Construction Labor Productivity: Determining the Optimum Values in Regard with Crew Size

FINAL YEAR PROJECT UG-2012

By

2012-NUST-SCEE-BE-CE-- Umair Ahmad Jan

2011-NUST-SCEE-BE-CE-120- Usman Talib

2011-NUST-SCEE-BE-CE- 033- Hassan Iftikhar

NUST Institute of Civil Engineering
School of Civil and Environmental Engineering
National University of Sciences and Technology

Islamabad, Pakistan

2012

This is to certify that the
Final Year Project Titled

Construction Labor Productivity: Determining the Optimum Values in Regard with Crew Size

Submitted by

2012-NUST-SCEE-BE-CE-- Umair Ahmad Jan

2011-NUST-SCEE-BE-CE-120- Usman Talib

2011-NUST-SCEE-BE-CE- 033- Hassan Iftikhar

Final Year Project Report

Submitted to

National University of Sciences and Technology

in partial fulfillment of the requirements

for the degree

in

CIVIL ENGINEERING

____

Dr. Jamaluddin Thaheem

Designation: Head of Department Construction Engineering and Management

NUST Institute of Transportation (NIT)

School of Civil and Environmental Engineering (SCEE)

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

Table of Contents

ABSTRACT

Labor results in about 50 to 60 percent of the total cost in any construction project and thus is an important factor to be considered in any construction. Labor productivity refers to the amount of work done by labor per unit hour in our research.

Labor productivity is an important aspect to be considered since its importance lies in the fact that is controls our decision to deploy a certain crew size on a specific stage of construction to get optimum results. Firstly we avoid the cost over runs if we know the productivity since we would know the optimum productivity so we can thus optimize our costs aswell.secondly the labor productivity would help us overcome the time over runs in any stage of construction since we would know the optimum productivity so we would easily be able optimize the time required to carry out the stage of construction and thus eventually optimize the total duration of the project.

We considered four major stages of construction in our study. Which were as follows

1. Concreting

2. Block masonry

3. Plaster

4. Paint

We first carried out the literature review to find out the details and research already carried in this field. After that we made a data sheet which was used to record the data on the sites having variable crew sizes for the stages chosen by us. We recorded hourly data on the sites and this way we collected the entire data from the sites. We then plotted the curves of crew size against the productivity and found out the optimum productivity and the optimum crew sizes for all the stages of construction. We also developed a predictive model for each stage.

CHAPTER1

1. Introduction

1.1 Background

The construction industry, world over, is considered a basic industry on which the development of a country depends to a great extent. The development status of a country and its growth is generally determined by the quality of its construction companies and their ability. A spurt in activity in this sector causes a chain reaction in other allied industries. Almost a total of 60 industries are thought to have been linked with construction sector.

Construction industry is majorly an outdoor industry with a huge diversity in its activities, some of which are labor intensive and other are equipment/machinery intensive. Labor is considered to be of vital importance in construction industry as much of the capital of construction projects is spent on the labor cost and it is the most fluctuating variable being prone to changes. External and internal factors affecting construction activities are difficult to anticipate and control, causing a variation in labor productivity. It is imperative to ensure that variation in labor productivity has not decreased the output, thus causing a delay in plan and schedule. As more time and manpower will be required to perform a certain task, the project is certain to have a time and cost overrun causing huge losses to the stakeholders[1].

Time is also a major factor in construction industry. Maximum benefits can only be harnessed from a project when it is timely completed and utilized. Moreover, where time overruns result in huge monetary losses, it also engenders adversarial relationships, litigation, arbitration, cash flow problems and a general feeling of apprehension between project participants[2]. Besides this, contractors also have an incentive to complete the project as early as possible so that they can move to other projects when the market is flourishing. Hence, contractors tend to deploy maximum resources to aproject to ensure timely finish. Since equipment and materials are less prone to variation in productivity, labor is most affected. As more and more labor is deployed to do a task, other factors are also revised. Generally adding more labor to a task does ensure early completion, however it does not guarantee maximum productivity per labor in that group. Resultantly, cost of labor increases and savings generated through early completion are compromised.

Hence there is a crucial need to understand labor productivity and its characteristics. Improving labor productivity can result in better quality of construction, timely completion of projects and fostering more revenues from contractor level to an overall national level. We also need to study crew level productivity in a task, to comprehend the threshold crew size that will not result in supernumerary labor.

1.2 Significance

Labor productivity loss is one of the grave and severe losses in construction industry. Labor cost comprises of 33-50% cost of overall the whole project. Project cost is decreased in a direct proportion when productivity is increased as more work is being done in lesser time[3]. Among the various cost components of a project i.e. Labor, Equipment and Materials, labor is considered to be most risky. Materials and equipment are generally determined by market prices, which after all is out of the control of project management. However, labor can be controlled and operated upon by the project management in an effort to increase labor productivity[4].

Coming to the effects of crew size on labor productivity, US Army Corps of Engineers showed that increasing the crew size indefinitely does not guarantee the same efficiency that would have been with the optimum crew size. Their model shows that when labor is doubled than the optimum requirement, production that should also double increases only about 57%[5].

As a result, what is evident from this discussion is that increased labor productivity will end up in creating more output units with lesser labor and time. Both of these results stipulate decreased costs for a construction activity and hence by managing labor productivity, overall costs of construction projects can be reduced and profits can be maximized. It is also shown that productivity variation has specially to be noted when increasing labor on a particular task. Optimum crew is hence the best and most cost effective approach to finishing a task in the best manner possible.

1.3 Why study labor productivity

The contractors in the construction industry of Pakistan are unaware of the concept of optimum crew productivity for an activity. They are wasting labor hours and money by deploying more and more labor on a task in order to perform it as early as possible. This decrease in productivity, which in other words can also be stated as inefficiency of the group due to over manning, needs to be brought into attention of construction industry in Pakistan and serious work needs to be done on this chapter of increasing productivity. This effect of decrease in productivity is further magnified by the fact that under normal conditions, a task is only overmanned to accelerate if it is contributing to a delay in overall project time i.e. a critical activity. The study of this effect, thus, becomes more important as it contributes to a sensitive aspect of a project life which is the critical path.

Also this study will help us to determine two very important aspects of construction industry. Firstly the time estimation of an activity can be only made accurately once an idea of the exact productivity is known. With this one can easily estimate the exact duration of each activity and thus the overall duration of the project under consideration. This will further help the manager to decide which activity to crash and which to stop and where to effectively add the labor required effectively to complete the project taken.

Secondly with the help of the knowledge of the productivity, we can easily estimate the cost of each activity in regard to the labor. We can thus find out the optimum productivity and the cost linked to it. After that we can perform a cost to benefit analysis to see if it is profitable to add the optimum labor economically for our project. With this we can thus estimate the long term total labor cost of the project effectively. We must not forget that labor cost results in 60% of the total project cost.

In our project, we will explore productivities of different activities on different sites by varying the crew size. We will plot productivities of various activities against crew size and see how it varies by varying the number of laborers in a crew. This way we can ascertain that productivity is being reduced as one increases the crew size beyond the optimum level for an activity. Corresponding to that optimum crew size, we can also perceive what is going to be an optimum productivity for a particular activity.

Different policies have been adopted in different countries to increase the productivity of labor according to the conditions governing their change. It has been highlighted already in a research by Polat and Arditi (2005) that the critical factors that have been affecting productivity in different countries are not same.Ergo, as a result of our study, the contractors in Pakistan will be able to identify the losses that were being incurred in absence of our study, when they were posting labor more than the threshold, and quite possibly their reasons as well. They will also be knowledgeable about how much loss of productivity, and hence the money is being incurred while they employ more and more labor believing that an activity is being accelerated. Consequently, they'll be able to ensure that the crew performs more efficiently with optimum productivity and save additional troubles that were being incurred due to posting of extra labor which was decreasing the productivity of the group as a whole.

1.4 Objectives of the study

The objectives of our study are as follows:

- Determine the optimum productivity of different activities
- Determine the optimum crew size corresponding to maximum productivity
- Show graphically that increased labor on an activity will not definitely increase overall productivity
- Develop a predictive model for the future reference
- Identify the reasons of decreasing productivity with increasing crew members
- To determine the reasons for the increased productivity with increased crew size.
- To find out the differences in productivity in fast tracking projects and normal projects

CHAPTER 2

2. LITERATURE REVIEW

2.1 Definitions

The definition of productivity has been known to vary widely from different perspectives. In its most basic form, productivity is the relation between the inputs (generally resources) deployed for a task to the outputs gained by deploying these resources. Its meaning has been known to vary from industry to industry, its usage, purpose of study and from individual to individual. For example, during the initial stages, while a contractor assesses the costs and times of a project, he is interested in overall cumulative productivity. Furthermore, after he gets the project, he will ensure that the desired level of productivity is at least matched or excelled. This way he can generate maximum profits by completing the project well within time and costs. Hence, it is safe to say that contractors are interested in cumulated average productivity applicable in broad conditions that are continued over the whole life of the project. On the other hand, the researchers are more focused on average level of productivity that prevails over a shorter period of time and only under a very specific set of conditions. Hence the basic difference in contractor's and researcher's productivity is the deeper level of details the researcher has to deal with while assessing productivity. Hence it stipulates that the researcher has also to deal with various factors affecting productivity that are paramount in decreasing or increasing productivity levels.

There have been different ranks of measuring and assessing productivity in different industries. The first rank not suitable for contractors is the **multi factor productivity** or **total factor productivity**. It is generally used by governmental agencies, Commerce institutes to evaluate the state of economy and policy making, usually dealt in dollars. The second rank is the **Project-Specific Productivity**, used in specific program planning and for conceptual estimates for projects by private sector. This form is used by design professionals usually. The model mostly used in construction industry by the contractors on site is the **Activity-Oriented Productivity.** It is a very narrowly defined version of MFP and project-specific productivity in which the units for outputs and inputs are units of generic kinds of works rather than dollars i.e. work hours, cubic yards, square feet, tons etc. Labor productivity is hence typically defined by the following equation:

Labor productivity = Output / Work hours

However, having no standard definition of productivity, some contractors use the inverse as a measure to calculate how much work hours have been utilized in accomplishing a certain task pertaining to an activity. [6]

When it comes to construction labor productivity, however, for an academic point of view, the researchers have managed to agree on certain principles of defining productivity which are described by Rowlinson and Proctor in 1999:

A perfect productivity (1.0) can be achieved with a 40-hour work week, with people taking all the holidays and vacation days as planned all of the engineering drawings would be 100% complete there would be no delays of any kind during 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)[7].

