Factors Affecting Labor Productivity

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This thesis is dedicated to my parents and my respected teachers!

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ABSTRACT

Construction industry confronts challenges connected with productivity and making matters even more tricky is the labor productivity. Construction labor productivity is of great interest to practitioners and researchers because it affects project's cost and time performance. Labor efficiency is affected by numerous factors and is usually linked to the performance of time, cost, and quality. In this context, large body of research has been conducted in the last decade or so identifying and evaluating factors that affect labor productivity. In spite of the previous research, assessing, controlling and improving labor productivity still present challenge to construction managers and site supervisors.

The aim of this research is to explore the possibility of improving upon the existing work and to attain latest information on key factors that affect project performance in terms of project completion time. It also develops prediction models for labor productivity. To find the factors affecting labor productivity questionnaire, survey was done. A total of 109 construction professionals and 13 construction sites were engaged for data collection. Results demonstrate the factors affecting the productivity, top in which is design changes during execution. The findings show that the productivity decreases with the increase of crew size.

Based on the analysis of the results, recommendations for the stakeholders have been proposed for the improvement of labor productivity. This study concludes that the design changes should be minimized during execution, material should be ordered prior start of work so it will be available on the time of activity. As a result, this study will be useful for clients, consultants, contractors and other stakeholders who desire to improve the productivity.

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Chapter 1

INTRODUCTION

1.1 GENERAL

Construction industry is Pakistan one of the largest industries. In 2014 construction industry provided 7.33% jobs (Pakistan Economic Survey, 2014-2015).

A successful construction project is one that is completed on time, within budget, meets specified standards of quality, and strictly conforms to safety policies and precautions. All of this is possible only if the planned levels of productivity can be attained. Decrease in productivity is one of the major problems of construction industry. Reduction in productivity can cause major financial problems to the owner and become the key factor for cost overrun.

Productivity in construction is decreased in previous years as compared to other sectors (Bernstein, 2007). Productivity is measured in terms of the rate of output per unit of input. Employers always try to get higher output with low unit input. But some factors decrease the output. While in the initial planning of the project number of labor and equipment is calculated on the basis of their productivity and their cost is included in the project. If the productivity decreases, the number of labor and equipment is increased to complete the project. Due to this the cost of the project increases and the profit of the company decreases or the time required to complete the project increases.

In today's era, one of the major concerns for any company is to increase their productivity (Wilcox et al., 2000). Therefore, studies are conducted to understand productivity due to which large number of productivity definitions are produced (Lema and Samson, 1995; Oglesby et al., 2002; Pilcher, 1997).

Productivity is commonly defined as the average direct labor hours required to install a unit of material. It is believed that ideal productivity (1.0) can be achieved with a 40-hour work week, with people taking all the holidays and vacation days, all of the drawings would be 100% complete, there would be no delays of any kind throughout construction; everyone would work safely; everything would fit perfectly the first time; the weather would be 70o F; and there would be no litigation at the end of the project (Rowlinson and Proctor, 1999).

Productivity is the relation between input and output (Borcherding and Liou, 1986). Input and output are different from one field to another.

Productivity has a great significance in construction. Labor productivity constitutes a major part of production input for construction projects. In the construction industry, many external and internal factors are never constant and are difficult to anticipate. This leads to a continuous variation in labor productivity. It is necessary to make sure that a reduction in productivity does not affect the plan and schedule of the work and does not cause delays. The consequences of these delays could result in serious money losses. Further, considerable cost can be saved if productivity is improved because the same work can be done with less manpower, thus reducing overall labor cost (Thomas, 1991).

1.2 PROBLEM STATEMENT

In building construction labor productivity plays an important role in planning and scheduling of the project. There are many factors which affect the labor productivity. Due to which the number of labor required to complete a work can increase and the cost of labor associated with it will also increase accordingly. In building construction productivity decrease is one of the greatest problems.

Contractors lack the knowledge of factors which affect productivity (Construction Industry Institute [CII], 2000). In project-costs i.e. materials and equipment's, labors, labor cost is considered the riskiest. while the cost of material and equipment is affected by market price which is beyond the control of management. The cost of labor is about 33%-50% of total project cost (Hanna et al., 2005). Because labor cost is more inconstant than other project components, it becomes necessary to understand the effects of different factors on labor productivity. If the productivity increase the labor cost will decrease. Which will increase or decrease the project profit (Hanna et al., 2005).

1.3 RESEARCH OBJECTIVES

The specific objectives of this research are:

1 To refine labor productivity factor taxonomy in construction industry.

2 To statistically analyze and rank the factors according to their criticality.

3 To propose productivity enhancement framework in construction.

4 To prepare productivity curves due to different crew size.

1.4 SCOPE OF RESEARCH STUDY

This research will explore the factors affecting productivity in building construction. Understating those factors will be useful for construction professionals who work on the early phases of construction planning in order to efficiently deliver the project plan. For building construction, extra care must be taken when developing the project time schedule, which is possible only with prior knowledge of factor causes. The research study goal to provide knowledge of building construction-related factors that affect the project's success and propose productivity enhancement framework.

Chapter 2

LITERATURE REIVIEW

2.1 WHAT IS PRODUCTIVITY?

There is no universal definition of productivity; the term has different meanings for different people (Adrian, 1987). Generally, productivity is the relationship between the output produced and one or more of the associated inputs devoted to the production process (National Research Council, 1979). Productivity may be defined as the ratio of output to input, via the arithmetical ratio between the amounts produced (output) and the amount of any resources used during the process of production (input) (Chan & Kumaraswamy, 1995).

There is difference of opinion on how to measure output and input. A vast number of output-to-input ratios can be formed; no single productivity measure works for all purposes. The selection of an appropriate concept of productivity depends on the objective of measurement, availability of data, and the researcher's preference.

2.2 REVIEW OF LABOR PRODUCTIVITY FROM PREVIOUS STUDIES

Previous studies show the number of factors affecting the productivity, there are still anonymous factors which need to be further studied even in developed countries (Makulsawatudom and Emsley 2002). Polat and Arditi (2005) arranged the factors affecting productivity according to their characteristics such as, design, working time, owner/consultant, material, execution plan, supervision, project factor, quality, equipment, leadership and coordination, labor, health and safety, organization, and external factors.

Olomolaiye et al. (1998) arranged the productivity factors into two groups: external factors those outside the control of the company's management and internal factors related to the productivity factors originating within the organization. Their study shows that some factor like design, rework and design changes affect the productivity. Sometime clients pose obstruction to construction productivity due to their less knowledge about construction.

2.3. FACTORS AFFECTING LABOR PRODUCTIVITY FROM PREVIOUS STUDIES

Discussed below are the different factors which affect the productivity and reviewed from previous studies.

Time; previous studies indicates that working overtime decreases the productivity. Working 7 days per week without holiday has a high effect on labor productivity, while working additional hours during the working day has an average effect (Enshassi et al., 2007). Some of the reasons caused by overtime are increase in accidents, moral decreased, supervision effectiveness reduces, increase in absenteeism and quality of work decrease which cause higher rework. (Horner and Talhouni 1995). In start out put increase when working overtime. But after continually working overtime can cause decrease in productivity and increase in cost. To improve project performance, variability in labor productivity should be reduced with regard to available workload and capacity (work hours) (Shehata et al., 2011; Hinze 1999). Construction laborer only work 30% of his available time on productive activities. A worker works efficiently for only 3.5 hours in his 8 hour working shift (Alinaitwe et al., 2005).

Schedule compression; according to Chan (2002) planning is one of the most critical factors which effect productivity. When projected is delayed in start, time line of activates is shorten to achieve milestones and to complete project on schedule. From an expert scheduling point of view, by using float in overall schedule, schedule compression can be possible without shorten the time of an activity. But sometimes schedules are not fully loaded with resources. Due to which an updated schedule shows the delay and can show the project finish date on time without changing the activities duration. To achieve targets daily work hours are increased instead of number of days which cause lose in productivity (Thomas and Randolph 2000).

Type of project; to achieve high productivity, each person of a crew requires acceptable space to execute work without being affected by other members of crew (Kazaz and Ulubeyli 2006). If the arge number of persons working in a small space then the productivity will decrease. Additionally, if different trade persons are working in same place then the productivity will also decrease (O'Connor and Yang 2004). Interference among the various crews and laborers is due to mismanagement on construction sites. For example, painter will wait for the work until the previous works are complete e.g. wood work and plaster. The types of activities and construction methods also influence labor productivity (Sanders and Thomas 1991).

Safety; accidents have great influences on productivity. Different accidens occur at site e.g. if death of any person occur at site during work it can cause the stoppage of work for days and cause the loss of productivity (Ismail et al., 2012). If during work person injured, it causes the loss of productivity for that activity due to the

shortage of crew member. Small accidents resulting from nails and steel wires can stop work and, thus, decrease productivity (Sanders and Thomas 1991). Inadequate lighting can also be the cause for reduction of productivity (Enshassi et al., 2007). hiring an experienced safety officer which can train labor how to prevent accidents and injuries can cause in the increase of productivity.

Quality; Alfred (1988) states that there are two measures for construction quality, they are accuracy and workmanship. Ineffectiveness of equipment and low quality of material are factors which can cause decrease in productivity. Productivity rate of old equipment is low. If the equipment is old, it will breakdown and cause in the loss productivity (Jha and Iyer 2006). Due to the low quality of raw material work cannot be of required quality due to which the consultant can reject the work and cause in loss of productivity (Rizzo et al., 1998).

Managerial factors; supervisors' skills and approaches have an essential effect on productivity. In some companies the productivity is very low however they use latest machinery and hire the skilled labor (Gundecha 2012). Incompetence supervisors become a problem in large companies in line with the increasingly high demands of the project (Soekiman et al., 2011). Due to inefficient management productivity decreases. Experienced and committed managers can obtain surprising results from average people. Employees' job performance depends on their ability and willingness to work.

Manpower; from the previous studies it was observed that unskilled labor causes the reduction in productivity. For attain high productivity companies should higher skilled labor (Assaf, & Al-Hejji 2006). Due to the absence of labor work cannot be complete on time due to the reduction in crew size. Misunderstanding among

laborers creates disagreements about responsibilities and the work bounds of each laborer, which leads to a lot of work mistakes and decreases labor productivity (Smith and Walker, 2000). Lack of compensation and increased laborer age negatively affect labor productivity because labor speed, agility, and strength decline over time and reduce productivity (Heizer and Render, 1990).

Motivation; it is one of the important factor affecting construction labor productivity. The relationship between motivation and productivity can be summarized as that productivity is directly linked to motivation, and motivation is, in turn, dependent on productivity (Kazaz, et al., 2008). Motivation can best be accomplished when labors personal ambitions are similar to those of the company. Factors such as payment delays, a lack of a financial motivation system, non-provision of proper transportation, and a lack of training sessions are grouped in this topic (DeCenzo and Holoviak 1990).

Material/tools; according to Makulsawatudom et al. (2004) material management is one of the most important factor in construction industry. Productivity can be affected if required materials, tools, or construction equipment for the specific are not available at the correct location and time (Alinaitwe et al., 2007). Selection of the appropriate type and size of construction equipment often affects the required amount of time it is, therefore, essential for site managers to be familiar with the characteristics of the major types of equipment most commonly used in construction. In order to increase job-site productivity, it is beneficial to select equipment with the proper characteristics and a size most suitable for the work conditions at a construction site. Laborers require a minimum number of tools and equipment to work effectively to complete the assigned task. If the improper tools or equipment is provided, productivity may be affected (Alum and Lim, 1995;

Guhathakurta and Yates, 1993). The size of the construction site and the material storage location has a significant impact on productivity because laborers require extra time to move required materials from inappropriate storage locations, thus resulting in productivity loss (Sanders and Thomas, 1991).

Project management factors; improper scheduling of work, shortage of critical construction equipment or labor, may result in loss of productivity. Improper planning of project-initiation procedures generally leads to lost labor productivity (Gundecha, 2012). Additionally, poor site layout can contribute to a loss of productivity. Laborers have to walk or drive a long way to lunch rooms, rest areas, washrooms, entrances, and exits, affecting overall productivity (Association for the Advancement of Cost Engineering (AACE) International Recommended Practice No. 25R-03, 2004).

Natural factors; some of the natural factor can affect labor productivity. Previous studies indicate some natural factor which are Job-site weather condition and geographical location. Labor is also affected poorly by unfavorable weather conditions. For instance, when weather apparel such as raincoats or heavy jackets is necessary, labor is hindered (Mincks and Johnston, 2003). Others factors like water, fuel and minerals can affect productivity to some extent. Psychologically workers tend to become restless and irritable. Physiologically they can acquire heat cramps, heat stroke, heat exhaustion, etc. (Kuykendall, 2007). If weather is to extreme such as heavy rain falls, too hot or too cold it can decrease productivity.

External factors; weather is important factor for the accomplishment of the construction projects (Makulsawatudom and Emsley, 2001). Varying weather conditions can change the productivity of labor. In rainy season external activities

such as backfilling, concreting activity, external plaster and paint. So times work stop totally due to adverse weather conditions. (Sanders and Thomas, 1991).

2.4 FACTORS AFFECTING LABOR PRODUCTIVITY

Table 2.1. Shows probable factors affecting labor productivity in building construction collected from previous studies and literature review. It does not take into consideration any significant value; they are arranged on the basis of frequency in different studies.

Table 2-1: Possible Factor Affecting Labor Productivity

Sr.	Factors Affecting Labor Productivity at Building Construction	Frequency	References
1	Climate change	7	(Soekiman et al., 2011; Assaf, & Al-Hejji 2006; Kazaz et al., 2008; Makulsawatudom & Emsley, 2001; Sanders and Thomas, 1991; Thomas et al., 1999; Chan, 2002)
2	Construction Schedule/Work Planning	5	(Hinze, 1999; Alinaitwe et al., 2005; Shehata et al., 2011; Kazaz, et al., 2008; Thomas et al., 1999)
3	Shortage of Tools and Equipment	5	(Makulsawatudom, et al., 2004; Alinaitwe et al., 2007; Alum and Lim, 1995; Guhathakurta and Yates, 1993;Kazaz, et al., 2008)

4	Construction method	5	(Shehata et al., 2011; Thomas, 1991; Hanna et al., 2005; Adrian, 1987; Polat and Arditi 2005)
5	Type of activities in the project	5	(Sanders and Thomas, 1991; Hanna et al., 2005; Makulsawatudom, & Emsley 2001; Assaf, & Al-Hejji, S. 2006)
6	Design Change During execution	5	(Olomolaiye et al. 1998; Hanna et al., 2005; Kazaz, et al., 2008; Olomolaiye et al. 1998; Soekiman et al., 2011)
7	Lack of labor experience	4	(Olomolaiye et al. 1998; Polat and Arditi 2005; Kazaz, et al., 2008; Hanna et al., 2005)
8	Language Difference	4	(Hanna et al., 2005; Olomolaiye et al. 1998; Kazaz, et al., 2008, Polat and Arditi 2005)
9	Bad relations between labors and management team	4	(Hanna et al., 2005; Olomolaiye et al. 1998; Kazaz, et al., 2008; Polat and Arditi 2005)
10	Material shortage	4	(Makulsawatudom, et al., 2004; Alinaitwe et al., 2007; Alum and Lim, 1995; Guhathakurta and Yates, 1993)

11	Swear Weather	4	(Sanders and Thomas, 1991; Makulsawatudom, & Emsley 2001; Hanna et al., 2005; Enshassi, et al., 2007)
12	Lack of financial motivation system	3	(Olomolaiye et al. 1998; DeCenzo and Holoviak, 1990; Kazaz, et al., 2008)
13	Labor's low wage	3	(Polat and Arditi 2005; Hanna et al., 2005; Assaf, & Al-Hejji, S. 2006)
14	Working overtime	3	(Enshassi, et al., 2007; Horner and Talhouni, 1995; Hinze, 1999)
15	Age of Worker	3	(Olomolaiye et al. 1998; Al-Hejji, S. 2006; Hanna et al., 2005)
16	Lack of training sessions	3	(Olomolaiye et al. 1998, Al-Hejji, S. 2006, Hanna et al., 2005)
17	Lack of Motivation	3	(Hanna et al., 2005; Olomolaiye et al. 1998; Wilcox et al., 2000)
18	Poor terrain conditions	3	(Sanders and Thomas, 1991; Hanna et al., 2005; Assaf, & Al-Hejji, S. 2006)
19	Project size	3	(Hanna et al., 2005; Makulsawatudom, & Emsley 2001; Assaf, & Al-Hejji, S. 2006)
20	Working at height	3	(Polat and Arditi 2005; Hanna et al., 2005; Wilcox

			et al., 2000)
21	Financial conditions of contractor	2	(Hinze, 1999; Wilcox et al., 2000)
22	Large Crew Size	2	(Enshassi, et al., 2007; Hinze, 1999)
23	Labor unfaithfulness	2	(Hanna et al., 2005; Makulsawatudom, & Emsley 2001)
24	Lack of cooperation	2	(Hanna et al., 2005; Olomolaiye et al. 1998)
25	Misunderstanding among laborers	2	(Polat and Arditi 2005; Olomolaiye et al. 1998)
26	Labor personal problems	2	Hanna et al., 2005; Polat and Arditi 2005)
27	Misunderstanding between laborers and superintendents	2	(Hinze, 1999; Wilcox et al., 2000)
28	Rework Due to Changes	2	(Enshassi, et al., 2007; Polat and Arditi 2005)
29	Poor site management	2	(Olomolaiye et al. 1998; Guhathakurta and Yates, 1993)
30	Inefficiency of equipment	2	(Hanna et al., 2005; Makulsawatudom, et al., 2004)
31	Unsuitability of materials storage location	2	(Polat and Arditi 2005; Makulsawatudom, et al., 2004)
32	Quality of Required Work	2	(Rizzo, et al., 1998; Alinaitwe et al., 2007)
33	Working within a confined space	2	(Assaf, & Al-Hejji, S. 2006; Kazaz, et al., 2008)

34	Political Insecurity	2	(Hinze, 1999; Wilcox et al., 2000)
35	Payment delays	1	Hinze, 1999
36	Labor absence	1	Assaf, & Al-Hejji, S. 2006
37	Lack of constant meeting with labor	1	Kazaz, et al., 2008
38	Lack of supervisor's experience	1	Thomas et al., 1999
39	Inspection delay	1	Makulsawatudom, & Emsley 2001
40	Low quality of raw materials	1	Alinaitwe et al., 2007
41	Humidity	1	Soekiman et al., 2011

2.5 GROUPING OF FACTORS

Factors which affect productivity can be organized or grouped in many ways. In this study factors are organized in six different groups. Those Groups are 1) Labor group 2) Project group, 3) Materials and equipment's group, 4) Managerial group, 5) External Group and 5) Financial group.

