# BENCHMARKING THE LABOR PRODUCTIVITY: AN ACTIVITY ANALYSIS ON SEMI HIGH RISE BUILDING PROJECTS IN PAKISTAN

**Thesis of**

**Master of Science**

***By***

**Engr. Noaman Akbar Sheikh**

**(**NUST201362151MSCEE15413F**)**

Department of Construction Engineering and Management
National Institute of Transportation (NIT)
School of Civil and Environmental Engineering (SCEE)
National University of Sciences and Technology (NUST),
Islamabad, Pakistan.

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This is to certify that the
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________________________________

**Dr. M. Jamaluddin Thaheem**

Supervisor,

Department of Construction Engineering and Management,

NIT, National University of Sciences and Technology (NUST), Islamabad

*This thesis is dedicated to my parents, siblings and respected teachers!*

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# ABSTRACT

Construction is a labor intensive industry and onsite labors are one of the most variable and costly factors which influence the project profits. Due to inconsistent nature of construction labor and its correlation with profits, construction managers require a comprehensive understanding of the activities of workers onsite. For project success, it is important that workers are spending the majority of their time doing the activities which advance the project usually known as “direct work” or “tool time”. It is important to assess these work activities in detail. For assessment of labor productivity, activity analysis technique based on Construction Industry Institute (CII) guideline is used in order to understand the distribution of labor time throughout the day with a good level of statistical accuracy.

The aim of this research is to assess the labor productivity of different construction projects in Pakistan, identify the productivity inhibitors and determine the causes of low labor productivity based on the results. It was found that on average the labor spends almost 35% of their time doing direct work and 37.25% in supporting work. Alarmingly, around 28% of the time is wasted due to delays which can be improved if effective planning and supervising of works is provided on site.

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*Chapter 1*

# INTRODUCTION

## 1.1 GENERAL

In a competitive construction environment, costs are decreased in order to increase market competitiveness and profits. Therefore, it is a common objective of all the construction companies to offer better value against minimum cost. Among all the factors which influence project profits, on-site labor costs are the most influential (Thomas and Mathews, 1986). To reduce costs, it is important to identify areas of high and low labor productivity.

Generally, there is no standard way or method for measuring labor productivity in the construction industry because it involves many very complex operations and relationships (Oglesby et al., 1989; Crawford and Vogl, 2006). Measuring the labor productivity of the construction industry remains a difficult task. The limitations of measuring labor productivity include lack of availability, productivity and reliability of data, and failure to measure more important things (e.g. the effectiveness of project management, the quality level achieved, and the innovations). Improvement in technology can also create hindrances in separating the contributions of technology management and labor to construction labor productivity. Further, owing to scarcity of reliable data, it is difficult to compare the construction labor productivity between various countries (Flanagan et al., 2007).

In the past, various studies have been conducted to understand productivity. This has given rise to a variety of definitions of the term (Oglesby et al., 1989; Pilcher, 1992; Lema, 1995). According to Rowlinson and Procter (1999), productivity is defined as the average direct labor hours required to install a unit of material. On the other hand, Hannula (2002) describes productivity as the ratio of total output to total input. Construction industry confronts challenges regarding issues related to productivity and the problems are usually linked with progress of labor. The performance of labor is affected by many elements and is associated with performance of time, cost, and quality. There is a strong need to assess the performance of labor during working in order to address the issue regarding productivity.

It is said that perfect productivity (1.0) can be achieved with a 40-hour work week; with people taking all the holidays and vacation days, all of the engineering drawings would be 100% complete and there would be no delays of any kind during construction. Thus, everyone would work safely, everything would fit perfectly the first time and there would be no litigation at the end of the project (Rowlinson and Procter, 1999).

Craft performance may be measured and reported in several ways. Of these, most popular methods or techniques to measure are calculation of direct productivity unit rates, percent rework, unit rates and activity levels (Yi Wen and Chan., 2013). Each measures the work in separate way and serves as a good metric for understanding actual craft performance. The team of craft productivity research program at Construction Industry Institute (CII) in July 2010 developed a comprehensive guide to Activity Analysis as there was no proper guide or procedure to assess productivity using this technique. Activity analysis includes significantly more detailed observations which are typically broken down into seven or more categories: direct work, preparatory work, tools and equipment, material handling, waiting, travel, and personal. These categories are monitored for each of the crafts on a jobsite.

## 1.2 PROBLEM STATEMENT

The main problem which exists in construction industry is loss of productivity. The cost on labor is 33% to 50% of total project cost (Jergeas, 2009). Construction requires extensive manual labor. Loss of its productivity results in increase in labor cost which ultimately affects the project cost (Gouett et al., 2011). Therefore, there is a strong need to identify the specific areas for improving labor productivity so that management may understand the real work percentages, implement improvements, and quantify the changes to increase the direct work.

For maximum productivity it is important that labors are spending maximum time doing the direct work which advances the project. So, it is important to measure the direct work time and other time that the labor spends during the total time. By assessing and analyzing portion of time that workers are spending on activities such as installing materials, planning work, travelling, waiting, and personal, productivity issues can be identified. Afterwards, guidelines to improve productivity can be proposed and implemented.

## 1.3 RESEARCH OBJECTIVE

The specific objectives of this research are:

- To provide a detailed study of various labor productivity assessment techniques.
- To assess the labor productivity of different building construction projects
- To analyze the data and examine the interrelation of productivity related labor activities.
- To provide productivity inhibitors and determine the causes of low productivity at each construction projects.
- To benchmark the overall labor productivity of construction projects.

*Chapter 2*

# LITERATURE REVIEW

## 2.1 BACKGROUND

Since the middle of the 20th century, productivity in the construction industry has been a challenging task to many researchers and practitioners (Asher, 1956; McNally and Havers, 1967). The construction industry also involves a large number of variables; the labor intensive work, the unique character and the occurrence of unpredictable events (Choromokos and McKee, 1981; Thomas and Yiakoumis, 1987; Thomas et al., 1990; Kaming et al., 1997; Arditi and Mochtar, 2000; Gulezian and Samelian, 2003; Ng et al., 2004; Zayed and Halpin, 2004; Abdel-Razek and Abdel-Hamid, 2007). Therefore, the construction process results in relatively high costs (Gambao et al., 2000) and labor becomes a more important input in the production phase. Moreover, the labor cost is somewhere between 20% and 50% of the total project cost and the reduction of these costs can be best carried out by improving productivity (Buchan et al., 1991; Kaming et al., 1997; Zakeri et al., 1997).

Improving productivity is a major concern for any profit-oriented organization, as representing the effective and efficient conversion of resources into marketable products and determining business profitability (Wilcox et al., 2000). Consequently, considerable effort has been directed to understanding the productivity concept, with the different approaches taken by researchers resulting in a wide variety of definitions of productivity (Pilcher, 1992; Lema, 1995). In addition, factors affecting productivity may vary from task to task. Although some factors could have similar influences on the productivity of a number of tasks, their rate of impact on productivity may vary (Sonmez and Rowings, 1998). The assignment decisions of resources such as labor, equipment and material control the overall duration and cost of a project (Hegazy, 1999). Construction productivity is traditionally identified as one of the three main critical success factors together with cost and quality for a construction project (Nkado, 1995; Walker, 1995). The application of productivity rate which is an indicator of the construction time performance is in the scope of planning and scheduling of the construction, controlling of the cost and worker performance, estimating and accounting.

Labor productivity has been identified as an index for measuring efficiency because labor is acknowledged as the most important factor of production since it is one of the major factors that creates value and sets the general level of productivity (Ameh and Odusami, 2002). Choy and Ruwanpura (2006), Hewage and Ruwanpura (2006), Da Silva and Ruwanpura, (2006). Ruwanpura et al., (2006), McTague et al., (2002) and McDonald and Zack (2004) conducted the tool time analyses, reiterate finding and have revealed that the composition of productive tool time on a construction site generally falls between 40 and 60% of the total work time. The studies also elaborated on the individual activities that a worker spends his time on and concluded that a considerable amount of time is spent mostly on nonproductive activities, such as searching for material, idling, and waiting for instructions. As a result, the construction and project management industries have already begun to experience an era of intensified research and development activities.

## 2.2 DEFINITION OF PRODUCTIVITY

Thomas et al., (1986) stated that no standardized productivity definition had been established in the construction industry. It is difficult to define a standard productivity measure because companies use their internal systems which are not standardized. Many definitions of the word "productivity" exist. Merriam-Webster defines productivity as the quality or state of being productive. According to Bernolak (1997) productivity means *"how much and how good we produce from the resources used"*. On the other hand, Hannula (2002) describes productivity as the ratio of total output to total input. Although there are endless definitions, they all refer to productivity as a comparison of input versus output. Productivity can be simply illustrated by an association between an output and an input. Two forms of productivity were used in previous industry studies are shown in Equation 1 and 2:

1) $$\text{Productivity} = \frac{\text{Output}}{\text{Input}} \qquad (1)$$

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

The second form has been widely used and existing in literature over the years in the construction industry. Therefore, we have adopted the second form to maintain consistency with other productivity research in construction and Construction Industry Institute (CII) benchmarking and metrics. Inputs include the resources associated with labor, tools and equipment, and materials. Outputs are deliverables that contribute to the completion of the project, whether it is cubic meters of concrete placed, tons of steel erected, or length of pipe welded. Low productivity is a result of too many inputs and too few outputs; that is, project costs are high with few deliverables completed. (Gouett et al., 2011).

In general, productivity means how one entity uses its resources to produce outputs from inputs (Enshassi et al., 2007b). Productivity can be defined as work performed with respect to time. Productivity can also be calculated by taking the ratio of real output of production to what we want to produce. The resources available to us for using input are normally cost of labor and output is in volume. Many guidelines are available for contractors to take the reference value for construction cost estimation. These guidelines are similar principle wise but may vary little bit in values.

### 2.2.1 Labor Productivity

Labor productivity ignores the cost of equipment and material, because in the short term these are difficult inputs to change. Further, the cost of labor is affected by factors such as craft, experience, geographic location, etc. For this reason, labor productivity also ignores the actual cost of labor, and instead considers the number of hours to produce one unit of output. This is indicated in Equation 3 (Thomas Jr, 1981; Groover, 2007).

$$\text{Labor Productivity} = \frac{\text{Labor hours}}{\text{Unit of physical output}} \quad (3)$$

In this form, a smaller labor productivity value is desirable since labor hours (an input) are used as the numerator in the equation. This is in contrast to factor productivity, where a higher value was the goal.

### 2.2.2 Productivity Factor

Productivity factor is the comparison between anticipated labor productivity and actual labor productivity. McDonald and Zack (2004) reported for the American Association of Cost Engineers providing an Equation 4 for productivity factor:

$$\text{Productivity factor} = \frac{\text{Actual Productivity}}{\text{Baseline Productivity}} \tag{4}$$

This can be clarified by Equation 5:

$$\text{Productivity factor} = \frac{\text{Actual Unit rate}}{\text{Planned Unit Rate}} = \frac{\text{Actual work}-\text{hours per unit of output}}{\text{Planned work}-\text{hours per unit of output}} \tag{5}$$

In this form, a productivity factor less than one is ideal since the actual work-hours per unit is less than the planned work-hours per unit of output. It is noted, that some contractors report productivity factor as the reciprocal: planned over actual. In this form, a productivity factor greater than one is ideal.

When calculating activity durations, historical unit rates from previous projects are used. As the project progresses it is important to measure actual labor productivity and compare to the unit rate to determine if the project is on schedule. A productivity factor, calculated as per the equation provided, greater than one indicates more work-hours are needed than anticipated. This could potentially lead to cost overruns and schedule delays.

### 2.2.3 Activity Level

Activity level is the percent of time craft spend on a particular activity such as direct-work, preparatory- work, material-handling, waiting, etc. For construction managers the direct-work rate is most important because it quantifies the amount of time workers are actively installing materials toward the completion of the project. The direct-work rate can be calculated using a statistical work measurement method known as work or activity sampling. Observations of work are categorized, and the direct-work rate is calculated as the number of direct-work observations divided by the total number of observations.

$$\text{Direct} - \text{Work rate} = \frac{\text{Observation of direct} - \text{work}}{\text{Total no. of observations}} \quad (6)$$

Equation 6 results in a percentage, which indicates the proportion of time craft is spending completing units of output. However, unlike the other three metrics, activity level does not actually consider the number of units produced. This is true for all activity level percentages.

## 2.3 LABOR PRODUCTIVITY MEASUREMENT AND ITS ISSUES IN CONSTRUCTION INDUSTRY

In general, there is no standard way or method for measuring labor productivity in the construction industry because construction involves many very complex operations and relationships (Oglesby et al., 1989; Crawford and Vogl, 2006). Productivity is a way of measuring how much a sector in the construction industry produces given an amount of resources or how much resources are needed when producing a given number/volume of a product. The reason for measuring productivity is to understand the production processes and learn about capacity of machinery and workers (Ingvaldsen et al., 2004).

According to Noor (1998), labor productivity measurement techniques fall within a spectrum between two broad categories of observational methods, namely continuous observation (e.g. direct observation and work study) and intermittent observation (e.g. audio-visual methods, delay surveys and activity sampling). In the construction productivity field, there is a need for measures of productivity at three levels:

a) *task* – which refers to specific construction activities;
b) *project* – which is the collection of tasks required for the construction of a new facility or renovation of an existing facility;
c) *Industry*– which represents the total portfolio of projects.

The measurement problem is exacerbated by the fact that the construction industry is composed of four sectors that differ significantly in; the outputs produced, firm size, and use of technology. The four sectors, which taken together define the construction industry, are residential, commercial/institutional, industrial, and infrastructure (Lin and Huang, 2009). This means that for each of these unique sectors, which in most cases construction companies are engaged in simultaneously, the contractor has to develop systems of measuring the different forms of output and the varied conditions under which all these projects are carried out.

Although rigorous analysis such as artificial intelligence based modeling was adopted for improvement in accuracy of the change/variation on Construction Labor Productivity, but these studies did not consider the learning-curve effects as it would lead to an overstatement of productivity losses. As the crew becomes more familiar with the task, continuous repetition of a task may improve productivity and this repetition may also lead to better management of equipment, crew, and material, resulting in productivity improvements (Thomas et al., 1986). Continued research on the relationship between change and Construction Labor Productivity included the effect of repetition is recommended for future research to generalize findings. Compared to various methods for baseline Construction Labor Productivity, not much attention has been given to Construction Labor Productivity metrics. Researchers have stressed the importance of standardized productivity data (Thomas and Yiakoumis, 1987) and Construction Industry Institute (CII) has long proposed the need for such metrics. More research on establishing a reasonable Construction Labor Productivity data collection tool for Construction Labor Productivity benchmarking and improvement is needed.

Numbers of publications exist on construction productivity, but there is no agreed upon definition of work activities nor a standard productivity measurement system. Researchers have concluded that it is difficult to obtain a standard method to measure construction labor productivity because of project complexity and the unique characteristics of construction projects (Oglesby et al., 1989).

The uniqueness and no repetitive operations of construction projects make it difficult to develop a standard productivity definition and measure (Sweis, 2000). A few researchers have attempted to develop common definitions and a standard productivity system; however, those were not based on the consensus of academia and industry. The

Construction Industry Cost Effectiveness (CICE) Project report reviewed construction productivity measurement procedures and then recommended that productivity measurement programs should be established. In 1990, CII developed a productivity measurement system that includes a reporting system, an output and input measuring system, and a performance evaluation system to measure site-level productivity (CII 1990). Adrian and Boyer (1976) established the method productivity delay model to measure, predict, and improve the productivity of a given construction method and reviewed the methods for measuring single factor productivity and total factor productivity in construction. Thomas and Yiakoumis (1987) described the factor model that contains environmental, site, management, and design factors for structural steel and masonry formwork activities. Sanders and Thomas (1993) further identified factors such as construction methods, design requirements, and weather that affect masonry productivity and investigated the effect of factors using the factor model with data obtained from standardized collection procedures. Another model, the action–response model, also provides a framework for evaluating the causes of productivity loss on projects to mitigate or eliminate the loss of productivity (Halligan et al., 1994). The CII research report also documented the factors that could affect craft worker productivity such as engineering/design, site conditions, materials, construction management, and labor problems (CII 2001).

Liou and Borcherding (1986) determined, productivity measurement is not a one-time task. Continuous measurement and comparison with other projects or companies are the keys to productivity improvement. Thomas and Yiakoumis (1987) stressed the importance of a standardized productivity data collection system to provide reliable analyses. The productivity measurement research studies mentioned above have focused on how to report, measure, control, evaluate, and improve construction productivity. Yet, those studies lack a common set of definitions of activities and a standard data collection method. Furthermore, the existing productivity measurement systems have focused on micro level activities to manage daily or monthly productivity during construction and that are tied to a sophisticated cost control system that is too complex to track and evaluate construction productivity. The construction productivity metrics system (CPMS) in this paper uses common definitions to establish industry productivity norms that can be utilized as a benchmarking tool over years.

Thomas and Završki (1999) developed a conceptual Construction Labor Productivity benchmarking model, which is widely applied in order to compare labor productivity in one construction project to that of another, and to establish the basis of benchmarking Construction Labor Productivity (Abdel-Razek and Abdel-Hamid, 2007). However, the baseline Construction Labor Productivity method was criticized for lack of objectivity. Thus, different methodologies such as control chart, K-means clustering method, data envelopment analysis for deriving baseline Construction Labor Productivity have been developed (Gulezian and Samelian, 2003; Ibbs and Liu, 2005). Several important benchmarking indicators have been used for construction projects (Yeung et al., 2009). Benchmarks such as disruption index, performance ratio and project management index were found to have correctly identified the best and worst performing projects (Abdel-Razek and Abdel-Hamid, 2007). Other indicators such as manpower loading charts and the related S-curves can be used to provide early warning signs for contractors and owners that the projects deviate from the planned benchmark (Hanna et al., 2002).

## 2.4 WHY TO INCREASE LABOR PRODUCTIVITY

One of the important and key components of success of every construction company is productivity (Mojahed, 2005). The ratio of output to input of labor is productivity; and there are many factors which affect the output that are not under the control of workers e.g. lack of equipment, the introduction of new technologies and so on (Parham, 1999). As Construction industry is one of the most labor incentive industries and human resource covers a large project cost. Project managers always face problems to improve their project results by improving labor productivity. Now developing countries are also giving importance to productivity. Building and infrastructure projects are normally included in construction industry. Mostly building projects are focused for productivity. The overall impact of factors varies with type of construction and other aspects of project.

Construction industry faces challenges and problems and these challenges and problems are also associated with labor. Many factors are there which affects labor productivity are usually related to time period, expenditure and better quality. In last decade recognition of those elements have been made which have a significant impact on labor productivity but still there is need of in-depth realization in order to enhance the productivity of labor. The factors which highly affect are execution plan, supervision, material shortage etc. Equipment factors also have high effect but in large construction companies. Owner and consultant factors may affect in small and medium companies. In small construction companies, importance is not given to health and safety factors and therefore has some effect, while in large companies it is a better, although not as major concern and has average effect (Soekiman et al., 2011). Productivity varies from country to country and also from company to company. It is also related to how the employee is motivated to do his work. To get better productivity one have to optimal utilization of manpower, accurate estimation of time and cost, high morale of employee, etc. (Ailabouni, 2005). In building projects one main reason of cost and time overruns is poor productivity of labor. In developing countries, productivity of labors is very important where still most work is done on manual basis. There are many ways that have been proposed to improve the productivity of the building industry (Alinaitwe et al., 2006).

Productivity is one of the significant issues in construction industry in both developed and developing countries. The developed countries are well aware of the importance of social welfare and economic growth. The developing countries are facing unemployment issues, inflation and resource scarcity hence they are seeking to utilize resources in such a way to achieve better economic growth and improve citizens' lives (Enshassi et al., 2007a). Cost overruns, delays and productivity issues are associated with construction projects everywhere. There are many poor management practices that results in poor productivity and hence delay and cost overruns. Many researchers strive to overcome these by recommendations but these recommendations have yet to be implemented (Jergeas, 2009). It is a big challenge for any manager to find appropriate ways to increase productivity. This is especially true in the field of labor productivity, where an accurate identification of output quantitatively is more difficult.

Level of skill, experience of work force, adequacy of method of construction and inadequate supervision are the constraints with high effect on labor productivity are concluded by Ismail and Durdyev (2012). To calculate productivity is a complex problem in construction projects, AbouRizk and Dozzi (1993) identified two major and important ways of labor productivity and they are the effectiveness with which labor is utilized and efficiency of labor to what is required. Six key factors which highly affect labor productivity are lack of material, supervision delays and lack of equipment, rework interference and absenteeism (Makulsawatudom and Emsley, 2001).

## 2.5 FACTORS AFFECTING LABOR PRODUCTIVITY IN CONSTRUCTION INDUSTRY

If productivity is to be increased, it is important to understand the factors which affect it and Understanding these factors affecting labor productivity at construction activity level would help designers to design structures that could be constructed more efficiently and would enable constructors to better estimate, plan, schedule, and manage tasks. Numerous studies have been identified and quantified the factors affecting labor productivity in different construction activities, including masonry, pipe installing, formwork, steel fixing, concrete pouring activity, rigging, and welding pipe (Sanders and Thomas, 1989; AbouRizk et al., 2001; Fayek and Oduba, 2005; Ezeldin and Sharara, 2006). The amount of work, crew size, buildability, environmental conditions, and learning effects produced a significant influence on the production rate of all construction tasks (Sanders and Thomas, 1993; Fayek and Oduba, 2005; Jarkas and Horner, 2011). The effect of the factors on productivity may vary from task to task. Although some factors could have similar influences on productivity of a number of tasks, their rate of impact on productivity may be different.

The way to find opportunities for construction labor Productivity improvement is to identify what factors are affecting it. There has been much work identifying the factors that affect productivity. It is known that Construction Labor Productivity is related to the following variables: management (proper planning, realistic scheduling, adequate coordination, and suitable control); labor (union agreements, restrictive work practices, absenteeism, turnover, delays, availability, level of skilled craftsmen, and use of equipment); government (regulations, social characteristics, environmental rules, climate, and political ramifications); contracts (fixed price, unit cost); owner characteristics; and financing (Koehn and Brown, 1986). Management is regarded as a major influence on Construction Labor Productivity (Maloney, 1983) in an early phase. There has been significant research on how to make management more effective in supporting crafts workers in the field. It was suggested that the first and fundamental management action was to reduce work flow variation from plan (Liu et al., 2011).

According to Thomas et al. (1990), list of factors which affect labor productivity are as follow:

1. Type of project;
2. Scope and size of project;
3. Complexity of project;
4. Stage of project;
5. Type of craft;
6. Geographical location of project;
7. Weather conditions;
8. Special site conditions;
9. Layout of project (including congestion issues);
10. Construction methods
11. Safety and housekeeping;
12. Labor skill level;
13. Absenteeism and labor turn overrates;
14. Distribution of workforce (journeyman to apprentice ratio, use of helpers);
15. Length of workday including schedule of breaks and over time
16. Use of automated tools over manual tools

Note that each factor is not completely independent of others. For instance, the scope and type of project affects the complexity of the project. Further, the stage and scope of the project will affect the types of craft onsite at any given time. Generally, the early stages of projects contain more civil related crews who work in excavation, concrete, and steel. However, in later stages when the building frame has been constructed, the majority of the crafts become electricians and pipefitters.

The list of factors affecting labor productivity has been organized so that the factors which construction site management can affect are isolated. Factors 1 through 8 cannot be changed by the management team. Obviously contract specifics like scope and type of project are set. Further, stage is a natural progression, and the type of crafts onsite will be determined by the stage of the project. When attempting to improve productivity, factors 9 through 16 must be considered.

Rojas and Aramvareekul (2003) presented the results of an industry survey which identified factors which affect labor productivity. This list included factors that were identified by Thomas in 1986 and 1993, but also others which were not:

17. Capability of supervisors to manage work;
18. Materials management;
19. Lack of quality leading tore work;
20. Change orders; and
21. Economic climate

The article points out that change orders can have significant impacts on labor productivity. In three case studies, the average loss of productivity due to changes in scope amounted to 30% (Rojas and Aramvareekul, 2003). Further, they argue that good economic climates encourage construction and leads to managers hiring workers with less skill due to labor shortages. Again it is important to notice that no factor is unaffected by others, which is witnessed by the connection between economic climate and skill level of craft workers.

Again it must be determined which factors on labor productivity can be affected by construction management. From the second list it is identified that factors 17 to 19 may be controlled, but the economic climate and change in scope of work are out of the hands of construction managers

Although technologies decidedly have the capability to improve labor productivity, it is more difficult in construction industry to introduce new technology than other industries (Brynjolfsson and Yang, 1996; Allmon et al., 2000). Innovation barriers such as diverse standard, business cycles, industry fragmentation, risk aversion and other factors can create hospitable climate for innovations. In many regions of world, labor costs for are relatively low many skills. When the associated labor is not expensive, then there is less motivation to automate a task (Allmon et al., 2000).

## 2.6 WORKFACE ASSESSMENT METHODS

There are several workface assessment methods. Of the most common are foreman delay surveys, craftsman questionnaires, five minute ratings, and work sampling.

### 2.6.1 Foreman Delay Survey

Foreman delay surveys are daily reports by the foreman which summarize issues which are adversely affecting productivity of their crew (Oglesby et al., 1989). These productivity issues are beyond the control of the foreman, and therefore reflect management's effectiveness at planning work, and allocating tools, equipment and materials (Rogge and Tucker, 1982; The Business Roundtable, 1982).

At the end of each period, the foreman estimates the number of hours his crew was delayed. The foreman delay survey provided in the Figure 2-1 was modified from Oglesby et al. After the time lost to each delay has been estimated, the foreman multiples the lost time by the number of members in a crew to determine the overall time the crew lost to that delay. This is summarized in the Equation 7:

$$\text{Labor hours delayed} = \text{Number of hours} \times \text{Number of crewmembers} \qquad (7)$$

These specific delays can be summed; however, the relevant information is the amount of time lost on each specific delay, so that major delays may be targeted first.

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

The benefits of the foreman delay survey include:

- A simple method to measure and interpret results;
- Data acquisition is quick and at a low cost;
- Can canvas the entire jobsite;
- Provides specific delay information;
- Data collected is current and up-to-date
- Delays can be separated by crew and/or craft (The Business Roundtable, 1982).

Disadvantages of foreman delay surveys include:

- More paperwork for foremen;
- Foremen may be concerned of repercussions from management
- Potential for inaccurate results due to estimations

Date: ____________ Name: ____________

Number in crew: ____________ General Foreman: ____________

Foreman's name: ____________

| Problems causing delay | Manhours lost | | | | |
|---|---|---|---|---|---|
| | Number of hours | X | Number of workers | = | Labor hours |
| Changes/redo (design error or change) | | X | | = | |
| Changes/redo (prefabrication error) | | X | | = | |
| Changes/redo (field error or damage) | | X | | = | |
| Waiting for materials (warehouse) | | X | | = | |
| Waiting for materials (vendor delay) | | X | | = | |
| Waiting for tools | | X | | = | |
| Waiting for construction equipment | | X | | = | |
| Construction equipment breakdown | | X | | = | |
| Waiting for information | | X | | = | |
| Waiting for other crews | | X | | = | |
| Waiting for fellow crew members | | X | | = | |
| Unexplained or unnecessary move | | X | | = | |
| Other: | | X | | = | |
| | | X | | = | |

Comments: ____________

**Figure 2-1 Example foreman delay survey template**

### 2.6.2 Craftsman's Questionnaire

Craftsman's questionnaires were first developed in the 1960's, around the same time as foreman delay surveys. Similar to foreman surveys, craftsman's questionnaires attempt to quantify time lost through asking the opinion of someone intimately involved at the workface. Oglesby et al. (1989) stated that simply asking the opinion of craft workers helped to identify weaknesses of the work process, create ideas how to solve productivity issues, and disclose workers' frustration over lack of tools, equipment and materials. It was the last benefit that the authors believed was most beneficial since it helped create a stronger site to management relationship.

Formal craftsman questionnaires aim to identify inefficiencies at the workface. Questions of typical craftsman questionnaires focus on issues with materials, tools, equipment, scaffolds, rework, crew interferences, information flow, inspection, and employee relations programs. The survey is meant to be anonymous so that workers can openly express their opinions. Typically, the only demographic questions asked are trade and area of site. In this way inefficiencies are identified and may be improved upon. Further, the surveys also provide management with the ability to do job-to-job comparisons of working conditions, methods, and materials management. Often the surveys also identify de-motivating policies.

Benefits of craftsman's questionnaire include:

- Data is simple to collect and analyze;
- Can canvas the entire site;
- Results can be separated by craft or area
- Provides craft with a voice on important subjects

Disadvantages of craftsman's questionnaire include:

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

### 2.6.3 Five Minute Rating

An older workface assessment method that is rarely used is the five minute rating technique. The method is used to create awareness of delays in a job, measure the effectiveness of a crew and indicate problem areas which require further study (Oglesby et al., 1989). The technique rates a crew's performance over a defined interval as either effective or non-effective (i.e. delay). This creates an awareness of the magnitude of delays and provides a measure of the effectiveness of a crew (Thomas and Daily, 1983).

During the interval, which ranges from 30 seconds to several minutes, the percentage of time actively working is estimated for each crew member using a form. The form has been modified and has been provided for the reader's reference. As the form indicates, each crew member is rated as effective or not, all at the same time. If the observer determines the amount of time spent working by the individual is greater than 50%, the entire interval is rated as effective and receives a mark (Oglesby et al., 1989; Thomas and Daily, 1983). If the time spent working is less than 50%, the entire interval is rated as ineffective and receives no mark. Immediately after one interval has ended the next interval begins. This process continues for the length of the study period. Several studies of the same crew should be completed in a day. Example of data collected is shown in Figure 2-2.

The overall crew effectiveness is calculated as shown in the Equation 8:

$$\text{Percent crew effectiveness} = \frac{\text{Total number of effective intervals}}{\text{Number of intervals x Numbers of crew members}} \quad (8)$$

Benefits of the five minute rating include:

- Data collection is relatively simple and easily understandable;
- Very quick estimate of the general work behavior
- Identifies areas that require further analysis

Disadvantages to the method include:

- Does not distinguish cause of delays;
- Difficult to accurately observe all crew members.

Date July 9, 2009
Job Erecting precast panels
Contractor N & E Corp.
Superintendent
Foreman

| Time | IRONWORKER | IRONWORKER | CARPENTER | CARPENTER | CARPENTER | WELDER | |
|---|---|---|---|---|---|---|---|
| START | 1 | 2 | 3 | 4 | 5 | 6 | |
| 10:13 | ✓ | | | | | | *Crew waiting for panel to be hoisted* |
| :14 | ✓ | ✓ | ✓ | ✓ | ✓ | | *Landing panel, welder waiting to* |
| :15 | ✓ | ✓ | ✓ | ✓ | ✓ | | *tack rebar* |
| :16 | | ✓ | ✓ | ✓ | ✓ | | *Install upper bolts from braces* |
| :17 | | ✓ | | ✓ | ✓ | | *Install braces* |
| :18 | | | ✓ | ✓ | ✓ | | *Align panels* |
| :19 | | | ✓ | ✓ | ✓ | | *Align panels* |
| :20 | | | ✓ | ✓ | ✓ | | *Align panels* |
| :21 | ✓ | ✓ | ✓ | | | | *Unhook crane* |
| :22 | ✓ | ✓ | ✓ | | | | *Unhook crane* |
| :23 | | | | | | ✓ | *Weldertacks rebar, crew waits for next* |
| :24 | | | | | | ✓ | *panel to be hoisted* |
| :25 | | | | | | ✓ | |
| | 5 | 6 | 8 | 7 | 7 | 3 | *Effective unit totals* |
| | | | | | | | |
| | | | | | | | |
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| | | | | | | | |
| | | | | | | | |

Total Man Units 78

Effective 36

Effectiveness 46 %

**Figure 2-2. Example five minute rating template**

### 2.6.4 Work Sampling

Randolph Thomas, the foremost academic on work sampling in construction, defined the method as “a productivity measurement technique used for the quantitative analysis, in terms of time, of the activities of men or equipment” (Thomas and Holland, 1980). The method estimates the proportion of time craft workers are spending on activities such as installing materials, planning work, waiting, travelling, etc. (Aft, 2000; Picard, 2004). It is of great concern that how labor spend their working time in construction. Work sampling is a technique that measures the time craft spent in various categories. In construction industry, work sampling use is not new but the consistent implementation has been rare. Few large construction companies on their projects conduct work-based studies periodically, the data of their assessments is generally kept away from public (CII, 2010). It is unlikely that subsequent work-sampling studies will show the effects of any corrective action (Thomas, 1991).