2.2 Misconceptions

Not much research has been carried out in past about construction labor productivity, neither has it been accepted as a cosmic term by the practitioners of civil engineering; especially in Pakistan. Certain generic trends have been defined in the industry, which are practiced like hard lined codes; without much understanding of how the mechanism of optimizing productivity works. These trends, instead of pointing towards an increasing productivity, are rather directed towards prevention of decrease of productivity, hence limiting the productivity growth after a certain point. Thus we need to grasp the concept rather more firmly and get rid of the misconceptions which are prevailing on the sites.

- Key factor for low productivity in construction industry is labor.
- Because the construction industry is controlled by the weather, productivity cannot be improved.
- The construction industry always has an unfavorable relationship process[8].

Current misunderstandings about productivity appear to stem from at least two problems. First is the nonstandard terminology. Lastly is the application of industrial engineering work-study techniques to construction. A crew-level model of construction labor productivity is needed before productivity can be adequately understood, and before improvement strategies can be designed and implemented [6].

2.3 Facts

Previous studies have resulted in compiling certain facts about labor productivity which are necessary to understand before one steps forward into data collection and its analysis. One certain study by Adrian in 1990 has resulted into following facts about construction labor productivity[8]:

- Tuesday is the most productive day of the week.
- Friday is the least productive day of the weak.
- 10 AM is most productive time of the day.
- Time just before finishing is the least productive of the day.
- A laborer can lift up to 94lbs alone.
- A laborer doing a repetitive task has a tendency of lowering productivity after 60-70 minutes.

Other facts found about labor productivity are also important:

- Labor cost comprises of somewhere between 20-50% of the total project cost[9].
- Reduction of these costs can be carried out by increasing labor productivity[10].
- Construction productivity is traditionally identified as one of the three main critical success factors together with cost and quality for a construction project[11].
- Under normal prevalence, two major categories of variables that influence labor productivity exist: (1) nature of work to be done and (2) work environment factors[12].
- The subcontract labor achieved on an average 33% higher productivity than the directly employed labor[13].

2.4 Factors affecting productivity

Monumental research has previously been done on the factors that affect labor productivity. Factors numbering up to 40 factors have been defined which have popularly been noted as having an impact on labor productivity. These factors have been divided into many groups as per requirements by various studies. A study by Mahesh Madan Gundecha[4] has classified these factors into manpower factors, external factors, communication factors, resource factors and miscellaneous factors. He further goes on to find relative importance indices of these factors and has marshaled them according to these indices.

Another study has also ordered these factors by their impact on time overruns of construction projects. Based on the respondent's profile of the survey, the study makes three categories and has described which of the factors are thought to be contributing most towards the time overrun by Constructors, Consultants and combined[2]. An auxiliary study has defined 15 groups of factors that affect productivity and defined the top ten factors which affect (1) small and medium companies (2) large companies (3) in general all. The same study goes further and delineates the barriers in improving construction labor productivity and advocates 16 measures that help in gaining increased labor productivity on construction sites. Furthermore, categorization of these factors on the basis of countries has also been done which includes countries such as UK, USA, UAE, Singapore, Iran, India, Indonesia, Thailand, New Zealand, Malaysia, Gaza,Kuwait, Egypt, Uganda, Nigeria andTurkey.

Extensive literature view to find out these factors affecting productivity can result in discovering at least a total of 113 factors. These key factors affecting labor productivity can be accumulated from the works done by:

- Oglesby et al. (1989)
- Sanders and Thomas (1991)
- Thomas (1992)
- Langford et al. (1995)
- Motwani et al. (1995)
- Lim and Alum (1995)
- Baba (1995)
- Zakeri et al. (1996)
- Lema (1995)
- Kaming et al. (1997)
- Olomolaiye et al. (1998)

- Thomas et al. (1999)
- Makulsawatudom and Emsley (2002)
- Ibbs (2005)
- Hanna et al. (2005)
- Nepal et al. (2006)
- Khoramshahi et al. (2006)
- Enshassi et al. (2007)
- Alinaitwe et al (2007)
- Weng-Tat (2007)
- Hanna et al. (2008)
- Kazaz et al. (2008).

These accumulated factors have been summed up into 15 different categories based on their characteristics and comprise of a total of 115 factors. The grouping is as follows:

- Design (5 factors)
- Execution plan (5 factors)
- Material (8 factors)
- Equipment (6 factors)
- Labor (18 factors)
- Health and safety (4 factors)
- Supervision (6 factors)
- Working time (6 factors)
- Project factor (15 factors)
- Quality (3 factors)
- Financial (6 factors)
- Leadership and coordination (5 factors)
- Organization (12 factors)
- Owner/consultant (4 factors)
- External factor (10 factors)

The most recognized factors affecting productivity in industry worldwide are as follows:

- Overtime
- Morale and attitude
- Fatigue
- Stacking of trades
- Joint occupancy
- Beneficial occupancy
- Concurrent operations
- Absenteeism and turnover
- Mobilize/demobilize
- Errors and omissions
- Start/stop
- Reassignment of manpower
- Late crew buildup
- Crew size inefficiency
- Site access
- Logistics
- Security check
- Learning curve
- Ripple effect
- Confined space
- Hazardous work area
- Dilution of supervision
- Holidays
- Shorter daylight hours
- Weather and season changes
- Rain
- Shift work
- Working in operating area
- Over-manning
- Tool and equipment shortage

- Area practices
- Proximity of work
- Alternating/staggered/rotating work schedules

Drewings open construction conversion system which is applied to most of the construction operations can be used to model any construction process and the factors affecting its productivity. Through an open conversion system, it depicts the complex nature of a construction process by citing examples of categorized factors affecting the productivity. Moreover, it also models the feedback information flow of the process which can later on contribute to improved construction labor productivity. Thus, a practitioner can assess and control or improve construction labor productivity by understanding the factors that cause lower productivity. A diagram showing Drewin's open construction conversion system (Thomas et. Al 1990 p. 711) is shown which describe the progression of a construction process, the factors that affect it at any stage and the flow of feedback information:

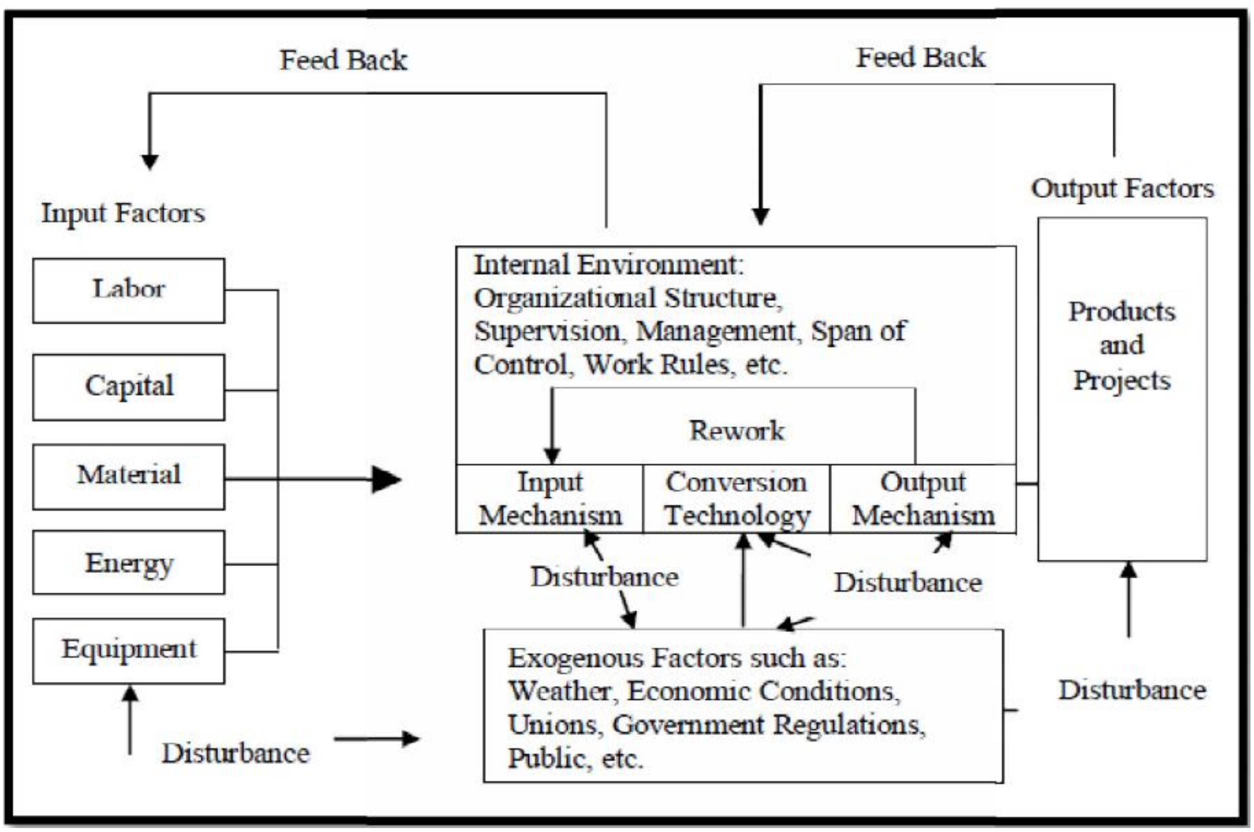


Figure 2-A Drewin's Open construction conversion system (Thomas et al., 1990, p711 with permission from ASCE)

Another technique to graphically show the factors affecting productivity and their groups according to the characteristics can be done using the fishbone diagram. In this particular study by Monaamee Hassan at civil engineering department at Alexandria University, he has grouped the factors affecting productivity in four categories:

1. Technological factors
2. Human and Labor factors
3. Management factors (between labor and materials)
4. External factors

These factors can be shown in following fishbone diagram:

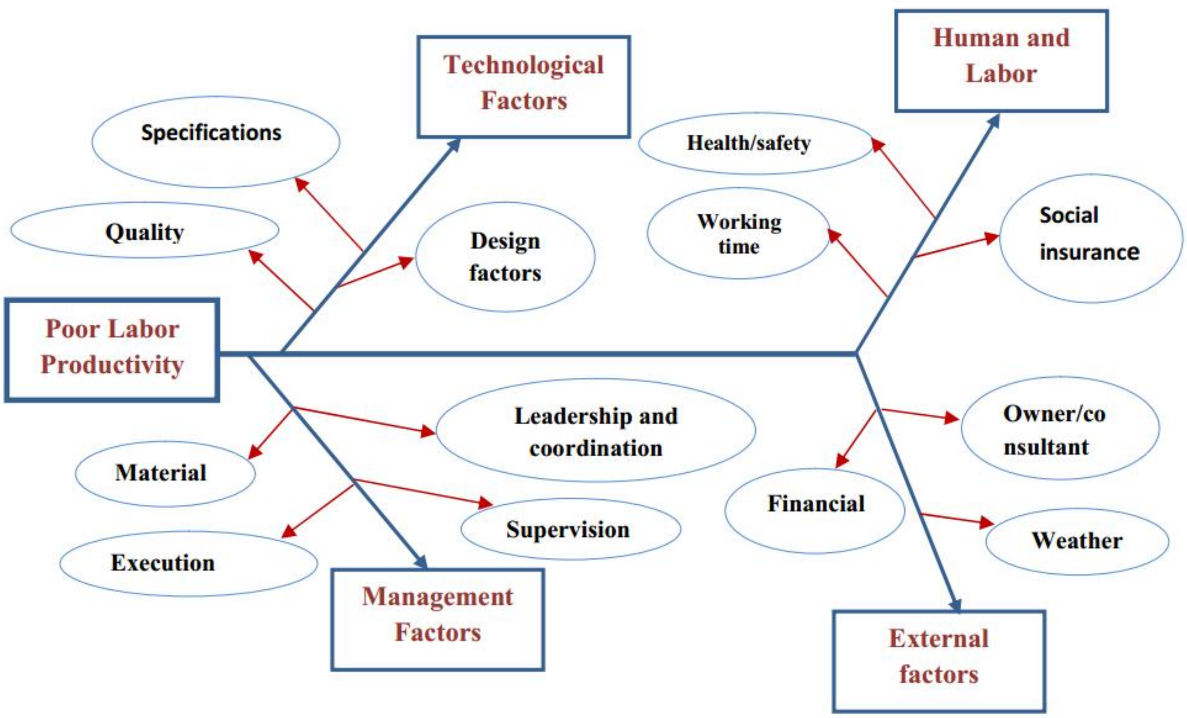


Figure 2-B

2.5 Crew Size Considerations about Labor Productivity

2.5.1 Accelerating an Activity/Project

Acceleration of a project is a recurrent routine in today's construction industry, where a contractor is forced to complete the project within finish date or sometimes even before completion date due to certain incentives. Project slippage a term that refers to a project running out of time and going beyond its expected finish date and it is not an uncommon phenomenon in civil engineering construction industry. A project may fall behind schedule because of various reasons. Late starts, delays like inclement weather, poor performance by previous work crews and additional work required to finish the project than expected or planned initially are some of the reasons why a construction project can run out of deadline. Another reason to accelerate a project if it is not delayed is the contractor's incentive to finish the project as early as possible. It can save costs to the contractor that are incurred due to equipment and labor that he has rented for the project. Furthermore, if the construction market is running good, a contractor might find a reason to finish present work earlier to start a new work and generate more profit. Hence there are certain reasons why a constructor would opt to accelerate a project.

Previous studies have shown that almost 75% of the construction projects that are on a delay are not given time extension[15]. Acceleration of a project is usually done by Schedule Compression. Schedule compression is defined as "a reduction from the normal experienced time or optimal time typical for the type and size of project being planned within a given set of circumstance" (CII 1990). According to a study more than 90% of projects relating to construction (electrical construction) have gone through schedule compression for their original or normal schedule. Two technical and legal terms are associated with schedule compression or acceleration namely mandated acceleration and constructive acceleration. Mandated acceleration occurs when the owner request has requested an earlier completion date than contractually agreed upon. Constructive acceleration occurs when the contract end date stays the same despite late start delay or increase scope, and the project has to be completed within the initially agreed end date. However both cases induce the same repeated response from constructors to accelerate the project. They tend to increase the on-site labor force, inclining them to work a longer time, implementing shift work, or increase the rate of project progress by adding more workers. Amid all these measures that can be carried out for acceleration of a project, the most common measure that the contractors, especially in Pakistan, has been known to take is the simple addition of more workers on the activities to increase the rate of progress[16].

2.5.2 Optimum Crew and over manning

Over manning refers to adding more workers to a jobsite than is optimal or typical for the type of work. Optimum crew can be defines as the minimum number of workers required to perform the task within the allocated timeframe. Optimum crew size for a project or an activity represents a balance between an acceptable rate of progress and maximum return from the labor cost invested[17]. As explained earlier, the most common way to accelerate an activity is increasing the number of workers on the site. This can be done in two ways: Firstly, add workers to existing optimal crew and secondly, increase the number of crews (multiple but identical crews). Increasing number of workers in an existing optimum crew is an easier and flexible way. Whereas, over manning by the second method is only possible when the task is big enough to accommodate the additional crews. Many studies do not differentiate between either of the methods used to increase the number of workers. With regard to other methods of acceleration of a project, over manning has an advantage over overtime and shift work in that it can produce a higher rate of progress without the physical fatigue problems associated with overtime and the coordination problems realized with shift works[3]. However, over manning causes a loss in productivity of the crew. As more workers are added to the optimum crew, each new worker will increase productivity less than the previously added worker. Carried to the extreme, adding new workers will contribute nothing to overall crew productivity[17]. Trade stacking is a term usually confused with over manning however, being different. Over manning differs from stacking of trades in that it considers only one trade while trade stacking deals with all the workers from all trades on the job site.

Other studies on over manning also consider the second definition of over manning: An increase of the peak number of workers over average number of workers of the same trade during project. These studies then also define productivity as the ratio between earned work hours and expended or used work hours[3]. Productivity on construction projects can be analyzed on a micro or a macro scale. A macro-analysis of productivity considers the project as a whole. While a micro-analysis looks at a specific activity of a project rather the whole project. Since it is difficult to quantify the impact of over manning on project as a whole through micro analysis, where productivity is measured by a time per unit production, macro analysis was adapted in many studies to determine the impact of over manning on labor productivity[18].

In order to consider different projects for studies relating to crew level losses in productivity and compare them, special considerations have to be given to how these projects are to be compared without providing any heed to differing characteristics of these projects. These characteristics include their geographical location, time of completion and their size. Hence, labor hour is used as a basis to compare all the projects which can now be combined into a single database. Resultantly, productivity loss and project size are defined in terms of labor hours rather than labor cost[3].

CHAPTER 3

3. Research Methodology

An extensive literature view about the construction labor productivity in construction activities has shown that an ample amount of studies have been carried out worldwide in many countries about construction labor productivity, as mentioned earlier in literature review. Most of these studies inquire about labor productivity in a qualitative manner. Many researchers have focused on the factors affecting productivity. Other studies determine the relation between cost and time overruns on projects due to decreasing productivity. These studies also categorize the factors that cause these overruns in order of their impact on construction labor productivity. Many studies have also been carried out to depict the variability in labor productivity on construction sites due to varying factors and changes. The common characteristic of most of these studies is that they take labor productivity as a quality of construction process. They generally don't measure labor productivity on site via measurement techniques. Only the increase or decrease in construction labor productivity is noted by changing the parameters and the results are jostled in the study. Many studies have been inquiring about construction labor productivity through questionnaires which they use to gather the impact of certain factors. These forms are sent to the people working on the field and the responses are analyzed and the results are hence published.

The scope of this project requires a thorough research of increasing or decreasing construction labor productivity on sites with varying the crew members. Thus, a quantitative analysis is the key to determine what crew is optimum for a certain activity going on the site that produces the optimum construction labor productivity. In order to gather such information, an extensive data collection is vital to learn the difference in construction labor productivity with different crew sizes. Furthermore, this data collection also realizes the need of a standardized system that we will use to collect data from the field. Hence the first practical step of this project will be to establish certain standards about construction labor productivity since most of the research has been qualitative in nature and what data we require for our project is purely quantitative; and too low a number of researches have been carried out in this field to set a precedent for us to follow when starting our data collection phase.

3.1 Measuring Productivity

To start with, even the basic definition of construction labor productivity itself is not standardized. The units have also not been defined and the option is open for anyone to use any units for his convenience as his study demands. So the first thing that needs to be done while carrying out this research is agreeing upon one definition of construction labor productivity. So, throughout the research, we will stick to the following definition of construction labor productivity described by Rowlinson and Proctor in 1999:

A perfect productivity (1.0) can be achieved with a 40-hour work week, with people taking all the holidays and vacation days as planned all of the engineering drawings would be 100% complete there would be no delays of any kind during 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)[7].

Next step, i.e. agreeing to a general from of units of construction labor productivity, also provided us with certain options and we chose to measure construction labor productivity in following units as described in (Modeling construction labor productivity, By H. Randolph Thomas, William F. Maloney, Members, ASCE,R. Malcolm W. Horner, Gary R. Smith, Member, ASCE,Vir K. Handa, Member, ASCE, and Steve R. Sanders):

$$\text{Labor productivity} = \frac{\text{Output}}{\text{Work-hour}}$$

Hence what we conclude from this definition of construction labor productivity is that we can use the units of outputs per unit of an hour. The outputs for this project will be the work accomplished by a crew for a certain activity. This work done will be measured in units of ft^2 m^2 m^3 etc. Hence we need to collect this information of work done in hourly intervals to see how a crew of a certain size is performing. The general units of the project will be in the form of **ft^2/hr** for an activity like plastering or painting in which we will be needed to measure the surface area. The volumetric measurements, however, will follow the trend of m^3/hr.

These standards have been selected for this project to measure construction labor productivity on site for a certain crew. All the units are consistent with this standard while the measurement phase of construction labor productivity, and the calculations and analysis also follow the same trend.

