end of the experiment by around fifteen minutes. If the timing chosen appeared to be in the beginning or at the end of the field experiment the excel tool is used to generate a random timing that reflects proper rating of the technique. Each crew member was observed quickly at first instance of observation for doing work or not. The results are shown TABLES 23 and 24.

TABLE 23 Head Count (Field Rating) Assessment Results

Field Experiment or Wall Number	Crew Size (Men)	Laborer Number				Overall Field Rating (Percentage)
		1	**2**	**3**	**4**	
		(Effectively, Ineffectively Work)				
1	2	E	E	-	-	100
2	2	E	I	-	-	50
3	2	E	E	-	-	100
4	2	E	E	-	-	100
5	2	E	I	-	-	50
6	2	E	I	-	-	50
7	2	E	I	-	-	50
8	2	E	E	-	-	100
9	2	E	I	-	-	50
10	2	E	E	-	-	100
11	2	E	E	-	-	100
12	2	E	I	-	-	50
13	2	E	I	-	-	50
14	2	E	E	-	-	100
15	2	E	E	-	-	100
16	2	E	I	-	-	100
17	2	E	I	-	-	50
18	2	E	E	-	-	100
19	2	E	E	-	-	100
20	2	E	I	-	-	50
21	2	E	E	-	-	100
22	4	E	I	I	E	50
23	4	E	E	I	E	75
24	4	E	E	I	E	75
25	4	E	E	I	I	50
26	4	E	I	I	E	50
27	4	E	E	E	I	75
28	4	E	I	I	E	50

TABLE 24 Comparison of Results Between Head Count Technique And Work Sampling

Field Experiment or Wall Number	Overall Field Rating (Percentage)	Work Sampling Effective and Essential Contributory Work (Percentage)	Difference Work Sampling and Field Rating (Percentage)
1	100	70.6	-29.4
2	50	72	22
3	100	70	-30
4	100	71	-29
5	50	72.5	22.5
6	50	70.3	20.3
7	50	73.3	23.3
8	100	69.8	-30.2
9	50	73.6	23.6
10	100	71.8	-28.2
11	100	74.9	-25.1
12	50	73.7	23.7
13	50	71.9	21.9
14	100	70.5	-29.5
15	100	73.9	-26.1
16	100	73	-27
17	50	70.9	20.9
18	100	71.1	-28.9
19	100	73.8	-26.2
20	50	73.4	23.4
21	100	74.9	-25.1
22	50	68.9	18.9
23	75	66.8	-8.2
24	75	68	-7
25	50	69	19
26	50	69.4	19.4
27	75	71.9	-3.1
28	50	72.4	22.4
Average	74.11	71.55	2.56
Standard Deviation	24.04	2.07	21.97

To assess the accuracy of the Head Count technique, the overall Field Rating percentages are compared to the combined percentages of the proportions for work sampling effective and essential contributory work categories. If the correlation, to show the strength of association, between the two criteria percentages is found high, the technique is then considered accurate. Similarly by a different means, if the standard deviation for the differences between the proportions percentages are found tight, the technique is also considered accurate.

As indicated in TABLE 24, the results show several indications as follows:

1. The overall Field Rating average is 74.1 which is slightly higher than the 71.5 average of the work sampling proportions of effective and essential contributory work categories.

2. The range of difference between both proportions is -30.2 to 23.7 percentage points.

3. The average absolute difference is 53.9%.

4. One of the experiments shows a difference that did not exceed 5 percentage points, two of the experiments have a difference that is within 10 percentage points while 22 experiments out of 28 show a difference of more than 20 percentage points.

5. The standard deviation of the Field Rating is about 24 which is much higher than the standard deviation of work sampling effective and essential contributory work categories.