Work sampling is a statistical technique where an observer collects a series of random observations from the worker population (Aft, 2000; Jenkins and Orth, 2003; Picard, 2004; Stoyanoff and Bowles, 1972). For each observation, the observer instantaneously determines the activity of the worker, and then records it in one of several activity categories. The categories included in the most general work sampling study are direct-work, preparatory-work, tools-and-equipment, material-handling, waiting, traveling, and personal- time. The proportion of time spent in each category is then determined by the percentage of observations of that activity from all of the observations. Further, the statistical accuracy of this measurement can be determined from the number of samples collected. Researchers have reported that the percentage of time spent in direct-work activities is correlated to labor productivity, that is, labor productivity is better as more time is spent in direct-work activities (Liou and Borcherding, 1986; Thomas et al., 1984; Handa and Abdalla, 1989).

Benefits of work sampling include:

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

- Ability to canvas an entire construction site;
- No disruption of the work activities of craft or foreman;
- Craft more likely to accept work sampling compared to continuous observation; and
- Desired level of accuracy possible through statistical techniques

Disadvantages of work sampling include:

- Less efficient on sites where craft are spaced further apart;
- Provides no information on specific crews;
- Observations need to adhere to stringent levels of accuracy
- Potential for individuals to behave differently (i.e. the Hawthorne effect)

It is important to note that some academic researchers are still applying work sampling. A study was completed for a major pharmaceutical company by James Jenkins of Purdue University in 2002. During that study he concluded that work sampling results would indicate productivity inhibitors for management to resolve in an attempt to improve productivity. Jenkins proposes the use of third party observers, since the results have a better opportunity of being unbiased (Jenkins and Orth, 2003). Other literature has supported this position, however from an operational standpoint. It was viewed that using construction management personnel was not an effective means, because the assigned observer would be too busy with regular duties to add on the task of conducting and analyzing work sampling data. Currently the few work sampling studies being conducted in the construction industry are being completed by third party observers whether by productivity consultants like Picard, or independent productivity departments of major construction companies.

The last significant contribution to work sampling was a brief note in a manual published in 2008 by Kerry O’Brien, a productivity consultant in Toronto. Similar to Picard, O’Brien travels North America, not only performing productivity reviews of construction sites, but also educating site personnel on productivity issues. O’Brien stresses that direct-work rates will increase through the reduction of material-handling and “get-ready” activities (O'Brien and Associates, Inc., 2008). For this reason, it is recommended to take actions to reduce the time spent handling material, onsite planning, getting tools, etc., with no information provided on how to perform work sampling studies.

### 2.6.5 Activity Analysis

According to the Construction Industry Institute (2010), Activity analysis is "*Activity analysis is a continuous process of measuring and improving the amount of time that craft workers spend on actual construction. This measured time is referred to as tool time, wrench time, or direct work time*"

Factors that influence the performance of a construction project, on-site operations are the most important factors (Gouett et al., 2011). Timely and accurate productivity information of labor and equipment involved in on-site operations during construction can bring into immediate notice of specific issues to concerned management of that project. It also enables them to take quick corrective actions, thus resulting costly delays. To streamline the cyclical procedure of measuring and improving the direct-work rates, the time proportion of activities devoted to actual construction, the Construction Industry Institute (CII) recently proposed new procedures for conducting activity analysis (CII, 2010). Activity analysis offers a convincing solution for monitoring on-site operations and supports root cause analysis on the issues that adversely affect their productivity.

Activity analysis is the extension of the work sampling technique into a continuous improvement process. There are two parts to activity analysis:

A. Workface assessment
B. Continuous improvement process.

Workface assessment part of activity analysis is the application of activity sampling or work sampling. It is the combination of this updated workface assessment method with a continuous improvement process that makes activity analysis such a powerful management tool. Moreover, it is a combination of assessment and continuous improvement that differentiates activity analysis from work sampling. Activity analysis provides the following benefits:

- detailed information similar to continuous observation studies, but obtained in less time and at a lower cost
- ability to canvas an entire construction site
- no disruption of the work activities of craft workers or foremen
- craft workers more likely to accept activity analysis compared to continuous observation
- desired level of accuracy possible through statistically-reliable techniques
- Identification of specific areas for improvement.

Disadvantages of activity analysis include the following:

- less efficient on sites where craft workers are spaced far apart
- observations need to adhere to stringent levels of accuracy and consistency
- Potential for individuals to behave differently.

**Difference between Activity Analysis and Work Sampling**

The practice of measuring direct work time originated in 1927 as an industrial engineering technique called the “snap reading method.” It primarily measured the simple ratio between production and delay. By the 1970s the practice had evolved into work sampling, a process primarily involving the measurement of the relative time that craft workers spent in direct, support, and delay activities. Activity analysis is the next evolution of the practice. Primary differences between activity analysis and work sampling include the following:

- Activity Analysis includes significantly more detailed observations and results. Typically, observations are broken down into seven or more categories: direct work, preparatory work, tools and equipment, material handling, waiting, travel, and personal. These categories are monitored for each of the crafts on a jobsite. The practice of conducting more detailed observations during every working hour of the day and of separating them out by craft provides a more descriptive assessment of how effectively craft workers’ time is being utilized.
- Activity Analysis is a continuous process. Activity analysis relies on a continuous process of improvement through observation, identifying areas for improvement, implementation, and reassessment.

*Chapter 3*

# METHODOLOGY

## 3.1 INTRODUCTION

As per the plan, an introductory study of the topic was performed at the beginning, followed by a comprehensive literature review. The findings of literature review provide an overview of productivity, and different assessment techniques use to assess labor productivity. Methodology of this thesis is given in detail describing all the methods used for research in this chapter. This research would be done in six distinct phases as stated under the heading of “Research Design”.

## 3.2 RESEARCH DESIGN

In first phase, after development of research proposal, extensive literature review was done to understand all the assessment processes which are used to measure labor productivity. Google Scholar was mainly used as search tool for different scholarly papers and writings. In the second phase, there was e a selection of suitable technique for labor productivity assessment that was later used to assess labor productivity at project and task level in various construction sites in order to enable us to understand the labor activities.

In the third phase, a comprehensive data of labor productivity will be collected from different construction sites in Pakistan. In this phase, numerous building construction sites were enlisted for data collection purpose and only those were selected which were large and labor dense. In fourth phase, there was a detail analysis of data which was collected from different construction projects. All the observed data was tabulated, quantified, calculated and assessed. In fifth phase, results of labor productivity will be discussed for finding out productivity inhibitors and labor productivity improvements. In the last phase, conclusions and recommendations will be given. Figure 3-1 explain the entire procedure briefly.

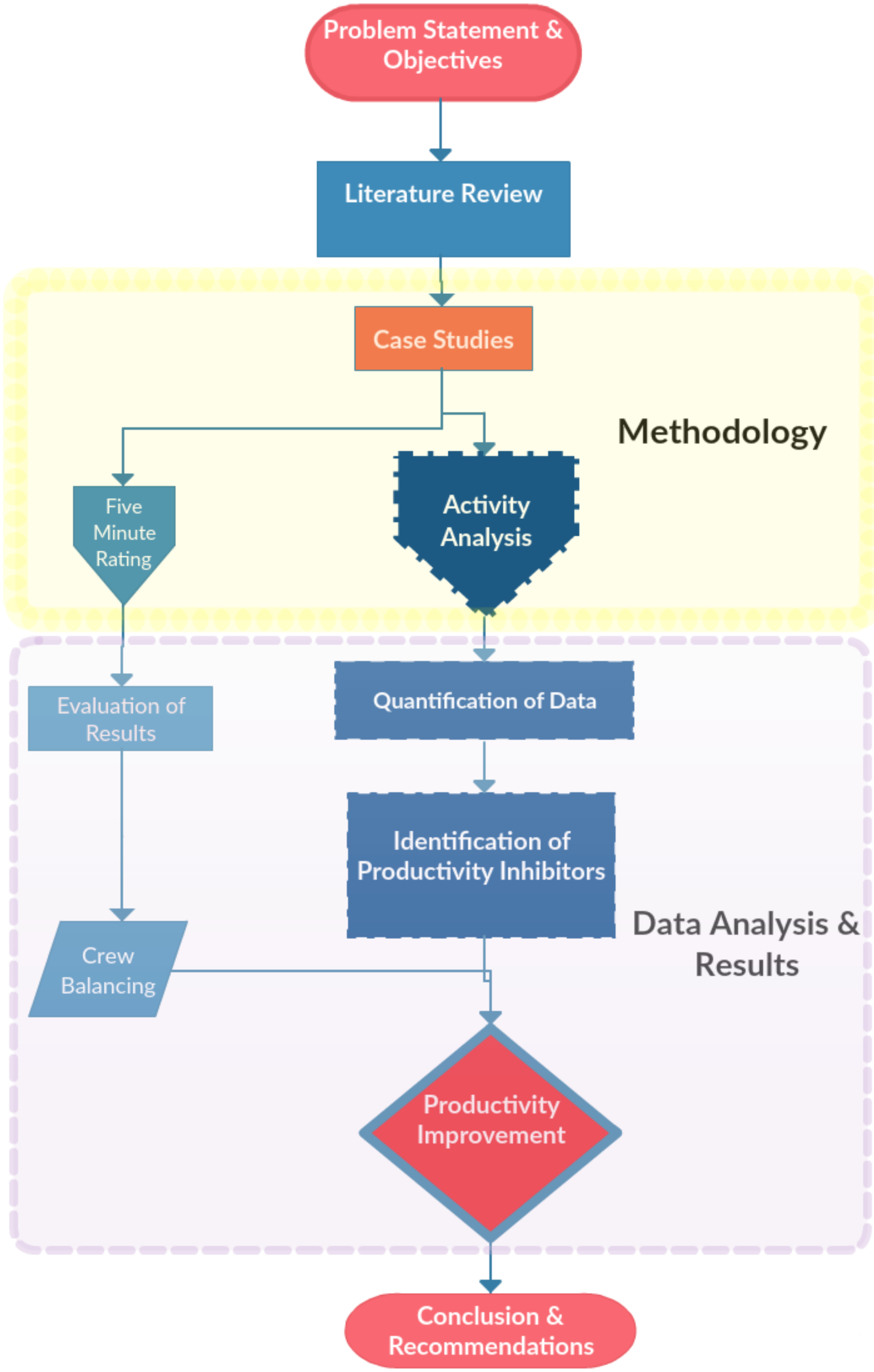


**Figure 3-1. Methodology**

## 3.3 DATA COLLECTION

The workforce assessment method mainly selected for labor productivity are as follow:

- Detailed activity analysis
- Five minute rating

A very comprehensive data collection was performed at various projects to understand that how the workers are spending their time during work day with good level of accuracy using both assessment method. Activity analysis determines the overall activity rate distribution throughout a day at project level while five minute rating was used to measure the effectiveness of a crew and to identify job delays at task level. Both the assessment method gives us the detail information on labor productivity and its inhibitors. It is important to mention here that during the various site visits at each project, safety of projects was also assessed in detail along with other important information regarding productivity.

During activity analysis observations, data were recorded for complete 8 hours a day for more than 5 days of detailed observations at each construction site in order to increase the data accuracy. Also it is noted here that some of the project information, details of operation and data has been expurgated which was not allowed by the contractor or client; who permitted project visits, of that project in order to protect their interest.

### 3.3.1 Other Related Information

During the data collection, various other information that can be physically observed as a productivity researcher and as civil engineer at each project site was recorded. These observations include important information and factors that affect productivity with their intensities on each project. These factors and important information includes:

- Project working environment
- Project site management
- Type of project

- Complexity of project
- Type of crafts mostly employed
- Geographical location of project
- Weather condition
- Scope and size of project
- Housekeeping
- Construction methods
- Labor skill level
- Layout of project site
- Safety conditions
- Work planning
- Supervision capability
- Jobsite conditions
- Construction stage
- Labor living conditions
- Number of activities
- Number of labors and their congestion rate at site
- Monitoring of work activities
- Quality of work
- Material management plan
- Tool management plan
- Types of tools
- Level of coordination from project personal etc.

It was observed that site management can change or control some factors like construction methods, supervision capability, material management etc. and some factors can't be changed by site management like scope of project, geographical location etc. Some of them were dependent on each other like construction stage will affect the type of craft working onsite at that time and some of them were independent like weather condition of project.

During quantification and analyzation of observed data collected using selected assessment techniques, these information plays an important role for finding out the productivity inhibitors at each project site.

The difficulty in analyzing data when someone other than the observer does the analysis has been recognized. In this light, it has been made clear that results from activity analysis really do reflect the conditions onsite which are witnessed by the observer. By recording comments on the side of the template, the observer (now the analyst) can think of examples of waiting, traveling, and personal activities, or the like. Causes of productivity issues are easier to identify when the analyst has intimate knowledge of the site and has made comments as to specific events.

Overall data of this research is analyzed by the same researcher who conducted the observations during data collection. During the data collection phase, observer noted down the main productivity inhibitors and issues that were directly observed during observations. By correlating those problems with labor productivity, causes of productivity issues were easy to identify during analysis phase.

## 3.4 ACTIVITY ANALYSIS

Already explained in literature review, activity analysis is a workface assessment tool, characterizes the proportion of time craft workers devote to specific work activities. Work activities that are included in a typical activity analysis study include direct work, preparatory work, tools and equipment handling, material handling, waiting, traveling, and personal time. Monitors use a random sampling technique to make observations throughout the work day. The randomness of the observations ensures that the proportion of time dedicated to each activity can be determined with statistical reliability.

The purpose of activity analysis is to first study and identify productivity barriers, and then to implement improvements to eliminate or reduce these barriers. The intent is to reduce activities that do not actively advance the finished product and thereby to increase the direct work rate.

It should be noted here this research follow the standard guide given by construction industry institute (CII) in 2010 named as “Guide to Activity Analysis” and more explanation on how to conduct activity analysis can be studied in this mentioned guide.

Here it will be briefly explained that how it is used during the research for labor productivity assessment at different building projects.

According to Construction Industry Institute (CII), activity analysis consists of five steps. These steps are later briefly explained in order to understand the whole process.

**1. Plan Study**

Process starts with planning a study; this entails defining the study objectives and scope, as well as determining other pertinent details.

**2. Sample Activity**

Next, activity sampling is done in order to collect a representative data sample. Each discrete data sample or observation is categorized as direct work, preparatory work, tools and equipment, material handling, waiting, travel, or personal.

**3. Analyze Data**

Once the data have been collected, observations are tabulated to determine activity percentages. The resulting percentages are analyzed to determine which types of activities are beyond the acceptable range.

**4. Plan Improvements**

After potential causes of unacceptable variances are identified, several potential solutions to improve productivity are considered. These improvements are based on a set of factors that include feasibility, logistics, and costs.

**5. Implement Improvements**

Finally, the improvements selected in the planning stage are implemented to increase the direct work rate.

### 3.4.1 Step 1: Plan Study

The first step of planning an activity analysis study is to develop the objectives of the study. This objective should reflect the information that management wishes to determine from the data (Thomas and Holland, 1980). For instance, a common objective which was used for the field trials was to:

"Quantify the time expended by craft on productive and non-productive activities so that productivity improvements may be determined and implemented."

This is a general objective and so general categories are created to reflect this. Example categories which reflect this general objective would be: direct-work; preparatory-work; material-handling; tools-and- equipment; waiting; travel; and personal. These categories will be defined in the following sections.

With the objective of the study determined, the study population may be defined. The population should be defined according to craft, shift, and job location. It is essential to understand the objective of the study to determine which craft workers should be included in the study. To reflect the common objective stated above, the population may be defined as the entire site. This means that all craft workers will be included. It is important to note at this point that foremen and superintendents are not to be included in the study, since they do not complete direct-work activities, and therefore they are excluded as to not skew the results.

Activity categories should be customized for every project and should reflect the objectives set for the study (Picard, 2004; Thomas and Mathews, 1986). The level of specificity desired by the objective will determine the number of categories necessary. For instance, the general objective of determining how the craft works are spending their time requires fewer categories than if the objective was to determine specific areas of delay. The more categories selected, the more comprehensive the data is; however, this is more cumbersome for the observer and therefore prone to errors. It has been recommended that only eight to ten categories be selected, though it has been suggested that this be a minimum and 15 to 20 is a realistic maximum (Groover, 2007; Stevens, 1969; The Business Roundtable, 1982). For the process presented in this thesis, seven categories were chosen.

In 1980, Thomas identified the key question that should be asked when defining activity categories: "Do the categories provide the manager with the type of information needed in order to take appropriate action?" (Thomas and Holland, 1980)

Guide to Activity Analysis by Construction Industry Institute (CII) define the activity categories used in the activity analysis process in following way, detailed understanding and explanation of each activity can be seen in their guide. (2010)

**1. Direct-work**

Direct-work is the act of exerting physical effort directed towards an activity or physically assisting in these activities. Direct-work often involves workers installing materials, but also includes the physical effort of support groups.

**2. Preparatory-work**

Preparatory-work includes those activities related to receiving assignments and determining requirements prior to performing tasks. Preparatory-work includes stretching activities, safety talks and start card processes. Preparatory-work also includes discussions to explain or plan the task at the work location. These discussions can take place between craft workers or between supervisors and craft workers.

**3. Tools-and-equipment**

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

**4. Material-handling**

This category includes transporting materials from one part of the facility to another, but does not include moving items in the general area of the task or into their final position.

**5. Waiting**

The activity category of waiting is defined as periods of waiting or idleness, even if attentive to ongoing work by others.

**6. Travel**

It includes walking or riding empty handed or without tools, materials, or technical information.

**7. Personal**

The personal category includes time taken or idleness during normal work hours and normally not attentive to work (this excludes normal breaks and lunch periods).

Several aspects of the study are also determined including the statistical accuracy desired, the corresponding sample size, length of the study, tour routes, and workday study windows. The determination of sample size is critical to the accuracy of the results.

Sampling routes need to be planned before the sampling period begins. It is important that each route cover the majority of the site, however it is preferable that it covers the whole site. It is important to the statistical accuracy of the sampling method that each worker has an equal opportunity of being witnessed. To do this, the observer needs to travel to the workface of each worker. Several routes are required, and should be selected randomly so that craft workers cannot anticipate the time of an observation and modify their behavior accordingly (Aft, 2000; Jenkins and Orth, 2003). The productivity expert of one consultant advised that when the same route is used over and over, craft workers have the opportunity to signal fellow workers of an impending observation. This is the Hawthorne effect and is a serious consideration for any activity analysis study. Using random routes will help to reduce or eliminate this statistical bias (Groover, 2007). With a random route, the craft worker will be unaware of any pattern. When a route is randomly selected, it is also suggested that the start location be randomly selected (Stevens, 1969). More tips and techniques to reduce the Hawthorne effect are discussed in the section regarding executing the study.

**Minimum Sample Size Determination**

Many construction and industrial engineering journals provide the following equation for determining sample size based on desired error, and anticipated category percentages (Aft, 2000; Groover, 2007; Picard, 2004; Stevens, 1969; Thomas Jr. et al., 1982; Thomas and Daily, 1983; Thomas et al., 1984; Thomas, 1991).

In above equation, $Z_{\alpha/2}$ is the standard normal variable corresponding to a confidence level of α, p is the anticipated category percentage, and d is the error between the true percentage and the estimated. For a confidence level of 95%, α = 0.05, and corresponds to a $Z_{\alpha/2} = 1.96$. If the anticipated percentage p is unknown, a value of 50% (0.5) may be used as a worst case scenario ensuring the number of samples will be overestimated. As stated, the general acceptable values for these variables in the construction industry are p = 0.5, $Z_{\alpha/2} = 1.96$, and d = 0.05, which results in a total minimum sample size of 384 observations (Oglesby et al., 1989; Picard, 2004).

Determining an adequate sample size is critical to the accuracy of the work sampling study. As more samples are collected, the results become more accurate as sampling error is reduced. However, there is a balance between statistical accuracy and the cost to collect samples. In most industries an error of ± 5% at a confidence level of 95% is generally acceptable.

The sample size equation is applicable to sampling exercises when the characteristic being sampled follows a binomial distribution; however, work sampling is multinomial. In sampling, a binomial distribution applies to two attributes. Either the observation falls into one attribute, or it doesn't and therefore is the other attribute. Binomial distribution would be valid for productive or unproductive categories, and direct-work or not direct-work categories. Work sampling generally has more than two categories, since if the observation is not direct-work, it can be one of several other categories, and so is multinomial. The characteristic being sampled is not the workers, but instead the workers' behavior at any one time (for example every minute, hour, etc.). It is this constantly changing behavior of hundreds of workers that is being sampled. It is not infinite, but it is large enough that the true population is unknown.

Solution to determining the sample size for multinomial distributions was developed by S.K. Thompson in 1987. He provided a table of sample size based on the preceding equation considering an error of ±5% (d = 0.05), for several confidence levels.

Table 3-1 appeared in the article "Sample size for estimating multinomial proportions" in *The American Statistician*. The values have been verified and reproduced here (Thompson, 1987; Thompson, 1992).

**Table 3-1 Sample Size for Varying Confidence Levels and Error d = 0.05**

| $\alpha$ | $d^2n_o$ | $n_o(d=0.05)$ | M |
|---|---|---|---|
| 0.5 | 0.44129 | 177 | 4 |
| 0.4 | 0.50729 | 203 | 4 |
| 0.3 | 0.60123 | 241 | 3 |
| 0.2 | 0.74739 | 299 | 3 |
| 0.1 | 1.00635 | 403 | 3 |
| 0.05 | 1.27359 | 510 | 3 |
| 0.025 | 1.55963 | 624 | 2 |
| 0.02 | 1.65872 | 664 | 2 |
| 0.01 | 1.96986 | 788 | 2 |
| 0.005 | 2.28514 | 915 | 2 |
| 0.001 | 3.02892 | 1212 | 2 |
| 0.0005 | 3.35304 | 1342 | 2 |
| 0.0001 | 4.11209 | 1645 | 2 |

For a given confidence level, the following equation is calculated at varying number of categories m to find the maximum number of observations n in the worst case scenario (Thompson, 1987).

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

For a 95% confidence and error of d = 0.05, the result is m = 3, and n = 510 observations. This means regardless of the category percentages; the confidence will always be greater than 95%. For the analysis presented in the next chapter, the actual error according to this new equation will be reported.

The required number of samples is calculated for a one-hour period, such as 8 to 9 am. However, it may be impossible for one observer to obtain the required sample size in one hour of one day, so sampling for that one-hour period (8 to 9 am) may be evenly distributed over several study days, and then the results summed up. Stacking, or summing up several days of observations for each period, increases accuracy.

### 3.4.2 Step 2: Sample

The details of how the craft workers are observed and sampled are presented in this section.

**Observer**

Observation criteria for the activity analysis study is critical to its success. A good observer has five qualities:

1. Have a comprehensive knowledge of construction;
2. Committed activity category definitions to memory;
3. Be able to easily identify crafts;
4. Adhere to the concept of instantaneous observation (the snap); and
5. Be free of bias.

When analyzing the activity analysis results, the observer has the greatest knowledge of the conditions onsite. Because of this, the observer will be the best analyst in identifying productivity problems and recommending solutions. In order to have this knowledge and be able to recommend solutions, a thorough knowledge of construction is required (Jenkins and Orth, 2003). Further, it is imperative that the observer knows both the categories and craft identifiers since it will make the study less cumbersome, and help the observer adhere to the instantaneous observation required. Often referred to as the snap, it must be as random as possible, but more importantly the observer must identify the craft and the activity category as soon as the worker is first seen (Stevens, 1969). Identifying the activity category at first sight minimizes the worker's opportunity to change his behavior. Also the instantaneous observation will help the observer to not reason about the activities of a worker, which is another key to activity analysis (Oglesby et al., 1989). In the light of above, trainers were not selected but the whole data collection was carried out by the researcher himself.

**Execute Study**

Before the beginning of the work day, the observer should prepare enough blank data collection sheets for each one-hour period of study. The data collection form as shown in Figure 3-2 contains spaces to insert the date, time of each one-hour observation period, and spots for each craft’s name, identifier and number of workers. Other information that could be recorded here includes temperature, location studied, and other pertinent details as the study progresses. These comments will prove valuable when identifying potential productivity problems.

At project site during the data collection phase in activity analysis process, supervisors and project management staff were not included in labor assessment observations. Similarly, observations were not recorded for 15 minutes at the start and at the end of working day due to excessive travelling activity of labors, in order to minimize the biasness in observations.

Just before the first study period of the day, the observer goes to the random start location, of a randomly selected route. The observer then walks along the pre-defined route, characterizing the activity of each worker seen. As the observer approaches a craft worker, they instantaneously identify the craft and activity category of the craft. This is done from a distance of between 15 to 30 meters, since this is close enough to make an accurate recording, but not close enough to cause worker discomfort. It is critical that the observation be made at first sight of the worker, and the observer must not reason about what the worker was doing, nor wait a second to see what he does next. This is extremely important to ensure accuracy of the results.

| Activity Analysis Log | | | | |
|---|---|---|---|---|
| Name of Observer | | | | |
| Site Access Date | | | | |
| # of Workers | | | | |
| Weather | | | | |
| Project Name | | | | |
| Trades Observed | | | | |
| Observation Records | | Observation Round 1 | Observation Round 2 | Observation Round 3 |
| Time (From\|To) | | | | |
| Direct Work | | | | |
| Support | Preparatory Work and Instructions | | | |
| | Traveling | | | |
| | Tools and Equipment | | | |
| | Materials Handling | | | |
| Delays | Personal | | | |
| | Waiting | | | |
| Note: | | | | |

**Figure 3-2 Example activity analysis log for data collection**

When the activity is identified, the observer places a mark in the box which cross corresponds to the activity. Figure 3-2 illustrates a completed form for a one-hour study period, with several marks. The observer should take every effort not to stand, characterize the activity, record on the form, and then walk away. This can cause discomfort on the part of the worker. Instead, it is recommended that the observer should collect the observations, and then walk past the workers or into a nearby quiet area out of sight, and record what was observed. This can be difficult at first; but the experience of the field trials was that with time this becomes possible. However, it is important that if accuracy cannot be ensured by recording away from the workface, the observer must record as soon as the work is characterized so that the results will accurately represent the true activities onsite. Ultimately, the accuracy of the data cannot be sacrificed to alleviate the workers momentary discomfort.

### 3.4.3 Step 3: Analysis

When all one-hour observation periods have been completed, the results are tabulated, the distribution of time spent on activities is calculated, graphic presentations of the total overall results and the hourly breakdown are developed, and the results are analyzed looking for productivity inhibitors. To illustrate the process of tabulating and calculating the results, data from a field trial will be worked through. The calculations will show how to calculate percentages for the entire site;

**Hourly no. of observations and respective confidence level**

After the complete data collection at each project, observation at each hour and their respective true confidence level was reported. The true confidence level was calculated using the actual number of samples collected, an error of 5.0%, and the actual measured proportions for each hour. The error associated with each proportion was calculated using the binomial distribution because the proportion indicates what percentage of observations has that attribute or not. This was completed for all seven categories. Then the confidence levels were summed. This was done according to the following logic. Assume the direct-work rate has a 95% confidence level, which is the probability of the proportion being incorrect once out of 20 times. Assume the preparatory-work rate also has a confidence of 95%, and therefore a probability of being incorrect once out of 20 times. It is unlikely that out of the 20 studies, both the direct-work rate and preparatory-work rate will incorrectly be estimated simultaneously. It is more likely that out of the 20 studies one proportion will be incorrect while the second proportion is correct, and eventually the second proportion will be incorrect while the first is correct. Sample hourly confidence level and respective number of observations per hour are summarized in Table 3-2.

**Table 3-2 Example number of Observations per Hour**

| Work Hour | Number of Observations | Confidence Level |
|---|---|---|
| 08:00-09:00 | 1899 | 86.6181643% |
| 09:00-10:00 | 2292 | 92.6857464% |
| 10:00-11:00 | 1928 | 86.9713170% |
| 11:00-12:00 | 1766 | 82.9972066% |
| 12:00-01:00 | 1798 | 83.9185673% |
| Lunch | - | - |
| 02:00-03:00 | 2216 | 91.8111944% |
| 03:00-04:00 | 1700 | 81.3014178% |
| 04:00-05:00 | 1265 | 61.1076759% |
| **Total** | **14864** | **99.9999999%** |

The calculated results of each activity at each Project are also summarized with percentage errors of respective category, as shown in the Table 3-3 in order to assess the accuracy of each category.

**Table 3-3 Example activity rates with respective error estimates for a 95% confidence level for project**

| Activity Category | Activity Percentage | Error Percentage |
|---|---|---|
| Direct Work | 41.12% | 0.791% |
| Preparatory Work and Instructions | 9.20% | 0.465% |
| Traveling | 12.63% | 0.534% |
| Tools and Equipment | 3.73% | 0.305% |
| Materials Handling | 4.33% | 0.327% |
| Personal | 17.75% | 0.614% |
| Waiting | 11.24% | 0.508% |

Sample size determination is a balance between error and confidence. If the error was maintained at 5.0%, the confidence level would be nearly 100% as reported in the above Table 3-3. However, it was determined it would be more meaningful to report the true error of each proportion based on a 95% confidence level which was originally intended.

## Calculating Total Overall Results

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

1. Summing observations per activity on the observation worksheets;
2. Inputting the observation counts into a spreadsheet according to hour and activity;
3. Summing total activity observations across all hours and days;
4. Summing total observations; and
5. Calculating study activity percentage.