3.2 Data Collection

Setting the standards for measuring construction labor productivity leads us to consider other things that are needed to be taken care of for this project. Leading among them is what activities need to be measured for the measurement of construction labor productivity. Again coming to the very basics, this project focuses on construction **labor** productivity, while on a construction site it is not difficult to notice that many activities don't involve labor as primary source of input for the work being done. For instance, excavation for a mega project will take months if no machinery is used and hence construction machinery is a suitable alternative for such a task. Another example is carrying immense loads to the upper floors of high rise building which would also be a cumbersome process if cranes are not used. Such equipment intensive activities usually involve only the productivity of the driver and helpers which has very low chances of changing from the standards already defined. For example, productivity of driver for an excavator is taken as 50 minutes per hour. This time inherently includes the breaks for the drivers which have a very low chance of being overrun except in extreme circumstances. This project which is focused on labor productivity needs to consider only the activities which are labor intensive and the main variable in whose productivity is human. One can find many such activities going on in any construction site. After considering almost all pros and cons for choosing certain activities, following four activities are selected to evaluate the construction labor productivity for a crew on them:

1. Concreting
2. Block Masonry
3. Plaster
4. Paint

- **Concreting** is labor intensive activity that is vital to almost any construction process going on in any project these days. The abundance of this activity means that it will be easily available to measure on many construction sites even within one city only. Usually the concreting activity involves 4 kinds of craftsmen namely Mason, Helper, Carpenter and a Scaffold man. The units for this activity will be m^3/hr for any crew size.
- **Block Masonry** is also another major labor intensive activity found on construction sites. Being a developing country, the trend of using block instead of bricks is still in progress in Pakistan and this activity will be found only in the mega-projects and also only in the major cities of Paksitan like Islamabad, Lahore etc. However, we expect to find sufficient

sites using block masonry in Islamabad. The units will be ft^2/hr. The typical crew for this activity will comprise of masons and helpers.

- **Platering** is also a labor intensive job. However, it is much simple to carry out than concreting and block masonry both for the crew doing it and the ones taking measurements of how much work has been accomplished in an hour. The typical units will again be ft^2/hr and the crew will comprise of helpers and masons, too.
- **Painting** is also a simple but totally labor intensive activity. Only helpers and painters will be comprising the crew and the units will also be the same of ft^2/hr. The simplest activity in the project which is chosen to easily depict the practical impact of this study as the change/decrease in construction labor productivity for painting will be more evident and understandable than for a complex activity like concreting.

A vast and extensive research needs to be done for this project and numerous site visits are required to gather the data. Considering that there are a total of 115 factors affecting construction labor productivity, which are always different on different sites and different locations, we need to collect such an amount of data that will aggregate the effect of all these individual factors. For example, we can consider that the highest productive time of the day is 11 AM to 1 AM as described above, and just before a break or end of the day construction labor productivity falls rapidly. We also have to consider that this trend may not be followed universally because of changing conditions on every site and location. Moreover, in certain cases certain activities may not be carried consistently for 8 hours of a workday, rather they are bound to change due to site and work requirements and conditions. These considerations lead us to believe that we may have to collect the data for an activity for a whole day in order to mitigate the increase/decrease of construction labor productivity depending on hour of the day or the hour before or after the break.

Before setting out for the data collection, a standard form needed to be established and followed throughout the study for collectio0n of data. The form required different fields like site name, crew size, activity, date etc. and it needed to enquire about the hourly construction labor productivity for the given crew for the duration of a whole day. A form was needed also because we needed to send the format of data collection process to people in other cities to get them to fill it for us. We designed and finalized the following form before setting out for the site visits:

Table 3A Form used for data collection

Plaster Productivity				
Project	NLC Askari X Housing, Lahore			
Activity	Wall Plaster			
Condition				
Date	XX/YY/ZZZZ			
Crew Size	Masons	X	Helper	X

Time		**Work Done**
8:00 AM	9:00 AM	
9:00 AM	10:00 AM	
10:00 AM	11:00 AM	
11:00 AM	12:00 PM	
12:00 PM	1:00 PM	
2:00 PM	3:00 PM	
3:00 PM	4:00 PM	
4:00 PM	5:00 PM	
	Average	

After understanding that a lot of data is required, which will be difficult to gather for us, it was decided to split the data gathering phase into three parts. The first part will consist of regular and abundant site visits to collect data personally by. We travelled to different sites in the city and also in other cities, visiting the sites that had the above mentioned activities going on. We split up on site and went to different places to find differing number of crew members in a crew on different activities. The visits provided us with the practical demonstration of how productivity varied with differing factors and what measures we could adopt to make our data collection as accurate as possible. In addition to it, the site visits also enlightened us on what factors might be the cause of decreasing productivity with increasing crew size. It also helped us realize how only the optimum crew size is the right way to carry out a job for best results of optimum construction labor productivity.

The second part was to approach people/organizations that have already undertaken such studies of measuring construction labor productivity on site and had the data matching our requirements. Unfortunately, such studies are not common in Pakistan and we could not find any organization that stored the works performed by a certain crew size for an activity, and that too for hourly durations of the whole day. However, luckily we were referred to students carrying such studies on construction labor productivity who could guide us to different sites that were suitable for our study and highlighted what we need to take care of while data collection phase. We also managed to secure some data from their studies which helped us in setting precedents on form development for the data and also described the range in which readings and measurements we will be expecting during our own site visits. It also helped us forecast what crew sizes we are going to encounter commonly on site for certain activities.

The third part was to approach people vie internet and e-mail to get them to send us the required data if they have already measured it for their study or to measure it right there and then for us. We requested engineers in different areas of Pakistan to collect the data. Such sites were as far off as Khushab, Gujranwala, Rawlakot, Lahore, Multan and Karachi. As already expected, not a very favorable number of responses were received since the data required a hectic process to collect and very less people took the initiative, but the data was enough for us to carry out our study.

3.3 Selection of Sites

After completing the initial requirements to set off on our data collection, next step was the tactical selection of sites. A total of six month period was available to us in order to gather the construction labor productivity data from the construction sites. Many construction projects are currently going on in Pakistan and also in Islamabad. Selection of sites was to be done on the basis of the current stage of construction going on them. We required concreting, block masonry, plaster and paint on these sites; therefore, we would need multiple sites which would be on multiple stages of construction. Concreting on sites is carried out in initial and middle stages where the foundations and frame of a building is being constructed. It is being done at different scales on different stages and can be found on sites at many different levels. Masonry starts after concreting has completed and is done in a single effort in a linear manner normally i.e. the crew carries out its job of block masonry when given the green light, and are independent of whatever is being done on other parts of building and they stop when the job is finished. Plaster is done when the building frame has completed and masonry has also been done, followed by painting. Hence, we expected plaster and paint to be found on sites which were on the later stages of construction.

We gathered all the construction sites of Islamabad and made a list of sites which were on a certain stage at that time. Accessibility to these sites was also an issue since many were located as far as 40km in the outskirts of the city i.e. World Trade Center Rawalpindi. Compiling all the sites and their stages and locations, we did our first site visit to Telenor Head Office, Gulberg Green, Islamabad; followed by many other locations. Following are the construction sites we visited to gather the data for our project:

- **Telenor Head Office, Gulberg Green, Islamabad** it is a mega project of Telenor Pakistan to construct its massive headquarters in Islamabad which will cost it $70 million. It will be an environment friendly building spanning an area of 150 kanals and housing almost 1100 employees. It will include amenities like gym, swimming pool, day care centers for employees etc. and other features that one usually associates with the Silicon Valley. Paragon Constructors (Pvt.) ltd. is constructing the headquarters.
- Mall of Islamabad, F – 11 Markaz, Islamabad
- House construction in G – 13/2
- House construction in G – 13/2
- NLC Army Housing Askari 10 Lahore
- Emporium Mall, Lahore The Universal Cinema, Emporium Mall, Hyperstar
- Superior College, Jauharabad
- UBL Building, Khushab
- Commercial Plaza, Jauharabad
- Parliament Lodges (Habib Rafique Limited)
- Construction of District Complex Rawalakot (Habib Rafique Limited)
- World Trade Center, DHA, Islamabad (Al Ghurair Giga)
- Ali Villas, Bahria Town, Islamabad

3.4 Important Considerations

Each and every aspect of the data collection phase of our project had to be critically planned and evaluated because of the nature of the study. We needed to study the differences in construction labor productivity that occur on the same activity with varying just the crew size. Hence the change in productivity was to be critically evaluated and studied in order to judge the correct trends of changes. In light of the literature view cited above, we knew what the governing factors which bring about a change in construction labor productivity were. We had to be vigilant about how these factors were affecting it and to be sure that their affects on these changes were aggregated when all of the data was to be compiled in a single database. We had to consider generally the following aspects while gathering the data:

- The sites selected would be using the commonly practiced methods of construction. For example, there are multiple ways of concreting which are practiced on construction sites in Pakistan and most of them involve a certain degree of mechanized process for it. Selecting the sites for concreting data was done in such manner to ensure that the all of the sites were roughly on the same level. As we have already discussed that contractor employed labor has different construction labor productivity than that of a hired one, we chose only the mega projects that involved only the contractor employed labor. Furthermore, collecting the concreting data was done from only the major constructors of the country which ensured at least some level of uniformity in the level of technology and mechanized equipment being used for the process.
- The scope of our project demands a varying crew size on sites with different number of labor and masons applied for a job. Special care was taken to take the data which included data points from as different crew sizes as possible on site. An adequate number of data points were required for each crew size. However, the odd crew size for any activity was not as easily available as the common crew size and the adequate number of extreme crew sizes was hard to match for some activities.
- A uniform number of data points were collected from each site and no one site was given extra value while collecting the data to keep the uniformity at balanced levels. A maximum of 5-7 data points were considered from each site and hence the averaged values of construction labor productivity was ensured.