6. The calculated strength of association i.e. the Correlation Coefficient is found positively weak at 0.103.

4.11   Discussion of Results of Head Count

As reported in the previous Section, the Correlation Coefficient strength of association, between the results of the Head Count and work sampling is found to be weak at about 0.103. This can be attributed to the very small sample size of the Head Count technique. Furthermore, this weak association can be attributed to the difference between both methods because work sampling provides more details of activity categorization than the Field Rating which only uses effective and ineffective work categories. In addition, the Field Rating technique may classify a certain observation as a delay while the work sampling may qualify it as an essential contributory work such as in the case of leaning to take a tool. This is also evident as the results in TABLE 24 show a considerable variation between the percentages of the Field Rating and the work sampling effective and essential contributory work categories since 22 experiments out of the 28 field experiments indicate a difference of more than 20 percentage points. The crew size and the type of activities performed by the workers explain the large range of variation which is about 53.9 percentage points as most of the crew activities are observed to be not working in the Field Rating technique. The standard deviation of the overall Field Rating is much higher than the standard deviation of work sampling effective and essential contributory work categories by about 23 percentage points, which is also very close to the average standard deviation of the difference between both proportions. This indicates, the technique is also inaccurate. The large variation in the standard deviation can be explained by a considerable amount of observed crew delays recorded by the Head Count technique when compared to work sampling activities which supports the finding of this examination. Hence, the

technique is considered inaccurate when compared to work sampling.

The adjusted 10% weight for the supervisors' instructions is not used in this study because it was not needed based on the design of the field experiment. This is because the types of work activities in this study are simple and do not need to be supervised. As a result, the researcher recommends to remove such adjustment factor and adds it only when there only is a supervisor for the job and within the crews.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1   Summary

Improvement of construction labor productivity is essential for the construction industry. A necessary pre-requisite for this improvement is the ability to measure and predict productivity. This study investigates work sampling as an empirical tool to measure labor productivity. It attempts to improve work sampling ability to predict construction labor productivity. Though several studies had been performed in the same field, the uniqueness of this study stems from the fact that it introduces a new variable potentially related to construction labor productivity, which is the workers' pace or rate of work.

This study is based on field experiments of constructing different block walls. It utilized 28 different field experiments with a large number of sampled observations totaling 35700, to estimate the population proportions. Two different crews with different workers roles have been studied. A reference film to determine a reference average pace to use in this study to rate the observations was determined from within one field experiment of around seven minutes that contain all possible work activities needed to construct the block wall and measure construction labor productivity. All observed work activities have been categorized in three major categories, effective work, essential contributory work and ineffective work. The work activities were then rated for pace against the reference film

as slow, average and fast. Each rating had a different ordinal scale weight to quantify productivity measurements. Several productivity relationships were investigated against the workers' pace to evaluate its contribution using multiple regression and the Coefficient of Determination as a basis to measure work sampling ability to predict construction labor productivity. The study consumed a long period of time due to the complexity of the objective and the meticulous approach followed in the methodology. This was especially true for watching the filmed experiments, recoding the observations, verifying their integrity and reliability, rating the observations, piloting initial results and finally evaluating multiple work sampling and productivity relationships to reach relevant conclusions about the effect of workers' pace on such relationships.

The results revealed significant but moderate relationships between the dependent variable (Productivity) and the independent variables of pace and various work sampling categories. Since the obtained Coefficients of Determination, R^2, for hypothesis one ranged moderately from 0.374 to 0.44, the effect of introducing workers' pace on the work sampling predictive ability to improve construction labor productivity is not supported. This demonstrates clearly that there are other influential productivity variables, other than work sampling proportions and pace that determine labor productivity.

Similarly for hypothesis two, the predictive ability of work sampling does not improve when more work sampling categories are considered in the form of non-paced categories while it does improve when more paced work categories are considered. This result is clear when the Coefficients of Determination, R^2, is compared for both sets of the second hypothesis. Hence, hypothesis two cannot be fully accepted.