Example of calculated activity analysis spreadsheet is shown in Figure 3-3.

| Time | | 8am-9am | | | | 9am-10am | | | | 10am-11am | | | | 11am-12pm | | | | 12pm-1pm | | | | n | 2pm-3pm | | | | 3pm-4pm | | | | 4pm-5pm | | | | Total Sum | Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observation Round | | 1 | 2 | 3 | Total | 1 | 2 | 3 | Total | 1 | 2 | 3 | Total | 1 | 2 | 3 | Total | 1 | 2 | 3 | Total | | 1 | 2 | 3 | Total | 1 | 2 | 3 | Total | 1 | 2 | 3 | Total | | |
| | | Day 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Direct Work | | 71 | 50 | | 121 | 55 | 61 | 69 | 185 | 55 | 48 | 47 | 150 | 40 | 52 | 46 | 138 | 69 | 51 | 62 | 182 | | 59 | 65 | 44 | 168 | 45 | 60 | 52 | 157 | 62 | 66 | | 128 | 1229 | 40.70 |
| | Preparatory Work and Instructions | 27 | 32 | | 59 | 21 | 17 | 12 | 50 | 10 | 12 | 14 | 36 | 11 | 7 | 9 | 27 | 7 | 12 | 8 | 27 | | 7 | 16 | 9 | 32 | 10 | 8 | 12 | 30 | 16 | 10 | | 26 | 287 | 9.50 |
| Suppor | Traveling | 30 | 19 | | 49 | 25 | 18 | 12 | 55 | 17 | 11 | 13 | 41 | 14 | 9 | 10 | 33 | 30 | 38 | 31 | 99 | | 19 | 11 | 15 | 45 | 7 | 12 | 5 | 24 | 17 | 21 | | 38 | 384 | 12.72 |
| | Tools and | 8 | 11 | | 19 | 5 | 4 | 7 | 16 | 4 | 6 | 8 | 18 | 6 | 4 | 3 | 13 | 6 | 5 | 5 | 16 | | 4 | 3 | 2 | 9 | 8 | 4 | 4 | 16 | 6 | 9 | | 15 | 122 | 4.04 |
| | Materials | 8 | 6 | | 14 | 9 | 3 | 5 | 17 | 2 | 5 | 9 | 16 | 4 | 9 | 4 | 17 | 5 | 3 | 4 | 12 | | 2 | 4 | 6 | 12 | 7 | 7 | 9 | 23 | 9 | 3 | | 12 | 123 | 4.07 |
| Delays | Personal | 38 | 29 | | 67 | 19 | 29 | 22 | 70 | 15 | 17 | 21 | 53 | 20 | 23 | 15 | 58 | 20 | 17 | 27 | 64 | | 26 | 31 | 29 | 86 | 37 | 35 | 32 | 104 | 27 | 16 | | 43 | 545 | 18.05 |
| | Waiting | 32 | 24 | | 56 | 13 | 20 | 17 | 50 | 7 | 10 | 9 | 26 | 9 | 5 | 9 | 23 | 11 | 6 | 8 | 25 | | 22 | 15 | 21 | 58 | 17 | 21 | 22 | 60 | 18 | 14 | | 32 | 330 | 10.93 |
| Date | | Day 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Direct Work | | 49 | 66 | | 115 | 66 | 71 | 51 | 188 | 44 | 39 | 34 | 117 | 32 | 29 | 41 | 102 | 29 | 31 | 21 | 81 | | 51 | 63 | 55 | 169 | 31 | 45 | 36 | 112 | 58 | 45 | | 103 | 987 | 38.30 |
| | Preparatory Work | 26 | 21 | | 47 | 17 | 13 | 22 | 52 | 21 | 11 | 17 | 49 | 9 | 9 | 5 | 23 | 8 | 11 | 4 | 23 | L | 17 | 11 | 7 | 35 | 8 | 11 | 6 | 25 | 8 | 5 | | 13 | 267 | 10.36 |
| Suppor | Traveling | 21 | 19 | | 40 | 28 | 16 | 12 | 56 | 18 | 13 | 16 | 47 | 6 | 12 | 7 | 25 | 12 | 17 | 20 | 49 | u | 21 | 11 | 15 | 47 | 5 | 7 | 3 | 15 | 19 | 11 | | 30 | 309 | 11.99 |
| | Tools and | 7 | 5 | | 12 | 4 | 7 | 5 | 16 | 8 | 4 | 9 | 21 | 4 | 4 | 6 | 14 | 3 | 2 | 7 | 12 | n | 2 | 2 | 6 | 10 | 4 | 6 | 2 | 12 | 5 | 7 | | 12 | 109 | 4.23 |
| | Materials | 7 | 6 | | 13 | 9 | 4 | 5 | 18 | 5 | 6 | 7 | 18 | 9 | 7 | 6 | 22 | 7 | 2 | 5 | 14 | c | 4 | 7 | 3 | 14 | 9 | 11 | 9 | 29 | 7 | 3 | | 10 | 138 | 5.36 |
| Delays | Personal | 33 | 29 | | 62 | 28 | 17 | 20 | 65 | 29 | 22 | 19 | 70 | 20 | 23 | 14 | 57 | 17 | 8 | 15 | 40 | h | 30 | 35 | 24 | 89 | 21 | 17 | 31 | 69 | 21 | 15 | | 36 | 488 | 18.94 |
| | Waiting | 31 | 27 | | 58 | 18 | 11 | 13 | 42 | 11 | 5 | 8 | 24 | 8 | 9 | 5 | 22 | 8 | 6 | 9 | 23 | | 25 | 16 | 18 | 59 | 5 | 9 | 13 | 27 | 15 | 9 | | 24 | 279 | 10.83 |
| | | Day 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Direct Work | | 58 | 67 | | 125 | 73 | 64 | 55 | 192 | 39 | 61 | 45 | 145 | 48 | 67 | 52 | 167 | 55 | 44 | 39 | 138 | | 51 | 43 | 61 | 155 | 59 | 43 | 41 | 143 | 51 | 55 | | 106 | 1171 | 42.57 |
| | Preparatory Work | 30 | 27 | | 57 | 21 | 13 | 17 | 51 | 14 | 12 | 10 | 36 | 8 | 9 | 7 | 24 | 9 | 8 | 2 | 19 | L | 17 | 11 | 9 | 37 | 8 | 9 | 5 | 22 | 11 | 7 | | 18 | 264 | 9.60 |
| Suppor | Traveling | 28 | 22 | | 50 | 25 | 18 | 14 | 57 | 17 | 15 | 13 | 45 | 15 | 11 | 9 | 35 | 15 | 7 | 12 | 34 | u | 16 | 12 | 19 | 47 | 13 | 11 | 2 | 26 | 15 | 15 | | 30 | 324 | 11.78 |
| | Tools and | 11 | 5 | | 16 | 7 | 5 | 4 | 16 | 4 | 6 | 8 | 18 | 3 | 5 | 3 | 11 | 6 | 3 | 3 | 12 | n | 2 | 4 | 5 | 11 | 3 | 4 | 1 | 8 | 10 | 2 | | 12 | 104 | 3.78 |
| | Materials | 9 | 6 | | 15 | 5 | 9 | 3 | 17 | 9 | 5 | 2 | 16 | 5 | 11 | 5 | 21 | 5 | 5 | 2 | 12 | c | 6 | 4 | 3 | 13 | 7 | 7 | 8 | 22 | 8 | 4 | | 12 | 128 | 4.65 |
| Delays | Personal | 34 | 30 | | 64 | 22 | 19 | 30 | 71 | 19 | 27 | 15 | 61 | 23 | 20 | 15 | 58 | 16 | 11 | 14 | 41 | h | 30 | 32 | 35 | 97 | 19 | 13 | 31 | 63 | 22 | 15 | | 37 | 492 | 17.88 |
| | Waiting | 27 | 31 | | 58 | 11 | 22 | 15 | 48 | 9 | 6 | 3 | 18 | 7 | 5 | 9 | 21 | 6 | 2 | 8 | 16 | | 22 | 21 | 19 | 62 | 5 | 4 | 7 | 16 | 18 | 11 | | 29 | 268 | 9.74 |
| | | Day 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Direct Work | | 80 | 72 | | 152 | 71 | 59 | 63 | 193 | 62 | 71 | 69 | 202 | 73 | 51 | 62 | 186 | 61 | 43 | 70 | 174 | | 57 | 64 | 43 | 164 | 35 | 30 | 34 | 99 | 61 | 65 | | 126 | 1296 | 41.49 |
| | Preparatory Work | 34 | 25 | | 59 | 18 | 11 | 16 | 45 | 7 | 7 | 11 | 25 | 9 | 8 | 4 | 21 | 10 | 11 | 7 | 28 | L | 7 | 17 | 9 | 33 | 9 | 11 | 8 | 28 | 15 | 9 | | 24 | 263 | 8.42 |
| Suppor | Traveling | 23 | 19 | | 42 | 26 | 17 | 15 | 58 | 19 | 21 | 15 | 55 | 23 | 18 | 14 | 55 | 29 | 38 | 33 | 100 | u | 20 | 11 | 16 | 47 | 8 | 6 | 4 | 18 | 18 | 19 | | 37 | 412 | 13.19 |
| | Tools and | 10 | 2 | | 12 | 5 | 2 | 4 | 11 | 9 | 9 | 5 | 23 | 8 | 6 | 6 | 20 | 6 | 4 | 5 | 15 | n | 4 | 4 | 2 | 10 | 4 | 5 | 3 | 12 | 8 | 6 | | 14 | 117 | 3.75 |
| | Materials | 10 | 2 | | 12 | 8 | 5 | 7 | 20 | 7 | 8 | 6 | 21 | 7 | 6 | 5 | 18 | 5 | 2 | 4 | 11 | c | 3 | 4 | 7 | 14 | 8 | 8 | 9 | 25 | 7 | 5 | | 12 | 133 | 4.26 |
| Delays | Personal | 21 | 33 | | 54 | 20 | 27 | 31 | 78 | 22 | 25 | 21 | 68 | 25 | 19 | 22 | 66 | 20 | 17 | 25 | 62 | h | 28 | 31 | 29 | 88 | 22 | 17 | 35 | 74 | 26 | 17 | | 43 | 533 | 17.06 |
| | Waiting | 29 | 26 | | 55 | 13 | 14 | 21 | 48 | 12 | 9 | 10 | 31 | 17 | 11 | 13 | 41 | 11 | 18 | 14 | 43 | | 29 | 20 | 30 | 79 | 8 | 14 | 17 | 39 | 19 | 15 | | 34 | 370 | 11.84 |
| | | Day 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Direct Work | | 75 | 78 | | 153 | 70 | 52 | 99 | 221 | 83 | 61 | 73 | 217 | 69 | 61 | 69 | 199 | 76 | 46 | 63 | 185 | | 66 | 81 | 70 | 217 | 44 | 40 | 49 | 133 | 54 | 50 | | 104 | 1429 | 42.13 |
| | Preparatory Work | 27 | 32 | | 59 | 20 | 7 | 27 | 54 | 11 | 4 | 10 | 25 | 15 | 12 | 11 | 38 | 13 | 7 | 9 | 29 | L | 9 | 21 | 12 | 42 | 9 | 7 | 11 | 27 | 10 | 3 | | 13 | 287 | 8.46 |
| Suppor | Traveling | 28 | 17 | | 45 | 27 | 11 | 26 | 64 | 35 | 23 | 20 | 78 | 16 | 21 | 25 | 62 | 26 | 39 | 31 | 96 | u | 25 | 14 | 21 | 60 | 6 | 11 | 4 | 21 | 12 | 10 | | 22 | 448 | 13.21 |
| | Tools and | 9 | 5 | | 14 | 4 | 4 | 3 | 11 | 4 | 7 | 4 | 15 | 4 | 6 | 4 | 14 | 3 | 6 | 4 | 13 | n | 7 | 6 | 3 | 16 | 7 | 5 | 2 | 14 | 4 | 2 | | 6 | 103 | 3.04 |
| | Materials | 8 | 6 | | 14 | 5 | 8 | 7 | 20 | 10 | 6 | 1 | 17 | 7 | 5 | 4 | 16 | 4 | 2 | 3 | 9 | c | 5 | 4 | 7 | 16 | 6 | 7 | 6 | 19 | 6 | 4 | | 10 | 121 | 3.57 |
| Delays | Personal | 35 | 19 | | 54 | 24 | 19 | 40 | 83 | 25 | 27 | 18 | 70 | 31 | 29 | 26 | 86 | 29 | 6 | 22 | 57 | h | 32 | 30 | 28 | 90 | 36 | 34 | 31 | 101 | 21 | 18 | | 39 | 580 | 17.10 |
| | Waiting | 30 | 27 | | 57 | 23 | 9 | 22 | 54 | 16 | 15 | 25 | 56 | 13 | 8 | 12 | 33 | 17 | 4 | 16 | 37 | | 26 | 21 | 38 | 85 | 29 | 27 | 31 | 87 | 7 | 8 | | 15 | 424 | 12.50 |

**Total**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm | Total | Percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Activities | | | | | | | | | | | | |
| Direct Work | | 666 | 979 | 831 | 792 | 760 | L | 873 | 644 | 567 | 6112 | 41.12 |
| | Preparatory Work | 281 | 252 | 171 | 133 | 126 | u | 179 | 132 | 94 | 1368 | 9.20 |
| Suppor | Traveling | 226 | 290 | 266 | 210 | 378 | n | 246 | 104 | 157 | 1877 | 12.63 |
| | Tools and | 73 | 70 | 95 | 72 | 68 | c | 56 | 62 | 59 | 555 | 3.73 |
| | Materials | 68 | 92 | 88 | 94 | 58 | h | 69 | 118 | 56 | 643 | 4.33 |
| Delays | Personal | 301 | 367 | 322 | 325 | 264 | | 450 | 411 | 198 | 2638 | 17.75 |
| | Waiting | 284 | 242 | 155 | 140 | 144 | | 343 | 229 | 134 | 1671 | 11.24 |
| Total no. of observations | | 1899 | 2292 | 1928 | 1766 | 1798 | | 2216 | 1700 | 1265 | 14864 | 100 |

**Figure 3-3 Example activity analysis spreadsheet**

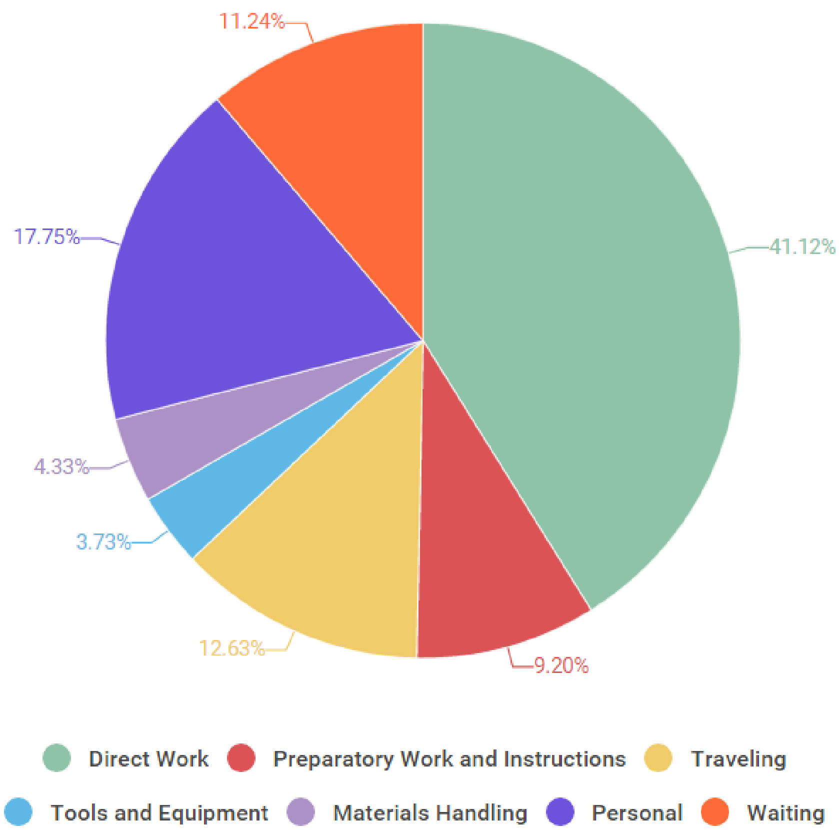


**Figure 3-4 Pie chart illustrating overall activity results**

## Data Interpretation

Correctly interpreting the results of studies is one of the most difficult parts of activity analysis because conditions differ from one project to another. However, it is an important step, since the data will indicate issues on site which management can take immediate action to remove constraints or obstacles that are interfering with work (Picard, 2002; Picard, 2004).

Thomas suggested that the observer would be the best person to analyze and interpret the data. The observer has developed an intimate knowledge of the issues affecting the whole site since he has been observing for several days or weeks (Thomas Jr. et al., 1982). Picard supports this position offering a question the observer should ask while collecting data: “What can be done to improve productive utilization, reduce wasted time, minimize travel, and streamline workflow?” (Picard, 2004). It is for this reason that the data collection form created for this thesis work includes areas for the observer to make general comments.

When interpreting the data, the observer must remember that the purpose of activity analysis is to remove productivity barriers so that the direct-work rate may increase. It is preferable that non-productive activities decrease so that amount of direct-work can increase. However, if preparatory-work, tools-and- equipment, and material-handling percentages are greater than targets, then these percentages should also be reduced thus making more time for direct-work activities. These inhibitors that are to be reduced or eliminated should be developed into a specific action items list presented to management in report form, and potentially through a presentation (Jenkins and Orth, 2003; Picard, 2004).

The recommendations regarding specific excessive activity rates were developed through the extensive literature review and interviews with several construction industry experts. These experts are actively involved in labor productivity issues for their respective companies. These experts have been an excellent resource for this research.

At this time, the author acknowledges that the following discussion of potential productivity issues as a result of specifically high activity percentages is not exhaustive. Further, if the specific cause of an undesirably high activity percentage is not determined through the first activity analysis study, a second may be required, or another workface assessment method such as foreman delay surveys should be used to augment the results from the study.

### 3.4.4 Step 4: Plan Improvements

The most significant inhibitor of implementing improvements is negative perceptions of change. The process of planning improvements has three steps: list probable causes, analyze alternatives, and create a plan for improvement implementation.

`

### List probable causes

For true improvement, it is important that changes be made at the root cause of problems. It is not sufficient to merely correct a problem, since if the root exists the problem will most likely re-occur. The scope and extent of a problem is identified based on the activity analysis results. The results of the study have identified the productivity issues. In this step, the reasons why this issue has occurred must be identified.

For instance, a problem may be improper crew balance. Causes of improper crew balance can be poor communication between management and site labor indicating needs and over-manning situations. Or, the poor crew balance could be a result of poor planning of work tasks. For example, at one moment less labor is needed, but in the near future more will be required, so the laborer remains on the crew in an inactive state until that time. The cause is most likely a combination of these scenarios.

For each cause, several solutions should be developed through experience, expert insights, and creative brainstorming. In this stage, no potential solution should be dismissed until properly analyzed in the next stage.

### Analyze alternatives

Each potential solution must be evaluated according to potential cost and anticipated benefits. The evaluation should also consider probability of success, limitations, stage of the project, duration of implementation, required resources, and necessary methods. Also, the effect of this change on other tasks and activities should be considered.

### Create a plan for improvement implementation

A successful plan is very detailed with all potential obstacles considered and with an outline how to handle each. The conceptual design of the solution is important; however, the components of the solution need also to be comprehensively designed. Considerations to include in the plan are the financial issues, a schedule, project culture, limitations, permitting process, etc.

### 3.4.5 Step 5: Implement Improvements

Consulting the productivity industry experts, the following list of activities need to be undertaken to implement the improvements which were planned:

1. Obtain real commitments from all levels of management;
2. Study each action element of the plan;
3. Define a schedule and timeline for each element;
4. Investigate cost of implementation including development, purchasing, maintenance, etc.;
5. Consider human resource issues (for example training and support on new implementations); and
6. Update forms and documents related to changed work processes.

## 3.5 FIVE MINUTE RATING

The five-minute rating is a technique used to measure the effectiveness of a crew and to identify job delays (Oglesby et al., 1989). To perform the five-minute rating technique data is collected on a single date and time, and through video recordings, pictures, and/or time lapse films the activity cycle for the trade observed is determined. For the observed activity each worker must perform his/her task within each minute of each cycle of work for at least 5 cycles. The cycles recorded are then examined for similarities and variability between them until stable data is established. The activity time determines the total data collection time, and if irregularity or outside intervention or disruption occurs during data collection or work performed, the data collection process must be repeated (Grau, 2014)

As name suggests, observation of crew should not be less than five minute. As a rule of thumb, some people recommend to add a minute for each worker in the crew under observation. Therefore, a crew of 6 workers should be observed about at least 11 minutes (5 minutes + 1 minutes * 6). The observation period is then broken down into arbitrary but equal sub-periods. For example, 11-minute observation could be broken down into 1-minute sub-periods. Workers are observed in each sub-period and they are classified as "effective" or "non-effective" as in field studies. Workers are observed for the full duration of the sub-period. Therefore, they are classified as "effective" only if they were working more than 50% of the sub-period according to judgment of the observer. Then the overall effectiveness of the crew is calculated as shown in the Equation 9:

$$\text{Percent crew effectiveness} = \frac{\text{Total number of effetive intervals}}{\text{Number of intervals x Numbers of crew members}} \quad (9)$$

The spreadsheet log used for calculation of effectiveness of entire task is shown in Figure 3-5.

**Date :** ______________________

**Time :** ______________________

**Job/Activity:** ______________________

**Additional information :** ______________________

**Superintendent:** ______________________

**Form no :** ______________________

| Minutes | Mason 1 | Mason 2 | Labor 1 | Labor 2 | Labor 3 |
|---|---|---|---|---|---|
| 1 | x | | x | x | x |
| 2 | x | x | x | | |
| 3 | | | x | | x |
| 4 | | | | x | x |
| 5 | x | x | | x | |
| 6 | x | x | x | x | x |
| 7 | x | x | x | | |
| 8 | x | | x | | |
| 9 | | | | | |
| 10 | x | | | x | x |
| 11 | | | x | | x |
| 12 | | x | x | | |
| **Effective Units** | **7** | **5** | **8** | **5** | **6** |

| | |
|---|---|
| Total Man Units | 60 |
| Effective Man Units | 31 |
| Effectiveness | 52% |

**Comments:** ______________________

**Figure 3-5 Calculation of effectiveness in five minute rating**

Oglesby et al. (1989) indicated that the purpose of this method is:

- To make management aware that a delay has occurred and communicate its importance;
- Check the adequacy of the crew in completing goals; and
- Pinpoint where planning could produce savings.

During the data collection phase at each construction site, five minute rating was performed in which video was recorded for approximately more than 45 minutes to collect data for the five-minute rating of the observed formwork construction. It was concluded after analyzing the video cycle time for the mostly activities were 10 minutes. Video was recorded intentionally at each project during data collection for accurate assessment for five minute rating as video can later be seen carefully for more accurate data input and later data processing of entire task. One of the video still recorded during data collection process at a particular project is shown in Figure 3-6.

**Figure 3-6 Sample Video still of five minute rating**

Based on the data collected construction activities, solution is proposed at each construction site for that particular task in which worker are assigned to other activity or reduced for that particular activity. Reassigning the workers to another task would be an application of the crew balancing technique because it would maximize the direct work performed on the task by maximizing the efficient use of time and resources.

*Chapter 4*

# DATA ANALYSIS AND DISCUSSIONS

Detailed observation were taken place on five large building construction projects. All the selected five projects were labor intense enough. Two projects were located in the Islamabad while the others were located near the capital city. It should be mentioned here that whole data for labor assessment was collected by the researcher himself in order to accurately interpret and analyze the data. At each Project, labors were observed for more than 5 days continuously in order to get accurate results during their working time of 8 hours. Data analysis of all the observations, related discussions and findings of all five projects are explained below in detail.

## 4.1 PROJECT A

First project was construction of large office building which will be eventually used as headquarter for one of the largest telecom company of Pakistan. It was located in Gulberg Greens near Islamabad express highway. The Client or owner of the project was international telecom group and they choose one of the largest contractor registered as Category A in Pakistan Engineering Council (PEC) as civil contractor for the execution of work while building was designed by a separate firm.

The project consists of construction of 6 large blocks which will be later used as office spaces for corporate head office complex. Contract was signed on 13$^{th}$ may, 2014 between client and general contractor of project, while the site was mobilized on 20$^{th}$ may, 2014. Data collection regarding activity analysis was gathered in early December, 2015 when the civil structure was almost 75% completed. Site was quite labor intense and total no. of labor in all site visit was greater than 700 during the data collection phase. All the workers were included in the study. General activities observed during the data collection phase at that project was concrete pouring, block masonry, formwork, material handling and plastering. Large no. of labors working at site was employed by the subcontractors while there was less no. of labor directly working for general contractor.

### 4.1.1 Number of observations and hourly confidence level

For the study of 1032 workers, a total of 342 samples per hour of study was determined to be required according to the binomial distribution However, as discussed in Chapter 3, these were incorrect assumptions. Instead the multinomial distribution should have been used without considering the finite population correction factor. For a 95% confidence level, and an error of 5.0%, a total of 510 samples are required per hour, regardless of the number of craft workers on site. Hourly confidence level and respective number of observations collected per hour is given in the table 4-1 while detailed separate tables for each hour are attached in the annexure.

**Table 4-1 Number of Observations per Hour in Project A**

| Work Hour | Number of Observations | Confidence Level |
|---|---|---|
| 08:00-09:00 | 1899 | 86.6181643% |
| 09:00-10:00 | 2292 | 92.6857464% |
| 10:00-11:00 | 1928 | 86.9713170% |
| 11:00-12:00 | 1766 | 82.9972066% |
| 12:00-01:00 | 1798 | 83.9185673% |
| Lunch | - | - |
| 02:00-03:00 | 2216 | 91.8111944% |
| 03:00-04:00 | 1700 | 81.3014178% |
| 04:00-05:00 | 1265 | 61.1076759% |
| **Total** | **14864** | **99.9999999%** |

It is important to note that though the individual hour confidence levels are less than 95%, the confidence level for the overall study is slightly less than 100%. This is because sample size does not consider duration of the study, and therefore for the overall results to have a confidence of 95% and an error of 5%, only 510 samples are required. The observer collected nearly thirty times this number of samples, and so the overall results are considered very accurate. The confidence levels for Project A are not drastically worse than the 95% confidence level that was originally intended. This is due to the observer collecting more samples than the original minimum sample size of 342 samples.

The number of labors at the construction site were greater in number which eventually helped research results accuracy. Overall observation can be explained in the Figure 4-1 where the graphical man is representing the behavior of labor which was observed during working hour performing the work at construction site and the characteristics of his working behavior is categorized into seven activities which are shown by different colors in Figure 4-1.

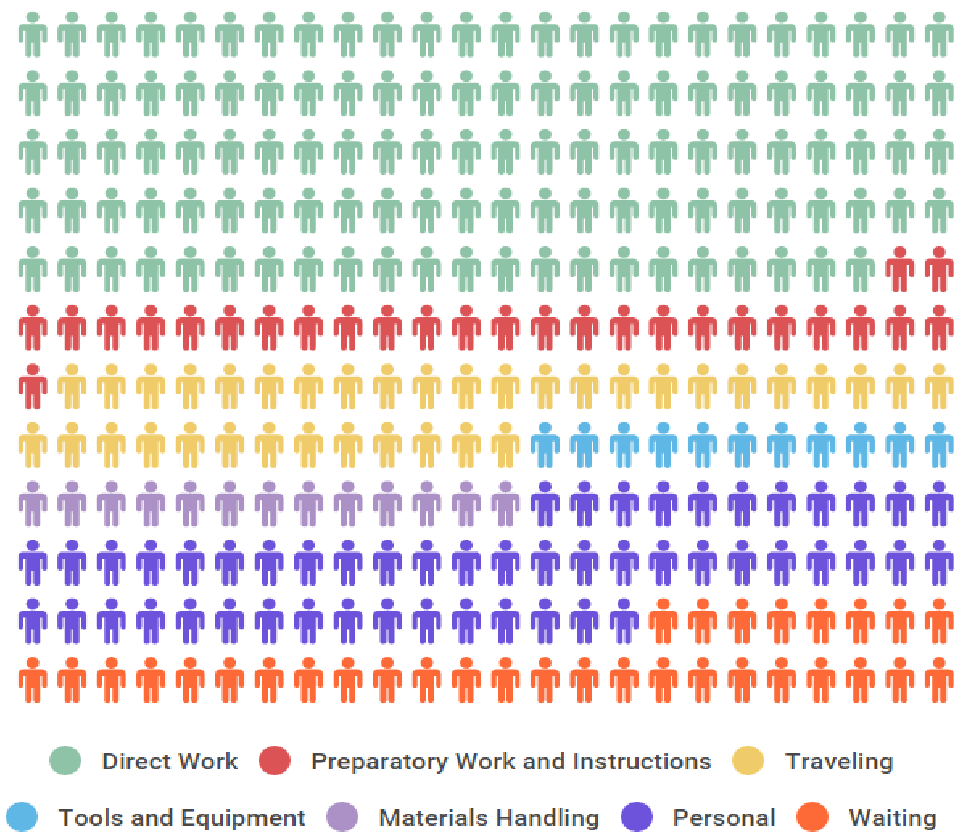


**Figure 4-1 Pictorial representation of labor activities**

After the observations of all 14864 observations were recorded and documented, the percentage of each of the seven activity categories were calculated from total observations classification. Results were tabulated, distribution of time spent on each activity were calculated, graphic presentations of the overall results and hourly breakdown were developed, and then the results were analyzed carefully looking for productivity inhibitors in order to devise the labor productivity improvement at that particular site.

### 4.1.2 Percentages of error with their respective activity category

The calculated results of each activity at Project A are summarized in the Table 4-2. Percentage errors of respective category are also shown in the table in order to assess the accuracy of each category.

**Table 4-2 Activity Rates and Error Estimates for a 95% Confidence Level for Project A**

| Activity Category | Activity Percentage | Error Percentage |
|---|---|---|
| Direct Work | 41.12% | 0.791% |
| Preparatory Work and Instructions | 9.20% | 0.465% |
| Traveling | 12.63% | 0.534% |
| Tools and Equipment | 3.73% | 0.305% |
| Materials Handling | 4.33% | 0.327% |
| Personal | 17.75% | 0.614% |
| Waiting | 11.24% | 0.508% |

The error indicates that for Project A, the overall study determined the direct-work rate was 41.12% ± 0.79% with a confidence of 95% and so on.

### 4.1.3 Overall hourly distribution of observations wr.t each activity

The whole observed data of total five days is given in detail in following Table 4-3 while the observed data tables and their respective activity rates for each day are attached in the annexure.

**Table 4-3 Distribution of whole observed data spreadsheet at project A**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm | Total observations of activities | Activity Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 666 | 979 | 831 | 792 | 760 | L | 873 | 644 | 567 | 6112 | 41.12 |
| Support | Preparatory Work and Instructions | 281 | 252 | 171 | 133 | 126 | u | 179 | 132 | 94 | 1368 | 9.20 |
| | Traveling | 226 | 290 | 266 | 210 | 378 | n | 246 | 104 | 157 | 1877 | 12.63 |
| | Tools and Equipment | 73 | 70 | 95 | 72 | 68 | c | 56 | 62 | 59 | 555 | 3.73 |
| | Materials Handling | 68 | 92 | 88 | 94 | 58 | h | 69 | 118 | 56 | 643 | 4.33 |
| Delays | Personal | 301 | 367 | 322 | 325 | 264 | | 450 | 411 | 198 | 2638 | 17.75 |
| | Waiting | 284 | 242 | 155 | 140 | 144 | | 343 | 229 | 134 | 1671 | 11.24 |
| Total Hourly Observations | | 1899 | 2292 | 1928 | 1766 | 1798 | | 2216 | 1700 | 1265 | 14864 | 100.00 |

### 4.1.4 Overall observed activity rates and productivity analysis

Overall activity rates of each category are graphically illustrated in Figure 4-2. The pie chart is showing that how large the proportion of each activity really is, and how other activities need to be reduced to increase the direct-work rate.

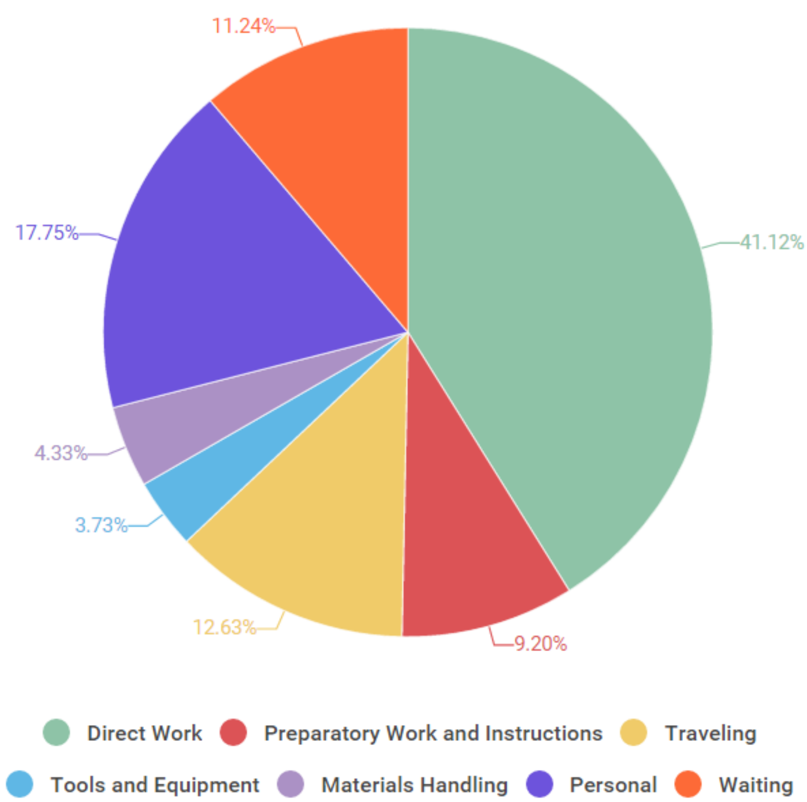


**Figure 4-2 Overall Activity rates for project A**

According to the Construction Industry Institute, direct work rates typically range from 27- 28% for pipefitters, electricians, and riggers in confined spaces, and 44-46% for civil trades including laborers, painters, and teamsters working in an open environment (CII 2010). Project A employed majority of civil trade labors. Direct rate for Project A was 41.12% which is closer to the direct rate referred by CII. Possible explanation for this particular direct rate is that the number of labors were quite higher which created the congestion and ultimately decreased the direct work rate overall. It was also observed that particular project was quite complex in term of construction of new facilities which are usually not constructed in a typical building. Although it was observed that the work supervision was quite effective at the site and site management was quite good in executing the project works. All the works activities were proper planned and monitored by a competent teams of different department at site. Subcontractor labor were also present at the site and high level of coordination between the contractor and subcontractor was witnessed at this project.