- Different days of the week and different hours of a single day bring about different construction labor productivity, as previously mentioned. But when it comes to productivity it is the work done only in an hour regardless of which hour of the day is being considered. Hence we decided to take our data for all hours of a certain day and average it at the end to get the mean value of construction labor productivity prevailing throughout the whole day on the site. As regard to the day of the week we chose to randomly collect data on any day, rather than focusing on weekends and holidays. This would also provide us with averaged values of productivity that prevailed during a week instead of the unsymmetrical data we would be collecting if we focused only on certain days of the week.
- Concreting involved four craftsperson namely mason, helper, scaffold man and carpenter; whereas other three activities involved two craftsperson each namely mason and helper. In order to consider the crew sized construction labor productivity, we considered all four craftsperson of concreting to form a single crew and all two craftsperson of the other activitiesas another group. This was the crew size which we varied during our data collection.
- A total of about 115 factors affecting productivity have been defined so far which are known to have an impact on construction labor productivity. All of them are present on the construction sites one way or another. We were to focus on the change in construction labor productivity only because of the varying crew sizes and only those factors which the changing crew size inherently brought it with itself. Hence as a generic assumption we assumed that no factors affecting construction labor productivity are in play while we were collecting the data and we tried to ensure the data collection was done from least interfered processes in order to mitigate the effect of these factors.
- Block masonry is not a commonly found process in Pakistan as much of the country uses brick masonry these days, despite the increasing trend of block masonry. Only the largest of projects use block masonry which too are located generally in the cities like Islamabad and Lahore etc only. Selection of sites was done in such manner to include such sites for block masonry which could be easily accessible to collect the data. Telenor Head Office in Gulberg Greens, Islamabad and Emporium Mall, Lahore were the major sources of block masonry data that we collected.

3.5 Limitations

Considering that this type of study has not been carried out professionally in Pakistan, we had to apply certain limitations and narrow down the broad scope of the project in order for it to be simple enough to focus on only the major things. Since construction labor productivity involves human and human is the most variable input for a construction process, there were a number of limitations that we applied:

1. Factors affecting construction labor productivity are constant i.e. zero effect. It has been mentioned that there are different reasons for increase/decrease in productivity on site. However, we attribute the increase or the decrease in construction labor productivity caused in our data, only to the varying crew sizes and the factors it inherently includes. No other factors have caused such changes in productivity during our project.
2. Each activity on different sites has different crew sizes to do a certain job. These crew sizes include the optimum crew for a job, as well as bigger as and smaller than optimum crews for a job.
3. The mean value of construction labor productivity for a day provides the best approximation of the productivity that prevails the whole day. Similarly, mean values for all days of the week provides the best approximation of the construction labor productivity prevailing throughout the week.
4. We have standardized the definition of productivity and assume throughout the project that the definition holds perfect. However, in certain cases we noted that the work we sampled was not carried out on the same grounds.

CHAPTER 4

4 Analysis and discussion about results

The data collection was the longest phase of this project which lasted about four months. We gathered already collected data from previous and ongoing studies, collected it ourselves from the sites and also contacted other members of engineering and construction community to collect the mentioned data for us. We received about a total of 100 days of data for 4 activities, which was collected throughout the day for 8 hours. Each activity was studied for an accumulated period of 25 days and the works performed by a certain crew were recorded and compiled. Microsoft excel sheets were made to keep all the data in a single database and to perform further actions.

Below is a sample of the data received for an activity of Block Masonry. This data is collected from the Hyperstar Market being built near Expo Center in Johar Town Lahore. It involves a crew of 6 labors which includes 3 masons and 3 helpers. The work was sampled from 9AM to 5PM throughout and the work done in each hour is noted here in the months of October and November. This data shows us that a group of 6 labors working on block masonry under normal conditions produce a work of 28.5 sq-ft/hour.

Table 4- A Bock Masonry Productivity

Block Masonry Productivity				
Project	Emporium Mall, Lahore			
Size of Block	4"			
Total Quantity				
Date	18-Oct			
Crew Size	Masons	3	Helper	3
Time		**Qty(sq-ft/hr)**		

8:00 AM	9:00 AM	24
9:00 AM	10:00 AM	35
10:00 AM	11:00 AM	31
11:00 AM	12:00 PM	33
12:00 PM	1:00 PM	26
2:00 PM	3:00 PM	32
3:00 PM	4:00 PM	28
4:00 PM	5:00 PM	19
5:00 AM	6:00 AM	
	Average=	28.5

Such results from each site were received and compiled in a single sheet as a single database for each activity. This example here involves a typical crew size of 6 labors while other results have been received which involves crew size of 6, 8, 13, 14, 15 and 16 labors. For a typical activity of block masonry the numbers of responses for a certain crew size are as under:

Table 4B block masonry no of responses

Crew Size	**No. of Responses**
6	4
8	8
13	1
14	1
15	2
16	1

Similarly, responses for other activities with the varying crew size are as follows:

Table 4C no of responses for concreting

Crew Size	**No. of Responses**
9	2
10	5
12	5
13	4
14	5
15	3

Table 4D no of responses for plaster

Crew Size	**No. of Responses**

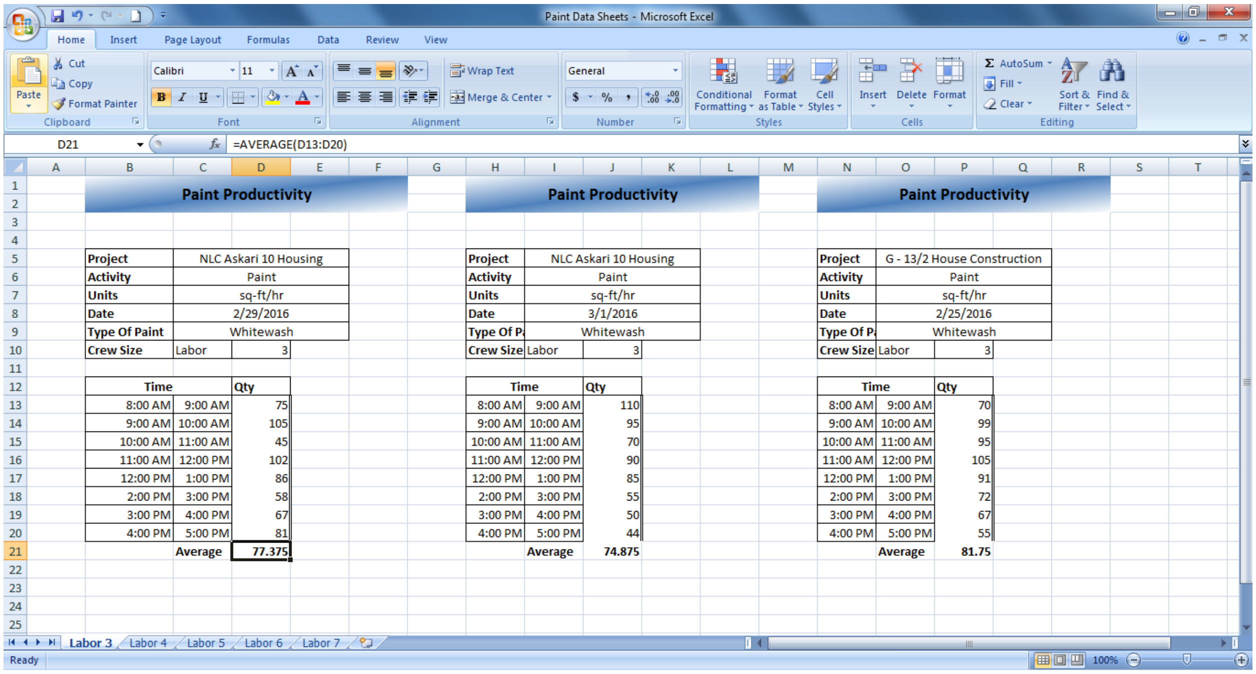
3	3
4	4
5	4
6	4
7	6
8	2
10	2

Table 4E no of responses for paint

Crew Size	No. of Responses
3	3
4	6
5	7
6	3
7	1

After receiving the responses and collecting them from the field, the data needed compilation so that each of the activity could individually be studied along with its crew sizes. Microsoft excel sheets were arranged for the individual activities showing the corresponding data, crew sizes with the productivity measured. Different tabs were made for different crew sizes and each tab contained all the data collected for a certain crew size. Following is a sample of how they were arranged:

Example: Paint Datasheet



Paint Productivity

Project	NLC Askari 10 Housing	
Activity	Paint	
Units	sq-ft/hr	
Date	2/29/2016	
Type Of Paint	Whitewash	
Crew Size	Labor	3

Time		**Qty**
8:00 AM	9:00 AM	75
9:00 AM	10:00 AM	105
10:00 AM	11:00 AM	45
11:00 AM	12:00 PM	102
12:00 PM	1:00 PM	86
2:00 PM	3:00 PM	58
3:00 PM	4:00 PM	67
4:00 PM	5:00 PM	81
	Average	**77.375**

Paint Productivity

Project	NLC Askari 10 Housing	
Activity	Paint	
Units	sq-ft/hr	
Date	3/1/2016	
Type Of P	Whitewash	
Crew Size	Labor	3

Time		**Qty**
8:00 AM	9:00 AM	110
9:00 AM	10:00 AM	95
10:00 AM	11:00 AM	70
11:00 AM	12:00 PM	90
12:00 PM	1:00 PM	85
2:00 PM	3:00 PM	55
3:00 PM	4:00 PM	50
4:00 PM	5:00 PM	44
	Average	**74.875**