In addition, the evaluation of different weights of work sampling categories on predicting labor productivity showed that the Labor Utilization Factor becomes a better estimate of the results of work sampling when the 50% factor for the essential contributory work category replaces the traditional 25% conservative factor. The accuracy of the Five Minute Rating is proven to be more than traditionally though where its effectiveness correlates moderately, R= 0.471, with work sampling. But more support for its accuracy comes from the small variation between the Five Minute Rating effectiveness and work sampling effective and essential contributory work categories proportions.

The accuracy of the Head Count technique relative to work sampling appears to be less than adequate as demonstrated by a large variation in the standard deviation and a weak Correlation Coefficient between the results of these two techniques.

5.2   Conclusions

Based on the results and discussions presented in Chapter four, the following is concluded:

1. The predictive ability of work sampling does not improve when the rate of work "pace" is included. Considering the workers' pace while performing effective work did not result in better prediction of productivity for the work sampling technique. This clearly suggests the presence of variables other than pace that impact productivity.

2. The predictive ability of work sampling does not improve when more work

sampling categories are considered in the non-paced form, while, it slightly improves when more pace weighted work sampling categories are considered. In fact, the results indicate that the best combination of work sampling to predict labor productivity in the non-paced form is when dual work sampling categories of effective and essential contributory work categories are considered. Overall, the second hypothesis cannot be fully accepted without further evaluation of other variables different than the workers pace.

3. The effective work category is considered the best work sampling predictor of productivity among the other work sampling categories which does not support the findings of Al-Ghamdi (1995) that the ineffective work category is considered a better work sampling predictor of labor productivity besides effective work category.

4. The impact of the number of work categories suggests the use of different weights in the calculation of Labor Utilization Factor, which has a two to one ratio for the effective and essential contributory work categories weight instead of the traditional, four to one ratio, to better reflect labor utilization. The traditional weight of 0.25 used in the Labor Utilization Factor for the essential contributory work category appeared to be conservative and did not reflect actual utilization of the crew, while a more realistic factor can be 0.5 instead of 0.25 factor.

5. The accuracy of the Five Minute Rating technique was found higher than actually thought as indicated by the small difference of the overall average between the effectiveness of the Five Minute Rating and that of work sampling.

6. The Head Count technique was found inaccurate relative to work sampling as

evidenced by a weak correlation of 0.103 and a large difference in the standard deviations between both techniques.

This study has investigated critical issues related to an important subject of labor productivity, which have never been addressed before. Irrespective of the unexpected findings and inferences, reported in this study, it helped reducing the controversy around the work sampling abilities for the prediction of construction labor productivity. After all, this is an academic intellectual responsibility to remove and annihilate ignorance from the scientific society for the greater good of the construction industry.

5.3   Limitations

1. The conclusions made in the study on predictive ability of work sampling are based on the assumption of linear relationships. Such assumption may not be accurate as there is a possibility that the relationship is nonlinear.
2. The conducted field experiments involving only one simple task which is building walls with small variations related to work sampling categories, and is not representative of all construction activities.

5.4   Recommendations For Future Research

In conjunction with the results and conclusions presented in this study, the following recommendations are suggested:

1. Evaluate the possible nonlinear impact of pace on work sampling ability and productivity relationship.

2. Evaluate the effect of pace and skill level combined on work sampling ability to predict construction labor productivity.

3. Develop a more refined method to measure pace of work.

4. Replicate this study on different construction activities and evaluate the impact of task characteristic on the predictive ability of work sampling.