2.5.1 Labor Group

Following are 10 factors which are grouped in Labor Group.

Table 2-2: Labor Group

1	Lack of labor experience
2	Language Difference
3	Working overtime
4	Age of Worker
5	Large Crew Size
6	Labor unfaithfulness
7	Lack of cooperation
8	Misunderstanding among laborers

9	Labor personal problems
10	Labor absence

2.5.2 Project Group

Following are 8 factors which are grouped in Project Group.

Table 2-3: Project Group

1	Construction method
2	Poor terrain conditions
3	Type of activities in the project
4	Design Change During execution
5	Project size
6	Working at height
7	Quality of Required Work
8	Working within a confined space

2.5.3 Material and Equipment Group

Following are 5 factors which are grouped in Material and Equipment's Group.

Table 2-4: Material and Equipment Group

1	Shortage of Tools and Equipment
2	Material shortage
3	Inefficiency of equipment
4	Unsuitability of materials storage location
5	Low quality of raw materials

2.5.4 Managerial Group

Following are 10 factors which are grouped in Managerial Group.

Table 2-5: Managerial Group

1	Lack of training sessions
2	Lack of Motivation
3	Misunderstanding between laborers and superintendents
4	Rework Due to Changes
5	Lack of constant meeting with labor
6	Lack of supervisor's experience
7	Inspection delay
8	Construction Schedule/Work Planning
9	Bad relations between labors and management team
10	Poor site management

2.5.5 External Group

Following are 4 factors which are grouped in External Group.

Table 2-6: External Group

1	Climate change
2	Political Insecurity
3	Severe Weather
4	Humidity

2.5.6 Financial Group

Following are 4 factors which are grouped in Financial Group.

Table 2-7: Financial Group

1	Lack of financial motivation system
2	Payment delays
3	Labor's low wage
4	Financial conditions of contractor

Chapter 3

METHODOLOGY

3.1 INTRODUCTION

The findings of literature review provide an overview of factors affecting labor productivity. Methodology of this thesis is given in detail in this chapter.

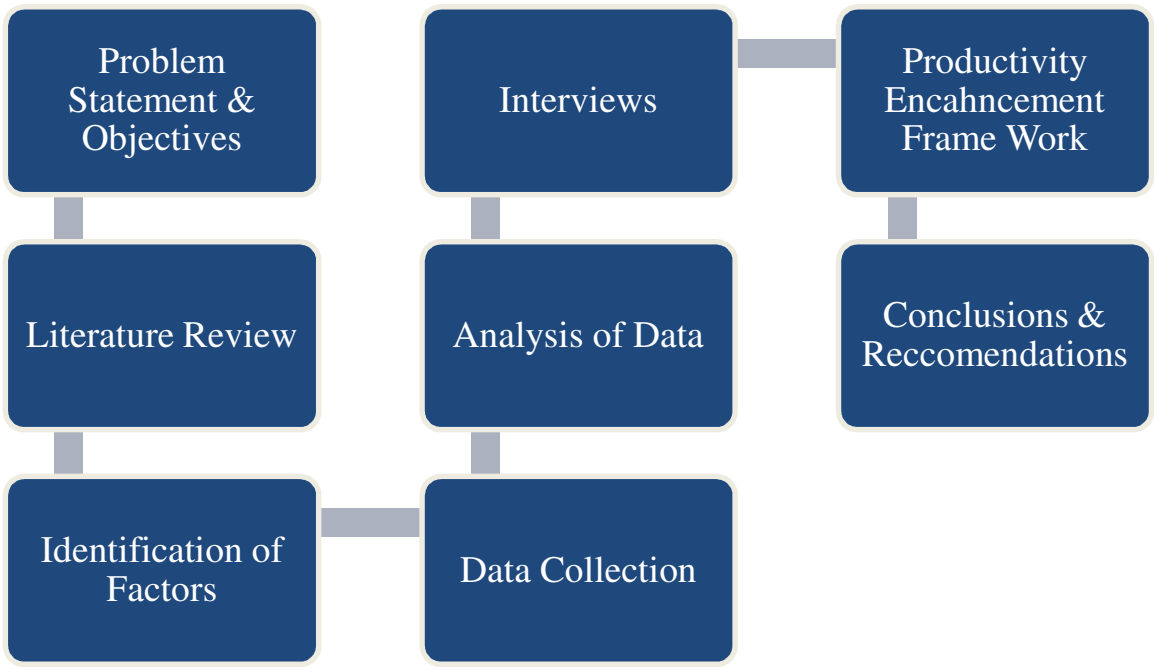
First the detail literature review was done to identify the factors which affect the productivity. Questionnaire survey was used to identify the factors affecting productivity. After that the data collection related to productivity was done from different sites. In this chapter whole method is discussed about data collection and its analysis.

3.2 RESEARCH DESIGN

The study was divided into five phases. In first phase, after development of research proposal, extensive literature review was done to understand those factors which affect productivity. Google Scholar was mainly used as search tool for different scholarly papers and writings.

In second phase, questionnaire survey was developed from extensive literature review, and then it was floated to professionals. In the third phase, data was collected from different sites. In fourth phase data collected from site and from interviews was analyzed and curves plotted between them to see the relation. In fifth phase, productivity enhancement frame work was proposed.

Figure 3.1: Flowchart



3.3 QUESTIONNAIRE SURVEY

Questionnaire was developed by extensive literature review. In questionnaire survey 41 factors were identified. Questionnaire survey was distributed to 375 respondents, out of which 122 responses were received. Questionnaire survey was based on Likert scale. Questionnaire survey is attached in Annexure I.

3.4 SAMPLE SIZE

As the population size for data collection is 40000. Registered engineer with Pakistan Engineering council are about 40000. For this population sample size is 96 according to Dillman (2000). Equation (3-1) provides formula to calculate the sample sizes.

$$Ns = [(Np)\ (P)\ (1-\ P)]\ [(Np - 1)\ (B / C)^2 + (P)\ (1 - P)] \quad \text{..... (3-1)}$$

Where;

Ns: sample size for the desired level of precision

Np: population size i.e. 40,000

P: proportion of the population that is expected to choose one of the responses

Categories (yes/no); P = 0.5

B: acceptable sampling error; (±10% or ±0.10)

C: Z statistic associated with the confidence level

(1.96 corresponds to 95% confidence level)

The sample sizes which were acceptable for various populations with different sampling errors for 95% confidence level are given as per Dillman (2000). These sample sizes can also be calculated by using the formula given in equation (3-1).

There were 122 replies out of 375 showing an overall response rate of 32.5%. As per (Black et al., 2000), *"in the construction enterprises, a good response rate is around 30%"*. Hence, the response rate for this research is adequate. The sample size is 122 for this survey, however to determine whether or not the following sample size is truly representing the population, table 3.1 is used which exhibits sample sizes required for various population sizes and characteristics at three level of precision.

3.5 DATA ANALYSIS

3.5.1 Cronbach's Coefficient Alpha Method

For the checking of reliability of the data collected on Likert scale Cronbach's Alpha method is used. If the value of Cronbach's Alpha is greater than .7, the data is reliable. Further, if the value is greater than .9, the data is highly consistent for

use (Li, 2007). The value of Cronbach's Alpha is .977 so the data was highly consistent for further analysis.

3.5.2 Shapiro-Wilk Test

Before using other test first normality of data was checked. It is important to check the normality of the data because if the data is not normal than further tests are different for non-parametric data. As the sample size was less than 2000 Shapiro-Wilk test was used to check the normality of the data. After the data analysis it was found that the data was non-parametric, so the Kruskal Wallis test was applied.

3.5.3 Kruskal Wallis test

If three or more independent groups (client, consultant and contractor) are identical or diverse on some variable of interest then the Kruskal-Wallis test and one-way analysis-of variance are used to determine the variation in the response of each group. It is most suitable to find the statistical indication of variation or dissimilarities in the perceptions of the stakeholders such as client, consultant and contractor, using average values or indices of the various groups. If the data is non-parametric the Kruskal-Wallis test is used whereas if the data is parametric in nature, then one-way ANOVA is used for further analysis. The data that was collected for this questionnaire based research was not able to be validated by the normality test that's why Kruskal-Wallis test was used for further analysis to check the variations in the perceptions of the stakeholders. It is very less sensitive to outliers. The H_o for the test is that the means of variables are same and is rejected if the result is meaning full. The results are tested against the difficulty of significance of 0.05. All the stakeholders will have same perception if the significance value is above 0.05 and vice versa.

3.5.4 Artificial Neural Network (ANN)

After the data collection from site some values were missing. For the purpose to find those missing values Artificial Neural Network (ANN) was used. ANN was trained by inputting the data in it. The number of training cycles ANN use are 1 to 50,000. For the training purpose 25,000 cycles were used. 90% data was used to train the network and 10% data used for the testing. If the error after testing is less than 30% than the network can be used for the prediction purpose. After the data input and testing it was found that the error was less than 30% so ANN was used for prediction.

3.5.5 Interviews

For the productivity improvement framework interviews were conducted with field professionals. 13 interviews were done. In interviews open ended questions was asked to the field professionals and their view about productivity improvements were noted. After their interviews a frame work was proposed to improve the productivity.

Chapter 4

DATA ANALYSIS AND RESULTS

4.1 INTRODUCTION

In this chapter the data analysis and the results are discussed. Firstly, the questionnaire survey was floated to rank the factors which affect the productivity. Various sites were visited to find the productivity of different activities. The activities which were selected to find the productivity of were paint, plaster, block masonry and concrete.

4.2 QUESTIONNAIRE SURVEY

4.2.1 Characteristics of respondents

Questionnaire survey was floated to 375 respondents out of whom 122 responses were collected yielding a response rate of 32.5%. However, after detail checking, 13 responses were found invalid and incomplete. Therefore, this analysis is based on 109 valid responses. The respondents are characterized such that owners/clients were 10.09%, consultants 26.61%, academia/students 15.6% and contractors 47.71%. Grouping and frequencies of respondents are shown in Table 4.1.

Table 4-1: Grouping of the respondents

Respondents	No of Questionnaires Returned	Percentage	Cumulative Percentage
Academia	17	15.6	15.6
Clients/Owner	11	10.09	25.69
Consultants	29	26.61	52.29
Contractors/Subcontractors	52	47.71	100
Total	109	100	-

The respondents with different years of experience are shown in the Table 4.2. In total, 30.2% respondents had experience more than 10 years, 44.9% respondents had experience 6 to 10 years and 24.7% respondents had experience less than 5 years.

Table 4-2: Experience of respondents in construction industry

Experience of Respondents	Frequency of Respondents	Percentage of Respondents	Cumulative Percentage
0-5	27	24.7	24.7
6-10	49	44.9	69.72
More Than 10	33	30.2	100
Total	109	100	-

4.3 STATISTICAL ANALYSIS

To statistically validate the collected data, various tests were conducted for which the details are discussed below.

4.3.1 Reliability of the Sample

Cronbach's Coefficient Alpha Method

For the checking of reliability of the data collected on Likert scale, Cronbach's Alpha method is used. If the value of Cronbach's Alpha is greater than .7, the data is reliable. Further, if the value is greater than .9, the data is highly consistent for use (Li, 2007). The value of Cronbach's Alpha is .977 so the data is highly consistent for further analysis.

Table 4-3: Cronbach's Coefficient Alpha

<table>
<tr><th colspan="4">Case Processing Summary</th><td rowspan="2">Cronbach's Alpha</td><td rowspan="2">0.977</td></tr>
<tr><td colspan="2"></td><td>N</td><td>%</td></tr>
<tr><td rowspan="3">Cases</td><td>Valid</td><td>109</td><td>100.0</td><td rowspan="3">Number of Items</td><td rowspan="3">41</td></tr>
<tr><td>Excluded[a]</td><td>0</td><td>.0</td></tr>
<tr><td>Total</td><td>109</td><td>100.0</td></tr>
<tr><td colspan="4">a. List wise deletion based on all variables in the procedure.</td></tr>
</table>

4.3.2 Measurement of Normality of Data

For checking the normality of data, Shapiro-Wilk test was carried out as the sample size was less than 2000. This test was conducted to evaluate whether the collected data was normally distributed or not, i.e. the data was parametric or non-parametric. As per the results of normality test, the data is not normally distributed and non-parametric test are needed to further analysis. Table 4.4 shows the results of Shapiro-Wilk test.

Table 4-4: Shapiro-Wilk Test

S. No	Parameter	Statistic	df	Sig.
1	Lack of labor experience	.695	109	.000
2	Language Difference	.904	109	.000
3	Working overtime	.888	109	.000
4	Age of Worker	.888	109	.000
5	Large Crew Size	.844	109	.000
6	Labor unfaithfulness	.775	109	.000
7	Lack of cooperation	.740	109	.000
8	Misunderstanding among laborers	.852	109	.000
9	Labor personal problems	.888	109	.000
10	Labor absence	.703	109	.000
11	Construction method	.739	109	.000
12	Poor terrain conditions	.848	109	.000
13	Type of activities in the project	.875	109	.000
14	Design Change During execution	.620	109	.000
15	Project size	.866	109	.000
16	Working at height	.852	109	.000
17	Quality of Required Work	.860	109	.000
18	Working within a confined space	.811	109	.000
19	Shortage of Tools and Equipment	.628	109	.000
20	Material shortage	.645	109	.000
21	Inefficiency of equipment	.772	109	.000
22	Unsuitability of materials storage location	.845	109	.000

23	Low quality of raw materials	.874	109	.000
24	Lack of training sessions	.881	109	.000
25	Lack of Motivation	.794	109	.000
26	Misunderstanding between laborers and superintendents	.809	109	.000
27	Rework Due to Changes	.727	109	.000
28	Lack of constant meeting with labor	.858	109	.000
29	Lack of supervisor's experience	.755	109	.000
30	Inspection delay	.815	109	.000
31	Construction Schedule/Work Planning	.775	109	.000
32	Bad relations between labors and management team	.730	109	.000
33	Poor site management	.647	109	.000
34	Climate change	.840	109	.000
35	Political Insecurity	.887	109	.000
36	Severe Weather	.828	109	.000
37	Humidity	.911	109	.000
38	Lack of financial motivation system	.786	109	.000
39	Payment delays	.693	109	.000
40	Labor's low wage	.788	109	.000
41	Financial conditions of contractor	.707	109	.000

4.3.3 Kruskal Wallis Test for Non-Parametric Data

Since the data collected for this research was non-parametric, Kruskal-Wallis test was used to check whether all respondents including academia, owners/clients, consultants and contractors had similar perception regarding the factors affecting productivity.