Preparatory work and instructions accounted for 9.2% of all work observed on Project A. In field trials conducted on 6 projects by the CII, preparatory work ranged from 8.5 to 15.7%, with an average of 12.1% (CII 2010). 9.2% seems quite reasonable as site supervision was fully coordinated with the labors. The work was fully planned on how to execute the work assignments plus labors were fully aware of necessary preparatory work activities and important information, which shows the effective planning and management of staff. Due to these reasons, preparatory work and instruction activity showed reasonable percentage with respect to other activities.

The percentage of work attributed to travelling activity was 12.63% of total observations, substantially lower than average of the CII field trials of 17.6%, falling low in the range from 13.0-23.6% (CII 2010). Overall construction areas in the site were too much near and all the necessary materials and equipment were stored near them, due to this a lot of time was saved which was going to be waste if the site layout were not properly planned. Due to excellent planning and good site layout, contractor easily saved a lot of time which was used for direct work activities.

Materials handling accounted for 4.33% of all work observations, however there were no average results from the CII to which to compare this figure. However, in a study carried out by Michael C. Gouett (2010) it was found that material handling was 8% which confirms the observed results. Tools & Equipment made up 3.33% of the work observations documented, as compared to the CII field trial average of 11.4% for a range from 6.7-19.3% (CII 2010). Both activities are too low as compared to CII field trail, this means contractor was doing excellent planning in material management. At site it was seen that here was a proper tool management program, site layout was excellent which ultimately decreased the material handling and tools equipment activity time. All the required tools were available, broken tools were repaired or replaced by site management in short period of time by the material department which were actively monitoring the tools and ensuring the labors are using the correct tools.

The percentage of work attributed to Personal time was 17.75% for the observations documented. The CII field trials measured Personal time ranging from 4.9-12.8%, with an average of 7.7% (CII 2010). The Personal time on project A is much greater than the CII results. During the observations, several labors were spotted doing smoke breaks or tea break along with the other crew. The crew size was around five to eleven persons so they did have much time to chat or joke during the working time. It is to be mentioned here that the site supervision was quite strong but due to large number of labors at construction building it was quite tough for site management to control the labors unnecessary talks or gossips during their working time. Site management were of view that labors feel uncomfortable if site staff try to control or monitor their personal activities too much and it was experienced that labors put maximum time in direct work activities if they are doing gossips with their fellow workers. In this way, direct work rate is not much affected.

Waiting had the percentage of 11.24% of all the work observations recorded for the study. However, for the field trials conducted by CII, the average was 14.9% ranging from 11.1% 3 to 20.5% (CII 2010). The percentage of waiting on project A comes in lower range by the CII, which also validate the strong planning of works by contractor at site. Due to clear job instructions and strong material management, labors were not wasting their time in waiting activity

### 4.1.5 Comparison of Activities with each other

If we compare the activities, we can clearly see the after the direct work activity, personal activity is dominating with respect to others with a value of 17.75% as clearly shown in the Figure 4-3.

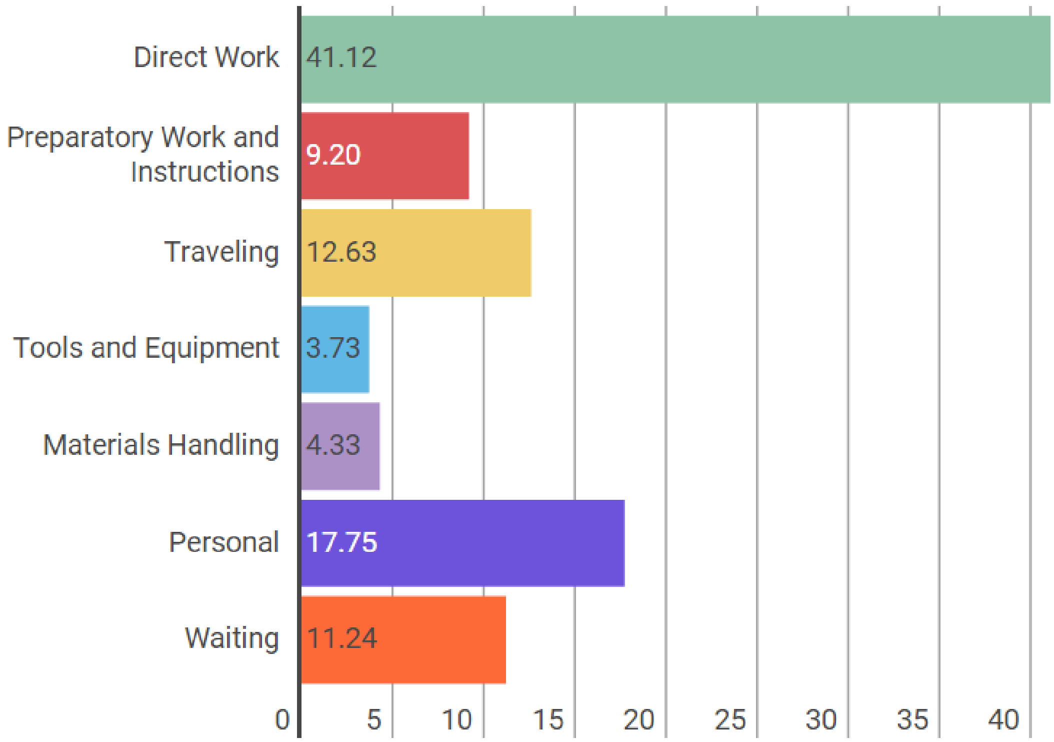


**Figure 4-3 Overall Activities comparison at project A**

If we assume the observed activity rates as time spent on each activity, then we can say that in the typical eight-hour work shift, average labor is spending 3.2 hours actually doing the direct work or directly developing the project, about 44 minutes doing preparatory work and instructions, about 1 hour doing the travelling between different location of work, about 18 minutes doing the tools and equipment related work, 20 minutes doing the material handling works, 1 hour 15 minutes doing his personal works and almost 54 minutes waiting to do work.

### 4.1.6 Hourly Distribution Analysis of Activity percentages

Observations were also calculated for hourly activity percentage and were further analyzed for each category of activity in hourly period of whole working day. Percentages of each activity were calculated for each hour from 8 A.M to 5 P.M and trend of each activity was assessed with respect to all related factors from the total observed labor data of five days. Hourly distribution percentages of each of the seven site activities for project A are given in the Table 4-4.

**Table 4-4 Percent Distribution of observed data percentages in each hour at project A**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm |
|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 35.07 | 42.71 | 43.10 | 44.85 | 42.27 | Lunch | 39.40 | 37.88 | 44.82 |
| Support | Preparatory Work and Instructions | 14.80 | 10.99 | 8.87 | 7.53 | 7.01 | | 8.08 | 7.76 | 7.43 |
| | Traveling | 11.90 | 12.65 | 13.80 | 11.89 | 21.02 | | 11.10 | 6.12 | 12.41 |
| | Tools and | 3.84 | 3.05 | 4.93 | 4.08 | 3.78 | | 2.53 | 3.65 | 4.66 |
| | Materials Handling | 3.58 | 4.01 | 4.56 | 5.32 | 3.23 | | 3.11 | 6.94 | 4.43 |
| Delays | Personal | 15.85 | 16.01 | 16.70 | 18.40 | 14.68 | | 20.31 | 24.18 | 15.65 |
| | Waiting | 14.96 | 10.56 | 8.04 | 7.93 | 8.01 | | 15.48 | 13.47 | 10.59 |

As we can clearly see that all activities are changing with respect to time. Some activities are quite low at start of day, while some activities are high at the start, similarly same can be said at the end of day. For a typical day, changes in these activities are graphically illustrated in the following time series stacked bar chart represented in Figure 4-4.

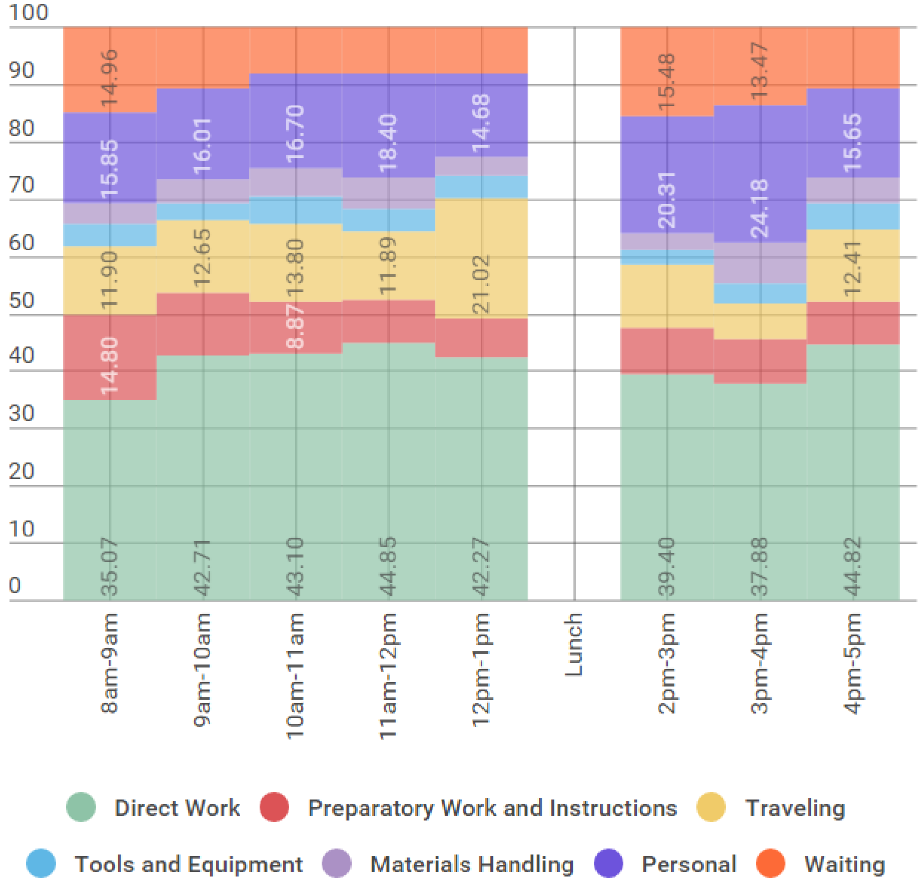


**Figure 4-4 Stacked bar chart representing hourly distribution of activity rates at project A**

Direct work rate of labors was observed low when the labors were going to start of work e.g. before the start of day and after the lunch. During the start of day, it is observed that direct work activities take time and during the start of day, other activities were high as compared to direct work. As the work will start worker will travel to the site, will gets the necessary instruction from senior and staff members, will get the required tools which he will use if the jobs require any kind of tools and get the material handle to complete the task. Due to these reasons, support activities will be greater as labor will be involved in greater support activities like preparatory work and instructions, travelling, material handling, tools and equipment, etc.

Individual behavior of all the activities are displayed in the Figure 4-5, where the lines of respective category are showing the hourly trend.

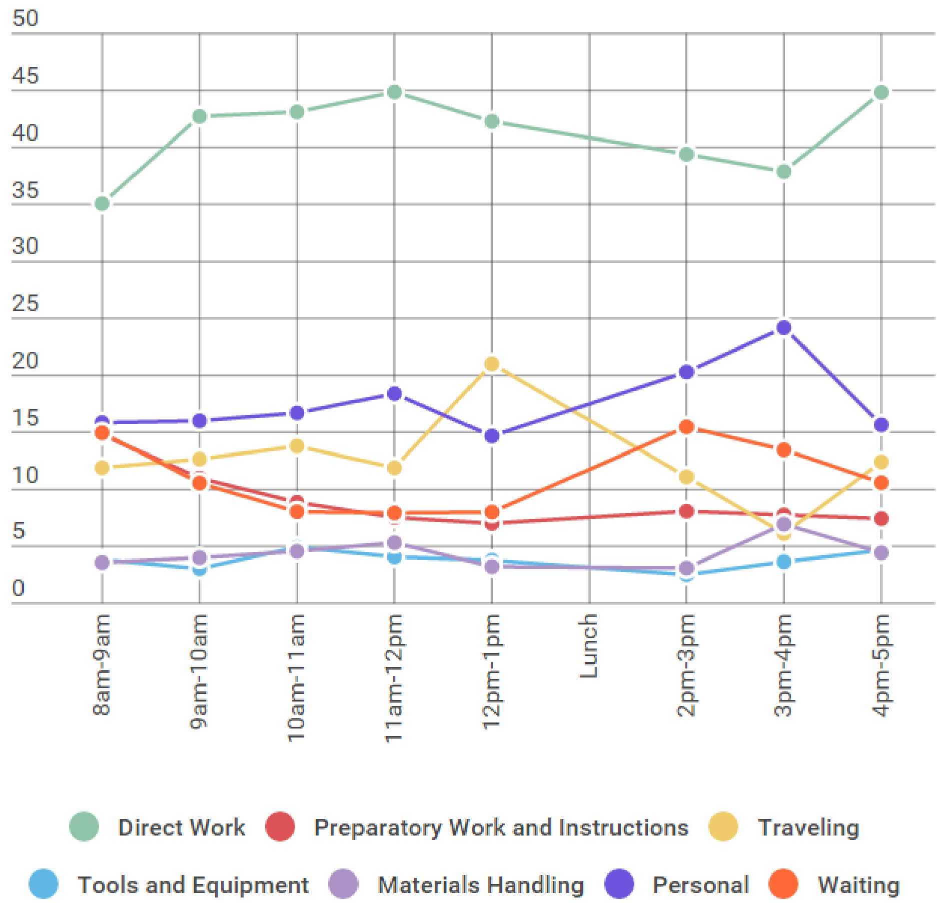


**Figure 4-5 Overall hourly trend of activities at project A**

Direct work rate trend throughout the working day of 8 hours is analyzed in detail. As it is clearly seen that it is lowest at the start of the work while increasing with respect to time and then start decreasing before the lunch. And after the lunch break, direct work rate is still less and after one hour, it gets lesser more with time and then increases in last hour. Direct work peaks during 11am to 12pm and 3pm to 4pm with a value of almost 44% of while it is lowest in the starting hour with a value of almost 35%. It can be said that direct work increase as the working time increases hours, and. The crews try to accomplish their set target so they work at a higher rate before the end of working day.

Activity “Preparatory work & instructions” is highest when the labor is going to start of working day and start of work after lunch. As it is shown in the last graph, activity is lowest during 8am to 9am and 2pm to 3pm. It is observed that before the starting the work, labor get necessary instructions and required information on how to perform the work along with that they get the safety equipment for themselves, which ultimately increases the preparatory work and instructions activity.

Travelling was observed highest during 11am to 12pm with a value of 21.02% and lowest during 3pm to 4pm with a value of 6.02%. During the data collection phase, it was observed that the number of labors were high when they were going or returning to their working areas. During the 12pm to 1pm, it was observed that number of labors travelling at this time was drastically larger and it was due to that the many labors leave their site early due to many reasons like they are tired or they want to reach at dining place as they are feeling hungry. It was also seen that many labors also have to do prayer and the mosque place is a quite far from working area that's why they try to leave early the working site in order to wash or clean themselves before performing the prayer.

Tools and equipment category is observed overall consistent of almost value of 4% with a peak value of 4.66% at 4pm-5pm and lowest value of 2.53% at 2pm-3pm. It was noticed that site staff usually execute some activities at the end of working day which involves some special tools and machinery which eventually increases the tools and equipment category in the last working hour.

Material Handling was spotted high during 3pm to 4pm with a value of 6.94 and another peak value is seen at11am to 12pm with a value of 5.32%. While the trend was seen lowest at 12pm to 1pm with value of 3.11%. An interesting fact is noted here that material handling is strongly correlated to material handling if both trend lines are observed. Both direct work and material handling peaks during mid of work before and after the lunch. The possible explanation of correlation of both activities is that labor will be handling much more material when they will be ding those activities which is directly developing the project.

Collectively, Personal activity is highest among other activities after the direct work activities in almost every hour of working day. It is seen increasing in mid-morning and right after the lunch break. It was observed high during 3pm-4pm with a value of 24.18%

and low during 12pm-1pm with a value of 14.68%. Large number of labors also have some fix teak break sessions. It is highly observed at many events during data collection phase that labors try to utilize the work supervision relaxation given during working time as much as they can. Labor were observed having smoke break at numerous event. Many times it was also observed that labors were listening to some songs or phone calls on their cellphones. In order to increase the direct work rate, personal activity should be lowered as much as it can be.

Second activity of delay “waiting” also following a similar trend to personal activity. Waiting activity peaks at 2pm-3pmwith a value of 15.48% while it is observed lowest at 11am-12pmwith a value of 7.93%. It was observed that the waiting activity was quite high during the start of work whether after the breakfast or lunch. It was also analyzed that values of waiting activity were found high where the direct work activity was low, similarly it was found that direct work activity was low where direct activity work activity was high and inverse relation between both activities were observed. So, in order to increase direct work, it should be important to make arrangement at site so that workers did not have to wait for work as this will directly increase the direct work rate. For this purpose, five minute rating was observed and crew balancing was also performed at site in order to minimize labor waiting time, which will directly increase the labor direct work and will collectively increase the labor productivity.

### 4.1.7 Safety Assessment

At Project A, safety arrangements were quite applaudable as compared to overall average construction industry of Pakistan. All the workers were wearing PPE such as hard hats, closed toe shoes and safety vests and client had ensured that no worker should be allowed to work if he is not following safety arrangements. Overall it was observed that all the staff and labors were working under the safe conditions and there were separate safety supervisory staff under safety manager which were hired in order to assure safety at the site. During the data collection phase, it was observed that safety signs were installed at many places and crane was tested before lifting of construction material and there was inspection or safety check of working area by safety officer before the start of any activity.

It was also told that the working labor were properly guided to follow the safety procedures at the site at start, that's why labor was cooperating with safety staff. Overall small drawbacks regarding the safety were observed at the site. One of the safety fault was the limited staircases as construction site was dense labor populated site and staircase was one of the high traffic area of site. Large number mosquitoes were also found in many places of site area due to poor drainage of water

### 4.1.8 Five Minute Rating and Crew balancing

Five minute analysis was also performed during site visit. During data collection, video was recorded for approximately 45 minutes to collect data for the five-minute rating of the observed brickwork construction. After analyzing the video, it was determined that the cycle time for the formwork activity was 12 minutes. There were 2 masons and 3 labors were working on a brickwork activity. Three labors or helpers were transporting, wetting, handing the bricks and making mortar for bricks so that other two mason can install the bricks to the wall structure. Table 4-5 are the data readings observed and their results.

**Table 4-5 Five minute analysis spreadsheet**

| Minutes | Mason 1 | Mason 2 | Labor 1 | Labor 2 | Labor 3 |
|---|---|---|---|---|---|
| 1 | × | | × | × | × |
| 2 | × | × | × | | |
| 3 | | | × | | × |
| 4 | | | | × | × |
| 5 | × | × | | × | |
| 6 | × | × | × | × | × |
| 7 | × | × | × | | |
| 8 | × | | × | | |
| 9 | | | | | |
| 10 | × | | | × | × |
| 11 | | | × | | × |
| 12 | | × | × | | |
| **Effective Units** | **7** | **5** | **8** | **5** | **6** |
| Total Man Units | 60 | | | | |
| Effective Man Units | 31 | | | | |
| Effectiveness | 52% | | | | |

Result shows that overall effectiveness of the brickwork activity was 52%. Thus, the observation based on the crew balancing and five-minute rating techniques was that the work was not evenly distributed. Out of ten minutes of work cycle activity, effectiveness of one mason was 50% and out of three labors, effectiveness of two labors were 50% and 60% respectively.

Hence, based on the results of data collected for the brickwork construction, a proposed solution is to have only two labors perform the work and reassign the third worker to another task. Reassigning the third labor to another task would be an application of the crew balancing technique because it would maximize the direct work performed on the task by maximizing the efficient use of time and resources.

## 4.2 PROJECT B

Second project was construction of large commercial building which will be eventually used as mega malls, offices and several apartments. This project overall covers 910,000sft area of land and was located in the main business hub of capital city of Pakistan. The Client or owner of the project was one of the largest real estate group of country and they choose as medium based firm as civil contractor for the execution of work while building was designed by a separate firm.

Contract was signed on 27$^{th}$ June, 2014 between client and general contractor of project, while the site was mobilized on 7$^{th}$ July, 2014. Data was collected first half of December, 2015 when ground floor was being constructed. At that time, project was around 26% completed with respect to time and major activities during the observation was formwork, steel fixing, concrete pouring of column and retaining wall was in progress. Overall average number of site labor working at the project B were more than two hundred during all visits. Workers of all crafts were included in the study. General activities observed during the data collection phase at that project was concrete pouring, formwork, plastering and block masonry. Large no. of labors working at site were employed by the subcontractors while there was less no. of labor directly working for general contractor.

### 4.2.1 Number of observations and hourly confidence level

For a 95% confidence level, and an error of 5.0%, a total of 510 samples were required per hour, regardless of the number of craft workers on site as multinomial distribution were used due to multiple work activities. Table 4-6 summarizes the number of samples collected for every observation hour with respective confidence level while detailed separate tables for each hour are attached in the annexure.

**Table 4-6 Project B- Number of Observations per Hour**

| Work Hour | No. of Observations | Confidence Level |
|---|---|---|
| 08:00-09:00 | 1483 | 73.6324698% |
| 09:00-10:00 | 1496 | 73.7743593% |
| 10:00-11:00 | 1435 | 70.7941837% |
| 11:00-12:00 | 825 | 15.6141787% |
| 12:00-01:00 | 972 | 35.3942191% |
| Lunch | - | - |
| 02:00-03:00 | 1451 | 71.9795132% |
| 03:00-04:00 | 1401 | 69.1534353% |
| 04:00-05:00 | 1189 | 55.8557617% |
| **Total** | **10252** | **99.9999364%** |

It is important to note that though the individual hour confidence levels are sufficiently low and during one working hour confidence level is about 15.61% but the confidence level for the overall study is slightly less than 100%. This is because sample size does not consider duration of the study, and therefore for the overall results to have a confidence of 95% and an error of 5%, only 510 samples are required. The observer collected nearly twenty times this number of samples, and so the overall results are considered very accurate.

Overall observation can be explained in the Figure 4-6 where the graphical man is representing the behavior of labor which was observed during working hour performing the construction work at construction site and the characteristics of his behavior is categorized into seven activities which are shown by different colors in Figure 4-6.

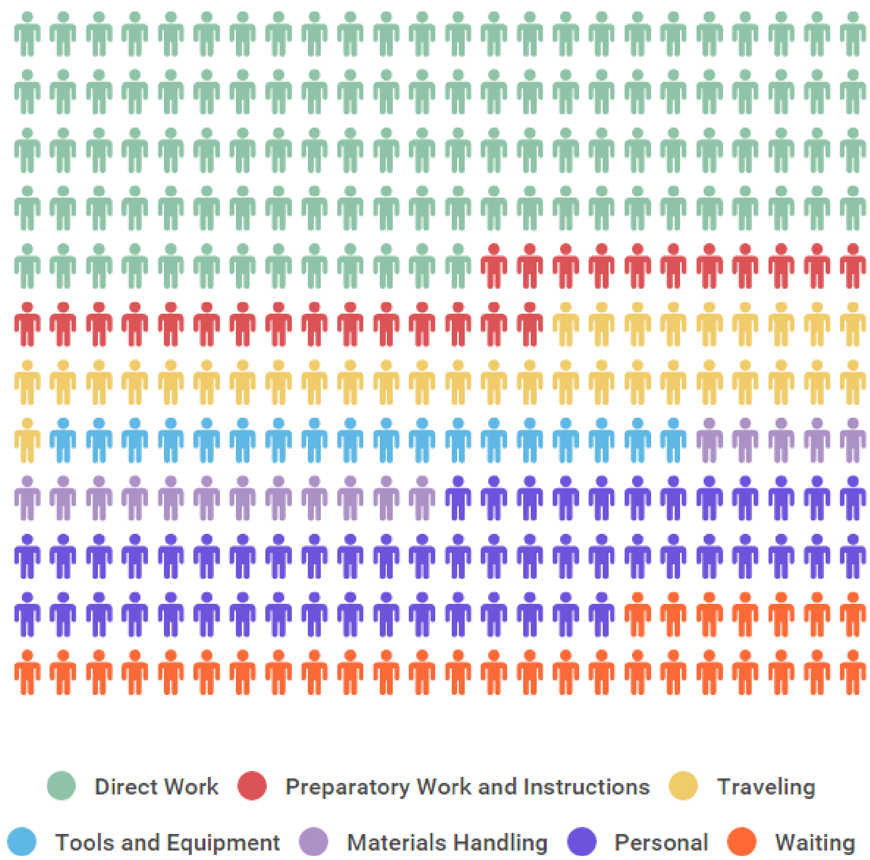


**Figure 4-6 Pictorial representation of labor activities**

Around 10252 observations were recorded and documented for project B, the percentage of each of the seven activity categories were later calculated from total observations classification.

### 4.2.2 Percentages of error with their respective activity category

The calculated results of each activity at Project B are summarized in the Table 4-7. Percentage errors of respective category are also shown in the table in order to assess the accuracy of each category.

**Table 4-7 Activity Rates and Error Estimates for a 95% Confidence Level for Project B**

| Activity Category | Activity Percentage | Error Percentage |
|---|---|---|
| Direct Work | 37.87% | 0.939% |
| Preparatory Work and Instructions | 8.83% | 0.549% |
| Traveling | 11.93% | 0.627% |
| Tools and Equipment | 6.37% | 0.473% |
| Materials Handling | 5.90% | 0.456% |
| Personal | 18.38% | 0.750% |
| Waiting | 10.73% | 0.599% |

Sample size determination is a balance between error and confidence. If the error was maintained at 5.0%, the confidence level would be nearly 100% as reported in the above table. However, it was determined it would be more meaningful to report the true error of each proportion based on a 95% confidence level which was originally intended. The error indicates that for Project B, the overall study determined the direct-work rate was 37.87% ± 0.939% with a confidence of 95% and so on.

### 4.2.3 Overall hourly distribution of observations wr.t each activity

The whole observed data for five days are given in detail in Table 4-8 while the observed data tables and their respective activity rates for each individual day are attached in the annexure along with other important information.

**Table 4-8 Distribution of whole observed data spreadsheet at project B**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | Lunch | 2pm-3pm | 3pm-4pm | 4pm-5pm | Total observations of activities | Activity Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 352 | 609 | 622 | 343 | 390 | | 483 | 602 | 481 | 3882 | 37.87 |
| Support | Preparatory Work and Instructions | 198 | 108 | 88 | 56 | 65 | | 155 | 134 | 101 | 905 | 8.83 |
| | Traveling | 223 | 157 | 133 | 97 | 166 | | 231 | 102 | 114 | 1223 | 11.93 |
| | Tools and Equipment | 145 | 92 | 74 | 49 | 46 | | 115 | 78 | 54 | 653 | 6.37 |
| | Materials Handling | 89 | 105 | 46 | 90 | 56 | | 106 | 61 | 52 | 605 | 5.90 |
| Delays | Personal | 264 | 284 | 325 | 112 | 162 | | 244 | 246 | 247 | 1884 | 18.38 |
| | Waiting | 212 | 141 | 147 | 78 | 87 | | 117 | 178 | 140 | 1100 | 10.73 |
| Total Hourly Observations | | 1483 | 1496 | 1435 | 825 | 972 | | 1451 | 1401 | 1189 | 10252 | 100.00 |

### 4.2.4 Overall observed activity rates and productivity analysis

Overall activity rates of each category are graphically illustrated in Figure 4-7. The pie chart is showing that how large the proportion of each activity really is, and how other activities need to be reduced to increase the direct-work rate.

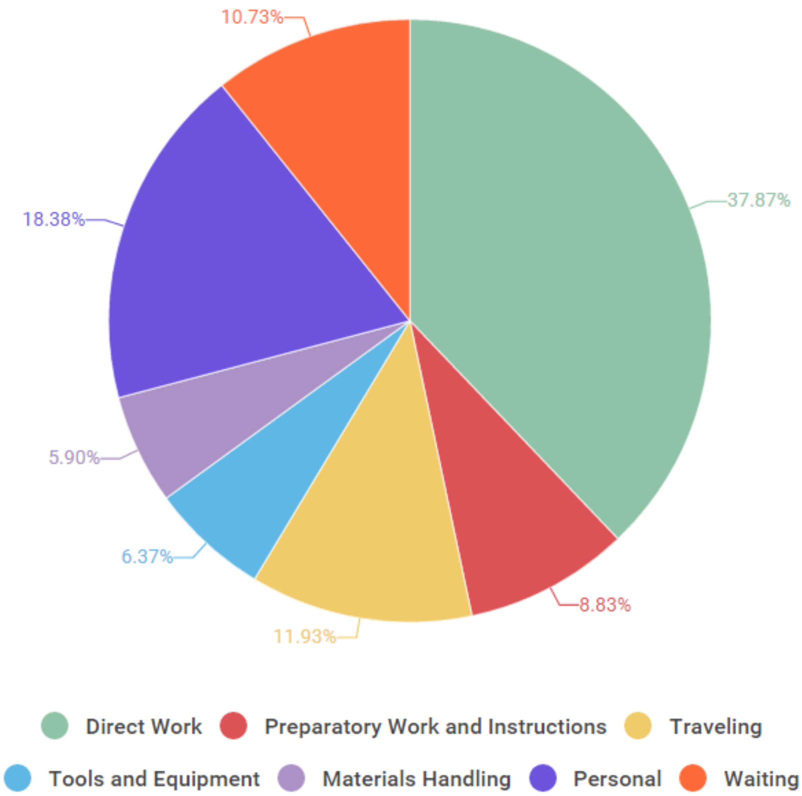


**Figure 4-7 overall Activity rates for project B**

According to the Construction Industry Institute, direct work rates typically range from 44-46% for civil trades including laborers, painters, and teamsters working in an open environment (CII 2010). Project B employed majority of civil trade labors as at the time of data observations, majority of activities were purely civil. Direct rate for Project B was 37.87% which is closer to the direct rate referred by CII. Possible explanation is that the number of labors were quite higher which created the congestion and ultimately decreased the direct work rate. It was also observed that this project has employed majority of subcontractor labor and it was quite difficult to supervise their progress work as compared to company own labor. Although it was observed that subcontractor was going quite good and fast both in the term of quality and speed of work. Project activities were planned at broad level and level of coordination was only seen between subcontractor himself and higher staff. If the worker or mason of subcontractor has to ask something about work, he usually calls directly the subcontractor in order to get instruction related to work. Contractor staff were not found as much supportive in case of coordination.

Preparatory work and instructions accounted for 8.3% of all work observed on Project B. In field trials conducted on 6 projects by the CII, preparatory work ranged from 8.5 to 15.7%, with an average of 12.1% (CII 2010). Value 9.2% seems quite good as it was observed that work activities were not as complex and majority of work were given to specialty contractor who were quite experienced and good in performing those works therefore they did not waste much of their time in understanding the information related to the work.

The percentage of work attributed to travelling activity was 11.93% of total observations, substantially lower than average of the CII field trials of 17.6%, falling low in the range from 13.0-23.6% (CII 2010). Construction site was not so big and as there was only one large building site therefore labors did not have to go to other areas, majority of labors were working there. As mostly specialty contractors were working on the site and they were quite familiar with the work to be performed, they usually came with the right tools and did not leave the site until their work is done. Due to this a lot of travelling activity time was saved as subcontractor labor were not moving from the site unless there is a strong cause to leave the working area.