5. Identify and assess the impact of other potential factors related to the prediction ability of work sampling.

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APPENDIX A Sample of The Observed Field Experiments

TABLE 25 Experiment 15 Observations

Observation Number	Observation Time (HH:MM:SS)	Worker	Work Category	Pace Rate
1	0:00:09	1	E	2
2		2	C	1
3	0:00:15	1	E	2
4		2	C	1
5	0:00:23	1	E	2
6		2	C	2
7	0:01:00	1	E	1
8		2	C	2
9	0:01:20	1	C	3
10		2	C	2
11	0:01:22	1	C	3
12		2	C	3
13	0:01:31	1	C	3
14		2	I	0
15	0:01:34	1	C	3
16		2	I	0
17	0:01:38	1	E	1

Observation Number	Observation Time (HH:MM:SS)	Worker	Work Category	Pace Rate
18		2	I	0
19	0:01:48	1	E	1
20		2	I	0
21	0:02:10	1	E	3
22		2	C	3
23	0:02:42	1	C	1
24		2	I	0
25	0:02:47	1	E	3
26		2	I	0
27	0:02:58	1	C	1
28		2	I	0
29	0:04:07	1	C	1
30		2	I	0
31	0:04:19	1	E	1
32		2	I	0
33	0:04:21	1	E	1
34		2	I	0
35	0:04:23	1	E	1
36		2	I	0

Observation Number	Observation Time (HH:MM:SS)	Worker	Work Category	Pace Rate
37	0:04:37	1	C	1
38		2	I	0
39	0:04:49	1	E	1
40		2	I	0
41	0:04:55	1	E	2
42		2	E	2
43	0:05:08	1	C	3
44		2	I	0
45	0:05:21	1	C	1
46		2	I	0
47	0:05:24	1	C	1
48		2	I	0
49	0:05:40	1	E	3
50		2	I	0

TABLE 26 Experiment 2 Observations

S.N.	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
1	0:00:11	1	I	0
2		2	E	3
3	0:00:32	1	C	1
4		2	C	2
5	0:00:39	1	C	1
6		2	E	1
7	0:00:54	1	C	1
8		2	E	1
9	0:01:00	1	C	1
10		2	E	1
11	0:02:02	1	I	0
12		2	E	3
13	0:02:05	1	I	0
14		2	E	3
15	0:02:09	1	I	0
16		2	C	2
17	0:02:13	1	E	3
18		2	C	2
19	0:02:27	1	I	0
20		2	E	1
21	0:02:32	1	I	0
22		2	C	1
23	0:02:38	1	C	2
24		2	E	1
25	0:02:40	1	C	2
26		2	E	1
27	0:02:47	1	I	0
28		2	E	2

29	0:02:55	1	I	0
30		2	E	1
31	0:02:59	1	I	0
32		2	C	3
33	0:03:02	1	I	0
34		2	C	3
35	0:03:05	1	I	0
36		2	C	3
37	0:03:08	1	I	0
38		2	E	1
39	0:03:28	1	I	0
40		2	E	1
41	0:03:33	1	I	0
42		2	E	1
43	0:03:38	1	I	0
44		2	E	1
45	0:03:39	1	I	0
46		2	E	1
47	0:03:46	1	I	0
48		2	E	1
49	0:03:53	1	I	0
50		2	E	2

TABLE 27 Experiment 3 Observations

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
1	0:00:13	1		
2		2		
3	0:00:16	1	E	2
4		2	I	0
5	0:00:21	1	C	1
6		2	E	3
7	0:00:35	1	E	3
8		2	E	1
9	0:00:54	1	E	1
10		2	I	0
11	0:01:03	1	E	1
12		2	I	0
13	0:01:05	1	E	1
14		2	I	0
15	0:01:11	1	E	1
16		2	E	3
17	0:01:18	1	E	1
18		2	E	3
19	0:01:45	1	E	3
20		2	I	0
21	0:01:57	1	E	1
22		2	I	0
23	0:02:07	1	E	1
24		2	E	3
25	0:02:16	1	C	1
26		2	E	3
27	0:02:23	1	E	3
28		2	E	3
29	0:02:32	1	C	3
30		2	I	0
31	0:02:37	1	E	1