Table 4-5: Kruskal Wallis test for Academia, Consultants, and Contractors and Clients

S. No	Parameter	Sig.
1	Lack of labor experience	.174
2	Language Difference	.902
3	Working overtime	.722
4	Age of Worker	.074
5	Large Crew Size	.821
6	Labor unfaithfulness	.481
7	Lack of cooperation	.458
8	Misunderstanding among laborers	.320
9	Labor personal problems	.146
10	Labor absence	.169
11	Construction method	**.038**
12	Poor terrain conditions	.286
13	Type of activities in the project	.166
14	Design Change During execution	.148
15	Project size	.180
16	Working at height	**.031**
17	Quality of Required Work	.660
18	Working within a confined space	.571
19	Shortage of Tools and Equipment	.161
20	Material shortage	.930
21	Inefficiency of equipment	.097

22	Unsuitability of materials storage location	.089
23	Low quality of raw materials	.219
24	Lack of training sessions	.066
25	Lack of Motivation	.198
26	Misunderstanding between laborers and superintendents	**.006**
27	Rework Due to Changes	.135
28	Lack of constant meeting with labor	.593
29	Lack of supervisor's experience	**.048**
30	Inspection delay	.134
31	Construction Schedule/Work Planning	.395
32	Bad relations between labors and management team	.170
33	Poor site management	**.022**
34	Climate change	.186
35	Political Insecurity	.723
36	Severe Weather	.161
37	Humidity	.571
38	Lack of financial motivation system	.313
39	Payment delays	.120
40	Labor's low wage	.525
41	Financial conditions of contractor	.142

For most of the factors, the stakeholder's perception was same but for the following factors difference in perception was observed

a) Construction Method

b) Work at height

c) Misunderstanding between laborers and superintendents

d) Lack of supervisor's experience

e) Poor site management

4.3.4 Relative Importance Index (RII)

The data collected through the questionnaire survey was analyzed and ranked using the RII as per Kometa et al. (1994). Using equation 4.1, RII was calculated for each factor available in the questionnaire by transforming the scale and assigning weighting. It was then used to determine the ranks of each factor.

$$RII = \sum w/(A*N) \text{ …….. } (0 \leq \text{RII} \leq 1) \quad (4.1)$$

Where:

w = Weight given to each factor by the respondents and ranges from 1 to 5 where '1' is 'Not Applicable' and '5' is 'Directly Affect it'

A = Highest weight (i.e. 5 in this case)

N = Total number of respondents (i.e. 109 in this case)

On the basis of the analysis, the results of the findings are presented and discussed in Table 4-6.

Table 4-6: Relative Importance Index of factors

S. No	Productivity Factor	RIF
1	Design changes during execution	0.86239
2	Material shortage	0.82798
3	Work within a confined space	0.81422
4	Large crew size	0.80734
5	Shortage of tools and equipment	0.80255
6	Payment delays	0.80147
7	Severe weather	0.80057
8	Financial condition of contractor	0.80046
9	Poor site management	0.80046
10	Labor absence	0.7867
11	Rework due to changes	0.77982

12	Construction schedule/work planning	0.75917
13	Inefficiency of equipment	0.75917
14	Lack of cooperation	0.75917
15	Labor unfaithfulness	0.75917
16	Labor's low wages	0.75229
17	Lack of supervisor experience	0.73853
18	Bad relations between labors and management	0.72477
19	Poor terrain condition	0.70413
20	Lack of financial motivation system	0.69725
21	Misunderstanding between laborers and superintendents	0.69495
22	Work at height	0.68807
23	Inspection delays	0.66972
24	Climate changes	0.66743
25	Unsuitability of materials shortage location	0.66743
26	Misunderstanding among laborers	0.65138
27	Construction method	0.64679
28	Quality of required work	0.64679
29	Low quality of raw material	0.6422
30	Lack of cooperation	0.63991
31	Lack of constant meeting with labor	0.63303
32	Political insecurity	0.62615
33	Age of worker	0.61697
34	Working overtime	0.61697
35	Lack of motivation	0.61239
36	Lack of training sessions	0.61009
37	Labor personal problems	0.61009
38	Language difference	0.57569
39	Lack of labor experience	0.5711
40	Humidity	0.56193
41	Project size	0.49541

As evident from the Table 4-6, the top factor which affects productivity is Design changes during execution. Second factor is material shortage and on third is work with in a confined space. Respondents give the lowest weight to project size and humidity.

As 41 factors was divided into six groups, their ranking according to groups is discussed in following tables.

Labor Group

In labor group the respondents ranked "large crew size" with RIF 0.80734 highly affecting factor while "lack of labor experience" with RIF 0.5711 is least affecting factor. The ranking of factors according to RIF is shown in Table 4-7.

Table 4-7: Labor group

S. No	Factor	RIF
1	Large crew size	0.80734
2	Labor absence	0.7867
3	Labor unfaithfulness	0.75917
4	Lack of cooperation	0.75917
5	Misunderstanding among laborers	0.65138
6	Working overtime	0.61697
7	Age of worker	0.61697
8	Labor personal problems	0.61009
9	Language difference	0.57569
10	Lack of labor experience	0.5711

Financial group

In project group the respondents ranked "payment delays" with RIF 0.80147 highly affecting factor while "lack of financial motivation system" with RIF

0.69725 is least affecting factor. The ranking of factors according to RIF is shown in Table 4-8.

Table 4-8: Financial group

S. No	Factor	RIF
1	Payment delays	0.80147
2	Financial conditions of contractor	0.80046
3	Labor's low wage	0.75229
4	Lack of financial motivation system	0.69725

Material and Equipment group

In Material and Equipment group the respondents ranked “material shortage” with RIF 0.82798 highly affecting factor while “low quality of raw material” with RIF 0.6422 is least affecting factor. The ranking of factors according to RIF is shown in Table 4-9.

Table 4-9: Material and Equipment group

S. No	Factor	RIF
1	Material shortage	0.82798
2	Shortage of tools and equipment	0.80255
3	Inefficiency of equipment	0.75917
4	Unsuitability of materials storage location	0.66743
5	Low quality of raw materials	0.6422

Managerial group

In managerial group the respondents ranked “poor site management” with RIF 0.80046 highly affecting factor while “lack of training session” with RIF 0.61009 is least affecting factor. The ranking of factors according to RIF is shown in Table 4-10.

Table 4-10: Managerial group

S. No	Factor	RIF
1	Poor site management	0.80046
2	Rework due to changes	0.77982
3	Construction schedule/Work planning	0.75917
4	Lack of supervisor's experience	0.73853
5	Bad relations between labors and management team	0.72477
6	Misunderstanding between laborers and superintendents	0.69495
7	Inspection delay	0.66972
8	Lack of constant meeting with labor	0.63303
9	Lack of motivation	0.61239
10	Lack of training sessions	0.61009

External Group

In external group the respondents ranked "severe weather" with RIF .80057 highly affecting factor while "lack of training session" with RIF .56193 is least affecting factor. The ranking of factors according to RIF is shown in Table 4-11.

Table 4-11: External Group

S. No	Factor	RIF
1	Severe weather	0.80057
2	Climate change	0.66743
3	Political Insecurity	0.62615
4	Humidity	0.56193

Project Group

In project group the respondents ranked "design changes during execution" with RIF 0.86239 highly affecting factor while "project size" with RIF 0.49541 is least affecting factor. The ranking of factors according to RIF is shown in Table 4-12.

Table 4-12: Project Group

S. No	Factor	RIF
1	Design Change During execution	0.86239
2	Working within a confined space	0.81422
3	Poor terrain conditions	0.70413
4	Working at height	0.68807
5	Construction method	0.64679
6	Quality of Required Work	0.64679
7	Type of activities in the project	0.5432
8	Project size	0.49541

The comparison of such studies has been shown in Table 4-13. The result of this study is different from the previous study which was carried out in Pakistan. But the results are somewhat similar to the previous studies of other countries. Top factor which affect the labor productivity in this study was "design changes during execution" but in previous studies it was not on the top ten factors except in the study of Egypt (Enshassi, Mohamed et al. 2007) it was on the fifth position. Second factor was material shortage but in previous Pakistan and Palestine (Ibrahim 2013) study it was not on the top ten factor while in USA (Gundecha 2012), Zimbabwe (Benviolent and Tirivavi 2014), Indonesia (Soekiman, Pribadi et al. 2008) and Egypt (Enshassi, Mohamed et al. 2007) study it was the top factor. Third factor was work within a confined space it is not in top ten factor of any previous study.

Table 4-13: Comparison of current and previous studies

S. No	Pakistan (Current Study)	Pakistan (Previous Study)	USA (Gundecha 2012)	Palestine (Ibrahim 2013)	Zimbabwe (Benviolent and Tirivavi 2014)	Indonesia (Soekiman, Pribadi et al. 2008)	Egypt (Enshassi, Mohamed et al. 2007)
1	Design Changes During Execution	Disloyalty with Work	Lack of required construction material	Political situation	Unavailability of Material	Lag of material	Material shortage
2	Material Shortage	Lack of Required Tools and Equipment's	Shortage of power and/or water supply	Equipment's shortage	Late Payment of Salaries and Wages	Labor strikes	Lack of labor experience
3	Work within a confined space	Safe Environment (as per OSHA's standards)	Accidents during construction	Lack of labor experience	Suitability/Adequacy of Plant and Equipment	Delay in arrival of materials	Lack of labor surveillance

4	Large crew size	Vague or Incomplete Instructions	Deficiency in provision of construction tools/equipment t	Improper site management	Supervisory Incompetency	Financial difficulties of the owner	Misunderstanding g between laborers and superintendents
5	Shortage of tools and equipment's	Payment Delays of Labor	Insufficient lighting	Poor communication and coordination between construction parties	Lack of Manpower Skills	Unclear instruction to laborer	Drawings and specifications change during execution
6	Payment delays	Incentives on Good Performance	Poor site condition	Delay payments by the owner	Lack of labor experience	High absenteeism of labors	Payment delay
7	Severe Weather	Accidents During Construction	Weather condition	Low wages	Plant Breakdown	Bad weather	Labor disloyalty

8	Financial Condition of Contractor	Permanent Induction of Labors	Differing site condition from plan	Rework	Late Deliveries of Material	Indiscipline labor	Inspection delays
9	Poor site management	Lack of Control Over Registration of Construction Companies	Material storage location	Misuse of time schedule	Shortage of Tools and Equipment	Use of alcohol and drugs	seven working days without any holiday
10	Labor absence	Alcoholism/Addiction of Drugs	Working overtime	Lack of training sessions for labors	Low remuneration	No supervision method	Tool and equipment shortages

4.4 PRODUCTIVITY IMPROVEMENT FRAMEWORK

After all the data collection, Interviews were conducted from the field professionals for the formation of framework for productivity improvement. The list of professionals is shown in Table 4-82.

Table 4-14: Details of professionals interviewed

Sr.No	Organization	Designation	Experience in years
1	Paragon Constructors	Project Director	14
2	Habib Rafiq	General Manager Works	27
3	Paragon Constructors	Deputy General Manager	22
4	Al-Teraz	Resident Engineer	19
5	Habib Rafiq	Project Manager	18
6	Gulberg Developers	Project Manager	20
7	MIDJAC	Project Manager	24
8	Paragon Constructors	Construction Manager	17
9	Paragon Constructors	Construction Manager	19
10	Abasian Company	Site Engineer	9

In the interviews, open ended questions were asked of each professional. Almost everyone agreed on the factors which affect the productivity in their view are material shortage, financial issues, long working time, construction method or quality requirement, design changes and rework. The professionals suggested

different methods to improve the labor productivity. From their interviews and field visits the productivity improvement frame work was developed. The key points highlighted during the interviews are as follow:

1) Productivity of labor can improve on site by fulfilling the needs of labor i.e. by providing them good quality food and by giving them sufficient time for rest.
2) Material required for the work should be ordered before the activity start so it can be available on time for work
3) Some incentive should be given to labor to complete work so they can work with their full dedication.
4) If the quality requirement of project is more than the skilled labor should be hired.
5) Design changes should be minimized.
6) Crew size should be kept in control. If the crew size is more than requirement it will decrease the productivity.
7) Complete review of drawings should be done by contractor in the start so any mistake in drawings can be identified as early as possible to avoid delays.
8) Proper planning should be done in the start and discussed with the site team so that everyone should the completion requirements and scope of work.
9) Payment to labor should be given on time so they can focus on work.

4.5 PROJECTS

The data was collected from 13 construction projects. Residential and commercial projects were chosen for the data collection purpose. The lowest cost of the project was 140 million PKR and the highest was 3,970 million PKR, with an average cost of PKR 2,142 million. In Table 4-14, the detail of projects is provided.

Table 4-15: Projects

S.No	Project	Contractor	Cost in Millions
1	Telenor Head office	Paragon	3,970
2	Gulberg Trade Center	Gulberg Developers	140
3	Smama Star Residential Apartments	Samam Star Builders	450
4	Palisade Apartments Bahria Town	Abasen	2,500
5	Commercial Plaza	MIDJAC	2,900
6	Ali Apartments Bahria Town	Paragon	1,500
7	Emmar Pearl Tower	Paragon	2,500
8	District Complex Rawalakot	HRL	1,490
9	Parliament Lodges	HRL	2,900
10	University of Poonch Rawalakot	Qadir Baksh Construction Company	1,850
11	2, 3 & 4 Bed Apartments	Paragon	1,400
12	Opal 225 Tower	HRL	3,500
13	Grand Mosque	Paragon	2,750

4.5.1 Data collected from sites

For collecting data from above mentioned projects, four activities were selected: concrete, plaster, block masonry and paint. Owing to the variety in size and magnitude of projects, various team formations were observed. For example, at some sites the concreting work was done by a small team of 8 members, while on others as many 16 labors were involved in this work. Therefore, a number of gaps were observed in the collected data e.g. in table 4-15 and in figure 4-1 average productivities of block masonry which was collected form sites is given with different crew sizes.it is clearly seen that there are gaps in the crew sizes. In order to resolve this issue, Artificial Neural Network (ANN) was used that gives the missing data points for regression analysis. After finding the missing values, the data was analyzed and equations were generated for productivity prediction.

Table 4-16: Actual average productivity

Crew size	Average Productivity/Hr.
6	4.49
8	4.85
13	3.69
14	2.51
15	2.42
16	2.55

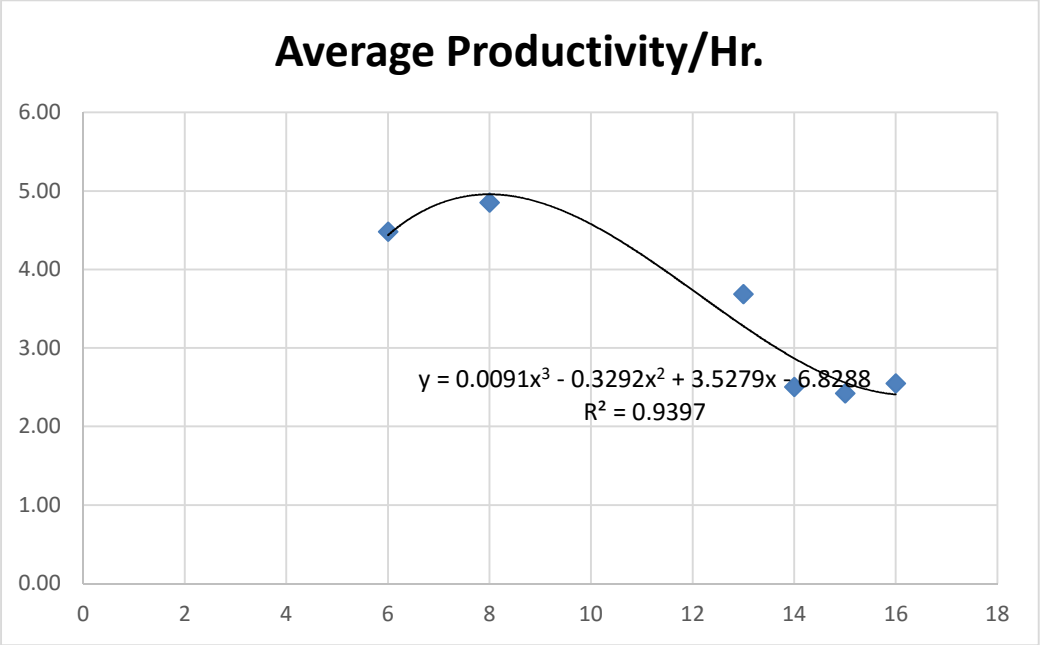


Figure 4-1: Actual average productivity

4.5.2 Concreting

First of all, the data was collected for concreting activity. For this purpose, different resources are used e.g. labor, scaffolders, carpenters, masons and operators, and machinery which is used for concrete are batching plant, concrete pump, transit mixer and vibrator. First of all, the data was collected for concreting activity. For this purpose,

Concrete activity is always a main part of the building projects. There are many factors which affect it. If the machinery is not in proper condition, then the time required for the completion of the activity is increased. The location of batching plant also plays a key role for the timely completion of the activity. During the visits of different projects, it was observed that in some projects batching plants are placed near to the building whereas in others they were far away from the project. This added additional delays to cover which, the companies added additional transit mixers for the timely delivery.

Data collected from different projects is shown in Tables. The data of concrete is in Cubic meters.

Table 4-16 shows the data of concreting activity with crew size of 9. The average productivity was 3.74m^3/hr.