Paint Productivity

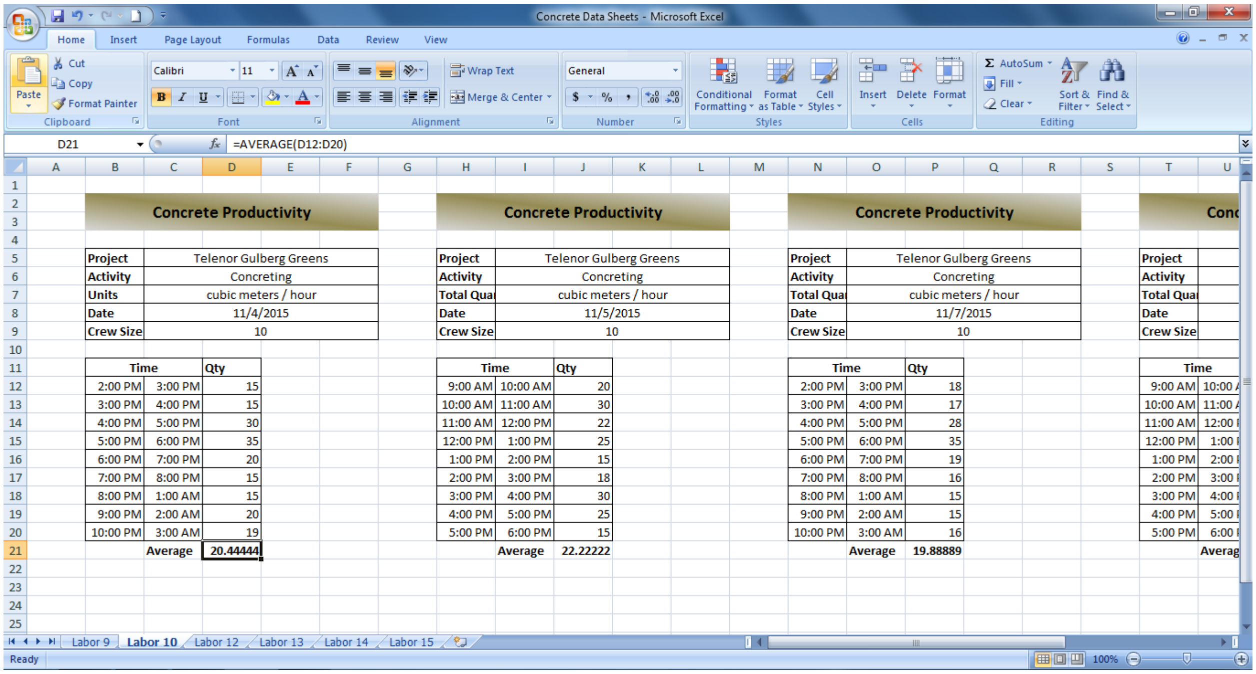
Project	G - 13/2 House Construction	
Activity	Paint	
Units	sq-ft/hr	
Date	2/25/2016	
Type Of P	Whitewash	
Crew Size	Labor	3

Time		**Qty**
8:00 AM	9:00 AM	70
9:00 AM	10:00 AM	99
10:00 AM	11:00 AM	95
11:00 AM	12:00 PM	105
12:00 PM	1:00 PM	91
2:00 PM	3:00 PM	72
3:00 PM	4:00 PM	67
4:00 PM	5:00 PM	55
	Average	**81.75**

Fig-4.1 Paint data sheet sample

Similar datasheets were developed for other activities namely concreting, plaster and block masonry.

Concreting datasheet



Concrete Data Sheets - Microsoft Excel

D21 =AVERAGE(D12:D20)

Concrete Productivity

Project	Telenor Gulberg Greens
Activity	Concreting
Units	cubic meters / hour
Date	11/4/2015
Crew Size	10

Time		Qty
2:00 PM	3:00 PM	15
3:00 PM	4:00 PM	15
4:00 PM	5:00 PM	30
5:00 PM	6:00 PM	35
6:00 PM	7:00 PM	20
7:00 PM	8:00 PM	15
8:00 PM	1:00 AM	15
9:00 PM	2:00 AM	20
10:00 PM	3:00 AM	19
	Average	20.44444

Concrete Productivity

Project	Telenor Gulberg Greens
Activity	Concreting
Total Qua	cubic meters / hour
Date	11/5/2015
Crew Size	10

Time		Qty
9:00 AM	10:00 AM	20
10:00 AM	11:00 AM	30
11:00 AM	12:00 PM	22
12:00 PM	1:00 PM	25
1:00 PM	2:00 PM	15
2:00 PM	3:00 PM	18
3:00 PM	4:00 PM	30
4:00 PM	5:00 PM	25
5:00 PM	6:00 PM	15
	Average	22.22222

Concrete Productivity

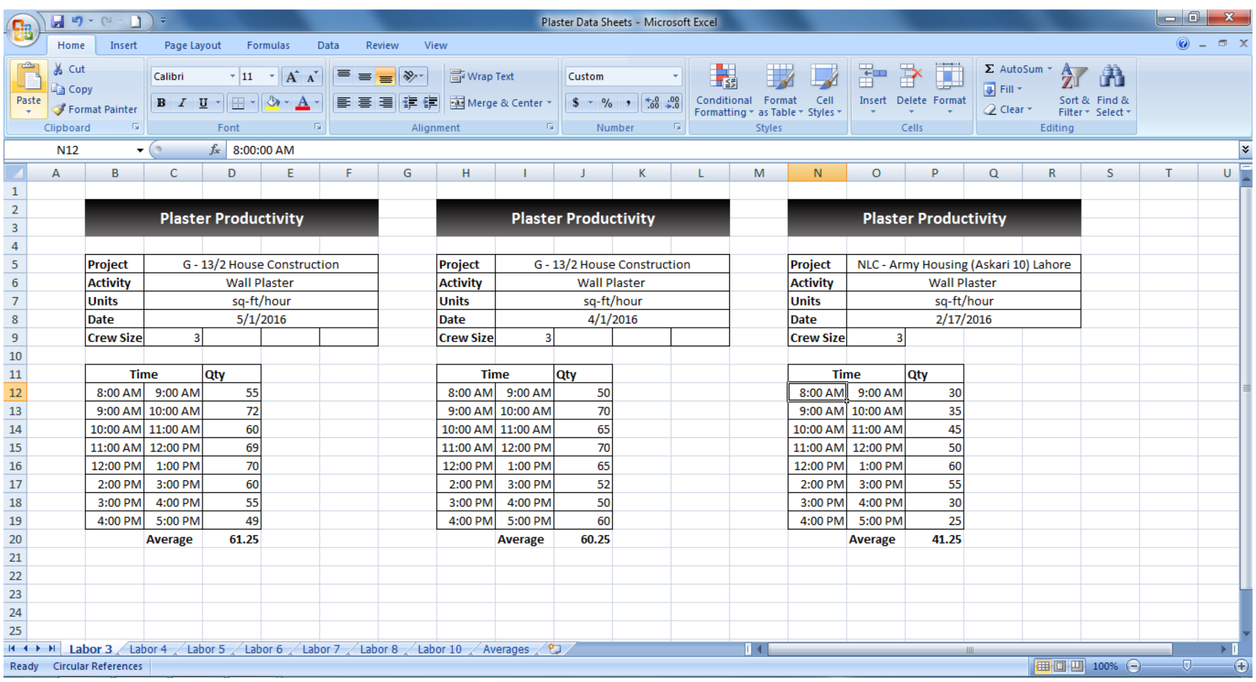
Project	Telenor Gulberg Greens
Activity	Concreting
Total Qua	cubic meters / hour
Date	11/7/2015
Crew Size	10

Time		Qty
2:00 PM	3:00 PM	18
3:00 PM	4:00 PM	17
4:00 PM	5:00 PM	28
5:00 PM	6:00 PM	35
6:00 PM	7:00 PM	19
7:00 PM	8:00 PM	16
8:00 PM	1:00 AM	15
9:00 PM	2:00 AM	15
10:00 PM	3:00 AM	16
	Average	19.88889

Labor 9 | Labor 10 | Labor 12 | Labor 13 | Labor 14 | Labor 15

Fig 4 -2 concreting data sheet sample

Plaster Datasheet



Plaster Data Sheets - Microsoft Excel

N12 8:00:00 AM

Plaster Productivity

Project	G - 13/2 House Construction
Activity	Wall Plaster
Units	sq-ft/hour
Date	5/1/2016
Crew Size	3

Time		Qty
8:00 AM	9:00 AM	55
9:00 AM	10:00 AM	72
10:00 AM	11:00 AM	60
11:00 AM	12:00 PM	69
12:00 PM	1:00 PM	70
2:00 PM	3:00 PM	60
3:00 PM	4:00 PM	55
4:00 PM	5:00 PM	49
	Average	61.25

Plaster Productivity

Project	G - 13/2 House Construction
Activity	Wall Plaster
Units	sq-ft/hour
Date	4/1/2016
Crew Size	3

Time		Qty
8:00 AM	9:00 AM	50
9:00 AM	10:00 AM	70
10:00 AM	11:00 AM	65
11:00 AM	12:00 PM	70
12:00 PM	1:00 PM	65
2:00 PM	3:00 PM	52
3:00 PM	4:00 PM	50
4:00 PM	5:00 PM	60
	Average	60.25

Plaster Productivity

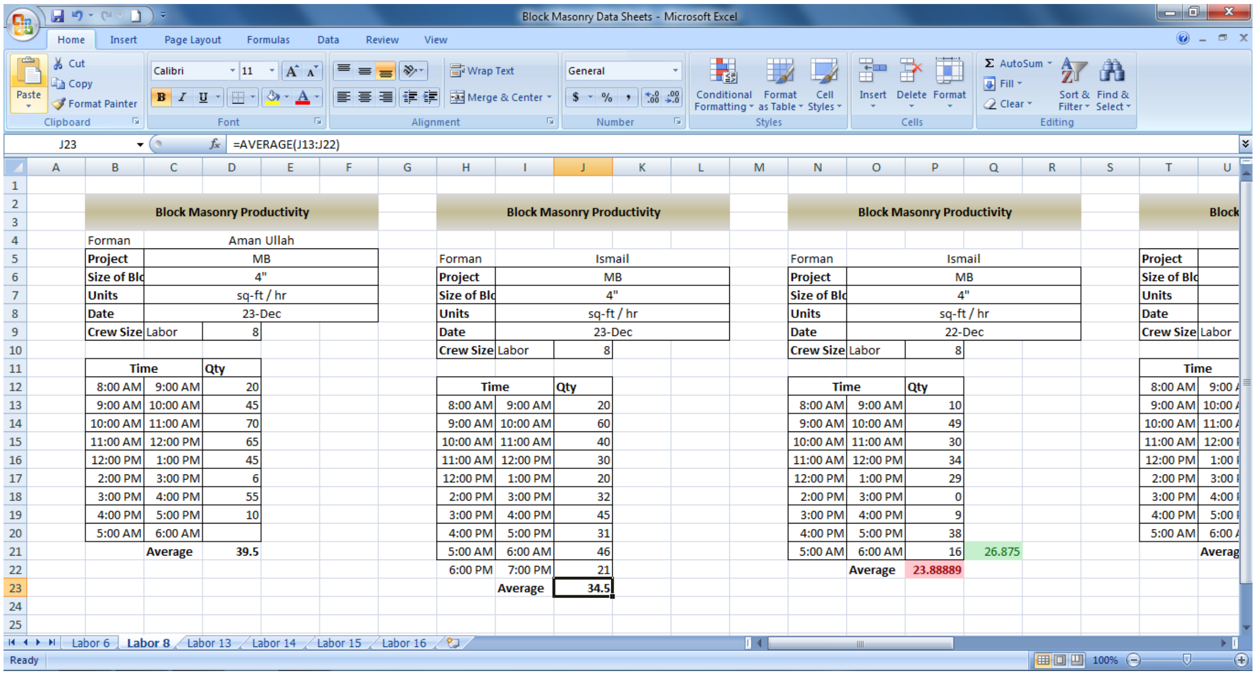
Project	NLC - Army Housing (Askari 10) Lahore
Activity	Wall Plaster
Units	sq-ft/hour
Date	2/17/2016
Crew Size	3