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
32		2	C	2
33	0:02:40	1	E	1
34		2	C	3
35	0:02:57	1	E	3
36		2	I	0
37	0:02:59	1	C	1
38		2	I	0
39	0:03:08	1	C	1
40		2	I	0
41	0:03:10	1	C	1
42		2	I	0
43	0:03:15	1	E	1
44		2	I	0
45	0:03:20	1	E	1
46		2	I	0
47	0:03:34	1	E	1
48		2	I	0
49	0:03:37	1	E	1
50		2	I	0
51	0:03:39	1	E	1
52		2	I	0
53	0:03:41	1	E	1
54		2	I	0
55	0:03:47	1	C	1
56		2	I	0
57	0:03:52	1	E	1
58		2	I	0
59	0:04:17	1	E	3
60		2	C	1
61	0:04:23	1	E	3
62		2	I	0
63	0:04:24	1	C	1
64		2	I	0

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
65	0:04:30	1	E	1
66		2	I	0
67	0:04:34	1	C	1
68		2	I	0
69	0:04:36	1	C	1
70		2	I	0
71	0:04:37	1	E	1
72		2	I	0
73	0:04:41	1	C	1
74		2	I	0
75	0:04:43	1	E	2
76		2	E	3
77	0:04:44	1	E	2
78		2	E	3
79	0:04:47	1	C	1
80		2	E	3
81	0:04:56	1	E	1
82		2	E	3
83	0:05:04	1	E	1
84		2	E	3
85	0:05:11	1	C	1
86		2	E	3
87	0:05:24	1	C	2
88		2	E	3
89	0:05:25	1	E	1
90		2	E	3
91	0:05:49	1	E	1
92		2	I	0
93	0:05:50	1	E	1
94		2	I	0
95	0:06:16	1	E	1
96		2	C	1
97	0:06:32	1	E	1

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
98		2	C	1
99	0:06:35	1	E	1
100		2	C	1
101	0:06:37	1	E	1
102		2	C	1
103	0:06:38	1	E	1
104		2	C	1
105	0:06:43	1	E	1
106		2	C	1
107	0:06:58	1	E	2
108		2	E	2
109	0:07:12	1	E	1
110		2	C	1
111	0:07:20	1	E	1
112		2	E	3
113	0:07:36	1	E	1
114		2	I	0
115	0:07:37	1	E	1
116		2	I	0
117	0:07:52	1	E	1
118		2	C	1
119	0:07:56	1	E	1
120		2	E	3
121	0:08:02	1	E	1
122		2	E	3
123	0:08:03	1	E	1
124		2	E	3
125	0:08:25	1	C	1
126		2	I	0
127	0:08:31	1	E	3
128		2	I	0
129	0:09:10	1	C	2
130		2	E	3

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
131	0:09:30	1	C	3
132		2	E	3
133	0:09:51	1	E	2
134		2	I	0
135	0:09:56	1	C	2
136		2	I	0
137	0:09:59	1	E	2
138		2	I	0
139	0:10:02	1	E	2
140		2	I	0
141	0:10:05	1	E	1
142		2	I	0
143	0:10:11	1	E	1
144		2	I	0
145	0:10:13	1	E	1
146		2	I	0
147	0:10:16	1	E	1
148		2	I	0
149	0:10:24	1	E	2
150		2	I	0
151	0:10:38	1	C	1
152		2	I	0
153	0:10:45	1		
154		2		
155	0:10:45	1	E	1
156		2	I	0
157	0:10:46	1	E	1
158		2	I	0
159	0:10:51	1	E	1
160		2	I	0
161	0:10:56	1	E	2
162		2	I	0
163	0:10:57	1	C	2