Table 4-17: Productivity of concreting crew size 9

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
9	9	25	25	2.78
18	9	45	70	3.89
27	9	40	110	4.07
36	9	40	150	4.17
45	9	20	170	3.78
Average Productivity Per Hour				**3.74**

In Figure 4-1, it can be clearly seen that the productivity increase with time. This increase is until 36 labor hours after which it starts declining.

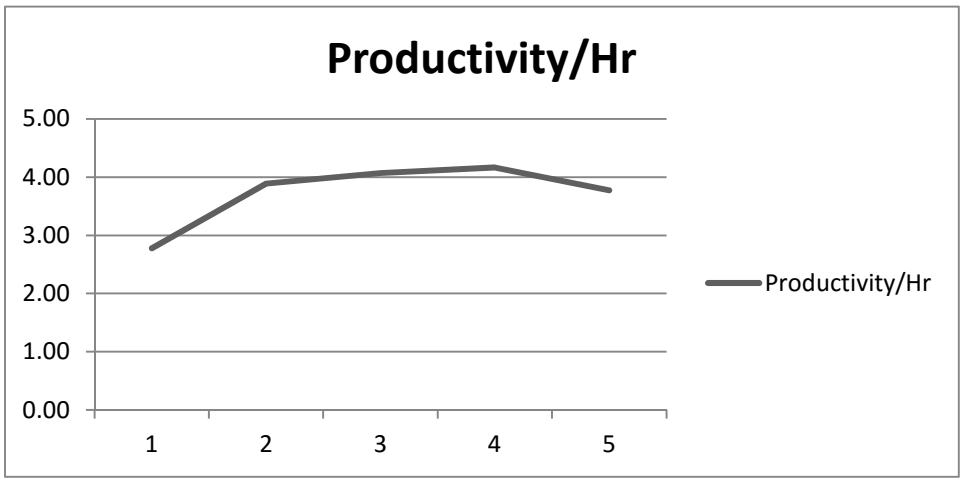


Figure 4-2: Productivity of concreting crew size 9

Tables 4-17 and 4-18 show the data of concreting activity with crew size of 10. The average productivity observed per hour was 2.13m^3/hr and 2.32m^3/hr respectively.

Table 4-18: Productivity of concreting crew size 10

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
10	10	15	15	1.50
20	10	19	34	1.70
30	10	30	64	2.13
40	10	35	99	2.48
50	10	20	119	2.38
60	10	22.5	141.5	2.36
70	10	15	156.5	2.24
80	10	20	176.5	2.21
90	10	19	195.5	2.17
Average Productivity Per Hour				**2.13**

Figure 4-2 shows that the productivity was less in the start and increase till 4 hours and then it declines.

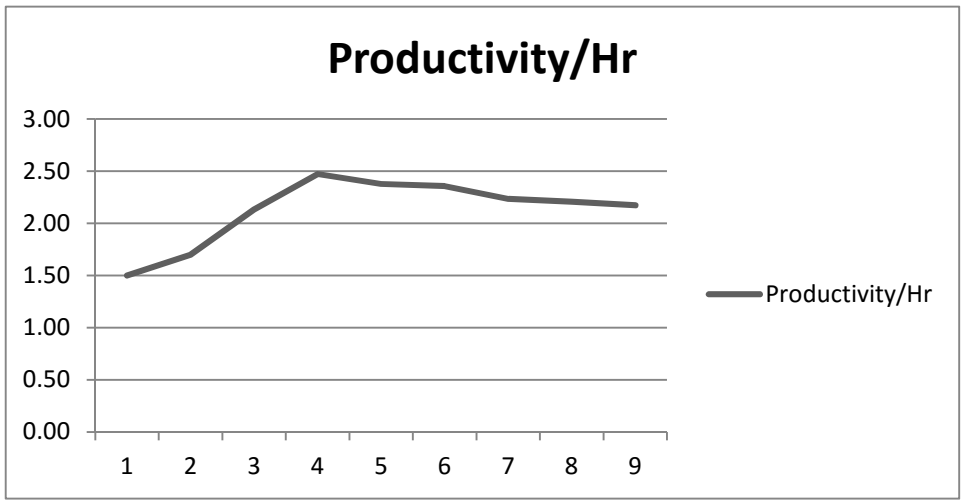


Figure 4-3: Productivity of concreting crew size 10

Tables 4-18 show the data of concreting activity with crew size of 10. The average productivity observed per hour was 2.32m^3/hr.

Table 4-19: Productivity of concreting crew size 10

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
10	10	20	20	2.00
20	10	30	50	2.50
30	10	22	72	2.40
40	10	25	97	2.43
50	10	15	112	2.24
60	10	24	136	2.27
70	10	30	166	2.37
80	10	25	191	2.39
90	10	15	206	2.29
Average Productivity Per Hour				2.32

Figure 4-3 shows that the productivity was stable for whole day there was a small difference in productivity. In this project it was observed that all the preparations were made and the proper planning was done before the start of activity.

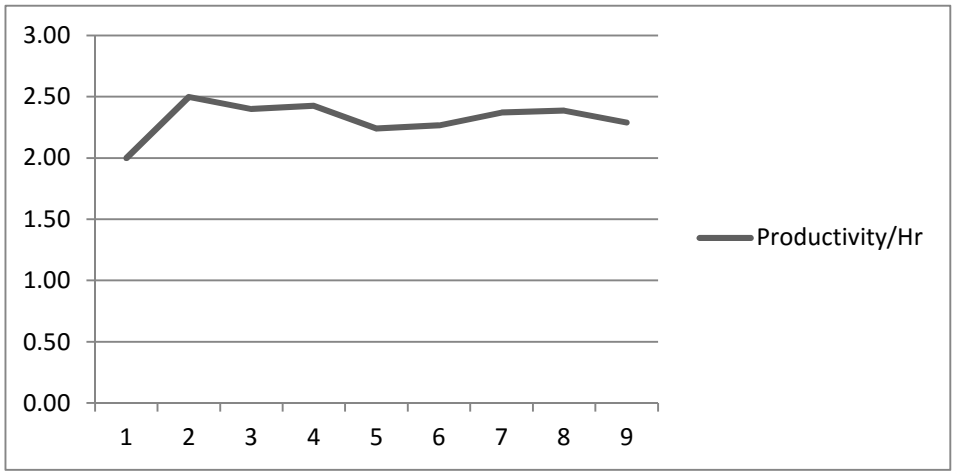


Figure 4-4: Productivity of concreting crew size 10

Table 4-19 shows the data of concreting activity with crew size of 12. The average productivity per hour was 2.11m^3/hr.

Table 4-20: Productivity of concreting crew size 12

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
12	12	15	15	1.25
24	12	30	45	1.88
36	12	30	75	2.08
48	12	35	110	2.29
60	12	30	140	2.33
72	12	30	170	2.36
84	12	28	198	2.36
96	12	20	218	2.27
108	12	20	238	2.20
Average Productivity Per Hour				**2.11**

Figure 4-4 shows that the productivity was less in the start but as the time passes, it gradually increased and then some drop was seen at the end of the work.

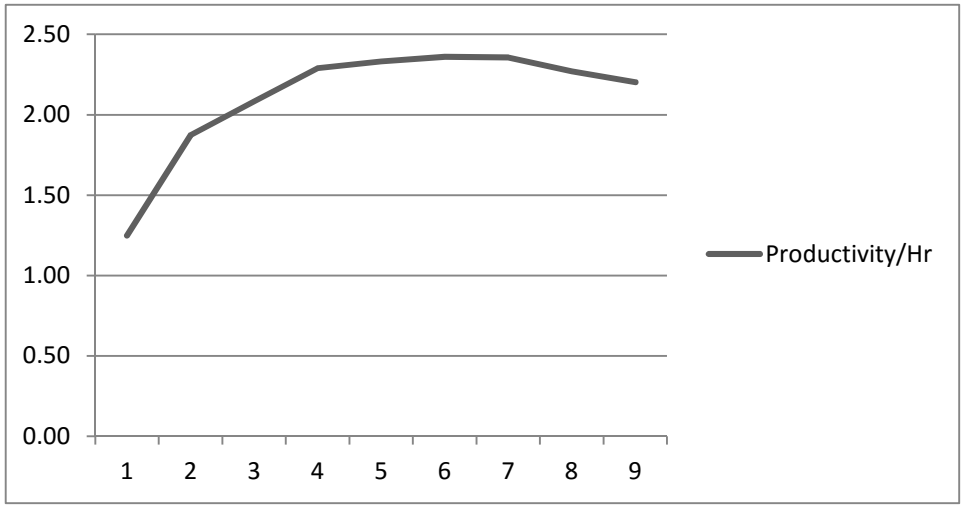


Figure 4-5: Productivity of concreting crew size 12

Table 4-20 shows the data of concreting activity with crew size of 12. The average productivity per hour was 1.56m^3/hr.

Table 4-21: Productivity of concreting crew size 12

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
12	12	5	5	0.42
24	12	25	30	1.25
36	12	30	60	1.67
48	12	25	85	1.77
60	12	25	110	1.83
72	12	30	140	1.94
84	12	15	155	1.85
96	12	16	171	1.78
Average Productivity Per Hour				**1.56**

Figure 4-5 shows that the productivity was less in the start. The reason was that when the activity of concreting started, after a while, the mobile pump of company stopped working and hence a lower productivity is observed in the start.

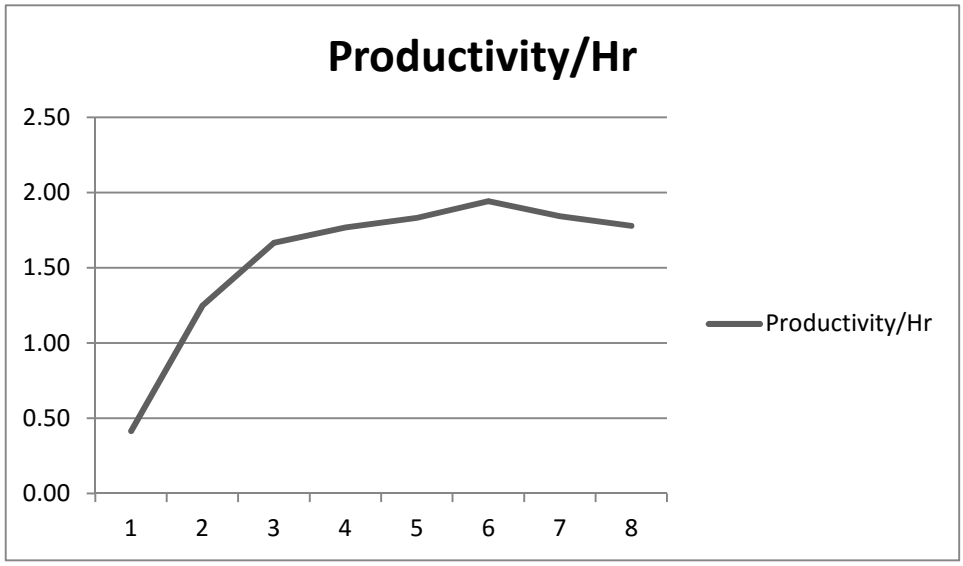


Figure 4-6: Productivity of concreting crew size 12

Table 4-21 shows the data of concreting activity with crew size of 13. The average productivity per hour was 1.96m^3/hr.

Table 4-22: Productivity of concreting crew size 13

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
13	13	25	25	1.92
26	13	25	50	1.92
39	13	25	75	1.92
52	13	30	105	2.02
65	13	25	130	2.00
78	13	25	155	1.99
91	13	20	175	1.92
104	13	25	200	1.92
117	13	30	230	1.97
130	13	27.5	257.5	1.98
Average Productivity Per Hour				**1.96**

Figure 4-6 shows that the there was a little fluctuation in the productivity. Productivity was stable from start to third hour after that it increases to fourth hour and then it decreases.

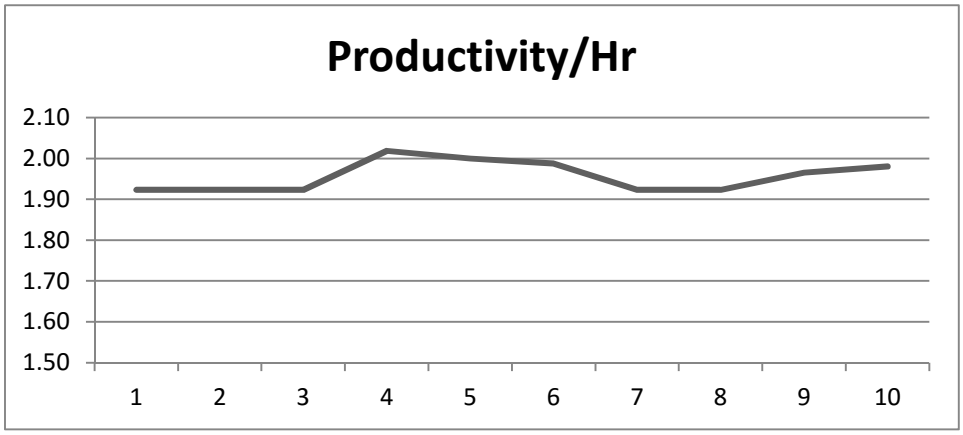


Figure 4-7: Productivity of concreting crew size 13

Table 4-22 shows the data of concreting activity with crew size of 14. The average productivity per hour was 2.03m^3/hr.

Table 4-23: Productivity of concreting crew size 14

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
14	14	24	24	1.71
28	14	35	59	2.11
42	14	27	86	2.05
56	14	30	116	2.07
70	14	35	151	2.16
84	14	27	178	2.12
98	14	19	197	2.01
Average Productivity Per Hour				**2.03**

It is clearly seen from Figure 4-7 that in start the productivity was less but after second hour it stabilized and there was little variation in it.

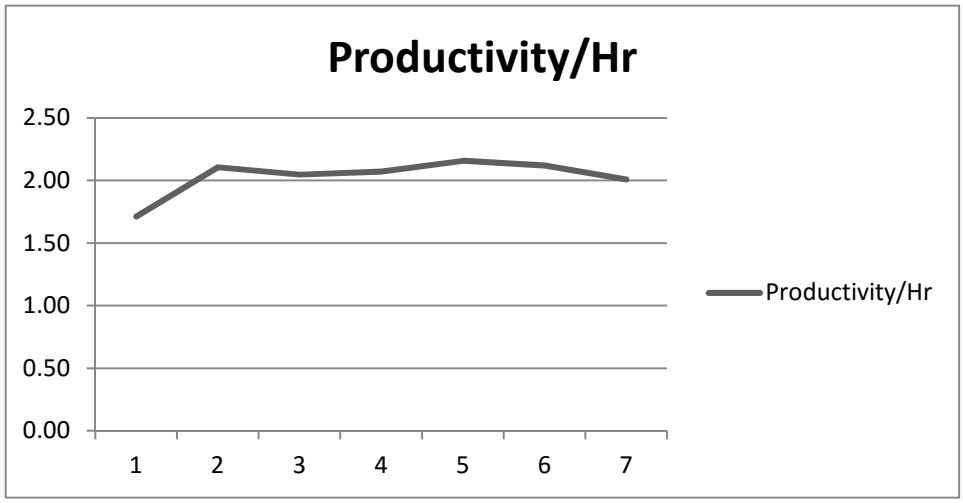


Figure 4-8: Productivity of concreting crew size 14

Table 4-23 shows the data of concreting activity with crew size of 14. The average productivity per hour was 1.65m3/hr.

Table 4-24: Productivity of concreting crew size 14

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
14	14	18	18	1.29
28	14	20	38	1.36
42	14	30	68	1.62
56	14	25	93	1.66
70	14	35	128	1.83
84	14	25	153	1.82
98	14	30	183	1.87
112	14	10	193	1.72
Average Productivity Per Hour				**1.65**

Figure 4-8 shows that the productivity was less in the start and then it increases up to seventh hour and decreases in the end.

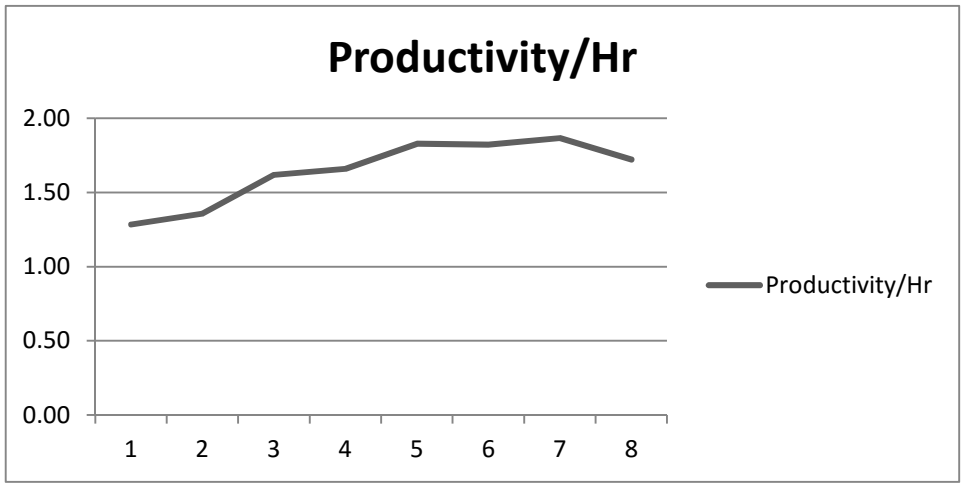


Figure 4-9: Productivity of concreting crew size 14

Table 4-24 shows the data of concreting activity with crew size of 15. The average productivity per hour was 1.80m^3/hr.