Materials handling accounted for 5.9% of all work observations, it is to be noted here that there were no average results from the CII to which to compare this figure. During the observations periods, work activities that were going on at that time needs large sizable material more like steel, concrete as compared to small size material which can be transported through labors. Site staff were using crane for steel transportation and concrete pump through pipes for concrete pouring at the required place. Many times it was seen that due to large number of steel to be transported to the required places, crane was unable to transport all materials on time. Similarly, tools & equipment activity made up of 6.37% of the work observations documented, as compared to the CII field trial average of 11.4% for a range from 6.7-19.3% (CII 2010). Both activities are too low as compared to CII field trail as it was observed that work activities were not complex at this project and specialty contractor were working there and they come ready with all their working tools which saves a lot of time.

The percentage of work attributed to Personal time was 18.38% for the observations documented. The CII field trials measured Personal time ranging from 4.9-12.8%, with an average of 7.7% (CII 2010). The Personal time on project B is much greater than the CII results. It was observed that site supervision of works was very weak as maximum amount of work were subcontracted to the petty contractors and site staff were overall dependent on them. Several labors were spotted doing tea breaks along with the other members of crew. The crew size was around four to nine. It was experienced that labors put maximum time in direct work activities if they are doing gossips with their fellow workers of crew. In this way, direct work rate is not much affected as it should be overall.

Waiting had the percentage of 10.73% of all the work observations recorded for the study. However, for the field trials conducted by CII, the average was 14.9% ranging from 11.1% 3 to 20.5% (CII 2010). Site work activities were quite simple and no. of workers employed by subcontractor were average low usually in every task, that’s why it was less observed that worker has to wait for other labor to complete the work. It was also observed overall work activities and task were not close to each other and there was very much confliction of activities due to simple activities. All these factors maintained the waiting activity value at 10.73% overall. Five minute rating was also performed at the site to assess the crew balancing of the project activities which is explained in detail.

### 4.2.5 Comparison of Activities with each other

If we compare the activities, we can clearly see the after the direct work activity, personal activity is dominating with respect to others with a value of 17.75% as clearly shown in the Figure 4-8.

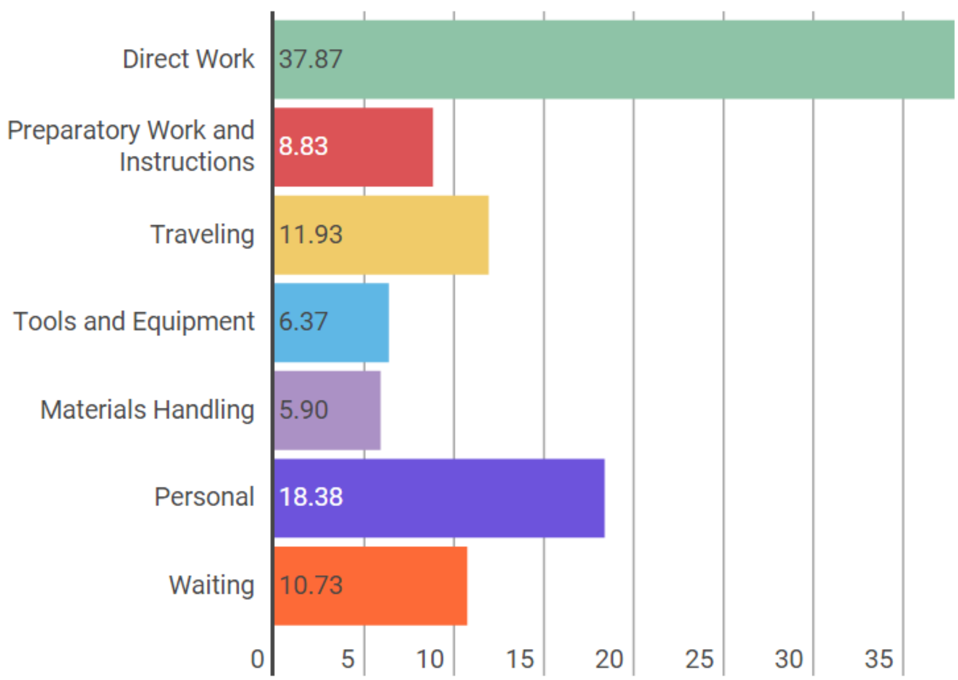


**Figure 4-8 Overall Activities comparison at project B**

If we assume the observed activity rates as time spent on each activity, then we can say that in the typical eight-hour work shift, average labor is spending 3 hours actually doing the direct work or directly developing the project, about 42 minutes doing preparatory work and instructions, about less than 1 hour doing the travelling during work, about 30 minutes doing the tools and equipment related work, 28 minutes doing the material handling works, 1.5 hours doing his personal works and almost 51 minutes waiting to do work.

### 4.2.6 Hourly Distribution Analysis of Activity percentages

Observations were also calculated for hourly activity percentage and were further analyzed for each category of activity in hourly period of whole working day. Percentages of each activity were calculated for each hour from 8 A.M to 5 P.M and trend of each activity was assessed with respect to all related factors from the total observed labor data of five days. Hourly distribution of site of each of the seven site activities for project B are given in the Table 4-9.

**Table 4-9 Distribution of observed data percentages in each hour at project B**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm |
|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 23.74 | 40.71 | 43.34 | 41.58 | 40.12 | Lunch | 33.29 | 42.97 | 40.45 |
| Support | Preparatory Work and Instructions | 13.35 | 7.22 | 6.13 | 6.79 | 6.69 | | 10.68 | 9.56 | 8.49 |
| | Traveling | 15.04 | 10.49 | 9.27 | 11.76 | 17.08 | | 15.92 | 7.28 | 9.59 |
| | Tools and Equipment | 9.78 | 6.15 | 5.16 | 5.94 | 4.73 | | 7.93 | 5.57 | 4.54 |
| | Materials Handling | 6.00 | 7.02 | 3.21 | 10.91 | 5.76 | | 7.31 | 4.35 | 4.37 |
| Delays | Personal | 17.80 | 18.98 | 22.65 | 13.58 | 16.67 | | 16.82 | 17.56 | 20.77 |
| | Waiting | 14.30 | 9.43 | 10.24 | 9.45 | 8.95 | | 8.06 | 12.71 | 11.77 |

As we can clearly see that all activities are changing with respect to time. Some activities are quite low at start of day, while some activities are high at the start, similarly same can be said at the end of day. For a typical day, changes in these activities are graphically illustrated in the following time series stacked bar chart. These increasing and decreasing trends are analyzed after the Figure 4-9 in detail.

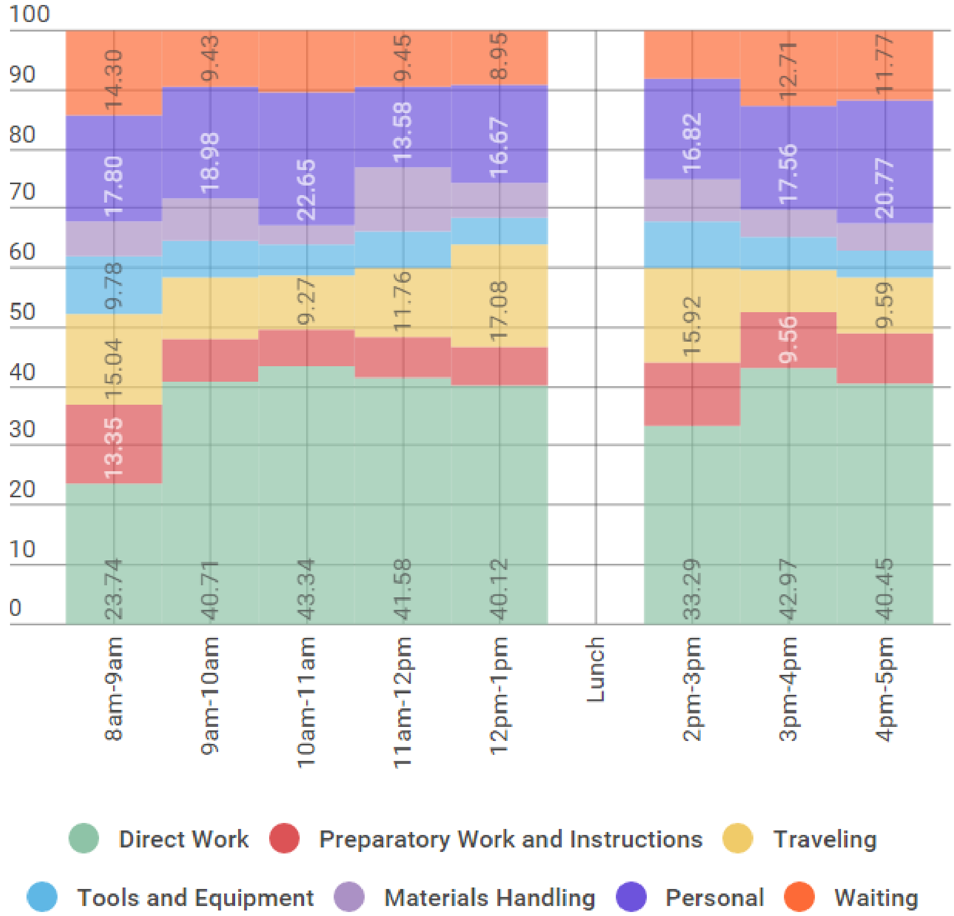


**Figure 4-9 Stacked bar chart representing hourly distribution of activity rates at project**

Activity direct work of labors were observed lowest when the labors were going to start of work at both time e.g. after the start of day and after the lunch. During the start of day. It is observed that direct work activities take time during the start of day, other activities were high as compared to direct work. . As the work will start worker will travel to the site, will gets the necessary instruction from senior and staff members, will get the required tools which he will use if the jobs require any kind of tools and get the material handle to complete the task. Due to these reasons, support activities will be greater as labor will be involved in greater support activities like preparatory work and instructions, travelling, material handling, tools and equipment etc.

Hourly trend of all the activities will be analyzed to know when the particular high gets low or high and it will help us to understand the factors that affect that activity.

Individual behavior of all the activities are displayed in the following Figure 4-10 where the lines of respective category are showing the hourly trend.

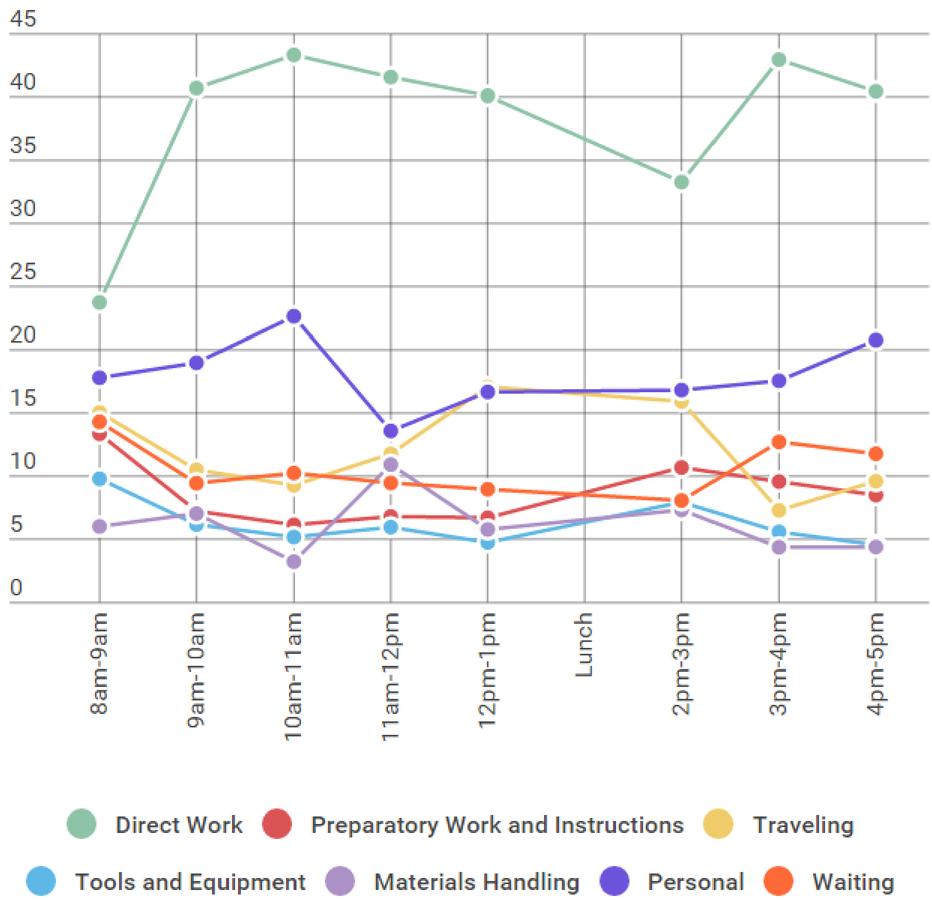


**Figure 4-10 Overall hourly trend of activities at project B**

Direct work rate trend throughout the working day of 8 hour is analyzed in detail. As it is clearly seen that it is lowest at the start of the work while increasing with respect to time and then start decreasing before the lunch. And after the lunch break, direct work rate is still less and after one hour, it gets higher more with time and then decreases in last hour. Direct work peaks during 10am to 11am with a value of almost 43.34% of while it is lowest in the starting hour with a value of almost 23.74%. It can be said that direct work increase as the working time increases hours.

Activity "Preparatory work & instructions" is highest when the labor is going to start of working day and start of work after lunch. As it is shown in the last graph, particular activity is highest during 8am to 9am and 2pm to 3pm. It is observed that before the starting the work, labor get necessary instructions and required information on how to perform the work along with that they get the safety equipment for themselves, which ultimately increases the preparatory work and instructions activity. Trend shows that activity peak at start of working day with a value of 13.35% at 8am-9am and it is lowest with a value of 6.13 at 11am-12pm.

Travelling was observed highest during 8am to 9am with a value of 15.04 and 15.92% respectively and lowest during 10am to 11am with a value of 6.13%. During the data collection phase, it was observed that the number of labors were high when they were going or returning to their working areas. During the 12pm to 1pm, it was observed that number of labors travelling at this time was drastically larger and it was due to that the many labors leave their site early due to many reasons like they are tired or they want to reach at dining place as they are feeling hungry. It was also seen that many labors also have to do prayer and the mosque place is a quite far from working area that’s why they try to leave early the working site in order to wash or clean themselves before performing the prayer.

Tools and equipment category is observed high at the start of day with a peak value of 9.78% at 8am-9am and low at the end of day with a value of 4.54% at 4pm-5pm. Site labors get the required tools and equipment at the start of day before the work which eventually increases the particular activity value.

Material Handling was spotted high during 11am to 12pm with a value of 10.91% while the trend was seen lowest at 10am to 11am with value of 3.21%. An interesting fact is noted here that material handling is strongly correlated to material handling if both trend lines are observed. It was seen that some activities are material based and site staff preferred to do them before the lunch after completing other activities due to site layout.

Collectively, Personal activity is highest among other activities after the direct work activities in almost every hour of working day. It is seen increasing in mid-morning and right after the lunch break. It was observed high during 10am-11am with a value of 22.65% and low during 12pm-1pm with a value of 13.58%. Labor were observed having smoke break at numerous event during the mid of work sessions. Many times it was also observed that labors were listening to some songs or phone calls on their cellphones. In order to increase the direct work rate, personal activity should be lowered as much as it can be.

It was observed that the waiting activity was quite high during the start of work because subcontractor's labor were waiting for exact information of work from their senior in the morning which eventually increased the value of this activity at the work's start. Waiting activity peaks at 8am-9amwith a value of 14.3% while it is observed lowest at 2pm-3pm with a value of 8.06%. So, in order to increase direct work, it should be important to make arrangement at site so that workers did not have to wait for work as this will directly increase the direct work rate. For this purpose, five minute rating was observed and crew balancing was also performed at site in order to minimize labor waiting time, which will directly increase the labor direct work and will collectively increase the labor productivity.

#### 4.2.7 Safety Assessment

At Project B, safety arrangement by the contractor were fine. Mostly labor were wearing hard hats, some were also seen wearing safety vest but there was no as such strictness on subcontractor's labor that's why there were overall not following the safety precautions. Due to requirement of client, safety officer was hired by the contractor at site to watch over safety of whole project but he was non-qualified and it was observed it was quite difficult for one person to assure the safety of big and labor intense construction site. Contractor staff were of the view that project is developing fast and it is difficult to them to ensure safety arrangements at site along with other construction works. Due to less priority of safety at site, considerable number of safety drawbacks were observed. There were no safety checks or inspection of work activities nor safety arrangement were followed especially during the material transportation through cranes. One of such incident was witnessed during data collection session when the steel bar was fell down during transportation, luckily there was nobody down at that time. It was observed that there were no safety signs, no covering of electric wires at passing routes and no guard rail at many spots. Overall safety measures which were implemented at site were due to the client demands. It was observed that safety can be improved drastically at site if contractor put the safety in their priority list.

### 4.2.8 Five Minute Rating and Crew Balancing

During the data collection video was recorded for almost 30 minutes for the activity of concrete laying. After analyzing the video, cycle time was determined and five minute rating was performed for 12 minutes as there was 7 members performing the task with addition to 5 minutes (5+7). Two masons were placing and finishing the task while 5 labors were helping them during the concreting. Labors were transporting and handling the overall concrete works so that mason can accurately place and finish the concrete layer as required. Table 4-10 represents the data readings observed with the effectiveness percentage of overall result.

**Table 4-10 Five minute analysis spreadsheet**

| Minutes | Mason 1 | Labor 1 | Labor 2 | Labor 3 | Labor 4 | Labor 5 |
|---|---|---|---|---|---|---|
| 1 | x | x | x | x | x | |
| 2 | x | x | | x | | |
| 3 | | x | | | | |
| 4 | | | | | | x |
| 5 | | | x | x | x | x |
| 6 | x | | | | | |
| 7 | x | | | | x | |
| 8 | x | | | x | | |
| 9 | x | x | | x | | x |
| 10 | | x | | | | |
| 11 | | x | x | | x | |
| 12 | x | | x | x | | x |
| **Effective Units** | **7** | **6** | **4** | **6** | **4** | **4** |
| Total Man Units | | | 72 | | | |
| Effective Man Units | | | 27 | | | |
| Effectiveness | | | 38% | | | |

Result shows that overall effectiveness of the brickwork activity was 38%. Thus, the observation based on the crew balancing and five-minute rating techniques was that the work was not evenly distributed. Out of twelve minutes of work cycle activity, effectiveness of one mason was 58% and five labor were 33%.

Hence, based on the results of data collected for the particular activity, proposed solution is to have only three labors perform the work and reassign the other two workers to another task. Reassigning the other labor to another task would be an application of the crew balancing technique because it would maximize the direct work performed on the task by maximizing the efficient use of time and resources.

## 4.3 PROJECT C

Third selected project was the construction of large 19 storey Golf Resort Hotel located in on main Muree express highway near Muree, Islamabad. An international group of golf resort was the funding body of this project and they choose a large and specialized supervision consultant for the supervision of work and a large national contractor for execution of project. Labor data was observed at project site in the second half of December, 2016 and in the start of January, 2016. During the time of Data collection, project progress was overall 30%, and substructure was being constructed where the major activities observed during the data collection was curing, steel fixing, formwork and concrete pouring. Average no. of labors working at the site were around 250 and they all were included in the data collection procedure.

During the data collection phase, project was going on crisis as the funding body has stopped the funding of project to some extent and due to no funding, contractor was reducing the overhead cost of project by dismissing the main staff members of project due to which project productivity was touching its lowest. It was later known that project was quite active around 6 month ago project progress were at peak at that time. But unexpectedly, the client reduced the financing of project due to which contractor was unable to continue the flow of that progress and minimized the execution of project.

Eventually large number of staff members and labors were dismissed from project due to limited availability of funds. Now the project is going from hard time due to lack of interest from concerned stakeholders.

### 4.3.1 Number of observations and hourly confidence level

For a 95% confidence level, and an error of 5.0%, a total of 510 samples are required per hour, regardless of the number of craft workers on site. Table 4-11 summarizes the number of samples collected and respective confidence level for every observed hour of project C. The true confidence level was calculated using the actual number of samples collected, an error of 5.0%, and the actual measured proportions for each hour.

**Table 4-11 Project C- Number of Observations per Hour**

| Work Hour | No. of Observations | Confidence Level |
|---|---|---|
| 08:00-09:00 | 1511 | 74.8671% |
| 09:00-10:00 | 1217 | 58.2238% |
| 10:00-11:00 | 1057 | 44.5652% |
| 11:00-12:00 | 1177 | 55.0862% |
| 12:00-01:00 | 1241 | 59.9233% |
| Lunch | - | - |
| 02:00-03:00 | 1501 | 74.3830% |
| 03:00-04:00 | 1107 | 49.2833% |
| 04:00-05:00 | 1179 | 55.3455% |
| **Total** | **9990** | **99.9999%** |

Sample size does not consider duration of the study, and therefore for the overall results to have a confidence of 95% and an error of 5%, only 510 samples are required. It is important to note that though the individual hour confidence levels are less than 95%, the confidence level for the overall study is slightly less than 100%. The observer collected more than nineteen times this number of samples, and so the overall results are considered very accurate.

For Project C, labors were observed for 5 days consecutively in order to get accurate results during their working time of 8 hours. Overall observation can be explained in the following figure where the graphical man is representing the behavior of labor which was observed during working hour performing the construction work at construction site and the characteristics of his behavior is categorized into seven activities which are shown by different colors in Figure 4-11.

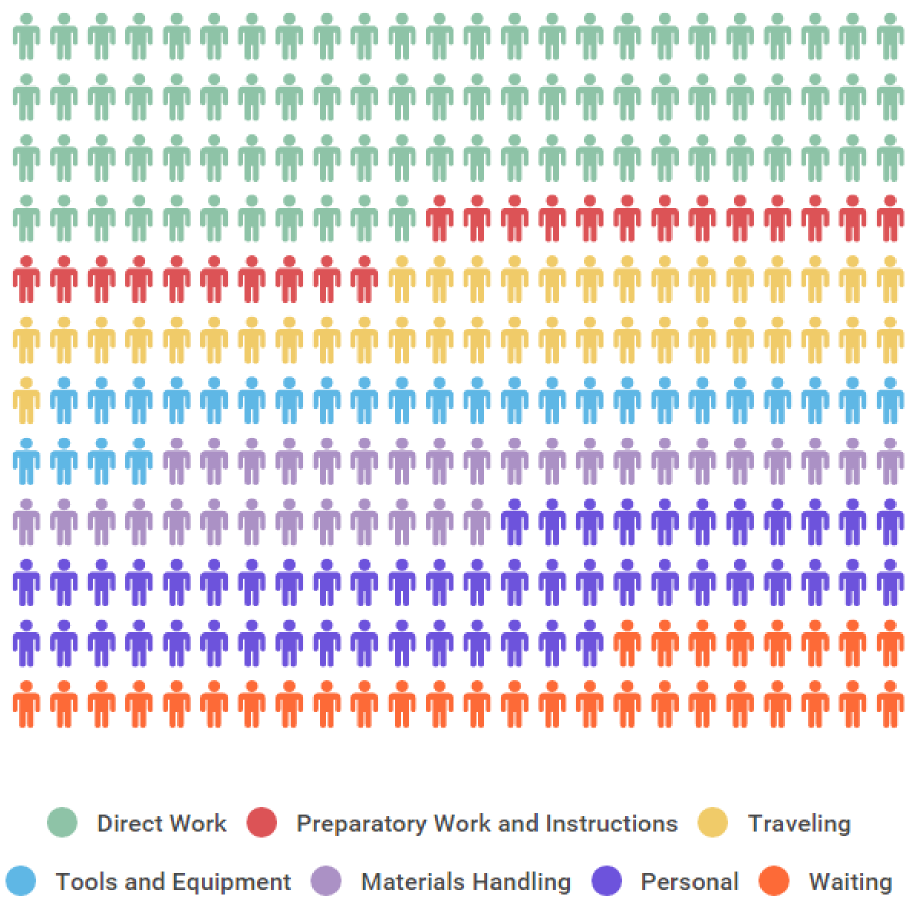


**Figure 4-11 Pictorial representation of observed labor activities**

All 9990 observations were recorded and documented, the percentage of each of the seven activity categories were calculated from total observations.

### 4.3.2 Percentages of error with their respective activity category

The calculated results of each activity at Project C are summarized in the following table. Percentage errors of respective category are also shown in the Table 4-12 in order to assess the accuracy of each category.

**Table 4-12 Activity Rates and Error Estimates for a 95% Confidence Level for Project C**

| Activity Category | Activity Percentage | Error Percentage |
|---|---|---|
| Direct Work | 28.99% | 0.890% |
| Preparatory Work and Instructions | 8.10% | 0.535% |
| Traveling | 13.59% | 0.672% |
| Tools and Equipment | 9.21% | 0.567% |
| Materials Handling | 11.47% | 0.625% |
| Personal | 17.61% | 0.747% |
| Waiting | 11.03% | 0.614% |

It was determined it would be more meaningful to report the true error of each proportion based on a 95% confidence level which was originally intended. The error indicates that for Project C, the overall study determined the direct-work rate was 28.99% ± 0.89% with a confidence of 95%.

### 4.3.3 Overall hourly distribution of observations wr.t each activity

The whole observed data of total five days is given in detail in Table 4-13 while the observed data tables and their respective activity rates for each day are attached in the annexure.

**Table 4-13 Distribution of whole observed data spreadsheet at project C**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm | Total observations of activities | Activity Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 383 | 342 | 331 | 410 | 351 | Lunch | 411 | 335 | 333 | 2896 | 28.99 |
| Support | Preparatory Work and Instructions | 164 | 114 | 74 | 79 | 80 | | 127 | 92 | 79 | 809 | 8.10 |
| | Traveling | 208 | 150 | 116 | 138 | 203 | | 231 | 143 | 169 | 1358 | 13.59 |
| | Tools and | 170 | 108 | 91 | 88 | 96 | | 134 | 107 | 126 | 920 | 9.21 |
| | Materials Handling | 173 | 146 | 123 | 133 | 157 | | 157 | 130 | 127 | 1146 | 11.47 |
| Delays | Personal | 241 | 219 | 192 | 213 | 226 | | 271 | 190 | 207 | 1759 | 17.61 |
| | Waiting | 172 | 138 | 130 | 116 | 128 | | 170 | 110 | 138 | 1102 | 11.03 |
| Total Hourly Observations | | 1511 | 1217 | 1057 | 1177 | 1241 | | 1501 | 1107 | 1179 | 9990 | 100.00 |

### 4.3.4 Overall observed activity rates and productivity analysis

Overall activity rates of each category are graphically illustrated in the Figure 4-12. The pie chart is showing that how large the proportion of each activity really is, and how other can be reduced to increase the direct-work rate.

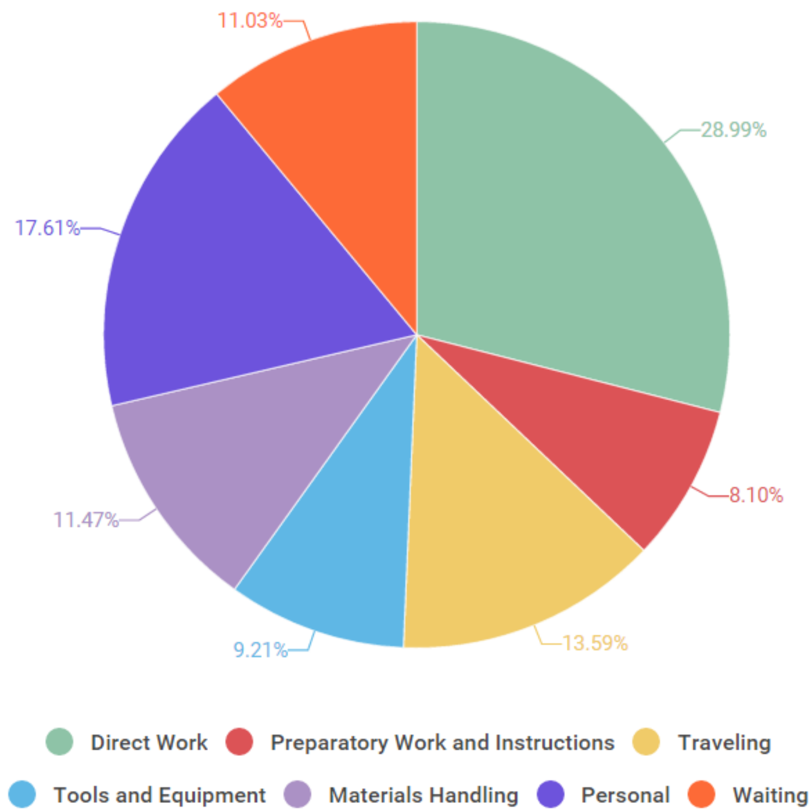


**Figure 4-12 overall Activity rates for project C**

Direct work rates typically range from 44 to 46% according to the Construction Industry Institute, for civil trades including laborers, painters, and teamsters working in an open environment (CII 2010). At Project C, majority of civil labors were working. Direct rate for Project C was recorded 28.99% which is much less to the direct rate referred by CII. Explanation for this lesser direct rate is that the work supervision was much lesser and labors were not monitored or checked. As project stakeholder were not interested in project progress at that time, this made the working staff less concerned toward the work. Apart from this, there were quite shortage of working staff and labors which ultimately affected the project supervision and work progress, therefore leaving the remaining workers to do the small task without any kind of supervision. There was no planning or monitoring of project activities nor the management was interested in any kind step that can increase the current development of project due to limited funds.

Preparatory work and instructions accounted for 8.1% of all work observed on Project C. Preparatory work ranged from 8.5 to 15.7%, with an average of 12.1% on project in which CII conducted filed trials.(CII 2010). Value of 8.1% for this particular activity seems normal as no special or tough assignment was given to workers of project. Current works doesn't include those kind of activities which include special instruction or some preparatory work that's why current preparatory work is satisfactory.

The percentage of work attributed to travelling activity was 13.59% of total observations, substantially lower than average of the CII field trials of 17.6%, falling low in the range from 13.0-23.6% (CII 2010). Site was quite large but the workers did not have to do much travelling as the rate of development was no quite high leaving the workers to do the single task all the day, due to which their rate of transportation was much less.

Materials handling accounted for 11.47% of all work observations, however there were no average results from the CII to which to compare this figure. However, in a study carried out by Michael C. Gouett (2010) it was found that material handling was 8% which confirms the observed results. Tools & Equipment made up 9.21% of the work observations documented, as compared to the CII field trial average of 11.4% for a range from 6.7-19.3% (CII 2010). Both activities are somehow high as compared to CII field trail, due to lack of planning and material management, it was observed that there was no proper material management at site nor any kind of planning on how to reduce the time of both activities.

The percentage of work attributed to Personal time was 17.61% for the observations documented. The CII field trials measured Personal time ranging from 4.9-12.8%, with an average of 7.7% (CII 2010). The Personal time on project C is much greater than the CII results. During the observations, several labors were observed doing personal chit chat or having break from the work along with the other crew. It was observed that site supervision was much low and workers were doing the things according to their will.

Second delay activity e.g. waiting had the percentage of 11.03% of all the work observations recorded for the study. However, for the field trials conducted by CII, the average was 14.9% ranging from 11.1% 3 to 20.5% (CII 2010). Due to low number of labors working at the large site, work areas were not so congested and it was observed that labors did not have to wait for their time to work. It should also be mentioned here that there was no planning or monitoring of undergoing works at the project site.

### 4.3.5 Comparison of Activities with each other

If we compare the activities, we can clearly see the after the direct work activity, personal activity is dominating with respect to others with a value of 17.61% closely following other activities as clearly shown in the Figure 4-13.