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Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
164		2	I	0
165	0:10:59	1	E	2
166		2	I	0
167	0:11:06	1	C	3
168		2	I	0
169	0:11:21	1	C	2
170		2	E	3
171	0:11:22	1	C	3
172		2	E	3
173	0:11:23	1	E	1
174		2	E	3
175	0:11:23	1		
176		2		
177	0:11:36	1	C	2
178		2	E	3
179	0:11:37	1	C	3
180		2	I	0
181	0:11:42	1	E	1
182		2	E	3
183	0:11:48	1	E	1
184		2	C	2
185	0:11:54	1	E	1
186		2	I	0
187	0:12:01	1	C	1
188		2	I	0
189	0:12:18	1	E	1
190		2	I	0
191	0:12:23	1	E	1
192		2	I	0
193	0:12:32	1	E	1
194		2	I	0
195	0:12:40	1	E	1
196		2	I	0

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Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
197	0:12:41	1	E	1
198		2	I	0
199	0:12:42	1	E	1
200		2	I	0
201	0:12:56	1	E	1
202		2	I	0
203	0:13:16	1	E	1
204		2	C	1
205	0:13:17	1	E	1
206		2	C	1
207	0:13:19	1	E	1
208		2	C	1
209	0:13:33	1	E	1
210		2	C	1
211	0:13:46	1	E	1
212		2	C	1
213	0:14:04	1	E	1
214		2	I	0
215	0:14:05	1	E	1
216		2	I	0
217	0:14:08	1	C	1
218		2	I	0
219	0:14:11	1	E	1
220		2	I	0
221	0:14:18	1	C	1
222		2	C	1
223	0:14:32	1	E	3
224		2	C	1
225	0:14:39	1	E	1
226		2	C	1
227	0:14:43	1	E	2
228		2	C	1
229	0:14:46	1	C	2

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
230		2	I	0
231	0:14:53	1	E	2
232		2	I	0
233	0:15:14	1	E	1
234		2	I	0
235	0:15:30	1	E	1
236		2	C	1
237	0:15:33	1	E	1
238		2	C	1
239	0:15:53	1	C	1
240		2	I	0
241	0:15:57	1	E	1
242		2	C	2
243	0:16:03	1	E	1
244		2	E	3
245	0:16:10	1	E	1
246		2	I	0
247	0:16:25	1	C	1
248		2	I	0
249	0:16:29	1	E	1
250		2	I	0
251	0:16:33	1	E	3
252		2	I	0
253	0:16:37	1	E	3
254		2	I	0
255	0:16:50	1	E	2
256		2	E	3
257	0:16:58	1	E	1
258		2	E	3
259	0:17:00	1	E	1
260		2	E	3
261	0:17:06	1	E	1
262		2	I	0

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
263	0:17:07	1	E	1
264		2	I	0
265	0:17:09	1	E	1
266		2	I	0
267	0:17:11	1	I	0
268		2	E	3
269	0:17:19	1	C	1
270		2	I	0
271	0:17:21	1	E	1
272		2	I	0
273	0:17:36	1	C	1
274		2	E	3
275	0:17:58	1	E	2
276		2	I	0
277	0:18:05	1	E	1
278		2	I	0
279	0:18:12	1	E	2
280		2	E	1
281	0:18:14	1	E	3
282		2	E	1
283	0:18:18	1	E	2
284		2	I	0
285	0:18:30	1	E	1
286		2	I	0
287	0:18:34	1	E	1
288		2	I	0
289	0:18:40	1	E	1
290		2	I	0
291	0:18:47	1	C	2
292		2	I	0
293	0:18:50	1	E	1
294		2	I	0
295	0:19:00	1	E	1

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
296		2	I	0
297	0:19:09	1	I	0
298		2	C	3
299	0:19:13	1	I	0
300		2	C	1
301	0:19:16	1	E	3
302		2	C	1
303	0:19:42	1	E	3
304		2	C	1
305	0:19:45	1	E	3
306		2	C	1
307	0:19:57	1	E	1
308		2	C	1
309	0:20:04	1	E	1
310		2	C	1
311	0:20:10	1	E	1
312		2	C	1
313	0:20:20	1	E	1
314		2	C	1
315	0:20:39	1	C	1
316		2	I	0
317	0:20:45	1	C	2
318		2	I	0
319	0:20:58	1	E	1
320		2	C	3
321	0:21:07	1	E	1
322		2	I	0
323	0:21:14	1	E	1
324		2	I	0
325	0:21:27	1	E	1
326		2	I	0
327	0:21:30	1	E	1
328		2	I	0