Table 4-25: Productivity of concreting crew size 15

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
15	15	20	20	1.33
30	15	35	55	1.83
45	15	20	75	1.67
60	15	35	110	1.83
75	15	25	135	1.80
90	15	30	165	1.83
105	15	40	205	1.95
120	15	15	220	1.83
135	15	35	255	1.89
150	15	30	285	1.90
165	15	35	320	1.94
Average Productivity Per Hour				**1.80**

Figure 4-9 shows that the productivity was less in the start and it increases till the end.

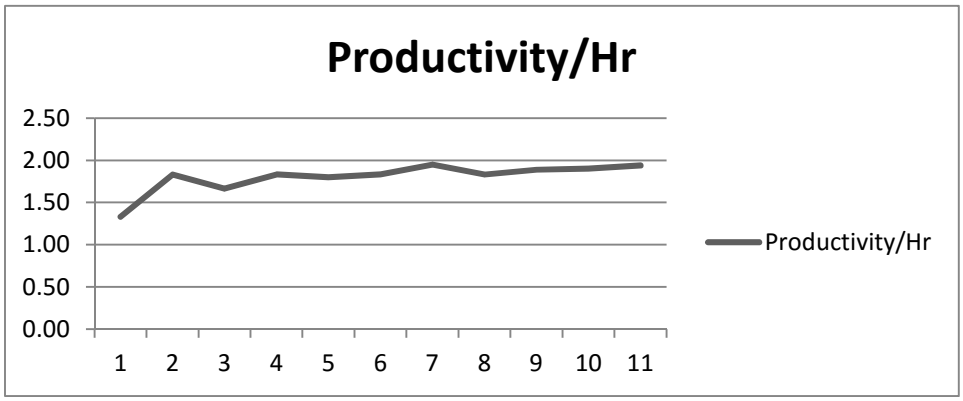


Figure 4-10: Productivity of concreting crew size 15

Table 4-25 shows the data of concreting activity with crew size of 15. The average productivity per hour was 1.87m^3/hr.

Table 4-26: Productivity of concreting crew size 15

Labor Hour	Crew Size	Productivity	Accumulative Productivity	Productivity/Hr
15	15	27	27	1.80
30	15	25	52	1.73
45	15	35	87	1.93
60	15	30	117	1.95
75	15	32	149	1.99
90	15	22	171	1.90
105	15	15.5	186.5	1.78
Average Productivity Per Hour				**1.87**

Figure 4-10 shows that the productivity was less in the start and then it increases till the half work is done after that it decreases. During this data collection it was being observed that the number of labors was more than the required labor.

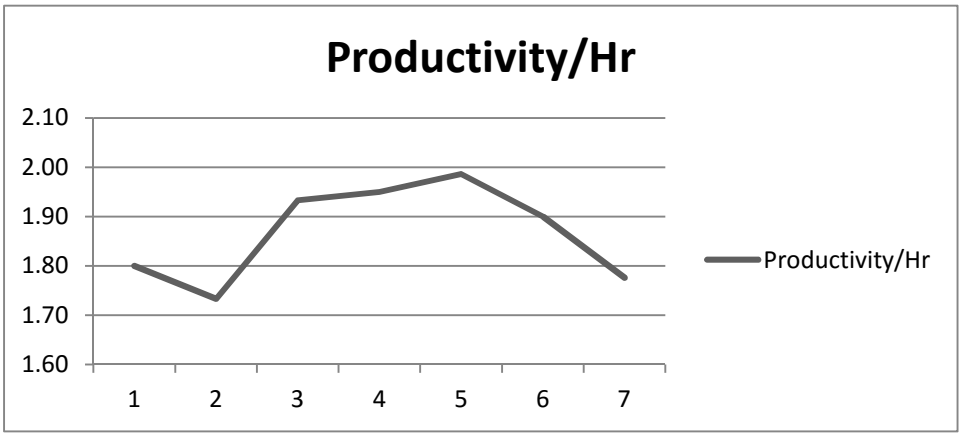


Figure 4-11: Productivity of concreting crew size 15

From the data it was observed that productivity is less in the start of the activity, increases as time passes and then decreases in the end. It was also observed that productivity decreases as the crew size increases.

After the collection of data, some data points were missing. For this purpose, ANN was used.

Table 4-26 shows the predicted productivity of concreting activity for crew size of 1 the average productivity is 7.06 m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-27: Predicted productivity for crew size 1

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
1.00	1.00	6.60	6.60	6.60
2.00	1.00	6.84	13.45	6.72
3.00	1.00	7.10	20.54	6.85
4.00	1.00	7.37	27.91	6.98
5.00	1.00	7.66	35.57	7.11
6.00	1.00	7.96	43.53	7.25
7.00	1.00	8.28	51.81	7.40
8.00	1.00	8.62	60.44	7.55
Average Productivity Per Hour				**7.06**

Table 4-27 shows the predicted productivity of concreting activity for crew size of 2 the average productivity is 7.46m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-28: Predicted productivity for crew size 2

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
2.00	2.00	13.84	13.84	6.92
4.00	2.00	14.37	28.21	7.05

6.00	2.00	14.96	43.17	7.20
8.00	2.00	15.62	58.80	7.35
10.00	2.00	16.36	75.16	7.52
12.00	2.00	17.17	92.33	7.69
14.00	2.00	18.04	110.37	7.88
16.00	2.00	18.95	129.32	8.08
Average Productivity Per Hour				**7.46**

Table 4-28 shows the predicted productivity of concreting activity for crew size of 3 the average productivity is 6.98m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-29: Predicted productivity for crew size 3

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
3.00	3.00	19.10	19.10	6.37
6.00	3.00	19.96	39.06	6.51
9.00	3.00	20.98	60.04	6.67
12.00	3.00	22.17	82.21	6.85
15.00	3.00	23.49	105.70	7.05
18.00	3.00	24.87	130.58	7.25
21.00	3.00	26.21	156.79	7.47
24.00	3.00	27.36	184.14	7.67
Average Productivity Per Hour				**6.98**

Table 4-29 shows the predicted productivity of concreting activity for crew size of 4 the average productivity is 5.49m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-30: Predicted productivity for crew size 4

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
4.00	4.00	19.37	19.37	4.84
8.00	4.00	20.62	39.99	5.00
12.00	4.00	22.17	62.16	5.18
16.00	4.00	23.95	86.11	5.38
20.00	4.00	25.78	111.89	5.59
24.00	4.00	27.36	139.25	5.80
28.00	4.00	28.40	167.65	5.99
32.00	4.00	28.76	196.41	6.14
Average Productivity Per Hour				**5.49**

Table 4-30 shows the predicted productivity of concreting activity for crew size of 5 the average productivity is 4.57m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-31: Predicted productivity for crew size 5

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
5.00	5.00	19.66	19.66	3.93
10.00	5.00	21.36	41.02	4.10
15.00	5.00	23.49	64.51	4.30
20.00	5.00	25.78	90.29	4.51
25.00	5.00	27.68	117.96	4.72
30.00	5.00	28.67	146.63	4.89
35.00	5.00	28.60	175.23	5.01
40.00	5.00	27.79	203.02	5.08
Average Productivity Per Hour				**4.57**

Table 4-31 shows the predicted productivity of concreting activity for crew size of 6 the average productivity is 3.92m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-32: Predicted productivity for crew size 6

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
6.00	6.00	19.96	19.96	3.33
12.00	6.00	22.17	42.13	3.51
18.00	6.00	24.87	67.01	3.72
24.00	6.00	27.36	94.36	3.93
30.00	6.00	28.67	123.03	4.10
36.00	6.00	28.48	151.51	4.21
42.00	6.00	27.40	178.91	4.26
48.00	6.00	26.61	205.52	4.28
Average Productivity Per Hour				**3.92**

Table 4-32 shows the predicted productivity of concreting activity for crew size of 7 the average productivity is 3.43m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-33: Predicted productivity for crew size 7

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
7.00	7.00	20.28	20.28	2.90
14.00	7.00	23.04	43.32	3.09
21.00	7.00	26.21	69.53	3.31
28.00	7.00	28.40	97.93	3.50
35.00	7.00	28.60	126.53	3.62

42.00	7.00	27.40	153.93	3.67
49.00	7.00	26.57	180.50	3.68
56.00	7.00	26.94	207.44	3.70
Average Productivity Per Hour				**3.43**

Table 4-33 shows the predicted productivity of concreting activity for crew size of 8 the average productivity is 3.06m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-34: Predicted productivity for crew size 8

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
8.00	8.00	20.62	20.62	2.58
16.00	8.00	23.95	44.57	2.79
24.00	8.00	27.36	71.93	3.00
32.00	8.00	28.76	100.69	3.15
40.00	8.00	27.79	128.48	3.21
48.00	8.00	26.61	155.09	3.23
56.00	8.00	26.94	182.03	3.25
64.00	8.00	27.84	209.87	3.28
Average Productivity Per Hour				**3.06**

Table 4-34 shows the predicted productivity of concreting activity for crew size of 9 the average productivity is 2.76m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-35: Predicted productivity for crew size 9

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
9.00	9.00	20.98	20.98	2.33

18.00	9.00	24.87	45.86	2.55
27.00	9.00	28.20	74.06	2.74
36.00	9.00	28.48	102.54	2.85
45.00	9.00	26.91	129.44	2.88
54.00	9.00	26.74	156.18	2.89
63.00	9.00	27.75	183.94	2.92
72.00	9.00	27.59	211.53	2.94
Average Productivity Per Hour				**2.76**

Table 4-35 shows the predicted productivity of concreting activity for crew size of 10 the average productivity is 2.52m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-36: Predicted productivity for crew size 10

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
10.00	10.00	21.36	21.36	2.14
20.00	10.00	25.78	47.14	2.36
30.00	10.00	28.67	75.81	2.53
40.00	10.00	27.79	103.59	2.59
50.00	10.00	26.56	130.15	2.60
60.00	10.00	27.43	157.58	2.63
70.00	10.00	27.82	185.40	2.65
80.00	10.00	25.81	211.21	2.64
Average Productivity Per Hour				**2.52**

Table 4-36 shows the predicted productivity of concreting activity for crew size of 11 the average productivity is 2.31m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-37: Predicted productivity for crew size 11

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
11.00	11.00	21.76	21.76	1.98
22.00	11.00	26.62	48.38	2.20
33.00	11.00	28.74	77.12	2.34
44.00	11.00	27.05	104.17	2.37
55.00	11.00	26.83	131.01	2.38
66.00	11.00	27.94	158.94	2.41
77.00	11.00	26.59	185.53	2.41
88.00	11.00	23.91	209.44	2.38
Average Productivity Per Hour				**2.31**

Table4-37 shows the predicted productivity of concreting activity for crew size of 12 the average productivity is 2.13m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-38: Predicted productivity for crew size 12

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
12.00	12.00	22.17	22.17	1.85
24.00	12.00	27.36	49.53	2.06
36.00	12.00	28.48	78.01	2.17
48.00	12.00	26.61	104.62	2.18
60.00	12.00	27.43	132.05	2.20
72.00	12.00	27.59	159.64	2.22
84.00	12.00	24.77	184.42	2.20
96.00	12.00	22.92	207.34	2.16
Average Productivity Per Hour				**2.13**

Table4-38 shows the predicted productivity of concreting activity for crew size of 13 the average productivity is 1.97m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-39: Predicted productivity for crew size 13

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
13.00	13.00	22.60	22.60	1.74
26.00	13.00	27.96	50.56	1.94
39.00	13.00	27.98	78.54	2.01
52.00	13.00	26.60	105.14	2.02
65.00	13.00	27.90	133.04	2.05
78.00	13.00	26.34	159.37	2.04
91.00	13.00	23.42	182.79	2.01
104.00	13.00	22.95	205.75	1.98
Average Productivity Per Hour				**1.97**

Table 4-39 shows the predicted productivity of concreting activity for crew size of 14 the average productivity is 1.84m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-40: Predicted productivity for crew size 14

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
14.00	14.00	23.04	23.04	1.65
28.00	14.00	28.40	51.44	1.84
42.00	14.00	27.40	78.84	1.88
56.00	14.00	26.94	105.78	1.89
70.00	14.00	27.82	133.61	1.91

84.00	14.00	24.77	158.38	1.89
98.00	14.00	22.83	181.21	1.85
112.00	14.00	24.39	205.60	1.84
Average Productivity Per Hour				**1.84**

Table 4-40 shows the predicted productivity of concreting activity for crew size of 15 the average productivity is 1.73m^3/hr. Productivity is less in the start and then it increases till the end.

Table 4-41: Predicted productivity for crew size 15

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
15.00	15.00	23.49	23.49	1.57
30.00	15.00	28.67	52.16	1.74
45.00	15.00	26.91	79.06	1.76
60.00	15.00	27.43	106.49	1.77
75.00	15.00	27.05	133.55	1.78
90.00	15.00	23.57	157.11	1.75
105.00	15.00	23.05	180.16	1.72
120.00	15.00	26.51	206.67	1.72
Average Productivity Per Hour				**1.73**

For the purpose of generating a generalized equation for predicting productivity the regression analysis was used as shown in equation 4.2. The value of R^2 = 0.97 which is within the allowed limits for reliability and hence the equation is reliable to predict the productivity. From the Table 4-41, it is clearly seen that as the crew size increase the productivity decreases.

$y = 0.0331x^2 - 0.9581x + 8.7401$ …… (4.2)

Where,

"Y" "Productivity per hour"

“X” “Crew size”

Table 4-42: Average productivity of concreting with different crew sizes

Crew Size	Average Productivity/Hr
1	7.06
2	7.46
3	6.98
4	5.49
5	4.57
6	3.92
7	3.43
8	3.06
9	2.76
10	2.52
11	2.31
12	2.13
13	1.97
14	1.84
15	1.73

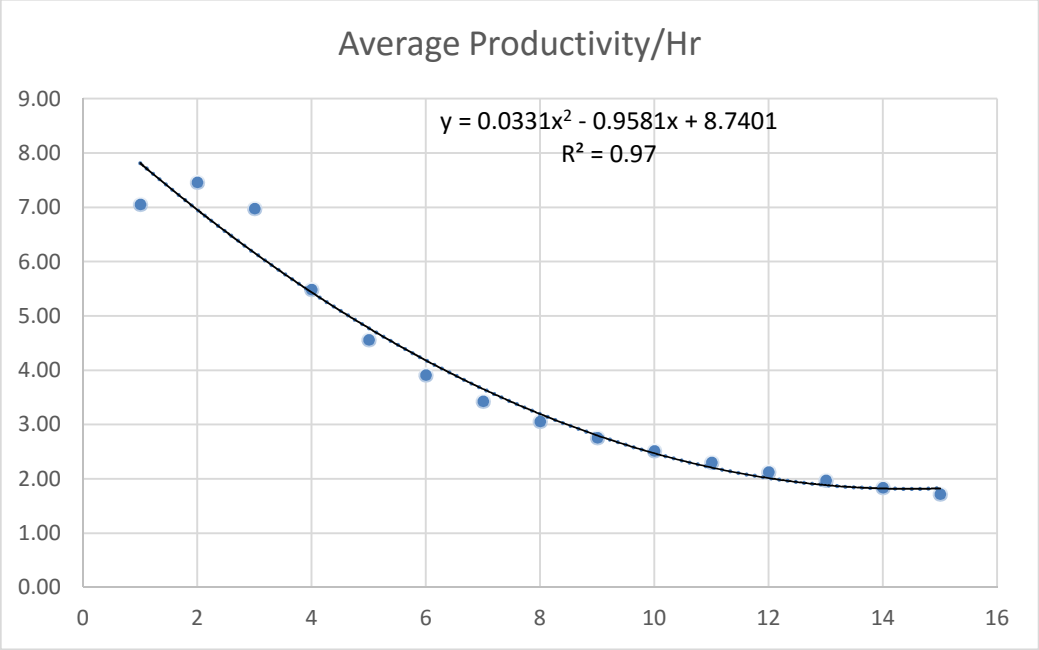


Figure 4-12: Average productivity of concreting with different crew sizes

4.5.3 Plastering

Plastering is one of the finishing activity of project. During this activity, great care is required to be taken because of the little margin of error which otherwise would leave the building aesthetically unpleasing and may prove costly later on. During this activity different resources are used e.g. Mason, Half Mason and labor. Plastering activity is affected by many factors. One such factor is the material location which plays an important role during the plastering. If the location is far off, then it will take time to move material to the location hence adding extra burden both in form of finances and human resources. Number of workers and the height also play a key role for the timely completion. If height is greater and the number of workers in the same location is more than the time taken to complete the activity will increase. The Data which was collected from different projects is attached in annexure II. In the data, it can be clearly seen that the productivity

increase with the passage of time. The data of provided is in Square Feet. To cater for the missing data ANN was used.