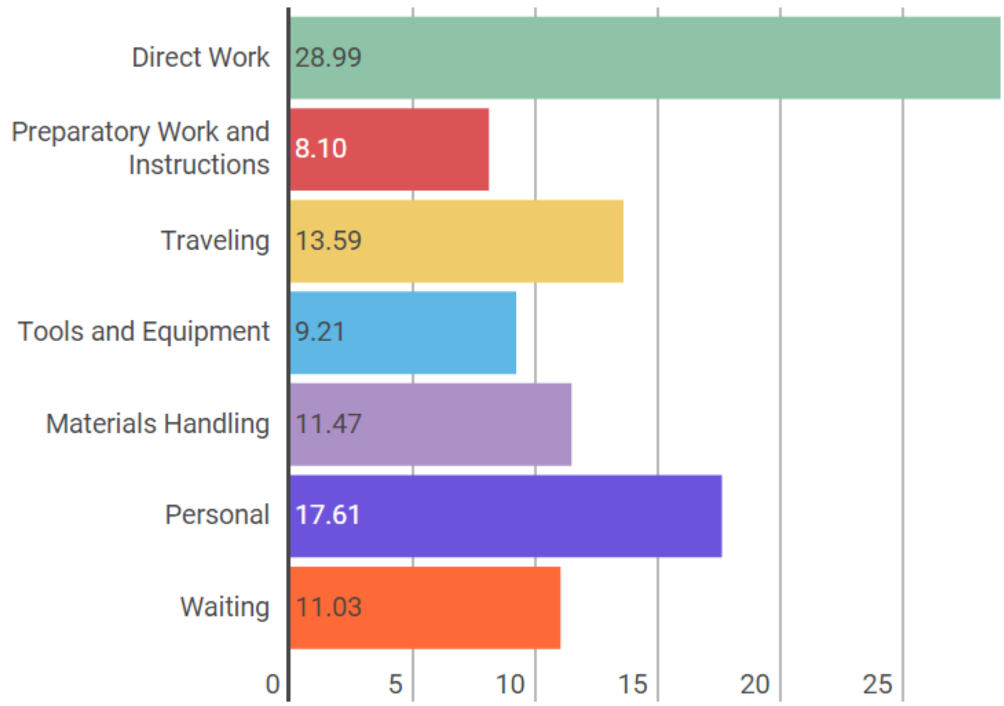


**Figure 4-13 Overall Activities comparison at project C**

If we assume the observed activity rates as time spent on each activity, then we can say that in the typical eight-hour work shift, average labor is spending 2.3 hours actually doing the direct work or directly developing the project, about 39 minutes doing preparatory work and instructions, about 1 hour and 6 minutes doing the travelling between different location of work, about 45 minutes doing the tools and equipment related work, 55 minutes doing the material handling works, 1 hour and 25 minutes doing his personal works and almost 52 minutes waiting to do work. Some of the preparatory work activities especially material handling and tools equipment activities are high along with both delay activities. In order to increase the direct work activities, all other activities should be minimized as much as possible.

### 4.3.6 Hourly Distribution Analysis of Activity percentages

Observations were also calculated for hourly activity percentage and were further analyzed for each category of activity in hourly period of whole working day. Percentages of each activity were calculated for each hour from 8 A.M to 5 P.M and trend of each activity was assessed with respect to all related factors from the total observed labor data of five days. Hourly distribution of site of each of the seven site activities for project C are given in the Table 4-14.

**Table 4-14 Distribution of observed data percentages in each hour at project C**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm |
|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 25.35 | 28.10 | 31.32 | 34.83 | 28.28 | L u n c h | 27.382 | 30.262 | 28.244 |
| Support | Preparatory Work and Instructions | 10.85 | 9.37 | 7.00 | 6.71 | 6.45 | | 8.461 | 8.311 | 6.701 |
| | Traveling | 13.77 | 12.33 | 10.97 | 11.72 | 16.36 | | 15.390 | 12.918 | 14.334 |
| | Tools and Equipment | 11.25 | 8.87 | 8.61 | 7.48 | 7.74 | | 8.927 | 9.666 | 10.687 |
| | Materials Handling | 11.45 | 12.00 | 11.64 | 11.30 | 12.65 | | 10.460 | 11.743 | 10.772 |
| Delays | Personal | 15.95 | 18.00 | 18.16 | 18.10 | 18.21 | | 18.055 | 17.164 | 17.557 |
| | Waiting | 11.38 | 11.34 | 12.30 | 9.86 | 10.31 | | 11.326 | 9.937 | 11.705 |

All activities are changing with respect to time. Some activities are quite low at start of day, while some activities are high at the start, similarly same can be said at the end of day. For a typical day, changes in these activities are graphically illustrated in the Figure 4-14.

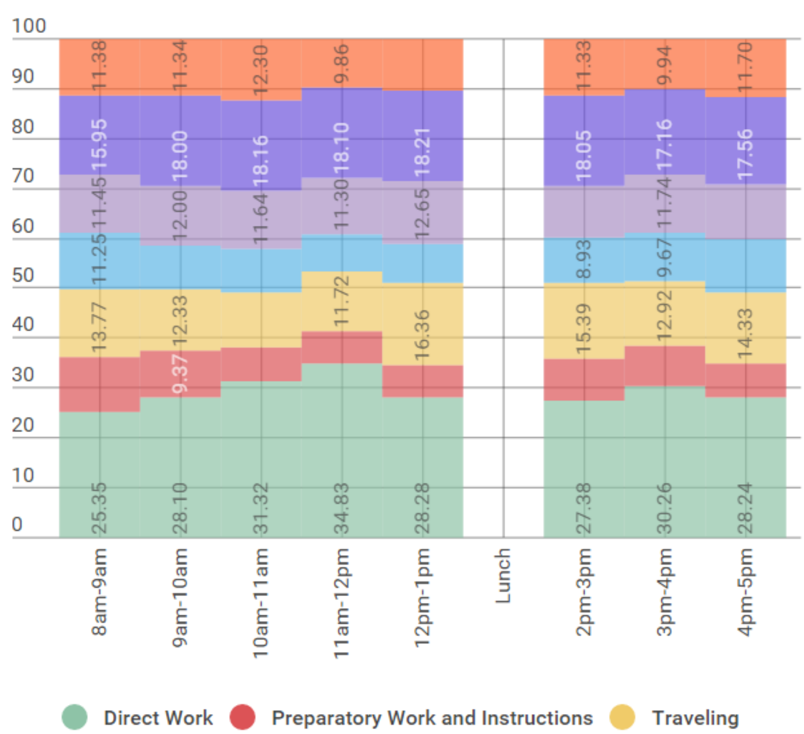


**Figure 4-14 Stacked bar chart representing hourly distribution of activity rates at project**

During the start of day, it is observed that direct work activities take time and during the start of day, other activities were high as compared to direct work. . As the work will start, worker will travel to the site, will gets the necessary instruction from senior and staff members, will get the required tools which he will use if the jobs require any kind of tools and get the material handle to complete the task. Due to these reasons, support activities will be greater as labor will be involved in greater support activities like preparatory work and instructions, travelling, material handling, tools and equipment etc.

Individual behavior of all the activities are displayed in the Figure 4-15 where the lines of respective category are showing the hourly trend.

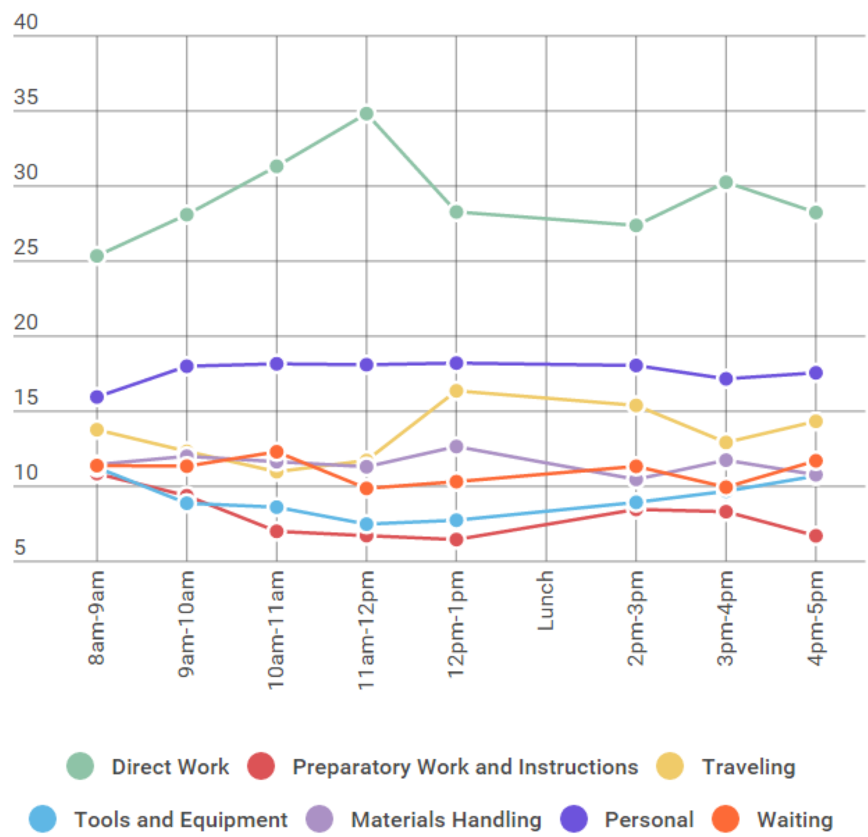


**Figure 4-15 Overall hourly trend of activities at project C**

Overall direct work rate is quite low and its trend for working day of 8 hour is analyzed in detail. As it is clearly seen that it is lowest at the start of the work while increasing at the peak value in mid-morning and then start decreasing till lunch. After the lunch break, it starts with a low value and then increase a little and after then again start decreasing.

Direct work peaks during 11am to 12pm with a value of almost 34.83% while it is observed lowest in the starting hour with a value of almost 25.35%. It can be said that direct work increase as the working time increases hours, and. The crews try to accomplish their set target so they work at a higher rate before the lunch.

Activity "Preparatory work & instructions" is highest when the labor is going to start of working day. As it is shown in the last graph, mentioned activity is highest during 8am to 9am. It is observed that before the starting the work, labor get necessary instructions and required information on how to perform the work along with that it was observed that labor usually start the work with lazy attitude. It was recorded highest during 8am to 9am with a value of 10.85% and lowest during 4pm to 5pm with a value of 6.7%.

Travelling was observed high before or after the break and start or end of work as it was observed that usually labors did not follow the exact timing of work and come usually late and some worker go for break before the time. Other than that some labors try to leave the site early in order to perform prayer and have lunch as these places were farther than the site area. Travelling activity of labors were recorded highest during 12pm to 1pm with a value of 16.36% and lowest during 10am to 11am with a value of 10.97%.

Tools and equipment category is observed high at the start and end of work with a peak value of 11.25% at 8am-9am, 10.67% at 4pm-5pm and lowest value of 7.4% at 11am-12pm. Site labors were using the tools mainly for maintenance purpose, electrical wiring and equipment setting were required which were done during the start of work and unfixing at end of work, which ultimately increased its value during these hours.

Overall Material handling activity was seen consistent through the working day. It was spotted high during 12pm to 1pm with a value of 12.65%, while the trend was recorded lowest at 2pm to 3pm with value of 10.3%. Particular activity was observed high consistently due to mainly maintenance works going on which requires material handling activity.

Main delay activity, Personal activity was recorded high continuously throughout the working day similarly to last activity. Due to not having supervisory staff, labors were seen doing their personal task during the working hours. Many workers were seen sitting in a corner of building and doing chitchat with other fellow workers, while some workers were spotted having long tea break at working area. Personal activity was observed high during 12pm-1pm with a value of 18.21% and low during 8pm-9pm with a value of 15.95%. A large number of labors were many time spotted doing rest during working hours.

Activity waiting was also following a similar trend to personal activity. Waiting activity peaks at 10am-11am with a value of 12.3% while it is observed lowest at 11am-12pm with a value of 9.86%. Due to lack of planning at the project, waiting activity was consistently recorded high. Man times, it was seen that workers were waiting for the staff instruction about where to perform the maintenance work. So, in order to increase direct work, it should be important to make arrangement at site so that workers did not have to wait for work as this will directly increase the direct work rate. For this purpose, five minute rating was observed and crew balancing was also performed at site in order to minimize labor waiting time, which will directly increase the labor direct work and will collectively increase the labor productivity.

### 4.3.7 Safety Assessment

At Project C, safety arrangement by the contractor at project site were less than average. Overall some of the labor were wearing the hard hats. There were no Safety officer or manager at site nor were the staff ensuring any kind of safety. It was came to know that in past, there was strong safety arrangements and it was assured that all the labors are working under the intense safety environment. Due to the project crisis, project staff were slowly discharged which led to the slow development and weak supervision of project. Now due to less no. of staff members and no safety staff, safety of working staff is compromised. Safety is no more concern at site and labors who are working are much prone to safety risks. There were no safety signs displayed at site and there were no guard rail installed. Some safety arrangements which were observed, was due to implementation of strong safety system in past

### 4.3.8 Five minute Rating and Crew Balancing

During data collection of five minute rating, video was recorded for approximately twenty minutes to collect data for the five-minute rating of the observed formwork construction. After analyzing the video, it was determined that the cycle time for the formwork activity was 10 minutes. There were 2 masons and 3 helpers were working on a for formwork erection. Three labors or helpers were transporting, and placing the formwork panels and rods, whole the skilled labor or mason were fixing them. Table 4-15 represents the data readings observed and their results.

**Table 4-15 Five minute analysis spreadsheet**

| Minutes | Mason 1 | Mason 2 | Labor 1 | Labor 2 | Labor 3 |
|---|---|---|---|---|---|
| 1 | x | | x | | x |
| 2 | x | | x | x | x |
| 3 | | | | x | x |
| 4 | | x | | | |
| 5 | | x | | | |
| 6 | | x | x | | x |
| 7 | | | x | x | |
| 8 | | | x | | x |
| 9 | x | x | x | | x |
| 10 | x | | | | x |
| 11 | x | | | | |
| **Effective Units** | **5** | **4** | **6** | **3** | **7** |
| Total Man Units | | | 55 | | |
| Effective Man Units | | | 25 | | |
| Effectiveness | | | 45% | | |

Result shows that overall effectiveness of the formwork activity was 45%. Thus, the observation based on the crew balancing and five-minute rating techniques was that the work was not evenly distributed and overall both mason and labors were more than the required amount of work hour needed. Hence, based on the results of data collected, proposed solution is to have only two labors perform the work and reassign the third worker and mason/skilled labor to another task while maintaining the work.

## 4.4 PROJECT D

The fourth project was large educational building located in the Islamabad, which will be eventually used for academic purposes for one of the leading university of Pakistan. Project was started in 20th January 2015, while the data was collected in mid-January, 2016 when the project 32% completed with respect to actual work done. Project site covers 5812 sq. meters and the major activities observed was excavation, block masonry, plastering, formwork and concrete pouring. Average of around 150 no. of labors were working at the project when the data was observed.

### 4.4.1 Number of observations and hourly confidence level

Table 4-16 summarizes the number of samples collected and true confidence level for every observation hour, while detailed separate tables for individual hours are attached in the annexure.

**Table 4-16 Project D- Number of Observations per Hour**

| Work Hour | No. of Observations | Confidence Level |
|---|---|---|
| 08:00-09:00 | 1585 | 77.7871911% |
| 09:00-10:00 | 1499 | 74.2493967% |
| 10:00-11:00 | 1189 | 55.9863163% |
| 11:00-12:00 | 1037 | 42.4072491% |
| 12:00-01:00 | 1295 | 63.4596035% |
| Lunch | - | - |
| 02:00-03:00 | 1376 | 68.2215299% |
| 03:00-04:00 | 984 | 36.7505791% |
| 04:00-05:00 | 1290 | 63.1472278% |
| **Total** | **10255** | **99.9999489%** |

The observer collected nearly twenty times this number of samples and overall observations can be explained in the following figure where the graphical man is representing the behavior of labor which was observed during working hour performing the construction work at construction site and the characteristics of his behavior is categorized into seven activities which are shown by different colors in Figure 4-16.

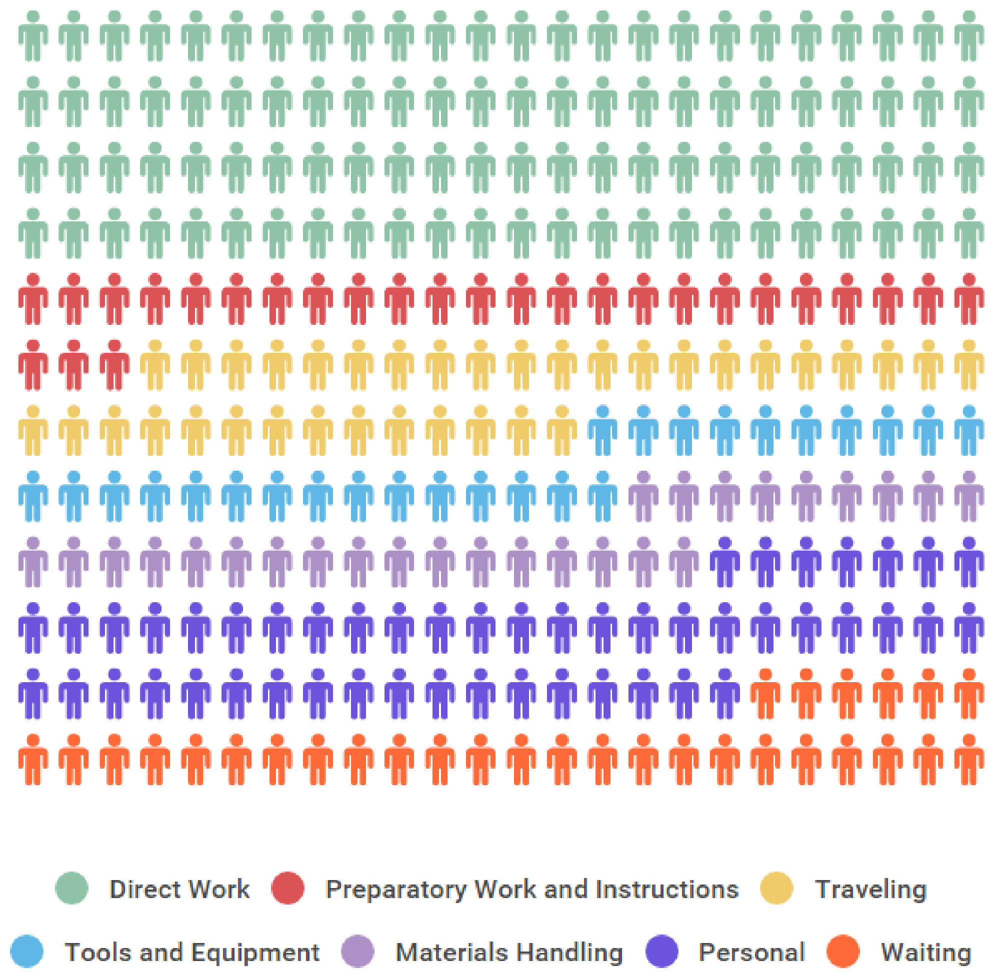


**Figure 4-16 Pictorial representation of labor activities**

### 4.4.2 Percentages of error with their respective activity category

The calculated results of each activity at Project D are summarized in the Table 4-17. Percentage errors of respective category are also shown in the table in order to assess the accuracy of each category. The error indicates that for Project D, the overall study determined the direct-work rate was 33.19% ± 0.911% with a confidence level of 95%.

**Table 4-17 Activity Rates and Error Estimates for a 95% Confidence Level for Project D**

| Activity Category | Percentage | Error |
|---|---|---|
| Direct Work | 33.19% | 0.911% |
| Preparatory Work and Instructions | 9.27% | 0.561% |
| Traveling | 12.04% | 0.630% |
| Tools and Equipment | 8.75% | 0.547% |
| Materials Handling | 9.14% | 0.558% |
| Personal | 17.00% | 0.727% |
| Waiting | 10.61% | 0.596% |

### 4.4.3 Overall hourly distribution of observations wr.t each activity

The whole observed data of total five days is given in detail in Table 4-18 while the observed data tables and their respective activity rates for each day are attached in the annexure.

**Table 4-18 Distribution of whole observed data spreadsheet at project D**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm | Total observations of activities | Activity Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 441 | 461 | 434 | 434 | 410 | Lunch | 428 | 399 | 397 | 3404 | 33.19 |
| Support | Preparatory Work and Instructions | 214 | 172 | 122 | 64 | 122 | | 123 | 57 | 77 | 951 | 9.27 |
| | Traveling | 238 | 166 | 119 | 74 | 168 | | 188 | 88 | 194 | 1235 | 12.04 |
| | Tools and | 174 | 146 | 98 | 78 | 96 | | 115 | 69 | 121 | 897 | 8.75 |
| | Materials Handling | 152 | 141 | 104 | 112 | 107 | | 116 | 90 | 115 | 937 | 9.14 |
| Delays | Personal | 228 | 240 | 193 | 171 | 234 | | 245 | 180 | 252 | 1743 | 17.00 |
| | Waiting | 138 | 173 | 119 | 104 | 158 | | 161 | 101 | 134 | 1088 | 10.61 |
| Total Hourly Observations | | 1585 | 1499 | 1189 | 1037 | 1295 | | 1376 | 984 | 1290 | 10255 | 100.00 |

### 4.4.4 Overall observed activity rates and productivity analysis

Overall activity rates of each category are graphically illustrated in Figure 4-17. The pie chart is showing that how large the proportion of each activity really is, and how other activities need to be reduced to increase the direct-work rate.

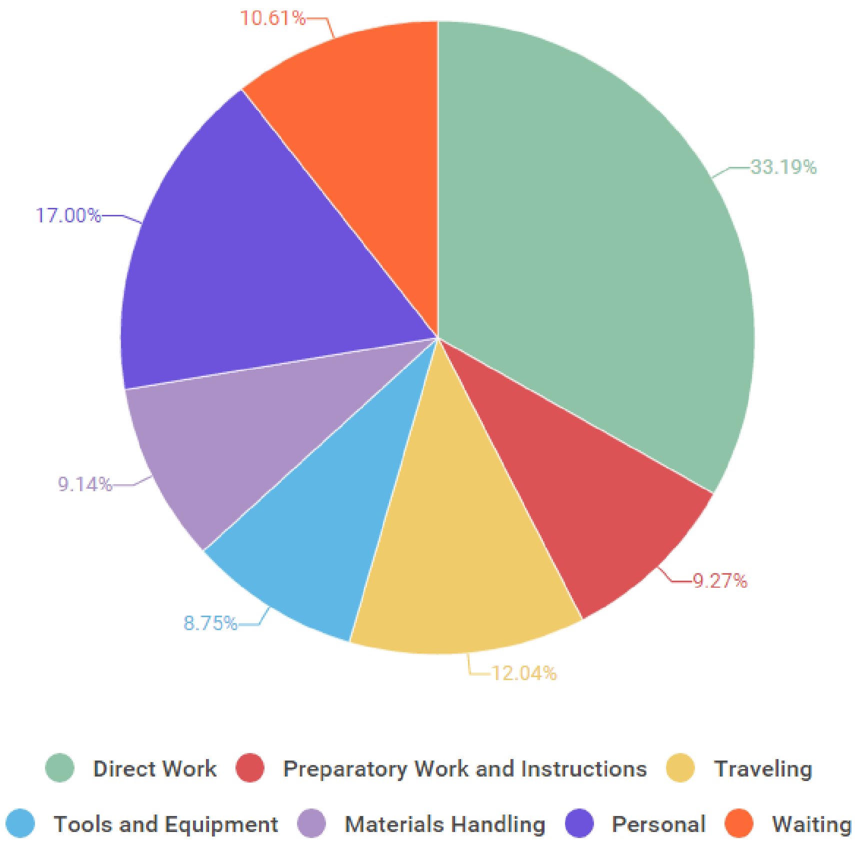


**Figure 4-17 overall Activity rates for project D**

Direct rate for Project D was 33.19% which is less than direct rate referred by CII which typically ranges from 44-46%. The reason behind this is that project structure was completed and project was in finishing phase and it is seen that when the project reaches to end, progress gets slow with time. Work supervision were strong at site but due to different ongoing complex tasks, direct work rate was observed low.

Activity preparatory work and instructions accounted for 9.27% of all work observed on Project D while according to CII field trials, preparatory work ranged from 8.5 to 15.7% with an average of 12.1% range (CII 2010). Value of 9.27% seems quite reasonable as site supervision was fully coordinated with the labors. The work was fully planned on how to execute the work assignments plus labors were fully aware of necessary preparatory work activities and important information, which shows the effective planning and management of staff. Safety was fully ensured and labors were following the safety rules. Due to these reasons, preparatory work and instruction activity showed reasonable percentage with respect to other activities.

The percentage of work attributed to travelling activity was 12.04% of total observations, substantially lower than average of the CII field trials of 17.6%, falling low in the range from 13.0-23.6% (CII 2010). Overall construction areas in the site were too much near as it was a large building construction and all the necessary materials and equipment were stored near them, due to this a lot of time was saved which was going to be waste if the site layout were not properly planned. Due to excellent planning and good site layout, contractor easily saved a lot of time which was used for direct work activities.

Materials handling accounted for 9.14% of all work observations, however there were no average results from the CII to which to compare this figure. However, in a study carried out by Michael C. Gouett (2010) it was found that material handling was 8% which confirms the observed results. Tools & Equipment made up 8.75% of the work observations documented, as compared to the CII field trial average of 11.4% for a range from 6.7-19.3% (CII 2010). Both activities are average as compared to CII field trail. It was seen that material transportation was taking much time as due to finishing activities, material was continuously demanded and many times labors were seen waiting at staircases as some other working was already carrying a material. Similarly, it was observed many time that workers were fixing the equipment machine as mostly finishing activities were equipment based. All the required tools and material were available at site in order to insure the ongoing activities did not get delayed due to these reasons.

The percentage of work attributed to Personal time was 17% for the observations documented. The CII field trials measured Personal time ranging from 4.9-12.8%, with an average of 7.7% (CII 2010). The Personal time on project D is much greater than the CII results. It was observed due to different variant nature of new activities labors take time to understand and during their learning, a lot of time is wasted in learning until they become familiar on how to perform the required activity in a perfect way. As this particular building was having some new facilities which were uncommon in a typical building, learning curve effect was noticed, due to which personal time was increased.

Waiting had the percentage of 10.61% of all the work observations recorded for the study. However, for the field trials conducted by CII, the average was 14.9% ranging from 11.1% 3 to 20.5% (CII 2010). The percentage of Waiting on project d comes in lower range by the CII, which also validate the strong planning of works by contractor at site. Due to clear job instructions and strong material management, labors were not wasting their time in waiting activity. Five minute rating was also performed at the site to assess the crew balancing of the project which is explained in detail.

### 4.4.5 Comparison of Activities with each other

Activities were compared to each other in which it was seen that after the direct work activity, personal activity is dominating with respect to others with a value of 17% as clearly shown in the Figure 4-18.

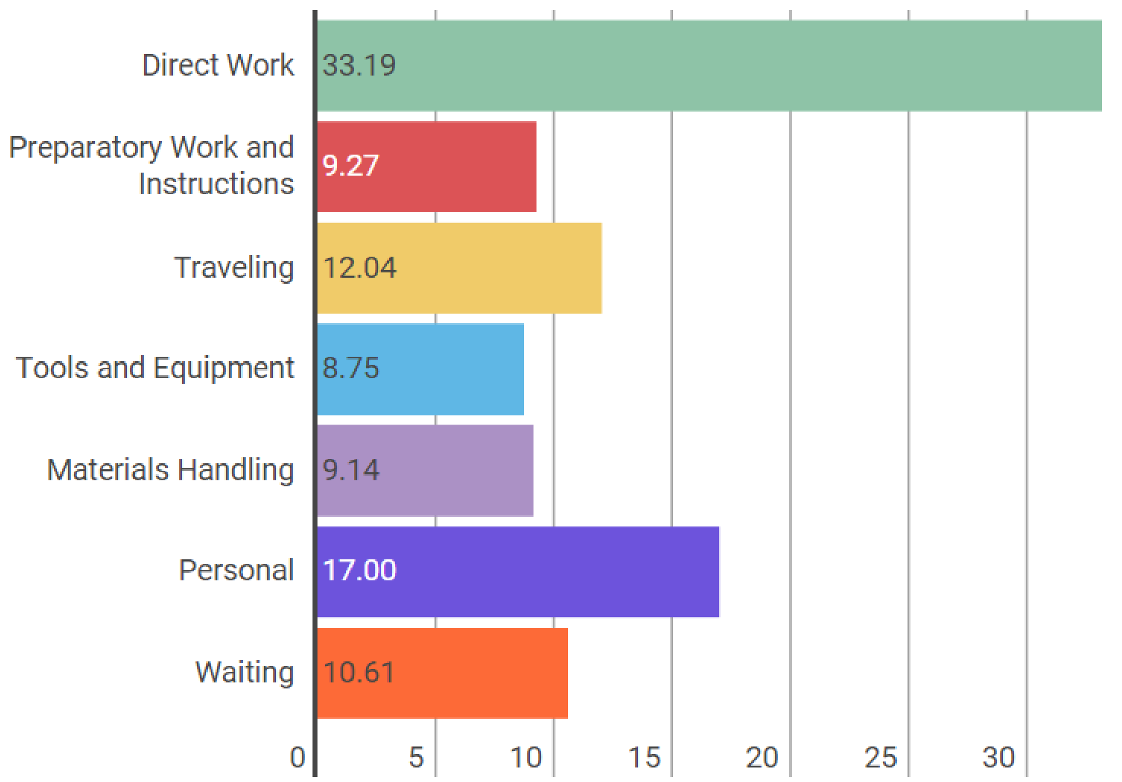


**Figure 4-18 Overall Activities comparison at project D**

If we assume the observed activity rates as time spent on each activity, then we can say that in the typical eight-hour work shift, average labor is spending 2.65 hours actually doing the direct work, 45 minutes doing preparatory work and instructions, almost1 hour doing the travelling between different location of work, about 42 minutes doing the tools and equipment related work, 44 minutes doing the material handling works, 1 hour 21 minutes doing his personal works and almost 51 minutes waiting to do work.

### 4.4.6 Hourly Distribution Analysis of Activity percentages

Observations were also calculated for hourly activity percentage and were further analyzed for each category of activity in hourly period of whole working day. Percentages of each activity were calculated for each hour from 8 A.M to 5 P.M and trend of each activity was assessed with respect to all related factors from the total observed labor data of five days. Hourly distribution of site of each of the seven site activities for project D are given in the Table 4-19.

**Table 4-19 Distribution of observed data percentages in each hour at project D**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm |
|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 27.82 | 30.75 | 36.50 | 41.85 | 31.66 | Lunch | 31.10 | 40.55 | 30.78 |
| Support | Preparatory Work and Instructions | 13.50 | 11.47 | 10.26 | 6.17 | 9.42 | | 8.94 | 5.79 | 5.97 |
| | Traveling | 15.02 | 11.07 | 10.01 | 7.14 | 12.97 | | 13.66 | 8.94 | 15.04 |
| | Tools and | 10.98 | 9.74 | 8.24 | 7.52 | 7.41 | | 8.36 | 7.01 | 9.38 |
| | Materials Handling | 9.59 | 9.41 | 8.75 | 10.80 | 8.26 | | 8.43 | 9.15 | 8.91 |
| Delays | Personal | 14.38 | 16.01 | 16.23 | 16.49 | 18.07 | | 17.81 | 18.29 | 19.53 |
| | Waiting | 8.71 | 11.54 | 10.01 | 10.03 | 12.20 | | 11.70 | 10.26 | 10.39 |

As we can clearly see that all activities are changing with respect to time. Some activities are quite low at start of day, while some activities are high at the start, similarly same can be said at the end of day. For a typical day, changes in these activities are graphically illustrated in the Figure 4-19.