Time		Qty
8:00 AM	9:00 AM	30
9:00 AM	10:00 AM	35
10:00 AM	11:00 AM	45
11:00 AM	12:00 PM	50
12:00 PM	1:00 PM	60
2:00 PM	3:00 PM	55
3:00 PM	4:00 PM	30
4:00 PM	5:00 PM	25
	Average	41.25

Labor 3 | Labor 4 | Labor 5 | Labor 6 | Labor 7 | Labor 8 | Labor 10 | Averages

Figure 4-3 Plaster data sheet sample

Brick Masonry Datasheet



Block Masonry Productivity

Forman	Aman Ullah	
Project	MB	
Size of Blc	4"	
Units	sq-ft / hr	
Date	23-Dec	
Crew Size	Labor	8
Time		Qty
8:00 AM	9:00 AM	20
9:00 AM	10:00 AM	45
10:00 AM	11:00 AM	70
11:00 AM	12:00 PM	65
12:00 PM	1:00 PM	45
2:00 PM	3:00 PM	6
3:00 PM	4:00 PM	55
4:00 PM	5:00 PM	10
5:00 AM	6:00 AM	
	Average	39.5

Block Masonry Productivity

Forman	Ismail	
Project	MB	
Size of Blc	4"	
Units	sq-ft / hr	
Date	23-Dec	
Crew Size	Labor	8
Time		Qty
8:00 AM	9:00 AM	20
9:00 AM	10:00 AM	60
10:00 AM	11:00 AM	40
11:00 AM	12:00 PM	30
12:00 PM	1:00 PM	20
2:00 PM	3:00 PM	32
3:00 PM	4:00 PM	45
4:00 PM	5:00 PM	31
5:00 AM	6:00 AM	46
6:00 PM	7:00 PM	21
	Average	34.5

Block Masonry Productivity

Forman	Ismail		
Project	MB		
Size of Blc	4"		
Units	sq-ft / hr		
Date	22-Dec		
Crew Size	Labor	8	
Time		Qty	
8:00 AM	9:00 AM	10	
9:00 AM	10:00 AM	49	
10:00 AM	11:00 AM	30	
11:00 AM	12:00 PM	34	
12:00 PM	1:00 PM	29	
2:00 PM	3:00 PM	0	
3:00 PM	4:00 PM	9	
4:00 PM	5:00 PM	38	
5:00 AM	6:00 AM	16	26.875
	Average	23.88889	

Figure 4-4 block masonry data sheet sample

After converting all the raw data into the excel sheets, it becomes organized and is ready to be analyzed. The computations of averages and standard deviations and other processes are illustrated and explained in the next section where the graphs were developed in later stages and the results of the study are explained.

4.1 Statistical Analysis

The first step in analyzing the data thus gathered is the computation of original readings of productivity that we get. It is to be noted here that these readings depict the productivity of labor groups for each activity, for each hour of the day. But as has already been mentioned, these readings of construction labor productivity are not the actual representative readings of the productivity, since they are rapidly falling and rising from one hour to another. That is why we have taken the readings for whole day for eight hours. Hence they will be averaged for each day of each activity to get the true representative construction labor productivity of that group for the whole day. In this way we will get the mean values of construction labor productivity for all 100 days of the data collection. Furthermore, as has been shown in the Microsoft excel sheet, there are many data points which have been repeated during the data. For example, paint in this example, has been employing 3, 4, 5, 6 and 7 labors and each of them has farther 3, 6, 7, 3 and 1 data points. These data point will further be averaged to get the true mean of the construction labor productivity for any activity for particular labor. In this manner we will be able to reach the value of construction labor productivity against the crew size and hence arrive upon a conclusion.

As explained earlier, optimum crew is the crew for which we get the maximum productivity against that particular group size and no other group size will be able to provide the same high level of construction labor productivity for the same activity. This means we will be getting the optimum construction labor productivity individually for each activity.

Starting with the calculation of average daily construction labor productivity of a labor group, we calculate the mean from the excel sheets and is written on bottom of each day's reading. This is the representative reading of the productivity with which that particular group has been working for the whole day. The averaged productivities for these groups must also incorporate the standard deviations that we get for these readings. The standard deviations will be a measure of how far each reading is located from the mean. They will show us the extent of spread of data and its distance from the mean value. This standard deviation will help us in quantifying the amount of dispersion and spread of the data. The following data is gathered and means and standard deviations are calculated:

Table 4F Average and standard deviation of concrete data

Crew Size	Work Done (m^3/hr)	Standard Deviation
9	34, 23.22	7.62104
10	20.44, 22.22, 19.89, 24.44, 21.89	1.591
12	20.75, 26.11, 26.44, 21.89, 22	2.36124
13	26.75, 26.7, 24.9, 25.8	0.73485
14	29.14, 22.5, 23.1, 26.2, 28.1	1.62138
15	25.64, 28.182, 26.8	1.03788

Table 4g Block masonry average and standard deviation

Crew Size	Work Done (ft^2/hr)	Standard Deviation

6	23.143, 26.5, 26.625, 25.375	1.613
8	39.5, 34.5, 26.875, 29.33, 48, 24.28, 36.5, 25.5	8.995
13	61.715, 61.33	0.1795
14	35.75	---
15	28.78, 35	1.36
16	51.75	---

Table 4H plaster average and standard deviation of data

Crew Size	Work Done (ft^2/hr)	Standard Deviation
3	61.25, 60.25, 41.25	11.26
4	65.75, 59.25, 54.5, 61.375	1.04
5	42.22, 41.22, 45.75, 39.75	2.213
6	65.11, 59.125, 61.875, 65.11	2.502
7	83.66, 77.125, 68.33, 71.625, 65.75, 69.625	6.42
8	80.25, 89125	4.437
10	70.75, 80.25	4.75

Table 4J paint average and standard deviation

Crew Size	Work Done (ft^2/hr)	Standard Deviation
3	77.375, 74.875, 81.75	2.8419
4	159, 151.75, 159.75, 162.25, 141.375, 144.375	7.933
5	166.625, 177.125, 161.75, 148.25, 188.875, 151, 155.25	10.53
6	225.125, 221.25, 195.625,	13.08
7	415.625	---

4.2 Plotting the Curves

After calculations of averages and standard deviations and cropping the data which we deem is not required or has some uncertainty and errors we come to the final stage i.e. the graphs. The averaged daily construction labor productivity values are shown in the previous section for each crew size multiple times along with their standard deviations from the mean. These values are the multiple data points for each crew size and now we get the average of these values to get to a better and final value of construction labor productivity for a certain crew size. These averaged values that are the true representatives of the average construction labor productivity for each crew in each activity. However, as the data shows that increase in crew size is going to make an increase in the work being done. This happens because the number of people doing a certain task has been increased for that certain task. Hence work produced per unit of an hour will increase as a result of increasing the number of people doing it. But the trend of increase/decrease in productivity can't be established just by looking at how much they have accomplished. As a result, we have to come up with a more evident measure to judge the change in productivity with increasing/decreasing crew members.

For our project, we have divided the total work produced by a crew in an hour by their crew size. Doing that, we get the averaged units of work produced by each and every single of the member of the group. For our convenience and developing a notation for denoting this work done, we have called it the Individual Work Done/Hour Now we can tell by looking at their individual work done per hour that how the group as a whole has performed. For example, if a group of 10 crew members has produced 35 units of works combined in an hour and a group of 20 crew members have produced 65 units of work in an hour combined, we can't tell just by looking at their combined work done that how efficient the group has been and which one of them has work with a greater construction labor productivity. But dividing the work done by crew size of members, we get the individual work done by the members of each group. In this case, we get 3.5 units of work done individually by the first group and 3.25 units of work done by the second group by each member individually. This division leads us to see which group has done the same task more efficiently and what productivity changes have been during the work done. It is clearly evident that the first group has a more construction labor productivity of 3.5units/hr and the second group has a lower construction labor productivity of 3.25units/hour. Hence by considering the work done individually by each member of a crew, we can better check how much work has been accomplished rather than comparing the real work done by each group.

There is still a better measure of construction labor productivity we have used in this project which is the Efficiency of the crew members of a group. The group which has done the most work per individual is the group with the highest efficiency. We divide the individual work done of each group by the individual work done of the group with the highest efficiency. This way the most efficient group has an efficiency of 1.00 whereas other groups have efficiencies lower than 1. The benefit of taking the work done by a group to the efficiency score is that one can readily tell which group has been more efficient and hence worked with higher construction labor productivity.