Table 4-42 shows the predicted productivity of plastering activity for crew size of 1 the average productivity is 15.26ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-43: Predicted productivity of plastering crew size 1

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
1	1	15.99	15.99	15.99
2	1	15.57	31.57	15.78
3	1	15.16	46.72	15.57
4	1	14.74	61.46	15.37
5	1	14.32	75.78	15.16
6	1	13.90	89.69	14.95
7	1	13.49	103.17	14.74
8	1	13.07	116.24	14.53
Average Productivity Per Hour				**15.26**

Table 4-43 shows the predicted productivity of plastering activity for crew size of 2 the average productivity is 14.7ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-44: Predicted productivity of plastering crew size 2

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
2	2	30.86	30.86	15.43
4	2	30.02	60.88	15.22

6	2	29.19	90.07	15.01
8	2	28.35	118.43	14.80
10	2	27.52	145.94	14.59
12	2	26.68	172.63	14.39
14	2	25.85	198.48	14.18
16	2	25.01	223.49	13.97
Average Productivity Per Hour				**14.70**

Table 4-44 shows the predicted productivity of plastering activity for crew size of 3 the average productivity is 14.18ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-45: Predicted productivity of plastering crew size 3

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
3	3	44.73	44.73	14.91
6	3	43.47	88.20	14.70
9	3	42.22	130.42	14.49
12	3	40.97	171.39	14.28
15	3	39.72	211.11	14.07
18	3	38.46	249.57	13.87
21	3	37.21	286.78	13.66
24	3	35.96	322.74	13.45
Average Productivity Per Hour				**14.18**

Table 4-45 shows the predicted productivity of plastering activity for crew size of 4 the average productivity is 14.67ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-46: Predicted productivity of plastering crew size 4

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
4	4	61.59	61.59	15.40
8	4	59.92	121.52	15.19
12	4	58.25	179.77	14.98
16	4	56.58	236.36	14.77
20	4	54.91	291.27	14.56
24	4	53.24	344.51	14.35
28	4	51.57	396.09	14.15
32	4	49.90	445.99	13.94
Average Productivity Per Hour				**14.67**

Table 4-46 shows the predicted productivity of plastering activity for crew size of 5 the average productivity is 13.16ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-47: Predicted productivity of plastering crew size 5

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
5	5	69.46	69.46	13.89
10	5	67.37	136.84	13.68
15	5	65.29	202.12	13.47
20	5	63.20	265.32	13.27
25	5	61.11	326.43	13.06
30	5	59.02	385.45	12.85
35	5	56.94	442.39	12.64
40	5	54.85	497.24	12.43
Average Productivity Per Hour				**13.16**

Table 4-47 shows the predicted productivity of plastering activity for crew size of 6 the average productivity is 12.16ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-48: Predicted productivity of plastering crew size 6

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
6	6	77.33	77.33	12.89
12	6	74.82	152.15	12.68
18	6	72.32	224.47	12.47
24	6	69.81	294.29	12.26
30	6	67.31	361.59	12.05
36	6	64.80	426.40	11.84
42	6	62.30	488.70	11.64
48	6	59.79	548.49	11.43
Average Productivity Per Hour				**12.16**

Table 4-48 shows the predicted productivity of plastering activity for crew size of 7 the average productivity is 11.44ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-49: Predicted productivity of plastering crew size 7

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
7	7	85.20	85.20	12.17
14	7	82.27	167.47	11.96
21	7	79.35	246.82	11.75
28	7	76.43	323.25	11.54
35	7	73.51	396.76	11.34

42	7	70.58	467.34	11.13
49	7	67.66	535.00	10.92
56	7	64.74	599.74	10.71
Average Productivity Per Hour				**11.44**

Table 4-49 shows the predicted productivity of plastering activity for crew size of 8 the average productivity is 10.9ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-50: Predicted productivity of plastering crew size 8

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
8	8	93.06	93.06	11.63
16	8	89.72	182.79	11.42
24	8	86.38	269.17	11.22
32	8	83.04	352.22	11.01
40	8	79.70	431.92	10.80
48	8	76.36	508.28	10.59
56	8	73.02	581.31	10.38
64	8	69.68	650.99	10.17
Average Productivity Per Hour				**10.90**

Table 4-50 shows the predicted productivity of plastering activity for crew size of 9 the average productivity is 10.48ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-51: Predicted productivity of plastering crew size 9

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
9	9	100.93	100.93	11.21

18	9	97.17	198.11	11.01
27	9	93.42	291.52	10.80
36	9	89.66	381.18	10.59
45	9	85.90	467.08	10.38
54	9	82.14	549.22	10.17
63	9	78.39	627.61	9.96
72	9	74.63	702.24	9.75
Average Productivity Per Hour				**10.48**

Table 4-51 shows the predicted productivity of plastering activity for crew size of 10 the average productivity is 10.15ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-52: Predicted productivity of plastering crew size 10

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
10	10	108.80	108.80	10.88
20	10	104.62	213.42	10.67
30	10	100.45	313.87	10.46
40	10	96.27	410.14	10.25
50	10	92.10	502.24	10.04
60	10	87.92	590.17	9.84
70	10	83.75	673.92	9.63
80	10	79.57	753.49	9.42
Average Productivity Per Hour				**10.15**

Table 4-52 shows the predicted productivity of plastering activity for crew size of 11 the average productivity is 9.88ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-53: Predicted productivity of plastering crew size 11

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
11	11	116.67	116.67	10.61
22	11	112.07	228.74	10.40
33	11	107.48	336.22	10.19
44	11	102.89	439.11	9.98
55	11	98.30	537.41	9.77
66	11	93.70	631.11	9.56
77	11	89.11	720.22	9.35
88	11	84.52	804.74	9.14
Average Productivity Per Hour				**9.88**

Table 4-53 shows the predicted productivity of plastering activity for crew size of 12 the average productivity is 9.65ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-54: Predicted productivity of plastering crew size 12

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
12	12	124.53	124.53	10.38
24	12	119.52	244.06	10.17
36	12	114.51	358.57	9.96
48	12	109.50	468.07	9.75
60	12	104.49	572.57	9.54
72	12	99.48	672.05	9.33
84	12	94.47	766.53	9.13
96	12	89.46	855.99	8.92
Average Productivity Per Hour				**9.65**

For the purpose of generating a generalized equation for predicting productivity the regression analysis was used as shown in equation 4.3. The value of $R^2 = 0.9794$ which is within the allowed limits for reliability and hence the equation is reliable to predict the productivity. From the Table 4-54, it is clearly seen that as the crew size increase the productivity decreases. Idiake & Ikemefuna (2004) also worked on the productivity of plaster and their finding shows that productvity decreases with increase of crew size.

$$\mathbf{y = 0.0086x3 - 0.1533x^2 + 0.1553x + 15.156\ldots\ldots\ldots} \qquad \mathbf{(4.3)}$$

Where,

"Y" "Productivity per hour"

"X" "Crew size"

Table 4-55: Average productivity of plastering with different crew sizes

Crew Size	Average Productivity/Hr
1	15.26
2	14.70
3	14.18
4	14.67
5	13.16
6	12.16
7	11.44
8	10.90
9	10.48
10	10.15
11	9.88
12	9.65

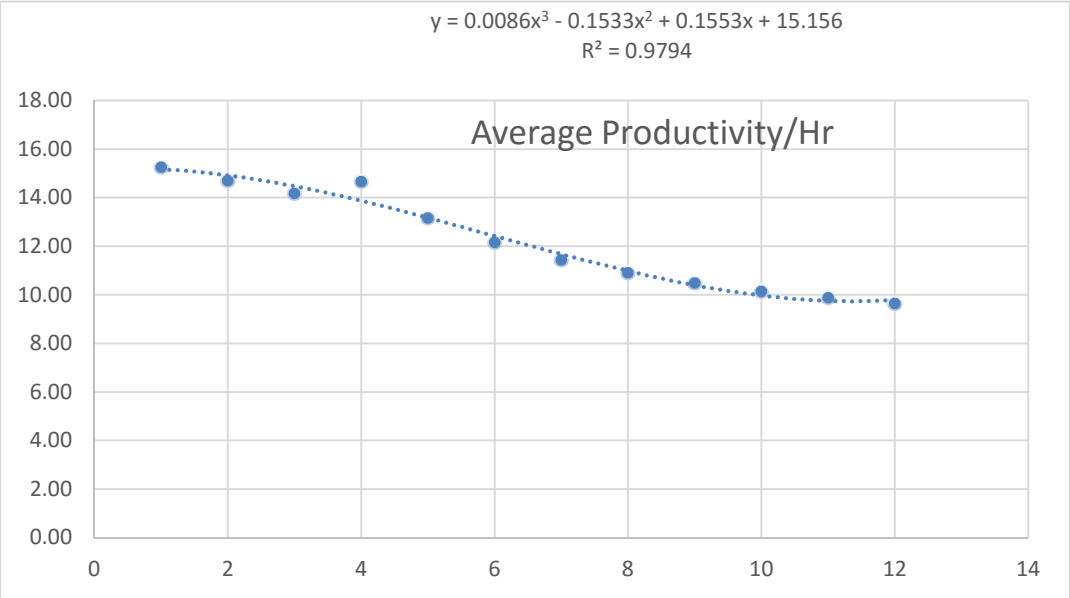


Figure 4-13: Average productivity of plastering with different crew sizes

4.5.4 Block Masonry

Block masonry is the architectural activity of the building projects. For the data collection purpose, 4-inch-thick hollow block masonry was taken. There are many factors which affect the productivity of Block masonry: Location of material, construction method, crew size and size of block. In some projects, there was rebar in the block masonry which makes it difficult to execute the job. The Data which was collected from different projects is attached in annexure ii. The data of Block Masonry is in Square Feet.

To cater for the missing data ANN was used. It was clearly seen in the data that the productivity decreases as the number of hours and crew size increases.

Table 4-55 shows the predicted productivity of Block Masonry activity for crew size of 1 the average productivity is 9.16ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-56: Predicted productivity of block masonry crew size 1

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
1	1	10.00	10.00	10.00
2	1	9.79	19.79	9.90
3	1	9.57	29.36	9.79
4	1	9.34	38.70	9.68
5	1	9.10	47.80	9.56
6	1	8.85	56.65	9.44
7	1	8.61	65.26	9.32
8	1	8.37	73.63	9.20
Average Productivity Per Hour				**9.61**

Table 4-56 shows the predicted productivity of Block Masonry activity for crew size of 2 the average productivity is 8.76ft^2/hr. Productivity is higher in the start and then it decreases till the end.

Table 4-57: Predicted productivity of block masonry crew size 2

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
2	2	18.29	18.29	9.15
4	2	17.84	36.13	9.03
6	2	17.35	53.48	8.91
8	2	16.87	70.36	8.79
10	2	16.45	86.81	8.68
12	2	16.16	102.97	8.58
14	2	16.07	119.04	8.50
16	2	16.22	135.27	8.45
Average Productivity Per Hour				**8.76**

Table 4-57 shows the predicted productivity of Block Masonry activity for crew size of 3 the average productivity is 8.25ft^2/hr. Productivity is higher in the start and then it decreases till twenty-one labor hour and some increase in the final hour.

Table 4-58: Predicted productivity of block masonry crew size 3

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
3	3	25.57	25.57	8.52
6	3	24.85	50.42	8.40
9	3	24.15	74.57	8.29
12	3	23.66	98.24	8.19
15	3	23.62	121.85	8.12
18	3	24.13	145.98	8.11
21	3	25.13	171.11	8.15
24	3	26.43	197.54	8.23
Average Productivity Per Hour				**8.25**

Table 4-58 shows the predicted productivity of Block Masonry activity for crew size of 4 the average productivity is 6.22ft^2/hr. Productivity is higher in the start and then it decreases till twenty-four labor hour and then it increases till the end.

Table 4-59: Predicted productivity of block masonry crew size 4

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
4	4	25.34	25.34	6.33
8	4	24.37	49.71	6.21
12	4	23.66	73.37	6.11
16	4	23.72	97.10	6.07
20	4	24.75	121.85	6.09

24	4	26.43	148.28	6.18
28	4	28.18	176.46	6.30
32	4	29.48	205.94	6.44
Average Productivity Per Hour				**6.22**

Table 4-59 shows the predicted productivity of Block Masonry activity for crew size of 5 the average productivity is 5.03ft^2/hr. Productivity is higher in the start and then it decreases till twenty-five labor hour and then it increases till the end.

Table 4-60: Predicted productivity of block masonry crew size 5

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
5	5	25.10	25.10	5.02
10	5	23.95	49.05	4.90
15	5	23.62	72.67	4.84
20	5	24.75	97.42	4.87
25	5	26.88	124.30	4.97
30	5	28.92	153.22	5.11
35	5	29.85	183.07	5.23
40	5	28.95	212.02	5.30
Average Productivity Per Hour				**5.03**

Table 4-60 shows the predicted productivity of Block Masonry activity for crew size of 6 the average productivity is 4.17ft^2/hr. Productivity is higher in the start and then it decreases till twenty-four labor hour and then it increases till the end.

Table 4-61: Predicted productivity of block masonry crew size 6

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
6	6	24.85	24.85	4.14

12	6	23.66	48.51	4.04
18	6	24.13	72.64	4.04
24	6	24.53	97.17	4.05
30	6	26.43	123.6	4.12
36	6	28.92	152.52	4.24
42	6	29.82	182.34	4.34
48	6	28.09	210.43	4.38
Average Productivity Per Hour				**4.17**

Table 4-61 shows the predicted productivity of Block Masonry activity for crew size of 7 the average productivity is 4.92ft^2/hr. Productivity is less in the start and it increases till thirty fifth labor hour and then it decreases till end.

Table 4-62: Predicted productivity of block masonry crew size 7

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
7	7	32.97	32.97	4.71
14	7	34.98	67.95	4.85
21	7	36.77	104.72	4.99
28	7	37.30	142.02	5.07
35	7	36.00	178.02	5.09
42	7	32.54	210.56	5.01
49	7	28.64	239.20	4.88
56	7	27.14	266.34	4.76
Average Productivity Per Hour				**4.92**

Table 4-62 shows the predicted productivity of Block Masonry activity for crew size of 8 the average productivity is 5.15ft^2/hr. Productivity is less in the start and it increases till thirty-two labor hour and then it decreases till end.

Table 4-63: Predicted productivity of block masonry crew size 8

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
8	8	39.96	39.96	4.99
16	8	44.64	84.59	5.29
24	8	46.64	131.24	5.47
32	8	43.69	174.93	5.47
40	8	37.52	212.45	5.31
48	8	31.47	243.91	5.08
56	8	28.57	272.49	4.87
64	8	28.90	301.39	4.71
Average Productivity Per Hour				**5.15**

Table 4-63 shows the predicted productivity of Block Masonry activity for crew size of 9 the average productivity is 4.53ft^2/hr. Productivity is less in the start and it increases till twenty seventh labor hour and then it decreases till end.

Table 4-64: Predicted productivity of block masonry crew size 9

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
9	9	40.53	40.53	4.50
18	9	45.56	86.09	4.78
27	9	46.09	132.18	4.90
36	9	40.81	172.99	4.81
45	9	33.50	206.49	4.59
54	9	28.94	235.42	4.36
63	9	28.74	264.16	4.19
72	9	30.59	294.75	4.09
Average Productivity Per Hour				**4.53**

Table 4-64 shows the predicted productivity of Block Masonry activity for crew size of 10 the average productivity is 4.03ft^2/hr. Productivity is less in the start and it increases till thirty labor hour and then it decreases till end.

Table 4-65: Predicted productivity of block masonry crew size 10

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
10	10	41.13	41.13	4.11
20	10	46.23	87.35	4.37
30	10	44.85	132.20	4.41
40	10	37.52	169.72	4.24
50	10	30.38	200.10	4.00
60	10	28.44	228.54	3.81
70	10	30.18	258.72	3.70
80	10	30.47	289.19	3.61
Average Productivity Per Hour				**4.03**

Table 4-65 shows the predicted productivity of Block Masonry activity for crew size of 11 the average productivity is 4.38ft^2/hr. Productivity is less in the start and it increases till fifty-five labor hour and then it decreases till end.