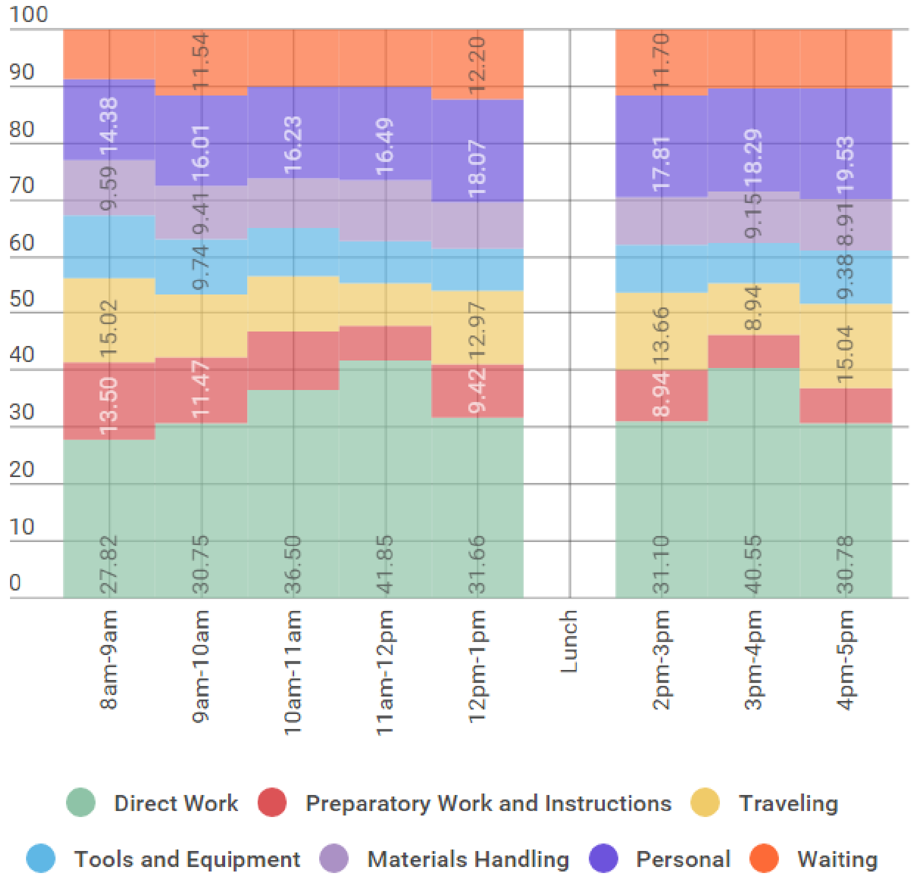


**Figure 4-19 Stacked bar chart representing hourly distribution of activity rates at project**

Direct work rate of labors were observed low when the labors were going to start of work e.g. before the start of day and after the lunch. During the start of day, it is observed that direct work activities take time and during the start of day, other activities were high as compared to direct work. . As the work will start worker will travel to the site, will gets the necessary instruction from senior and staff members, will get the required tools which he will use if the jobs require any kind of tools and get the material handle to complete the task. Due to these reasons, support activities will be greater as labor will be involved in greater support activities like preparatory work and instructions, travelling, material handling, tools and equipment etc.

Individual behavior of all the activities are displayed in the Figure 4-20 where the lines of respective category are showing the hourly trend.

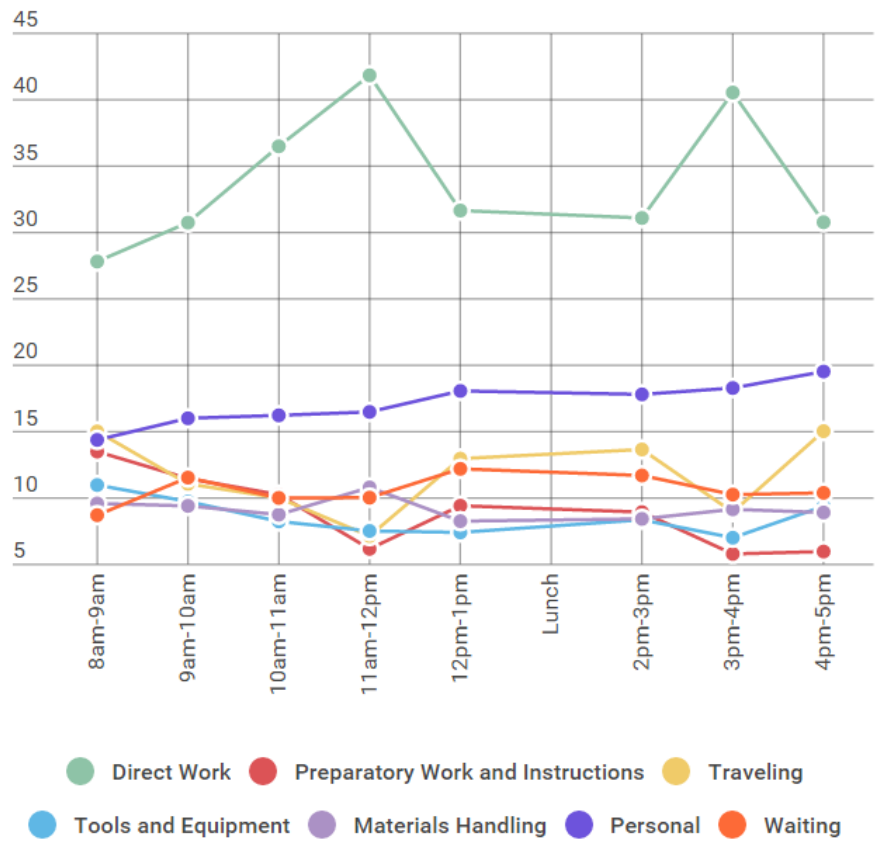


**Figure 4-20 Overall hourly trend of activities at project D**

Direct work rate trend throughout the working day of 8 hour is analyzed in detail. As it is clearly seen that it is lowest at the start of the work while increasing with respect to time and then start decreasing before the lunch. And after the lunch break, direct work rate is still less and then gets peak both time during the mid of work. Direct work peaks during 11am to 12pm and 3pm to 4pm with a value of almost 41.85% and 40.55% respectively, while it is lowest in the starting hour at 8am to 9am with a value of 27.82%. It can be said that direct work increase as the working time increases hours and labor crew try to put efforts between the mid times.

Activity "Preparatory work & instructions" is highest with a value of 13.5% at 8am-9am when the labor is going to start of working day and lowest in the ending hours with a value of 5.79% and 5.97% at 3pm-4pm and 4pm-5pm respectively. Before the starting the work, labor get necessary instructions and required information on how to perform the work along with that they get the safety equipment for themselves, which ultimately increases the preparatory work and instructions activity. It was overall observed that site planning and coordination was impressive overall and labors were guided well which kept that activity value low throughout the day. As it is shown in the graph, activity starts high and then eventually get decreases with time. It is observed that as the time passes labors get more information regarding work with time and in this way time wasted in this activity gets lowered with increasing time

Workers were seen travelling in the site during the whole time for various reasons but they were more travelling before and after the break and starting or end of work. Travelling was observed higher during starting and ending of working day i.e. 8am to 9am and 4pm to 5pm with a value of 15.02% and 15.04% respectively and it was observed lowered during the mid of work during 11am to 12pm with a value of 7.14%.

Tools and equipment usage was overall observed high as some ongoing activities were dependent on equipment. Particular activity is recorded peak at the start of work value of 10.98% at 8am-9am and lowest value of 7.01% at 3pm-4pm. It was seen that equipment fixing or connecting to the electricity takes a lot of time when the crew has to use some equipment for their work.

Material Handling was recorded high during 11am to 12pm with a value of 10.8%, while the trend was seen lowest at 12pm to 1pm with value of 8.26%. It was high throughout the day as the ongoing activities were material dependent and labors and if the one crew member is doing the direct work then the other one was preparing the material to be used later by other crew member.

Collectively, Personal activity is highest among other activities after the direct work activities. The trend shows that personal activity is continuously increasing with the time as It was recorded lowest during the start of work i.e. 8am-9am with a value of 14.38% and then get increased with time slowly, this continues unless the work ended and at that time personal activity is seen highest with a value of 19.53% at 4pm-5pm. It was observed during data collection phase that crew members get relaxed as their work gets executed with time and during their relaxation they get themselves entertain using the cellphone for calls or songs. Many of the subcontracted labors were seen having fixed break during working hours. Some of them were also seen having smoke breaks.

Although the site works were planned impressive and site supervisor were putting efforts in order to execute the work efficiently but due to complicated nature of number of ongoing works kept the value of waiting activity moderate. Waiting activity peaks at 12pm-1pm with a value of 12.2% while it is observed lowest at starting hour e.g. 8am-9pm with a value of 8.71%. It was seen that the worker of different craft gets were waiting in order to get their job done as some other craft activity were ongoing. Sometimes crew members were waiting as one of their main worker is performing the direct work activity and they are dependent on him, till he completes his job they all are waiting. In order to accurately overcome this issue, five minute rating were also implemented and crew balancing were performed based on the results.

### 4.4.7 Safety Assessment

At Project D, safety arrangement by the contractor were good at construction site. All the labors were following the safety measures. Client has ensured that all the necessary safety procedures and safety management plan should be implemented. Labor were wearing the PPE such as hard hats, safety vest, closed toe shoes and gloves. During the data collection phase, it was observed that overall safety arrangement were strictly followed, no labor were allowed to enter the site area without safety equipment, proper safety signs were marked at hazardous areas, safety check was ensured before the start of activity or work and there were guard rail installed at heighted and excavated areas. Safety Manager was hired along the other safety supervision staff to implement safety procedures and necessary arrangements. Worked was being executed under strong safety facilities.

### 4.4.8 Five Minute Rating and Crew Balancing

Five minute analysis was also performed during site visit for plaster activity. During data collection, video was recorded for approximately thirty minutes to collect data for the five-minute rating of the observed plaster work activity. There were three plasterer and two labors were working on that activity. Laborers were transporting making and transporting the mortar while the plasterer were doing plaster to the walls of second floor of that building. Table 4-20 represents the data readings observed and their results

**Table 4-20 Five minute analysis spreadsheet**

| Minutes | Plasterer 1 | Plasterer 2 | Plasterer 3 | Labor 1 | Labor 2 |
|---|---|---|---|---|---|
| 1 | | | | x | |
| 2 | x | | | x | |
| 3 | x | | x | x | |
| 4 | | x | x | x | x |
| 5 | | x | x | | x |
| 6 | | x | x | | x |
| 7 | | x | | | x |
| 8 | | | x | | |
| 9 | | | x | | |
| 10 | x | | x | | |
| 11 | x | | x | | x |
| 12 | x | | | x | x |
| **Effective Units** | **5** | **4** | **8** | **5** | **6** |

Result shows that overall effectiveness of the plaster activity was 46%. Thus, the observation based on the crew balancing and five-minute rating techniques was that the work was not evenly distributed. Out of twelve minutes of work cycle activity, effectiveness of one plasterer were 47% and effectiveness of two labors were 45%. Based on the results of data collected for the particular activity, a proposed solution is to have only one labor and two plasterer perform the work and reassign the remaining workers to another task while maintaining the overall task schedule.

## 4.5 PROJECT E

First project was construction of a large public hospital which includes number of buildings of various hospital department and facilities. Project was started on 20th August, 2015 and expected data of completion was 20th August, 2016. Data was collected during first half of February 2016, when the civil structure were about 40% completed and ongoing main activities were brick masonry, concrete poring, formwork, steel fixing, excavation. Average number of working labors present at project site were about 400. Large number of labors working at site was employed by the subcontractors.

### 4.5.1 Number of observations and hourly confidence level

. For a 95% confidence level, and an error of 5.0%, a total of 510 samples are required per hour, regardless of the number of craft workers on site. Hourly true confidence level and respective number of observations per hour is given in the Table 4-21 while detailed separate tables for each hour are attached in the annexure.

**Table 4-21 Number of Observations per Hour**

| Work Hour | No. of Observations | Confidence Level |
|---|---|---|
| 08:00-09:00 | 1280 | 62.6110007% |
| 09:00-10:00 | 1311 | 64.4944830% |
| 10:00-11:00 | 1184 | 55.6617186% |
| 11:00-12:00 | 1087 | 47.3802591% |
| 12:00-01:00 | 1190 | 56.1422349% |
| Lunch | - | - |
| 02:00-03:00 | 1332 | 65.7946228% |
| 03:00-04:00 | 1076 | 46.3183770% |
| 04:00-05:00 | 1029 | 41.7199685% |
| **Total** | **9489** | **99.9998552%** |

The confidence levels for Project E are not drastically worse than the 95% confidence level that was originally intended. This is due to the observer collecting more samples than the original minimum sample size of 342 samples. The observer collected nearly eighteen times number of samples, and so the overall results are considered very accurate. Overall observation can be explained in the following figure where the graphical man is representing the behavior of labor which was observed during working hour performing the construction work at construction site and the characteristics of his behavior is categorized into seven activities which are shown by different colors in Figure 4-21.

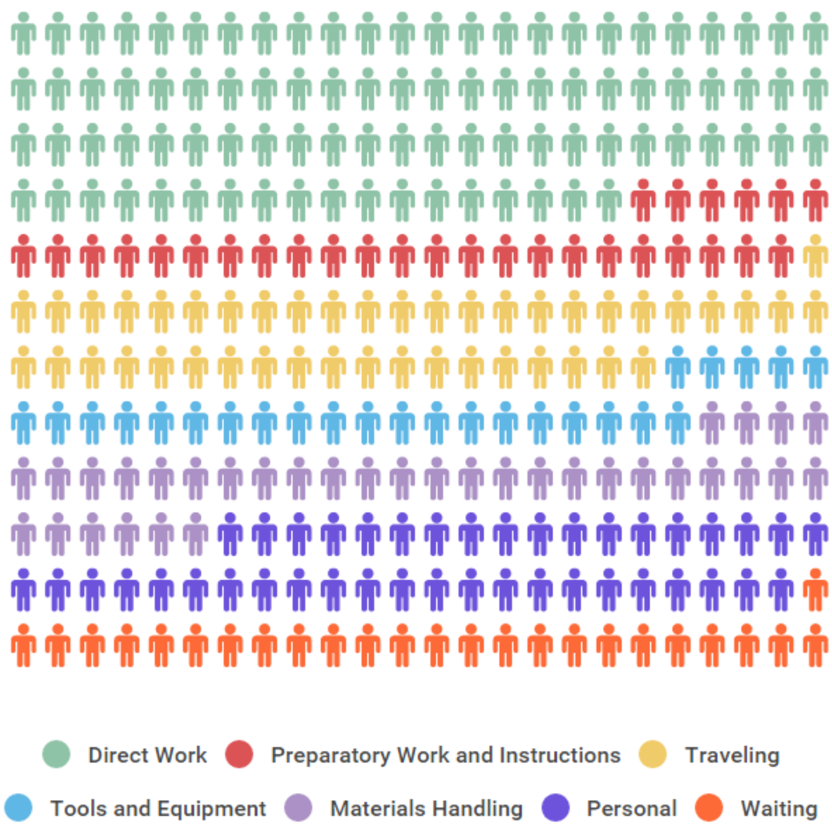


**Figure 4-21 Pictorial representation of labor activities**

After all 9489 observations were recorded and documented, the percentage of each of the seven activity categories were calculated from total observations classification. Results were tabulated, distribution of time spent on each activity were calculated, graphic presentations of the overall results and hourly breakdown were developed, and then the results were analyzed carefully looking for productivity inhibitors in order to devise the labor productivity improvement at that particular site.

### 4.5.2 Percentages of error with their respective activity category

The calculated results of each activity at Project E are summarized in the Table 4-22. Percentage errors of respective category are also shown in the table in order to assess the accuracy of each category.

**Table 4-22 Activity Rates and Error Estimates for a 95% Confidence Level for Project E**

| Activity Category | Percent age | Error |
|---|---|---|
| Direct Work | 31.05% | 0.931% |
| Preparatory Work and Instructions | 10.18% | 0.608% |
| Traveling | 15.33% | 0.725% |
| Tools and Equipment | 8.75% | 0.568% |
| Materials Handling | 11.58% | 0.644% |
| Personal | 14.33% | 0.705% |
| Waiting | 8.78% | 0.569% |

The error indicates that for Project E, the overall study determined the direct-work rate was 31.05% ± 0.931% with a confidence of 95%. If the error was maintained at 5.0%, the confidence level would be nearly 100% as reported in the above table. However, it was determined it would be more meaningful to report the true error of each proportion based on a 95% confidence level which was originally intended.

### 4.5.3 Overall hourly distribution of observations wr.t each activity

The whole observed data of total five days is given in detail in Table 4-23 while the observed data tables and their respective activity rates for each day are attached in the annexure.

**Table 4-23 Distribution of whole observed data spreadsheet at project E**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm | Total observations of activities | Activity Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 284 | 397 | 398 | 392 | 375 | Lunch | 360 | 407 | 333 | 2946 | 31.05 |
| Support | Preparatory Work and Instructions | 213 | 176 | 126 | 100 | 77 | | 139 | 80 | 55 | 966 | 10.18 |
| | Traveling | 239 | 173 | 112 | 92 | 246 | | 250 | 126 | 217 | 1455 | 15.33 |
| | Tools and | 132 | 108 | 96 | 91 | 106 | | 133 | 82 | 82 | 830 | 8.75 |
| | Materials Handling | 196 | 165 | 142 | 117 | 135 | | 147 | 111 | 86 | 1099 | 11.58 |
| Delays | Personal | 125 | 176 | 192 | 185 | 153 | | 192 | 169 | 168 | 1360 | 14.33 |
| | Waiting | 91 | 116 | 118 | 110 | 98 | | 111 | 101 | 88 | 833 | 8.78 |
| Total Hourly Observations | | 1280 | 1311 | 1184 | 1087 | 1190 | | 1332 | 1076 | 1029 | 9489 | 100.00 |

### 4.5.4 Overall observed activity rates and productivity analysis

Overall activity rates of each category are graphically illustrated in the Figure 4-22. The pie chart is showing that how large the proportion of each activity really is, and how other activities need to be reduced to increase the direct-work rate.

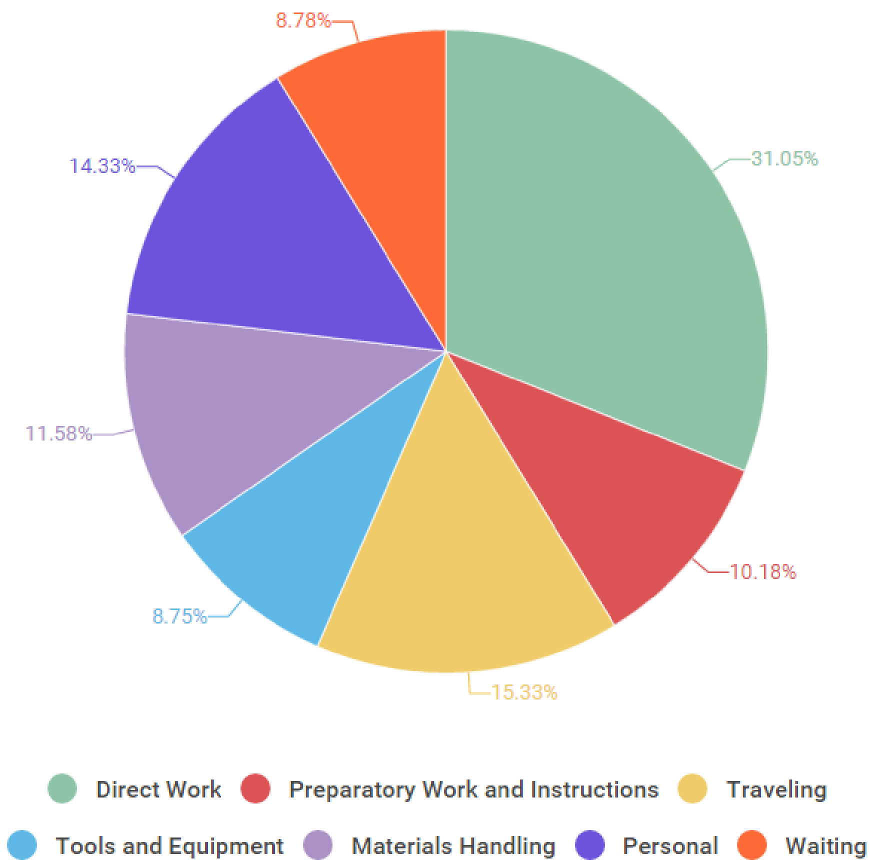


**Figure 4-22 overall Activity rates for project E**

At project E, majority of civil trade labors were working whose direct rate were observed was 31.05% which is lesser to the direct rate referred by CII. It was observed that this particular construction site lacks of planning, work monitoring and good site management. Works were poorly executed and labors were seen many time waiting for job instructions. Many time it was observed that labors were doing rework due to lack of project planning. Overall activity congestion was observed too at many times as it was not planned whether the particular activity need how many number of labors. Another reason of low direct work observed at site was lack of subordination with subcontractors.

Preparatory work and instructions accounted for 10.18% of all work observed on Project E comparative to the average of 12.1% in field trials conducted by the CII (CII 2010). It was observed that there was no safety regulation followed by labors, due to this a lot of time was saved as workers did not have to issue safety equipment and wear those safety arrangements. Other than this, majority of labor were of subcontractor who come to work area directly and they did not have to wait for work instruction by staff or site members, due to this reasonable amount of time is saved.

The percentage of work attributed to travelling activity was 15.33% of total observations, second higher most activity after the direct work rate. It was observed that all the building where construction was being done were quite far from each other and large number of labors were seen moving between these buildings, other than that labor residence was much far then the working site. Due to lack of planning, labors have to move back to site office for necessary tasks and other works. It is to be mentioned here that necessary facilities were not provided at working here like drinking water, toilet etc., due to his many of labors were travelling outside of construction site to avail these facilities. It was observed during site visits that there was a lot of room of improvement for travelling activity with just little planning by site staff.

Materials handling accounted for 11.58% of all work observations, while tools & equipment activity made up 8.75% of the work observations documented. It was observed that there were no material management of any kind due to this, labors have to transport the material to the working space. Similarly, lack of equipment management, but subcontractor labors were usually seen coming to site with their own proper tools an according to their nature of job, which saved a lot of time.

The percentage of work attributed to Personal time was 14.33% for the observations documented. The CII field trials measured Personal time ranging from 4.9-12.8%, with an average of 7.7% (CII 2010). Site management, supervision and monitoring of ongoing works were less than average. Workers were observed many time engaged in their personal activities during working times. Many of them were observed having tea or qawaa break, others were mostly using their cellphone for different purposes. A lot of them were also seen having rest in the building room where they were working.

The Personal time on project E is much greater than the CII results. During the observations, several labors were spotted doing smoke breaks or tea break along with the other crew .The crew size was around five to eleven persons so they did have much time to chat or joke during the working time. It is to be mentioned here that the site supervision were quite strong but due to large number of labors at construction building it was quite tough for site management to control the labors unnecessary talks or gossips during their working time. Site management were of view that labors feel uncomfortable if we try to control or monitor their personal activities too much and it was experienced that labors put maximum time in direct work activities if they are doing gossips with their fellow workers. In this way, direct work rate is not much affected.

Waiting had the percentage of 8.78% of all the work observations recorded for the study. However, for the field trials conducted by CII, the average was 14.9% ranging from 11.1% 3 to 20.5% (CII 2010). Overall scope of work was quite large as compared to the labor working on project. Almost all the work was subcontracted in the form of work packages for each building and mostly subcontractor hired less labor for each work package, due to this labors were lesser times waiting so that they can perform their job. Apart from this, nature of work activities were no so complicated, due to this labors were confident about how a particular work should be done

Due to clear job instructions and strong material management, labors were not wasting their time in waiting activity. Five minute rating was also performed at the site to assess the crew balancing of the project which is explained in detail.

### 4.5.5 Comparison of Activities with each other

If we compare the activities, we can clearly see the after the direct work activity, Travelling activity is dominating with respect to others with a value of 15.33% as clearly shown in the Figure 4-23.

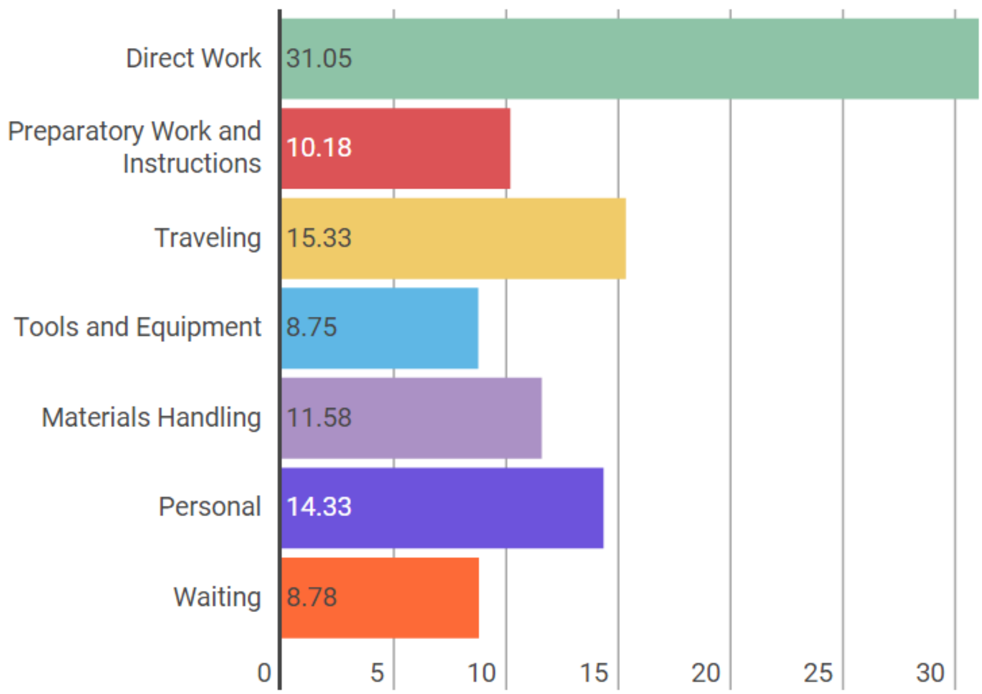


**Figure 4-23 Overall Activities comparison at project E**

If we assume the observed activity rates as time spent on each activity, then we can say that in the typical eight-hour work shift, average labor is spending 2.5 hours actually doing the direct work or directly developing the project, about 48 minutes doing preparatory work and instructions, about 1 hour and 13 minutes doing the travelling between different location of work, about 41 minutes doing the tools and equipment related work, 56 minutes doing the material handling works, 1 hour 9 minutes doing his personal works and almost 43 minutes waiting to do work.

### 4.5.6 Hourly Distribution Analysis of Activity percentages

Observations were also calculated for hourly activity percentage and were further analyzed for each category of activity in hourly period of whole working day. Percentages of each activity were calculated for each hour from 8 A.M to 5 P.M and trend of each activity was assessed with respect to all related factors from the total observed labor data of five days. Hourly distribution of site of each of the seven site activities for project E are given in the Table 4-24.

**Table 4-24 Distribution of observed data percentages in each hour at project E**

| Time | | 8am-9am | 9am-10am | 10am-11am | 1am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm |
|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 22.19 | 30.28 | 33.61 | 36.06 | 31.51 | Lunch | 27.03 | 37.83 | 32.36 |
| Support | Preparatory Work and Instructions | 16.64 | 13.42 | 10.64 | 9.20 | 6.47 | | 10.44 | 7.43 | 5.34 |
| | Traveling | 18.67 | 13.20 | 9.46 | 8.46 | 20.67 | | 18.77 | 11.71 | 21.09 |
| | Tools and | 10.31 | 8.24 | 8.11 | 8.37 | 8.91 | | 9.98 | 7.62 | 7.97 |
| | Materials Handling | 15.31 | 12.59 | 11.99 | 10.76 | 11.34 | | 11.04 | 10.32 | 8.36 |
| Delays | Personal | 9.77 | 13.42 | 16.22 | 17.02 | 12.86 | | 14.41 | 15.71 | 16.33 |
| | Waiting | 7.11 | 8.85 | 9.97 | 10.12 | 8.24 | | 8.33 | 9.39 | 8.55 |

All activities are changing with respect to time. Some activities are quite low at start of day, while some activities are high at the start, similarly same can be said at the end of day. For a typical day, changes in these activities are graphically illustrated in the following time series stacked bar chart in Figure 4-25.

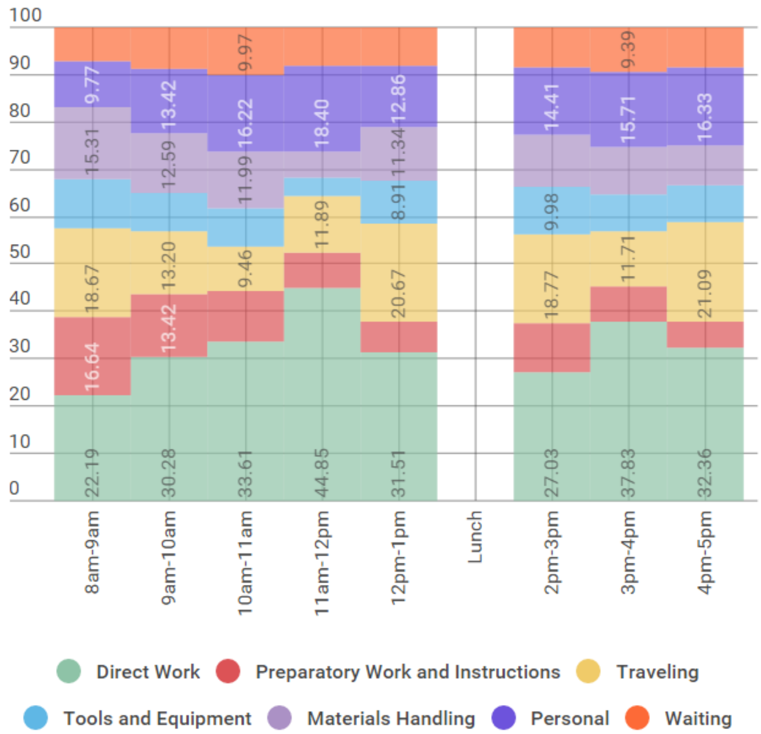


**Figure 4-25 Stacked bar chart representing hourly distribution of activity rates at project E**

Individual behavior of all the activities are displayed in the Figure 4-24 where the lines of respective category are showing the hourly trend.

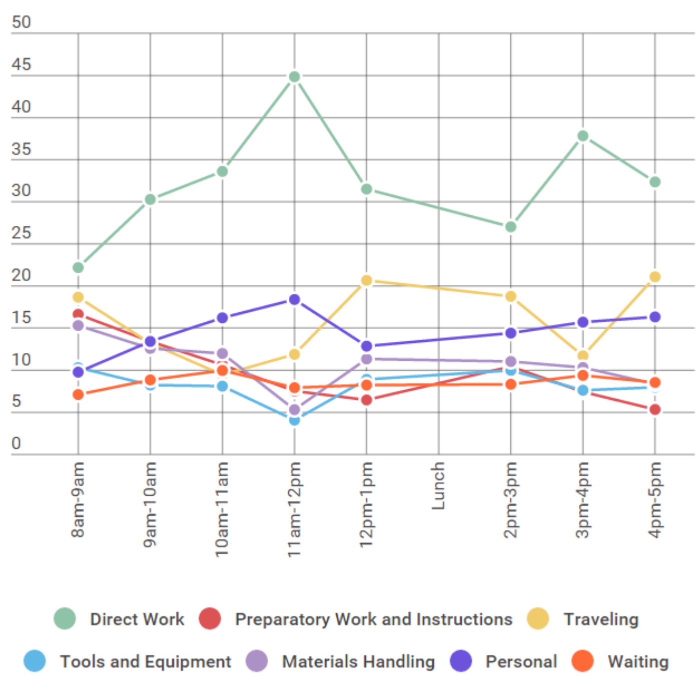


**Figure 4-24 Overall hourly trend of activities at project E**

Direct work rate trend throughout the working day of 8 hour is analyzed in detail. As it is clearly seen that it was too much low at the start of the work while increasing with respect to time and then start decreasing before the lunch. And after the lunch break, direct work rate is still less and after one hour, it get lesser more with time and then increases in last hour. Direct work peaks during 11am to 12pm and 3pm to 4pm with a value of 36.06% and 37.84% respectively, while it is lowest in the starting hour with a value of almost 22.19%.