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
329	0:21:35	1	E	1
330		2	E	3
331	0:21:38	1	C	2
332		2	E	3
333	0:21:39	1	C	3
334		2	E	3
335	0:21:43	1	E	1
336		2	E	3
337	0:21:48	1	I	0
338		2	C	3
339	0:21:52	1	E	1
340		2	C	3
341	0:21:57	1	E	1
342		2	I	0
343	0:21:58	1	E	1
344		2	I	0
345	0:22:00	1	E	1
346		2	I	0
347	0:22:03	1	E	1
348		2	C	3
349	0:22:06	1	E	1
350		2	C	3
351	0:22:09	1	E	1
352		2	C	3
353	0:22:10	1	E	1
354		2	C	3
355	0:22:16	1	E	1
356		2	I	0
357	0:22:36	1	E	1
358		2	I	0
359	0:22:45	1	E	1
360		2	I	0
361	0:22:47	1	I	0

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
362		2	I	0
363	0:22:51	1	C	2
364		2	I	0
365	0:23:08	1	I	0
366		2	I	0
367	0:23:14	1	E	1
368		2	I	0
369	0:23:16	1	C	2
370		2	I	0
371	0:23:36	1	C	2
372		2	I	0
373	0:24:25	1	C	1
374		2	E	3
375	0:24:28	1	E	1
376		2	C	3
377	0:24:29	1	C	1
378		2	I	0
379	0:24:31	1	E	2
380		2	I	0
381	0:24:46	1	C	1
382		2	E	3
383	0:24:51	1	C	1
384		2	I	0
385	0:24:52	1	C	1
386		2	I	0
387	0:24:55	1	E	3
388		2	E	3
389	0:25:02	1	C	1
390		2	I	0
391	0:25:10	1	C	1
392		2	I	0
393	0:25:12	1	E	1
394		2	E	3

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
395	0:25:14	1	E	1
396		2	I	0
397	0:25:23	1	E	1
398		2	I	0
399	0:25:27	1	E	1
400		2	I	0
401	0:25:37	1	E	1
402		2	I	0
403	0:25:38	1	E	1
404		2	I	0
405	0:25:41	1	E	3
406		2	I	0
407	0:25:42	1	E	1
408		2	I	0
409	0:25:46	1	C	1
410		2	I	0
411	0:25:54	1	E	1
412		2	I	0
413	0:26:03	1	E	1
414		2	I	0
415	0:26:05	1	E	1
416		2	I	0
417	0:26:25	1	E	1
418		2	C	1
419	0:26:26	1	E	1
420		2	C	1
421	0:27:09	1	E	1
422		2	I	0
423	0:27:17	1	C	2
424		2	I	0
425	0:27:33	1	C	1
426		2	I	0
427	0:27:51	1	E	1

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
428		2	I	0
429	0:27:55	1	E	1
430		2	C	1
431	0:28:08	1	C	2
432		2	C	1
433	0:28:13	1	C	2
434		2	C	1
435	0:28:24	1	E	1
436		2	C	1
437	0:28:39	1	E	1
438		2	C	1
439	0:28:43	1	E	1
440		2	C	1
441	0:28:46	1	E	1
442		2	C	1
443	0:28:51	1	E	1
444		2	C	1
445	0:28:54	1	E	1
446		2	C	1
447	0:29:09	1	E	1
448		2	I	0
449	0:29:11	1	E	1
450		2	C	3
451	0:29:21	1	E	1
452		2	C	1
453	0:29:42	1	E	1
454		2	C	1
455	0:29:50	1	C	1
456		2	I	0
457	0:29:51	1	C	1
458		2	I	0
459	0:30:00	1	E	1
460		2	C	1