Table 4-66: Predicted productivity of block masonry crew size 11

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
11	11	31.98	31.98	2.91
22	11	51.61	83.59	3.80
33	11	61.63	145.21	4.40
44	11	64.36	209.57	4.76
55	11	59.93	269.50	4.90
66	11	44.77	314.27	4.76

77	11	50.45	364.72	4.74
88	11	52.18	416.90	4.74
Average Productivity Per Hour				**4.38**

Table 4-66 shows the predicted productivity of Block Masonry activity for crew size of 12 the average productivity is 4.08 ft^2/hr. Productivity is higher in the start and then it decreases till the end. Productivity is less in the start and it increases till forty-eight labor hour and then it decreases till end.

Table 4-67: Predicted productivity of block masonry crew size 12

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
12	12	33.19	33.19	2.77
24	12	55.12	88.31	3.68
36	12	61.69	150.00	4.17
48	12	65.46	215.46	4.49
60	12	51.35	266.81	4.45
72	12	46.64	313.45	4.35
84	12	52.41	365.86	4.36
96	12	52.76	418.62	4.36
Average Productivity Per Hour				**4.08**

Table 4-67 shows the predicted productivity of Block Masonry activity for crew size of 13 the average productivity is 3.80ft^2/hr. Productivity is less in the start and it increases till fifty-two labor hour and then it decreases till end.

Table 4-68: Predicted productivity of block masonry crew size 13

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
13	13	34.33	34.33	2.64

26	13	57.71	92.03	3.54
39	13	61.87	153.91	3.95
52	13	63.29	217.19	4.18
65	13	45.16	262.35	4.04
78	13	50.77	313.12	4.01
91	13	51.96	365.08	4.01
104	13	54.34	419.42	4.03
Average Productivity Per Hour				**3.80**

Table 4-68 shows the predicted productivity of Block Masonry activity for crew size of 14 the average productivity is 2.70ft^2/hr. Productivity is less in the start and it increases till fifty-six labor hour, then it decreases till eighty-four labor hour, it again increases till ninety-eight labor hour and then decreases till end.

Table 4-69: Predicted productivity of block masonry crew size 14

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
14	14	24.51	24.51	1.75
28	14	45.39	69.90	2.50
42	14	48.93	118.82	2.83
56	14	46.78	165.61	2.96
70	14	38.82	204.42	2.92
84	14	41.01	245.43	2.92
98	14	39.75	285.17	2.91
112	14	26.85	312.02	2.79
Average Productivity Per Hour				**2.70**

Table 4-69 shows the predicted productivity of Block Masonry activity for crew size of 15 the average productivity is 2.85ft^2/hr. Productivity is less in the start and

it increases till thirty labor hour, then it decreases till seventy-five labor hour, it again increases till ninety labor hour and then decreases till end.

Table 4-70: Predicted productivity of block masonry crew size 15

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
15	15	44.28	44.28	2.95
30	15	56.85	101.13	3.37
45	15	32.43	133.56	2.97
60	15	29.43	162.98	2.72
75	15	40.62	203.61	2.71
90	15	41.93	245.54	2.73
105	15	37.69	283.23	2.70
120	15	37.67	320.90	2.67
Average Productivity Per Hour				**2.85**

Table 4-70 shows the predicted productivity of Block Masonry activity for crew size of 16 the average productivity is 2.55ft^2/hr. Productivity is less in the start and it increases till end.

Table 4-71: Predicted productivity of block masonry crew size 16

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
16	16	25.70	25.70	1.61
32	16	40.49	66.19	2.07
48	16	49.06	115.25	2.40
64	16	48.59	163.84	2.56
80	16	59.98	223.82	2.80
96	16	52.39	276.21	2.88

112	16	62.31	338.52	3.02
128	16	50.44	388.95	3.04
Average Productivity Per Hour				**2.55**

For the purpose of generating a generalized equation for predicting productivity the regression analysis was used as shown in equation 4.4. The value of $R^2 = 0.9254$ which is within the allowed limits for reliability and hence the equation is reliable to predict the productivity.

$$y = -2.592\ln(x) + 10.036 \quad (4.4)$$

Where,

"Y" "Productivity per hour"

"X" "Crew size"

Table 4-72: Average productivity of block masonry with different crew sizes

Crew Size	Average Productivity
1	9.61147
2	8.76333
3	8.25161
4	6.21752
5	5.03128
6	4.22622
7	4.9199
8	5.14802
9	4.52781
10	4.03152
11	4.3757
12	4.07707
13	3.79985
14	2.69637
15	2.85278

16	2.54642

From the Figure 4-13, it is clearly seen that as the crew size increases the productivity decreases. Idiake & Ikemefuna (2004) also worked on the productivity of block masonry and their finding shows that productvity decreases with increase of crew size.

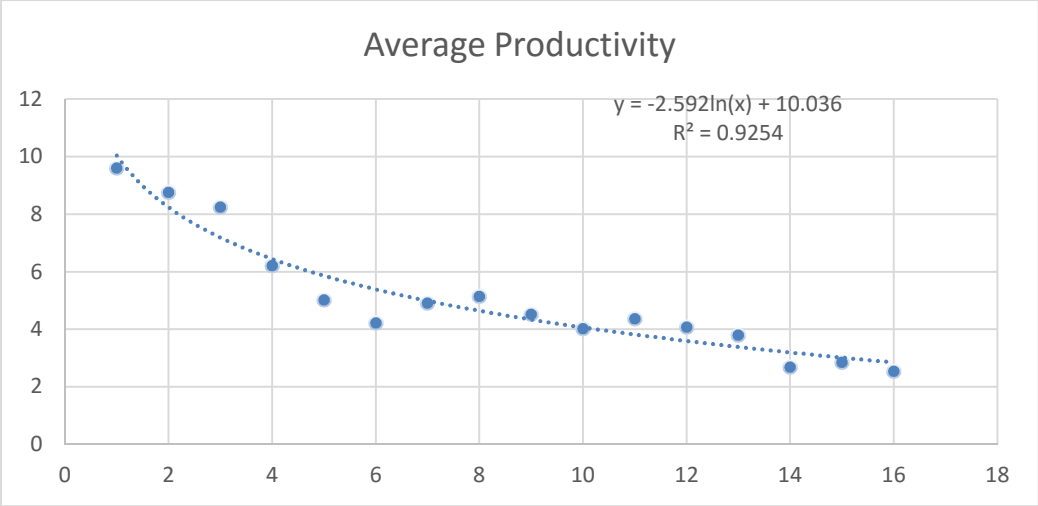


Figure 4-14: Average productivity of block masonry with different crew sizes

4.5.5 Paint

Paint is the architectural activity of the building projects and it is one of the most important activity regarding finishing. Paint covers the problems which are in plaster. Therefore, a great care must be taken while executing this job. During this activity different resources are used e.g. Painter, Painter helper and Labor. Different factors were identified during the site visits which affect the productivity of paint: crew size, quality of previous work, height and the labor experience. The Data which was collected from different projects is attached in annexure IV. The data of Paint is in Square Feet.

After the collection of data some data points were missing for the purpose to find the missing data values the ANN was used.

Table 4-72 shows the predicted productivity of Paint activity for crew size of 1 the average productivity is 59.25ft^2/hr. Productivity is higher in the start and it decreases till end.

Table 4-73: Predicted productivity of paint crew size 1

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
1	1	80.11	80.11	60.13
2	1	79.73	159.84	59.93
3	1	79.24	239.08	59.71
4	1	78.67	317.74	59.45
5	1	78.02	395.76	59.16
6	1	77.32	473.08	58.86
7	1	76.61	549.69	58.54
8	1	75.93	625.61	58.21
Average Productivity Per Hour				59.25

Table 4-73 shows the predicted productivity of Paint activity for crew size of 2 the average productivity is 38.94ft^2/hr. Productivity is higher in the start and it decreases till end.

Table 4-74: Predicted productivity of paint crew size 2

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
2	2	79.79	79.79	39.90
4	2	78.74	158.53	39.63
6	2	77.40	235.93	39.32
8	2	76.03	311.96	38.99
10	2	74.97	386.93	38.69

12	2	74.54	461.48	38.46
14	2	74.74	536.22	38.30
16	2	75.20	611.42	38.21
Average Productivity Per Hour				**38.94**

Table 4-74 shows the predicted productivity of Paint activity for crew size of 3 the average productivity is 29.24ft^2/hr. Productivity is less in the start and it increases till end.

Table 4-75: Predicted productivity of paint crew size 3

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
3	3	86.51	86.51	28.84
6	3	86.22	172.73	28.79
9	3	86.67	259.40	28.82
12	3	88.63	348.03	29.00
15	3	91.19	439.21	29.28
18	3	92.45	531.66	29.54
21	3	92.69	624.35	29.73
24	3	93.66	718.02	29.92
Average Productivity Per Hour				**29.24**

Table 4-75 shows the predicted productivity of Paint activity for crew size of 4 the average productivity is 34.86ft^2/hr. Productivity is less in the start, it increases till twenty-eight labor hour and the decreases till end.

Table 4-76: Predicted productivity of paint crew size 4

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr

4	4	135.64	135.64	31.91
8	4	142.72	278.37	32.80
12	4	152.64	431.01	33.92
16	4	161.25	592.26	35.02
20	4	165.46	757.73	35.89
24	4	165.22	922.95	36.46
28	4	157.57	1080.52	36.59
32	4	144.17	1224.69	36.27
Average Productivity Per Hour				**34.86**

Table 4-76 shows the predicted productivity of Paint activity for crew size of 5 the average productivity is 30.90ft^2/hr. Productivity is less in the start and it increases till end.

Table 4-77: Predicted productivity of paint crew size 5

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
5	5	137.65	137.65	27.53
10	5	144.30	281.95	28.20
15	5	154.36	436.31	29.09
20	5	174.23	610.53	30.53
25	5	192.44	802.97	32.12
30	5	188.32	991.29	33.04
35	5	173.57	1164.86	33.28
40	5	173.09	1337.95	33.45
Average Productivity Per Hour				**30.90**

Table 4-77 shows the predicted productivity of Paint activity for crew size of 6 the average productivity is 40.47 ft^2/hr. Productivity is less in the start and it increases till thirty-six labor hour and then decrease till end.

Table 4-78: Predicted productivity of paint crew size 6

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
6	6	204.48	204.48	34.08
12	6	224.68	429.16	35.76
18	6	236.93	666.08	37.00
24	6	291.93	958.01	39.92
30	6	343.58	1301.59	43.39
36	6	309.68	1611.27	44.76
42	6	256.58	1867.85	44.47
48	6	263.26	2131.11	44.40
Average Productivity Per Hour				**40.47**

Table 4-78 shows the predicted productivity of Paint activity for crew size of 7 the average productivity is 57.85 ft^2/hr. Productivity is less in the start and it increases till twenty-eight labor hour and then decrease till end.

Table 4-79: Predicted productivity of paint crew size 7

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
7	7	380.18	380.18	49.51
14	7	457.10	837.28	55.00
21	7	533.07	1370.35	60.45
28	7	502.92	1873.26	62.10
35	7	433.32	2306.58	61.10
42	7	404.30	2710.88	59.74
49	7	384.64	3095.52	58.37
56	7	340.50	3436.02	56.55
Average Productivity Per Hour				**57.85**

Table 4-79 shows the predicted productivity of Paint activity for crew size of 8 the average productivity is 56.61 ft^2/hr. Productivity is less in the start and it increases till thirty-two labor hour and then decrease till end.

Table 4-80: Predicted productivity of paint crew size 8

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
8	8	407.41	407.41	50.93
16	8	507.72	915.14	57.20
24	8	547.47	1462.61	60.94
32	8	464.50	1927.11	60.22
40	8	413.29	2340.39	58.51
48	8	398.58	2738.98	57.06
56	8	342.34	3081.31	55.02
64	8	312.13	3393.45	53.02
Average Productivity Per Hour				**56.61**

Table 4-80 shows the predicted productivity of Paint activity for crew size of 9 the average productivity is 50.01 ft^2/hr. Productivity is less in the start and it increases till twenty-seven labor hour and then decrease till end.

Table 4-81: Predicted productivity of paint crew size 9

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
9	9	417.15	417.15	46.35
18	9	531.82	948.97	52.72
27	9	522.39	1471.36	54.49
36	9	428.98	1900.34	52.79
45	9	410.45	2310.79	51.35

54	9	356.24	2667.03	49.39
63	9	313.96	2980.99	47.32
72	9	306.07	3287.06	45.65
Average Productivity Per Hour				**50.01**

Table 4-81 shows the predicted productivity of Paint activity for crew size of 10 the average productivity is 48.61 ft^2/hr. Productivity is less in the start and it increases till twenty labor hour and then decrease till end.

Table 4-82: Predicted productivity of paint crew size 10

Labor Hour	Crew Size	Predicted Productivity	Accumulative Predicted Productivity	Predicted Productivity/Hr
10	10	427.93	427.93	46.79
20	10	547.91	975.83	52.79
30	10	487.54	1463.38	52.78
40	10	413.33	1876.71	50.92
50	10	386.12	2262.83	49.26
60	10	322.29	2585.12	47.09
70	10	306.73	2891.85	45.31
80	10	305.15	3197.00	43.96
Average Productivity Per Hour				**48.61**

For the purpose of generating a generalized equation for predicting productivity the regression analysis was used as shown in equation 4.5. The value of $R^2 = 0.9034$ which is within the allowed limits for reliability and hence the equation is reliable to predict the productivity. Figure 4-14 shows the relationship of productivity with the crew size. Productivity behavior of paint was different to other activates. Other activities productivity decreases with the increase of crew size but in paint case, it decreases up-to crew size three and then increases up-to crew size eight and again decreases after that.

$$y = 0.0153x^5 - 0.4066x^4 + 3.4733x^3 - 8.4898x^2 - 11.108x + 75.12 \ldots\ldots \quad (4.5)$$

Where,

"Y" "Productivity per hour"

"X" "Crew size"

Table 4-83: Average productivity of paint with different crew sizes

Crew Size	Average Productivity
1	59.2487
2	38.9385
3	29.2397
4	34.8556
5	30.904
6	40.4723
7	57.8523
8	56.6131
9	50.008
10	48.6125

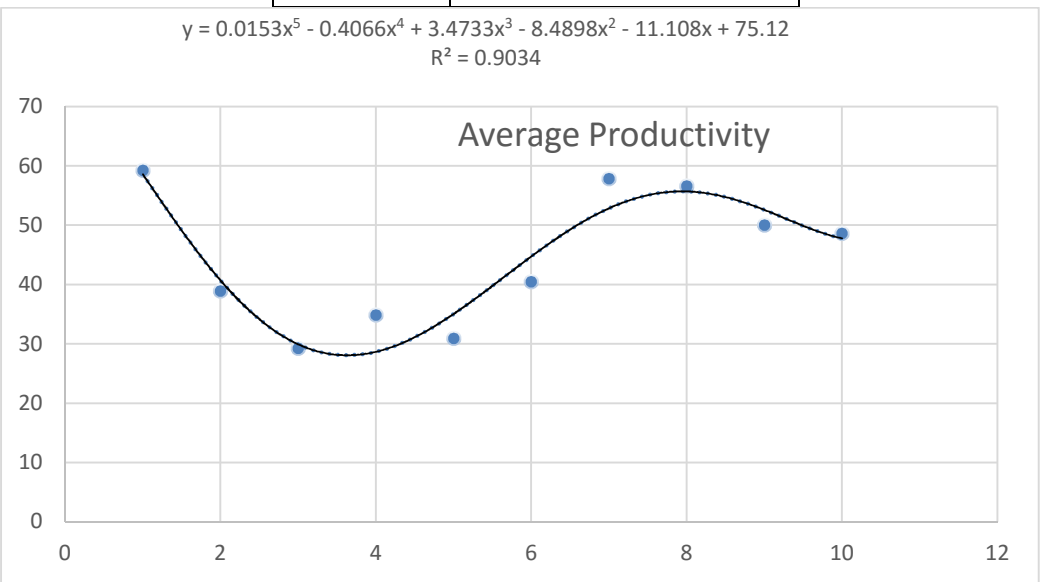


Figure 4-15: Average productivity of paint with different crew sizes

Chapter 5

CONCLUSION AND RECOMMENDATIONS

REVIEW OF RESEARCH OBJECTIVES

The objectives of this study as the result of research are:

- To refine labor productivity factor taxonomy in construction industry.
- To statistically analyze and rank the factors according to their criticality.
- To prepare productivity curves due to various influencing factors.
- To propose productivity enhancement framework in construction.

First objective of this study was achieved by extensive literature review and questionnaire was floated to field professionals. To achieve second objective, statistical methods was used i.e. Shapiro-Wilk test, Kruskal-Wallis test and RII. To achieve third objective data related productivities of activates was collected from site and analyzed by using Excel and ANN. For fourth and final objective interviews were done with the 13 field professionals and productivity enhancement frame work was proposed.

5.1 CONCLUSIONS

After carrying out detailed statistical analysis on questionnaire survey and the data of productivity, major findings of the research are:

In the labor group top most affecting factor is “large crew size” with RIF 0.80734.

In the project group top most affecting factor is “payment delays with RIF 080147.