Activity “Preparatory work & instructions” is highest when the labor is going to start of working day and start of work after lunch. As it is shown in the last graph, activity is highest during 8am to 9am during 16.64% and lowest during 4pm-5pm with a value of 5.34%. It is observed that before the starting the work, labor get necessary instructions and required information on how to perform the work along with that they get the safety equipment for themselves, which ultimately increases the preparatory work and instructions activity.

Travelling was observed highest consistently throughout the day, workers were seen travelling everywhere. Due to limited facilities available at project site, workers were going out of site area to avail these facilities. Many subcontractor labor were observed coming to the project site between the working times as they were not bound by site management to come on time, they were just liable for timely completion of their works. Many of labors were also assigned to different building so they have to travel to next building in order to perform he task at that building which is located quite far from others. Travelling were recorded at peak value of 21.09% at 4pm-5pm and lowest with a value of 8.46% at 11am-12pm.

Tools and equipment category is observed high overall with a peak value of 10.31% at 8am-9am and lowest value of 7.62% at 3pm-4pm. Due to unplanned activities, workers were taking time in adjusting the equipment that will be used later. Material Handling was spotted high during the first hour e.g. 8am-9am with a value of 15.31% and lowest in the last working hour e.g. 4pm to 5pm with a value of 8.36%. Due to lack of material management, it was seen that labors were putting a lot of time during working as almost all ongoing activities were material dependent. Material was poorly placed outside of project site therefore labor has to carry the material and it takes a lot of their time.

Collectively, Personal activity is third highest activity among other activities after the direct work and travelling at this particular construction site and contribute a lot of time of labor. It is recorded that personal time starts with low value at the start of day and then eventually increase till the mid-morning and then decrease in last hour before the lunch, after lunch it start with a high value and slowly increase till the last hour. It was observed highest during 11am-12pm with a value of 17.02% and lowest during 8am-9am with a value of 9.77%. Due to low supervision and lack of monitoring of project activities, labor were usually seen roaming, taking rest and having break during working hours.

Delay activity "waiting" also following a similar trend to personal activity. Waiting activity peaks at 11am-12pm with a value of 10.12% while it is observed lowest at 8am-9am with a value of 7.11%. Although there was no planning of works by site management, but due to simple nature of ongoing activities labors were observed less waiting for their activities during their working time. It is to be mentioned here that contractor has subcontracted most of the work and working crew of subcontractor were proficiently coordinated with other during work which ultimately reduced the waiting time of labors.

### 4.5.7 Safety Assessment

At project E, it was observed that no safety arrangement was followed by contractor. Labors were working without any kind of safety equipment or PPE. Contractor staff were of view that safety arrangements are hindrance to project progress and if they implement the safety procedures then they will lag behind the base schedule and it will effectively lower the project profit of contractor. During the data collection phase, it was observed that labors were quite exposed to safety risks. Overall a lot of safety drawback were observed at site. Nothing was taken serious while executing work regarding safety wise. Labors were fully exposed to some serious risks while performing their activities. While interviewing, when the site manager was asked regarding the safety of construction workers, he was of view that it is not their responsibility and according to them they will not be liable if some safety mishap occurs.

### 4.5.8 Five Minute Rating and Crew Balancing

Five minute analysis was also performed during steel binding. During data collection, video was recorded for approximately 25 minutes to collect data for the five-minute rating. After analyzing the video, effectiveness was determined. There were five members binding the steel of a slab which was later to be concreted. They were continuously binding the steel with binding bars. Table 4-25 represents the data readings observed and their results.

**Table 4-25 Five minute analysis spreadsheet**

| Minutes | Member 1 | Member 2 | Member 3 | Member 4 | Member 5 |
|---|---|---|---|---|---|
| 1 | | | | x | |
| 2 | x | | | x | |
| 3 | x | | x | x | |
| 4 | | x | x | x | x |
| 5 | | x | x | | x |
| 6 | | x | x | | x |
| 7 | | x | | | x |
| 8 | | | x | | |
| 9 | | | x | | |
| 10 | x | | x | | |
| 11 | x | | x | | x |
| **Effective Units** | **5** | **4** | **8** | **5** | **6** |

| | |
|---|---|
| Total Man Units | 55 |
| Effective Man Units | 28 |
| Effectiveness | 51% |

Result shows that overall effectiveness of the mentioned activity was 51%. Thus, the observation based on the crew balancing and five-minute rating techniques was that the work was not evenly distributed and out of 5 members, only two members can perform the same work and other can be reassigned to other activity. Reassigning the other two members to another task would be an application of the crew balancing technique because it would maximize the direct work performed on the task by maximizing the efficient use of time and resources.

## 4.6 COMPARISON

Percentage of all the observed activities for all the projects are given in the Table 4-26.

**Table 4-26 Total activity percentages on each project**

| Activities | Projects | A | B | C | D | E |
|---|---|---|---|---|---|---|
| Direct Work | | 41.12 | 37.87 | 28.99 | 33.19 | 31.05 |
| Support | Preparatory Work and Instructions | 9.20 | 8.83 | 8.10 | 9.27 | 10.18 |
| | Traveling | 12.63 | 11.93 | 13.59 | 12.04 | 15.33 |
| | Tools and Equipment | 3.73 | 6.37 | 9.21 | 8.75 | 8.75 |
| | Materials Handling | 4.33 | 5.90 | 11.47 | 9.14 | 11.58 |
| Delays | Personal | 17.75 | 18.38 | 17.61 | 17.00 | 14.33 |
| | Waiting | 11.24 | 10.73 | 11.03 | 10.61 | 8.78 |

All the working activities are changing for each project with respect to other project due to various factors. If the projects are compared with respect to direct work, then project A is highest among all other projects, following project B, D, E and C which means that at this particular project labor were giving maximum time to direct work activities as compared to other projects. Similarly, personal activity and waiting activity was recorded high at project B and A respectively as compared to other projects due to various reasons which were explained earlier in detail. It should be noted here that individual behavior of each activity is explained for each project earlier where reasons for particular behavior were described in detail. Figure 4-26 represents the stepped area chart, activities for all the project are represented graphically.

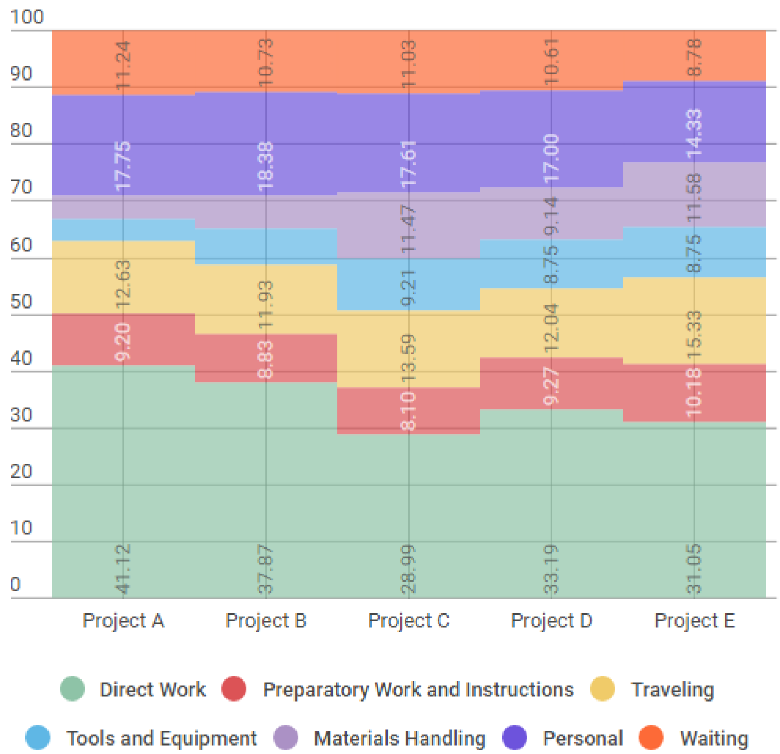


**Figure 4-26 Graphical comparison of projects with respect to activities**

Detail comparison of all activities with respect to all projects are shown in Figure 4-27 in form of grouped bar chart.

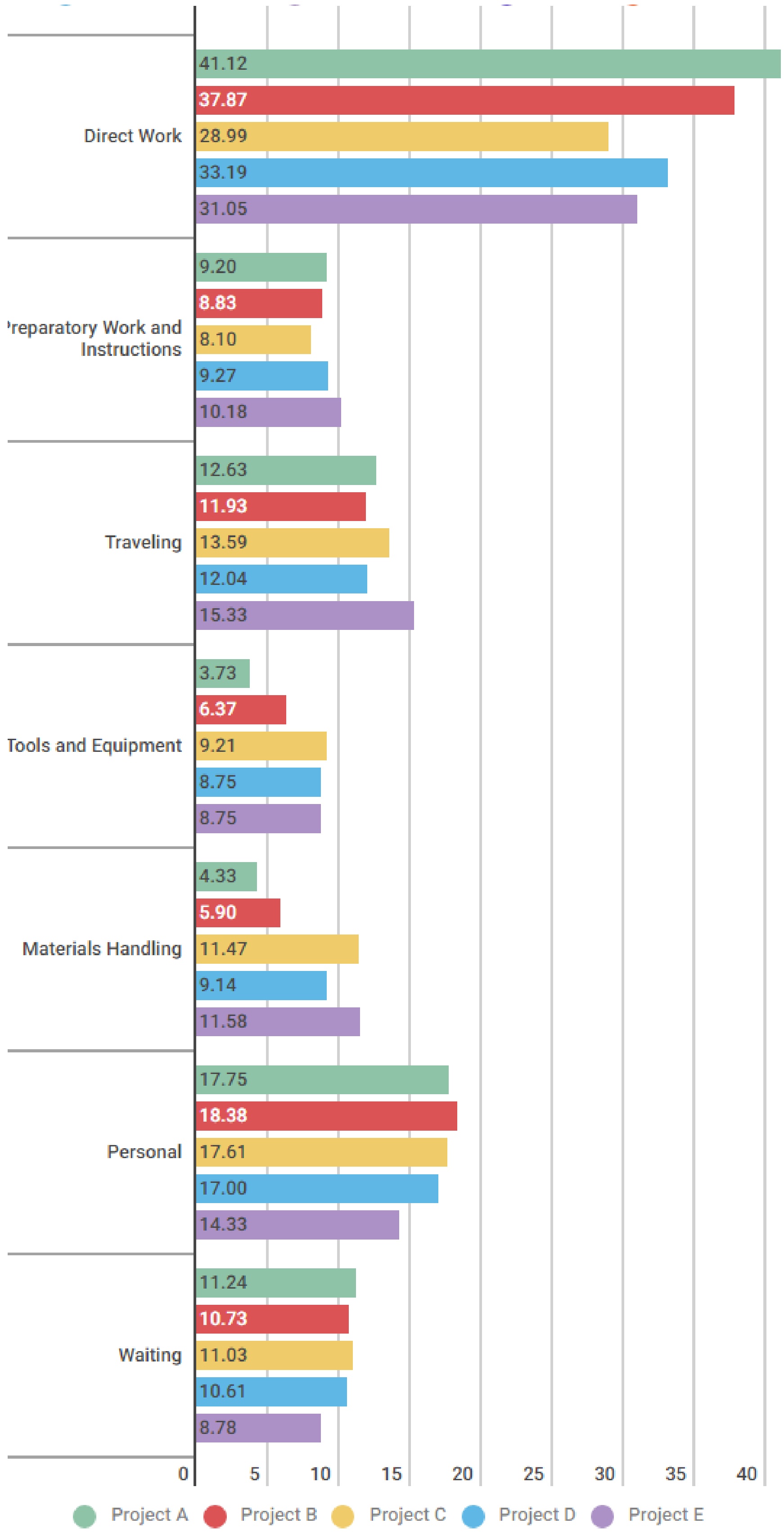


Figure 4-27 Detail comparison of projects for each activity

### 4.6.1 Hourly direct work rates of all projects

Direct activity percentages were also evaluated and compared for all projects for each hour as shown in Table 4-27.

**Table 4-27 Hourly direct work activity rates of all projects**

| Hourly Direct Work Percentage with respect to other activities | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | Lunch | 2pm-3pm | 3pm-4pm | 4pm-5pm |
|---|---|---|---|---|---|---|---|---|---|
| **All Projects** | 27.40 | 35.67 | 38.51 | 40.24 | 35.19 | - | 32.44 | 38.08 | 35.47 |
| **Project A** | 35.07 | 42.71 | 43.10 | 44.85 | 42.27 | - | 39.40 | 37.88 | 44.82 |
| **Project B** | 23.74 | 40.71 | 43.34 | 41.58 | 40.12 | - | 33.29 | 42.97 | 40.45 |
| **Project C** | 25.35 | 28.10 | 31.32 | 34.83 | 28.28 | - | 27.38 | 30.26 | 28.24 |
| **Project D** | 27.82 | 30.75 | 36.50 | 41.85 | 31.66 | - | 31.10 | 40.55 | 30.78 |
| **Project E** | 22.19 | 30.28 | 33.61 | 36.06 | 31.51 | - | 27.03 | 37.83 | 32.36 |

As seen clearly in above table that the direct work activity is changing in each hour for all projects throughout the day due to different factors at each project. Some projects its rate of change is high during some hours and some projects observed low rate of change in many hours. As compared to other projects, project A was observed having direct work rate high in all hours due to strong planning and supervision of works by site management whereas project C is recorded low in all hours due to various reasons.

In all projects, peak direct rate is recorded during 11am-12 pm hour and lowest direct rate is overall observed during first working hour e.g. 8am-9am. It should be noted here that direct work activity is at maximum value before the last hour both before and after the lunch. Possible explanation is that it is observed that direct work rate increase with time but in the last hour both before and after lunch, direct work rate is observing a low value due to increased travelling activity which was observed high during last hours due to movement of labors out of working area too early before the time.

In each project, work is started with lowest direct work rate, then the direct work rate increases with time until the 11am-12pm where it peaks and then its start decreasing until lunch break, direct work activity again start slowly increasing after the lunch and then again reached at high value in second last hour and then stat decreasing in last hour until the works end. In the following chart shown below, lines of different color are showing the trend of direct work rate during the working time at each project. In order to show the overall trend of direct work rate, average project line is also shown in the figure 4-28.

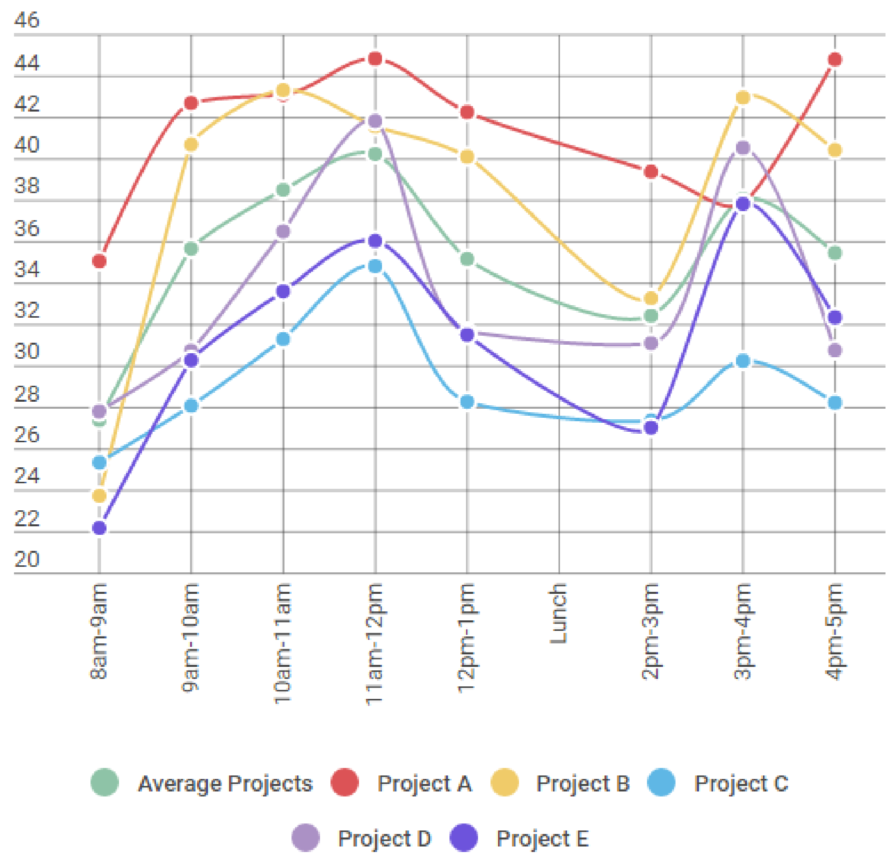


**Figure 4-28 Hourly trend of direct work rate of all projects**

### 4.6.2 Safety

If we compare the safety arrangements of all the project observed for assessment of labor productivity then we can confidently say that the project A was quite good with respect to safety arrangements, followed by project D, project B, project C and project E. Out of five, civil structure construction were going on four projects as project D was in finishing stage. It should be mentioned here that project C was going through some administration issues due to funding. If we correlate the safety with direct work of projects with safety then it can be observed in projects with similar stage of construction that higher direct rate projects were those with relatively good safety facilities with respect to each other.

### 4.6.3 Five minute rating plus crew balancing conclusion

Overall crew balancing and five-minute rating techniques were focused on highlighting four improvement objectives or goals.

- Minimizing the number of moves to perform a job by either eliminating movements or reducing the number of workers used to complete the task,
- Minimizing the length of the movements required for completed the task,
- Minimizing the number hand movements required for the task, and
- Maximizing the efficient use of time and resources for completing the task.

These improvement objectives are all achieved by eliminating, combining or reducing the inputs that take the shape of either the number of workers, and/or the amount of time and/or materials that must be expended for each of the tasks that when combined deliver the desired outcome. Hence, again when inputs are effectively reduced through the use of logical and proved techniques then increased productivity results because the outputs are then able to be maximized without an adverse impact to the quality of overall product.

## 4.7 OVERALL ANALYSIS OF TOTAL RESULTS

Results of all the observations on five construction projects is expressed in detail in Table 4-28 for further analysis where number of observations of each activity during all observing hours are mentioned.

**Table 4-28 Distribution of whole observed data spreadsheet of all projects**

| Time | | 8am-9am | 9am-10am | 10am-11am | 11am-12pm | 12pm-1pm | | 2pm-3pm | 3pm-4pm | 4pm-5pm | Total observations of activities |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Direct Work | | 2126 | 2788 | 2616 | 2371 | 2286 | Lunch | 2555 | 2387 | 2111 | 19240 |
| Support | Preparatory Work and Instructions | 1070 | 822 | 581 | 432 | 470 | | 723 | 495 | 406 | 4999 |
| | Traveling | 1134 | 936 | 746 | 611 | 1161 | | 1146 | 563 | 851 | 7148 |
| | Tools and Equipment | 694 | 524 | 454 | 378 | 412 | | 553 | 398 | 442 | 3855 |
| | Materials Handling | 678 | 649 | 503 | 546 | 513 | | 595 | 510 | 436 | 4430 |
| Delays | Personal | 1159 | 1286 | 1224 | 1006 | 1039 | | 1402 | 1196 | 1072 | 9384 |
| | Waiting | 897 | 810 | 669 | 548 | 615 | | 902 | 719 | 634 | 5794 |
| Total | | 7758 | 7815 | 6793 | 5892 | 6496 | | 7876 | 6268 | 5952 | 54850 |

All the recorded observations of each activity for the whole working day were analyzed in detail for further conclusion. All the activities were analyzed and their individual percentages were evaluated on the basis of recorded observation. Percentages of Primary and respective secondary activities are shown in the expressed in the Table 4-29.

**Table 4-29 Percentage of overall observed activities**

| Activities | | Percentage | |
|---|---|---|---|
| Direct Work | | 35.08 | |
| Support | Preparatory Work and Instructions | 37.25 | 9.11 |
| | Traveling | | 13.03 |
| | Tools and Equipment | | 7.03 |
| | Materials Handling | | 8.08 |
| Delays | Personal | 27.67 | 17.11 |
| | Waiting | | 10.56 |

As represented in Table 4-29, support activities share large percentage following direct work and delay activity with values of 37.25%, 35.08 and 27.67 respectively. Overall supporting activity is holding a paltry larger percentage than direct work and it is normal as these activities help and boost direct work activity. Primary activities was analyzed in detail by exploring their secondary activities in which comprehensive investigation of recorded data was done and all the percentages of secondary activities were calculated. These percentages are also shown in the above table and also graphically illustrated in the Figure 4-29.

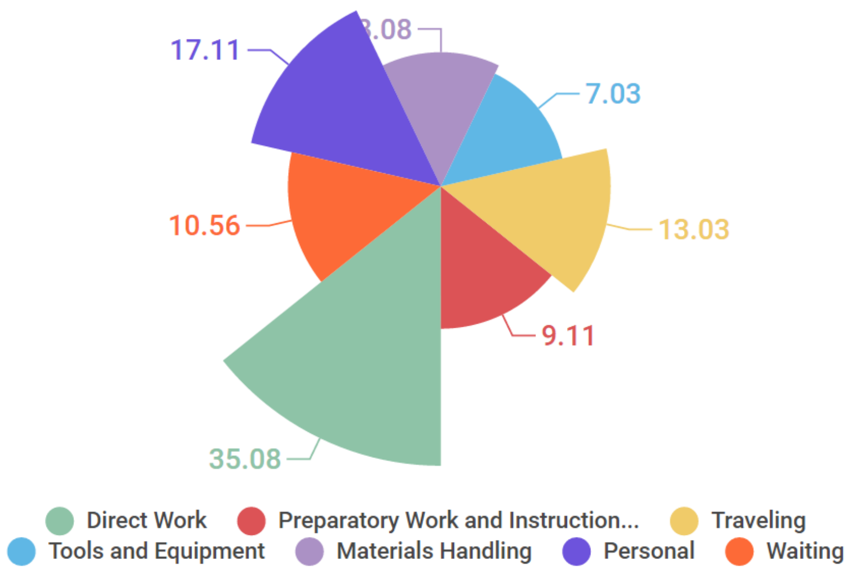


**Figure 4-29 Overall percentage of total observed activity rates**

Overall percentage of direct work activity for all project is about 35%, while percentages of delay activities e.g. personal activity and waiting activity are 17.11% and 10.56%. Similarly percentages for supporting activities e.g. preparatory work instruction, travelling, tools equipment and material handling are 9.11%, 13.03%, 7.03% and 8.08% respectively. If we analyze these activities, then it can be observed that activities which hold larger percentage after direct work activity are personal activity, travelling and waiting activity. In order to increase the direct work, these activities should be controlled as much as they can be. Further other activities should also be minimized as reduction of all these activities will eventually increase the direct work activity. In this way labor productivity will be increased resulting in project success.

### 4.7.1 Sensitivity Analysis

In order to find out relation between direct work activity with other activities, Sensitivity Analysis was performed using @RISK ® software with all 54850 observed data inputs. Firstly, an equation was derived using regression analysis. Following this equation, regression and correlation factors of each activity with direct work were calculated as shown in Table 4-30.

**Table 4-30 Regression and correlation factor of direct work with respective activities**

| Regression and Rank Information for Direct Work | | | |
|---|---|---|---|
| **Rank** | **Name** | **Regression** | **Correlation** |
| 1 | Personal | 0.589 | 0.585 |
| 2 | Waiting | -0.562 | -0.549 |
| 3 | Preparatory Work and Instructions | 0.443 | 0.448 |
| 4 | Tools and Equipment | -0.339 | -0.343 |
| 5 | Materials Handling | 0.133 | 0.115 |
| 6 | Traveling | 0.045 | 0.045 |

From the Table, it can be observed that personal activity is highly sensitive to the direct work activity with a correlation and regression coefficient of 0.585 and 0.589 respectively. Afterwards, waiting is the second activity which negatively affects the direct work with a correlation and regression coefficient of 0.562 and 0.549 respectively. After these activities, preparatory work and instructions, and tools and equipment activities are ranked third and fourth. Lastly, materials handling and travelling activities are ranked fifth and sixth respectively as shown in the following Figure 4-30.

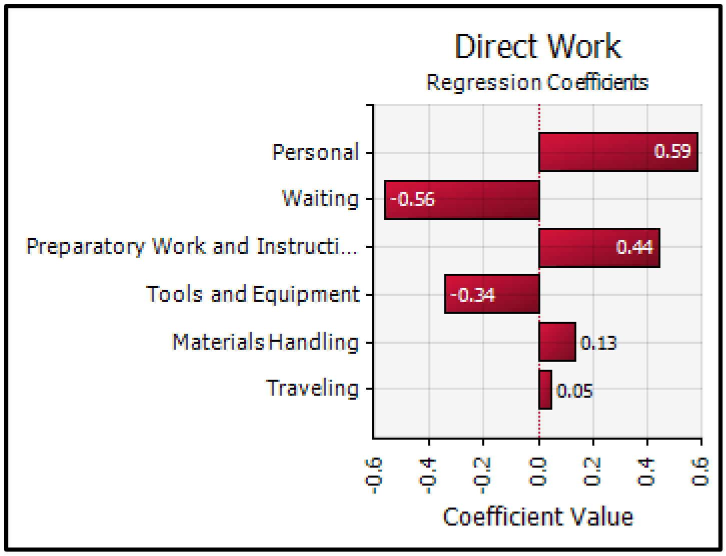


**Figure 4-30 Regression coefficients of direct work with other activities**

Personal, and preparatory work and instructions positively affect the direct work activity while waiting, and tools and equipment inversely affect it. From Table 4-30, it can be inferred that when the workers are comfortable while doing their work, they will exert more efforts in their activities hence enhancing the project (Böckerman and Ilmakunnas, 2012). It was observed that that labors feel uncomfortable when project staff overly controls or restricts their personal activities (gossiping and having tea or smoke break). To this extent, after spending some time in personal activities, they concentrate effectively on direct activities. On the other hand, if their mind is pre-occupied with the unfriendly restrictions, they find it hard to concentrate effectively on their tasks. It is a commonly perceived notion in local projects that subcontracted labors who work on their own schedules with more liberty to set their work plans perform better. Not only they complete tasks in optimum time, a cost reduction is also realized due to reduced supervision expenses.

Instead of restricting personal activities, management should focus on areas of pilferage activities: late starts at start of day, around lunch, and the early quits at the end of the day. Better planning and a greater presence on-site during these times should limit the number of craft purposely starting slowly, or waiting to clock-out. Also, increased sense of job satisfaction will positively drive the workers towards enhanced productivity.

Similarly, it is analyzed that more the labors are spending time in preparatory work and instruction activity, the more direct work will be carried out. Many times during construction, labors are unable to determine the job requirements usually due to lack of necessary instruction to perform the work. So, if more time is allocated to preparatory work instruction, the increased understanding of job requirements and proper execution methods will ensure the timely completion of complex work. So more direct work activities can be performed (Jarkas and Bitar, 2011). Further, the unnecessary tasks should be eliminated, while the essential activities may still be excessive depending upon their job related criticality. These include ergonomics, safety talks and stretching activities as they are crucial for maintaining a well-functioning and safe construction site.

Talking about the negative relation, it is concluded that more the labors will be spending their time in waiting, and tools and equipment activities, lesser will be the direct work activity. An explanation is that when the labor is involved in waiting activity, though the time is essentially spent on project activities, the result is not so effective mainly due to poor activity planning. Due to this lack of planning, they are not actually performing the work but are waiting for someone to finish their job resulting in delayed work and queuing. Though in some instances waiting is unavoidable like electricians waiting for a cable pull, usually it is caused by poor planning and crew balance, and is therefore avoidable (Vilasini et al., 2011). To improve the productivity, site management team should properly plan the work in order to minimize the labor waiting or use innovative and latest techniques like lean management (Song and Liang, 2011).

Tools and equipment also follow a negative relation with direct work. It is observed that more the labors will be putting their efforts in tools and equipment activities, lesser will be the direct work activities. More time spent in tools and equipment activities eventually decrease the time of direct work (Ghoddousi and Hosseini, 2012). It is usually caused due to poor tool management at project site. So, it is suggested that site management should properly implement tool management program and ensure timely availability of tools and equipment at project site.

*Chapter 5*

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 BACKGROUND

To increase profit and market competitiveness, construction companies try to cut their costs (Thomas et al., 1986). Construction costs include labor, material and overhead, of which labor and overhead varies the most. This ultimately sums into the variable labor productivity which must be kept in check to ensure project success in terms of cost. This research is mainly focused on assessment of labor productivity in building projects by crew time utilization during working hours and uses activity analysis for this purpose.

## 5.2 SYNOPSIS OF RESEARCH

In literature review, background of labor productivity, major challenges faced at industrial level and different factors affecting labor productivity were described. Labor productivity and challenges during its measurement, justifications for labor productivity improvement and use of different workface assessment methods in past are also discussed in detail. It is established in literature review that for maximum productivity it is required that labors should be spending more time doing the direct work which advances the project. To measure the direct and indirect work time of labor, most relevant technique identified in literature is activity analysis.

Activity analysis is based on calculating different kind of activities including direct work activity. The analysis eventually helps to identify the causes of low labor productivity areas and assists mangers in planning and implementing improvements. Detailed activity analysis was carried out at five unique building construction projects. The overall activity rates of workers and the distribution of activity rates throughout a typical workday were determined. The rates were analyzed in detail to identify productivity inhibitors, which should be reduced or eliminated in an attempt to improve the direct-work rate of that particular site. Furthermore, five minute analysis was conducted at task level to further strengthen the results of previous analysis which in turn suggested that labor productivity can be improved.

## 5.3 RESEARCH FINDINGS

It is observed during the analysis that the direct work is strongly correlated to delay and support work activities. But in the support activity, material handling and travelling are weakly correlated to direct work. It is established that personal and preparatory works positively influence the overall direct work. Similarly, waiting, and tools and equipment activities negatively influence the direct work. Hence in order to maximize labor productivity, direct as well as support work activities should be efficiently managed. Further, planning, coordination and supervision are essential for increasing the effectiveness of employees and maintaining the required daily output level. The case studies present that the projects with better planning, monitoring and control practices, perform better in terms of direct work. Improving the productivity of the entire project is not possible until everyone on the project is committed to improvement (Little and Little, 2006).

By the analysis of hourly direct work rate of labor at all projects, it was found that the direct work rate peaks during the 11am to 12pm slot and minimizes during the start and end of working day. Also, in general about 35% of the working time is utilized in direct work, 37% in support work and 28% in delay work activities. Specifically, in terms of individual activities, about 17% time is utilized in personal activities which is the 2nd highest proportion after direct work. Hence, the personal time must be properly managed in conjunction with the direct work in order to ensure project success and achieve maximum labor productivity.

In order to increase the direct work, it is recommended to hire experienced craft workers or provide proper trainings, plan good site layout, ensure availability of all required materials and tools, and plan the work task for timely execution of works. This will ensure maximum productivity in terms of more direct work and reduced undesired work. For future research, labor productivity should be continuously monitored throughout the life of a construction project for more in-depth analysis. The current study uses the workface assessment technique which can be further enhanced in future by not only increasing the number of projects but also using it in conjunction with other monitoring techniques to add value to the existing body of knowledge.

## 5.4 RECOMMENDATIONS

Based on the observations and their results, it is recommended that in order to increase the direct work rate, prefer experienced craft workers, plan good site layout, ensure availability of all required materials and tools, and plan the work task for timely execution of works. Detailed work packages that include an outline of works tasks should be issued and work task should be properly planned so that labors shouldn't have to wait for their turn. Stakeholder should employ significantly greater planning resources to ensure a larger percentage of direct work and focus on reducing the controllable personal activities of working labor which are non-essential.

## 5.5 LIMITATION

One of the limitations of this study has been time constraints and limited resources. Only the data collection part of activity analysis was executed and results were not implemented and monitored due to limited time.

## 5.6 FUTURE DIRECTIONS

As mentioned, one of the great limitations of this study has been time constraints. The activity analysis process has not been applied fully to specifically validate the construction productivity improvement process as outlined in activity analysis by Construction Industry Institute (CII). Instead this research entirely focused on workface assessment part of activity analysis. It would be of great value if this entire process could be validated through monitoring direct-work rates and implementing improvements through the life of a construction project.

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