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
461	0:30:01	1	E	1
462		2	C	1
463	0:30:02	1	C	1
464		2	C	1
465	0:30:19	1	E	1
466		2	C	1
467	0:30:35	1	E	1
468		2	E	3
469	0:30:41	1	C	2
470		2	C	3
471	0:30:46	1	C	3
472		2	I	0
473	0:30:47	1	C	3
474		2	I	0
475	0:30:51	1	E	1
476		2	I	0
477	0:30:56	1	E	1
478		2	E	3
479	0:31:06	1	E	1
480		2	E	3
481	0:31:11	1	E	1
482		2	E	3
483	0:31:12	1	E	1
484		2	E	3
485	0:31:17	1	E	1
486		2	E	3
487	0:31:28	1	E	1
488		2	C	1
489	0:31:30	1	E	1
490		2	I	0
491	0:31:38	1	E	2
492		2	I	0
493	0:31:49	1	E	1

Observation Number	Observation Time (HH:MM:SS)	Worker	Work category	Pace Rate
494		2	I	0
495	0:31:58	1	E	1
496		2	I	0
497	0:32:12	1	E	1
498		2	I	0
499	0:32:20	1	C	2
500		2	I	0
501	0:32:29	1	E	2
502		2	I	0
503	0:32:34	1	C	2
504		2	I	0
505	0:32:38	1	E	2
506		2	I	0
507	0:32:52	1	E	1
508		2	I	0
509	0:32:53	1	E	1
510		2	I	0
511	0:33:01	1	E	2
512		2	I	0
513	0:33:04	1	E	3
514		2	I	0
515	0:33:09	1	E	1
516		2	I	0
517	0:33:14	1	E	2
518		2	I	0
519	0:33:16	1	C	2
520		2	I	0
521	0:33:27	1	E	1
522		2	I	0
523	0:33:28	1	C	3
524		2	I	0

APPENDIX B Examples of Different Average Pace Calculations

TABLE 28 Determining Average Pace Rate for Traveling Speed With a Block in Hands By Laborer 2

	Traveled Distance (Meters)	Time (Seconds)	Pace Rate "Speed" (Meters/Second)
Total Counts 10	2	7	0.29
	3.5	5	0.70
	4	5	0.80
	4.8	5	0.96
	5.4	6	0.90
	5.6	7	0.80
	5.6	7	0.80
	6	5	1.20
	6.05	6	1.01
	41.95	53	0.79
Total	84.9	106	8.25
Average	84.9	106	0.8

TABLE 29 Determining Average Pace Rate for Leaning to Reload Mortar From The Bucket By Laborer 1

	Traveled Distance (Meters)	Time (Seconds)	Pace Rate "Speed" (Meters/Second)
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
Total Counts 24	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
	1.1	1	1.1
Total	22	20	22
Average	1.1	1	1.1

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TABLE 30 Determining Average Pace Rate for Kneeling Down to Pick or Lift a Block By Laborer 2

	Traveled Distance (Meters)	Time (Seconds)	Pace Rate "Speed" (Meters/Second)
Total Counts 6	0.2	1	0.2
	0.2	1	0.2
	0.4	1	0.4
	0.4	1	0.4
	0.4	1	0.4
	0.4	1	0.4
Total	2	6	2
Average	0.33	1	0.33

TABLE 31 Determining Average Pace Rate for Lifting The Block Fully By Laborer 2

	Traveled Distance (Meters)	Time (Seconds)	Pace Rate "Speed" (Meters/Second)
Total Counts 5	0.3	1	0.3
	0.3	1	0.3
	0.3	1	0.3
	0.3	2	0.15
	0.3	2	0.15
Total	1.5	7	1.3
Average	0.3	1.4	0.21

Vitae

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