In material and equipment group the top most affecting factor is “material shortage” with RIF 0.82798. In managerial group top most affecting factor is “poor site management” with RIF 0.80046. In external group the top most affecting

factor is “severe weather” with RIF 0.80057. In project group the top most affecting factor is “design changes during execution” with RIF 0.86239.

Overall top five factors which affect productivity are: 1) Design changes during execution, 2) Material shortage, 3) Working within confined spaces 4) Large crew size and 5) shortage of tools and equipment’s.

For the prediction of productivity of four activities equations was generated by using regression analysis. Equation 5.1 was generated to predict the productivity of concreting. The value of $R^2 = 0.97$ which is within the allowed limits for reliability and hence the equation is reliable to predict the productivity. It was also observed that as the crew size increases productivity decreases.

$$\mathbf{y = 0.0331x^2 - 0.9581x + 8.7401 \ldots\ldots\ldots} \qquad \mathbf{(5.1)}$$

Equation 5.2 was generated to predict the productivity of block masonry. The value of $R^2 = 0.9254$ which is within the allowed limits for reliability and hence the equation is reliable to predict the productivity. It was also observed that as the crew size increases productivity decreases.

$$\mathbf{y = -2.592\ln(x) + 10.036} \qquad \mathbf{(5.2)}$$

Equation 5.3 was generated to predict the productivity of plaster. The value of $R^2 = 0.9794$ which is within the allowed limits for reliability and hence the equation is reliable to predict the productivity. It was also observed that as the crew size increases productivity decreases.

$$\mathbf{y = 0.0086x3 - 0.1533x^2 + 0.1553x + 15.156\ldots\ldots\ldots} \qquad \mathbf{(5.3)}$$

Equation 5.4 was generated to predict the productivity of paint. The value of $R^2 = 0.9034$ which is within the allowed limits for reliability and hence the equation is reliable to predict the productivity. Productivity behavior of paint was different to other activates i.e. productivity decreases with the increase of crew size but in paint

case, it decreases up-to crew size three and then increases up-to crew size eight and after that again decreases.

$$y = 0.0153x^5 - 0.4066x^4 + 3.4733x^3 - 8.4898x^2 - 11.108x + 75.12 \ldots\ldots \quad (5.3)$$

5.3 RECOMENDATIONS

Some recommendations are listed below based on the findings of research.

- This research mainly focused on four activates block masonry, concreting, plaster and paint. Further activities can be selected to expand the research on this topic.
- Equation generated in this research should be utilized on the site to check their validation.
- Crew size should be selected such that the activity may not be disturbed due to large crew.

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ANNEXURE I

Questionnaire Survey

Questionnaire Survey

Dear Respondent,
Construction industry faces challenges with regard to problems associated with productivity and the problems are usually associated with performance of labor. The aim of this research is to explore that possibility and to attain latest information on key factors that affect project performance in terms of project completion time and to model the interaction relationships between key factors affecting productivity. The study shall greatly help to make recommendations for timely completion of the projects. It is assured that the information we will gain from your side shall be strictly kept secret and it will only be used for the academic purposes.
Your feedback will help in to find critical factors affecting labor productivity in construction industry and to develop a framework to improve labor productivity.
In case you have any questions, please feel free to contact me.

Best Regards,
Engr. Bilal Malik
CE & M Department , NIT
NUST H-12 Islamabad
+923335763329

* Required

2. **Gender**
Mark only one oval.

- ◯ Male
- ◯ Female

3. **Qualification** *
Mark only one oval.

- ◯ Certificate/Diploma
- ◯ Graduate
- ◯ Post graduate
- ◯ Doctorate
- ◯ Other: .....

4. **You belong to which stakeholder organization?** *
Mark only one oval.

- ◯ Owner
- ◯ Contractor
- ◯ Consultant
- ◯ Subcontractor
- ◯ Other:

A. Personal Information:

1. **Name**

5 **Name of Organiza ion**

.....

6. **Position/Designation:**

.....

7. **Experience in Construction Industry (years)** *
Mark only one oval.

- ◯ Less than 5 Years
- ◯ 5-10 years
- ◯ More than 10 years

8. **How long you have worked in this company (years)**
Mark only one oval.

- ◯ Less than 1 year
- ◯ 1-5 years
- ◯ 5-10 years
- ◯ More than 10 years

9. **Typical Size of Projects**
Mark only one oval.

- ◯ Less than 1000 million
- ◯ 1000-5000 million
- ◯ More than 5000 million

10. **Geographical location of Project undertaken** *
Mark only one oval.

- ◯ Federal
- ◯ Punjab
- ◯ Sindh
- ◯ KPK
- ◯ .Balochistan
- ◯ AJK

B. Questionnaire:

Please indicate to what extent following factors affect labor productivity at construction site.
0– Not applicable; 1– Does not affect it; 2 – Somewhat affects it; 3 – Moderately affects it; 4 – Directly affects it

11 **Taking in accoun Labor Group, how much the following factors affect the Productivity?** *

Mark only one oval per row.

	Not Applicable	Does not Affect it	Somewhat Affect it	Moderately Affect it	Directly Affect it
Lack of labor experience					
Language Difference					
Working overtime					
Age of Worker					
Large Crew Size					
Labor unfaithfulness					
Lack of cooperation					
Misunderstanding among laborers					
abor persona problems					
Labor absence					

12. **Taking in account Project Group, how much the following factors affect the Productivity?** *

Mark only one oval per row.

	Not Applicable	Does not Affect it	Somewhat Affect it	Moderately Affect it	Directly Affect it
Construction method					
Poor terrain conditions					
Type of activities in the project					
Design Change During execution					
Project size					
Working at height					
Quality of Required Work					
Working within a confined space					

13. **Taking in account Material and Equipment's Group, how much the following factors affect the Productivity?** *

Mark only one oval per row.

	Not Applicable	Does not Affect it	Somewhat Affect it	Moderately Affect it	Directly Affect it
Shortage of Tools and Equipment					
Material shortage					
Inefficiency of equipment					
Unsuitability of materials storage location					
Low quality of raw materials					

14 **Taking in accoun Managerial Group, how much the following factors affect the Productivity?** *

Mark only one oval per row.

	Not Applicable	Does not Affect it	Somewhat Affect it	Moderately Affect it	Directly Affect it
Lack of training sessions					
Lack of Motivation					
Misunderstanding between laborers and superintendents					
Rework Due to Changes					
Lack of constant meeting with labor					
Lack of supervisors experience					
Inspection delay					
Construction Schedule/Work Planning					
Bad relations between labors and management team					
Poor site management					

15. **Taking in account External Group, how much the following factors affect the Productivity?** *

Mark only one oval per row.

	Not Applicable	Does not Affect it	Somewhat Affect it	Moderately Affect it	Directly Affect it
Climate change					
Political Insecurity					
Severe Weather					
Humidity					

16. **Taking in account Financial Group, how much the following factors affect the Productivity?** *

Mark only one oval per row.

	Not Applicable	Does not Affect it	Somewhat Affect it	Moderately Affect it	Directly Affect it
Lack of financial motivation system					
Payment delays					
Labor's low wage					
Financial conditions of contractor					

17. **Other Factors affecting Labor Productivity at Construction Job sites.**

18. **Any Comments/Remarks.**

ANNEXURE II

Block masonry data collected form site

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
6	6	31	31	5.17
12	6	30	61	5.08
18	6	20	81	4.50
24	6	29	110	4.58
30	6	26	136	4.53
36	6	43	179	4.97
42	6	10	189	4.50
48	6	14	203	4.23
Average Productivity Per Hour				**4.70**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
6	6	33	33	5.50
12	6	32	65	5.42
18	6	21	86	4.78
24	6	30	116	4.83
30	6	27	143	4.77
36	6	45	188	5.22
42	6	22	210	5.00
48	6	14	224	4.67
Average Productivity Per Hour				**5.02**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
6	6	32	32	5.33

12	6	21	53	4.42
18	6	12	65	3.61
24	6	27	92	3.83
30	6	32	124	4.13
36	6	44	168	4.67
42	6	31	199	4.74
48	6	13	212	4.42
Average Productivity Per Hour				**4.39**
Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
6	6	25	25	4.17
12	6	23	48	4.00
18	6	26	74	4.11
24	6	16	90	3.75
30	6	11	101	3.37
36	6	27	128	3.56
42	6	34	162	3.86
Average Productivity Per Hour				**3.83**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
8	8	20	20	2.50
16	8	45	65	4.06
24	8	70	135	5.63
32	8	65	200	6.25
40	8	45	245	6.13
48	8	35	280	5.83
56	8	55	335	5.98
64	8	27	362	5.66
Average Productivity Per Hour				**5.25**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
8	8	29	29	3.63
16	8	46	75	4.69
24	8	35	110	4.58
32	8	33	143	4.47
40	8	34	177	4.43
48	8	20	197	4.10
56	8	30	227	4.05
64	8	25	252	3.94
72	8	35	287	3.99
Average Productivity Per Hour				**4.21**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
8	8	20	20	2.50
16	8	48	68	4.25
24	8	40	108	4.50
32	8	35	143	4.47
40	8	20	163	4.08
48	8	32	195	4.06
56	8	45	240	4.29
64	8	31	271	4.23
72	8	46	317	4.40
80	8	21	338	4.23
Average Productivity Per Hour				**4.10**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
8	8	51	51	6.38
16	8	51	102	6.38
24	8	33	135	5.63
32	8	55	190	5.94
40	8	57	247	6.18
48	8	30	277	5.77
56	8	18	295	5.27
64	8	25	320	5.00
Average Productivity Per Hour				**5.82**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
8	8	46	46	5.75
16	8	50	96	6.00
24	8	55	151	6.29
32	8	5	156	4.88
40	8	34	190	4.75
48	8	21	211	4.40
56	8	21	232	4.14
64	8	25	257	4.02
72	8	18	275	3.82
Average Productivity Per Hour				**4.89**
Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
13	13	12	12	0.92
26	13	65	77	2.96
39	13	38	115	2.95
52	13	49	164	3.15

65	13	60	224	3.45
78	13	40	264	3.38
91	13	60	324	3.56
104	13	20	344	3.31
Average Productivity Per Hour				**2.96**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
13	13	25	25	1.92
26	13	69	94	3.62
39	13	57	151	3.87
52	13	86	237	4.56
65	13	21	258	3.97
78	13	64	322	4.13
91	13	45	367	4.03
104	13	74	441	4.24
Average Productivity Per Hour				**3.79**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
13	13	38	38	2.92
26	13	69	107	4.12
39	13	73	180	4.62
52	13	86	266	5.12
65	13	21	287	4.42
78	13	64	351	4.50
91	13	45	396	4.35
104	13	74	470	4.52
Average Productivity Per Hour				**4.32**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
14	14	21	21	1.50
28	14	43	64	2.29
42	14	47	111	2.64
56	14	48	159	2.84
70	14	35	194	2.77
84	14	39	233	2.77
98	14	33	266	2.71
112	14	25	291	2.60
126	14	16	307	2.44
Average Productivity Per Hour				**2.51**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
15	15	25	25	1.67
30	15	68	93	3.10
45	15	23	116	2.58
60	15	24	140	2.33
75	15	40	180	2.40
90	15	41	221	2.46
105	15	33	254	2.42
120	15	35	289	2.41
135	15	42	331	2.45
Average Productivity Per Hour				**2.42**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
16	16	23	23	1.44
32	16	41	64	2.00

48	16	61	125	2.60
64	16	59	184	2.88
80	16	69	253	3.16
96	16	40	293	3.05
112	16	74	367	3.28
128	16	47	414	3.23
Average Productivity Per Hour				2.71

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
16	16	19	19	1.19
32	16	31	50	1.56
48	16	44	94	1.96
64	16	64	158	2.47
80	16	70	228	2.85
96	16	66	294	3.06
112	16	75	369	3.29
128	16	45	414	3.23
144	16	35	449	3.12
Average Productivity Per Hour				**2.53**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
16	16	25	25	1.56
32	16	50	75	2.34
48	16	42	117	2.44
64	16	27	144	2.25
80	16	52	196	2.45
96	16	41	237	2.47
112	16	51	288	2.57

128	16	47	335	2.62
144	16	70	405	2.81
160	16	29	434	2.71
Average Productivity Per Hour				**2.42**

ANNEXURE III

Plaster data collected from sites

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
4	4	71	71	17.75
8	4	54	125	15.63
12	4	83	208	17.33
16	4	64	272	17.00
20	4	77	349	17.45
24	4	48	397	16.54
28	4	69	466	16.64
32	4	60	526	16.44
Average Productivity Per Hour				**16.85**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
5	5	36	36	7.20
10	5	41	77	7.70
15	5	57	134	8.93
20	5	51	185	9.25
25	5	31	216	8.64
30	5	46	262	8.73
35	5	41	303	8.66
40	5	44	347	8.68
45	5	33	380	8.44
Average Productivity Per Hour				**8.47**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
6	6	65	65	10.83

12	6	82	147	12.25
18	6	80	227	12.61
24	6	69	296	12.33
30	6	57	353	11.77
36	6	62	415	11.53
42	6	53	468	11.14
48	6	45	513	10.69
54	6	73	586	10.85
Average Productivity Per Hour				**11.65**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
6	6	79	79	13.17
12	6	85	164	13.67
18	6	98	262	14.56
24	6	88	350	14.58
30	6	91	441	14.70
36	6	69	510	14.17
42	6	60	570	13.57
48	6	63	633	13.19
Average Productivity Per Hour				**13.95**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
7	7	61	61	8.71
14	7	89	150	10.71
21	7	86	236	11.24
28	7	68	304	10.86
35	7	83	387	11.06

42	7	95	482	11.48
49	7	77	559	11.41
56	7	58	617	11.02
Average Productivity Per Hour				**10.81**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
7	7	75	75	10.71
14	7	95	170	12.14
21	7	98	268	12.76
28	7	84	352	12.57
35	7	95	447	12.77
42	7	85	532	12.67
49	7	88	620	12.65
56	7	57	677	12.09
63	7	76	753	11.95
Average Productivity Per Hour				**12.26**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
7	7	75	75	10.71
14	7	67	142	10.14
21	7	91	233	11.10
28	7	71	304	10.86
35	7	83	387	11.06
42	7	66	453	10.79
49	7	58	511	10.43
56	7	54	565	10.09
63	7	50	615	9.76

Average Productivity Per Hour	10.55

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
8	8	75	75	9.38
16	8	108	183	11.44
24	8	69	252	10.50
32	8	105	357	11.16
40	8	66	423	10.58
48	8	93	516	10.75
56	8	45	561	10.02
64	8	81	642	10.03
Average Productivity Per Hour				**10.48**

ANNEXURE IV

Paint data collected from sites

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
3	3	75	75	25.00
6	3	105	180	30.00
9	3	45	225	25.00
12	3	102	327	27.25
15	3	86	413	27.53
18	3	58	471	26.17
21	3	67	538	25.62
24	3	81	619	25.79
Average Productivity Per Hour				**26.55**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
4	4	146	146	36.50
8	4	207	353	44.13
12	4	152	505	42.08
16	4	164	669	41.81
20	4	122	791	39.55
24	4	158	949	39.54
28	4	189	1138	40.64
32	4	134	1272	39.75
Average Productivity Per Hour				**40.50**

Labor Hour	Crew Size	Actual Productivity	Accumulative Productivity	Actual Productivity/Hr
4	4	115	115	28.75
8	4	74	189	23.63

12	4	140	329	27.42
16	4	235	564	35.25
20	4	160	724	36.20
24	4	220	944	39.33
28	4	185	1129	40.32
32	4	85	1214	37.94
Average Productivity Per Hour				**33.60**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
5	5	95	95	19.00
10	5	175	270	27.00
15	5	145	415	27.67
20	5	156	571	28.55
25	5	210	781	31.24
30	5	105	886	29.53
35	5	152	1038	29.66
40	5	170	1208	30.20
Average Productivity Per Hour				**27.86**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
5	5	153	153	30.60
10	5	204	357	35.70
15	5	95	452	30.13
20	5	175	627	31.35
25	5	242	869	34.76
30	5	108	977	32.57
35	5	165	1142	32.63

40	5	191	1333	33.33
Average Productivity Per Hour				**32.63**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
6	6	176	176	29.33
12	6	252	428	35.67
18	6	198	626	34.78
24	6	270	896	37.33
30	6	379	1275	42.50
36	6	148	1423	39.53
42	6	126	1549	36.88
48	6	252	1801	37.52
Average Productivity Per Hour				**36.69**

Labor Hour	**Crew Size**	**Actual Productivity**	**Accumulative Productivity**	**Actual Productivity/Hr**
7	7	360	360	51.43
14	7	475	835	59.64
21	7	610	1445	68.81
28	7	520	1965	70.18
35	7	395	2360	67.43
42	7	230	2590	61.67
49	7	430	3020	61.63
56	7	305	3325	59.38
Average Productivity Per Hour				**62.52**