Table 4K concreting efficiency

Crew Size	Work Done (m^3/hr)	Per Person Productivity	Efficiency
9	28.61	3.7777	1.0000
10	21.33	2.13333	0.5647
12	23.43	1.9525	0.51685

13	26.75	2.0577	0.5447
14	25.8215	1.8444	0.48823
15	26.9215	1.7942	0.47495

Table 4L Block Masonry efficiency

Crew Size	Work Done (ft^2/hr)	Per Person Productivity	Efficiency
6	25.41	4.235	0.892
8	33.06	4.1325	0.8705
13	61.715	4.7473	1
14	35.75	2.5536	0.5379
15	31.889	2.1259	0.4478
16	51.75	3.2344	0.68131

Table 4M plaster efficiency

Crew Size	Work Done (ft^2/hr)	Per Person Productivity	Efficiency
3	54.25	18.08	1
4	60.22	15.055	0.8327
5	42.23	8.446	0.4671
6	62.805	10.4675	0.5795
7	72.687	10.384	0.5743
8	84.6875	10.586	0.5855
10	75.5	7.55	0.4176

Table 4N Paint efficiency

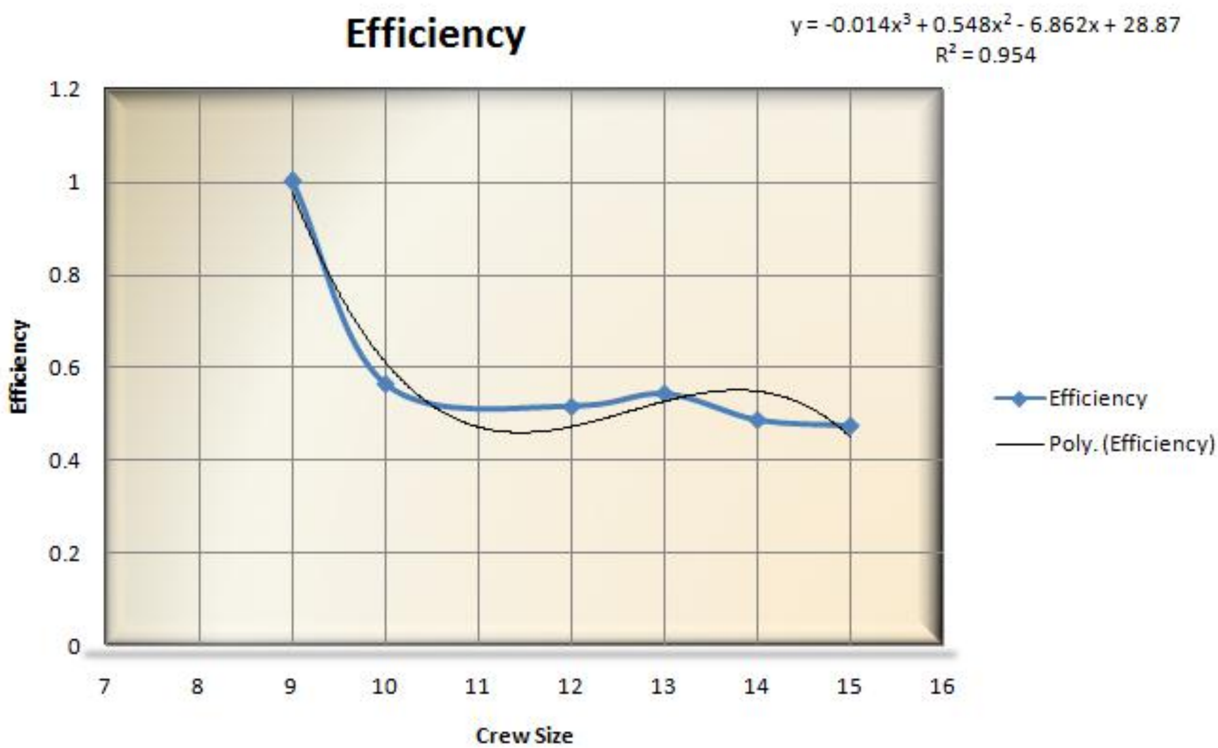
Crew Size	Work Done (ft^2/hr)	Per Person Productivity	Efficiency
3	78	26	0.4385
4	153.08	38.27	0.6455
5	165.604	22.1208	0.5587
6	208.21	34.7	0.5587
7	415	59.286	1

Using the above mentioned values in tables for each activity and each crew size, we have plotted the graphs for them. There are two types of graphs that have been plotted for each activity. The first type of graph shows what work done has been achieved in an hour for a certain crew size. This work done is shown for its respective units which are cubic meters per hour for concreting (volumetric measure) and square feet per hour for block masonry, plaster and painting (area units). These graphs show the trends of works accomplished as a whole group. For example, we expect a group of 16 people to do more work than a group containing 15 members. This graph tells us if this is really true in the field or not. As we can see from the graphs it is mostly true, however we can also find certain cases where a group of lesser people has done more cumulative work actually than a group of more people. This deviation is attributed to the factors affecting construction labor productivity which are dominant in those conditions.

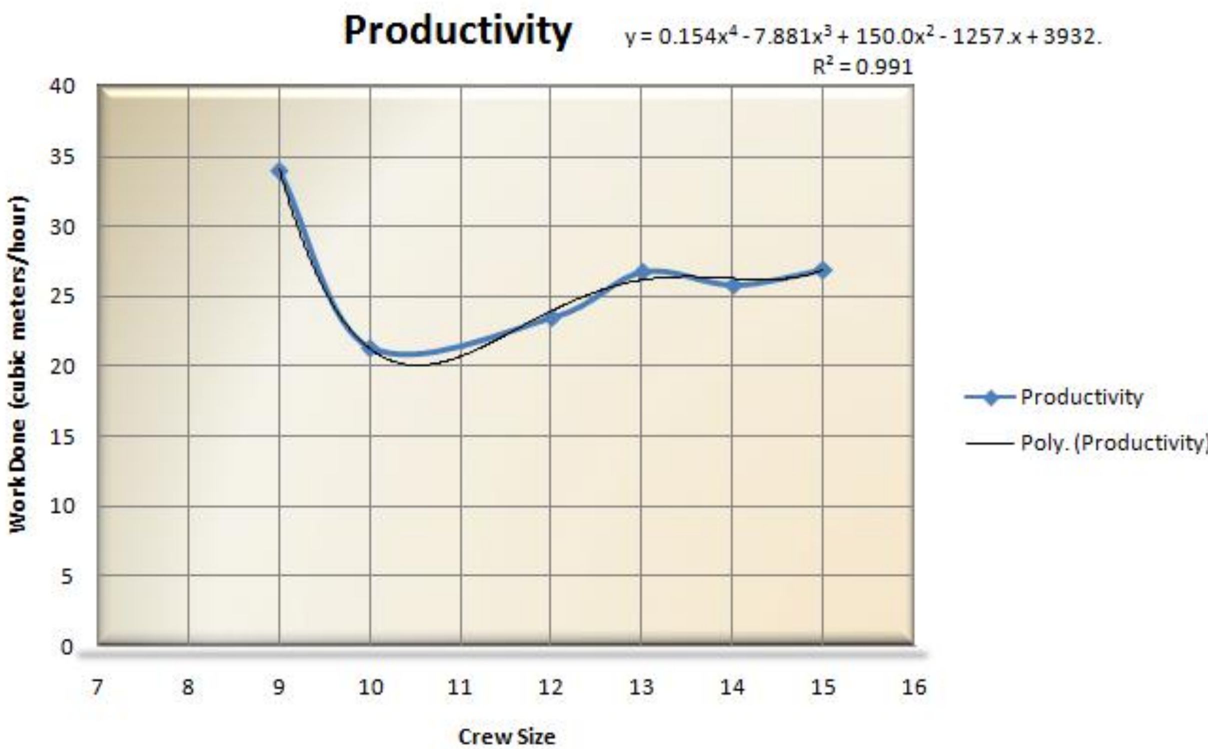
The second type of graphs shows us the efficiency of the individuals in a certain group. Our scope focuses on this efficiency. We believe that as we increase members in a group, we reach an optimum point of maximum efficiency which begins to decrease with every next members added to the group. Hence increasing the members of a group does not necessarily imply a more work done as the individual people perform lesser due to certain factors discussed in the next section.

Graphs

1. **Concreting**

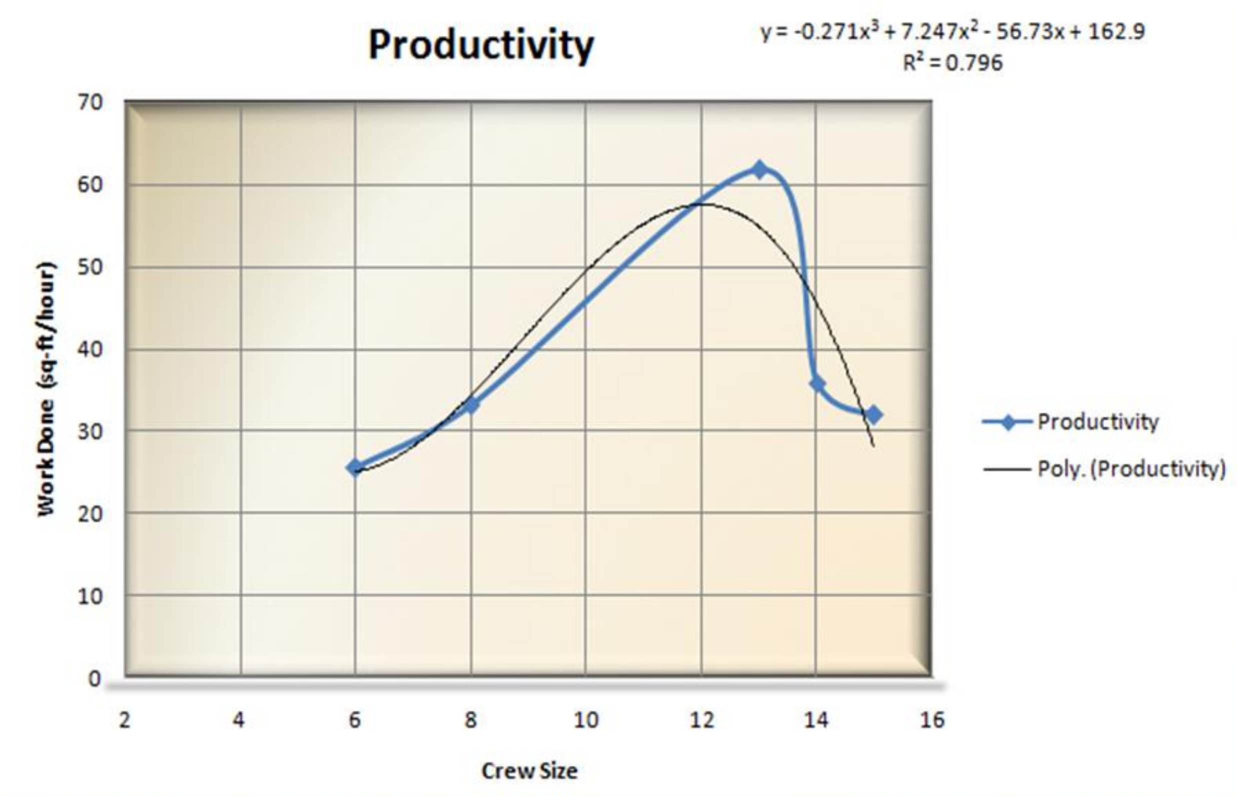


Graph 1 Concrete efficiency curve

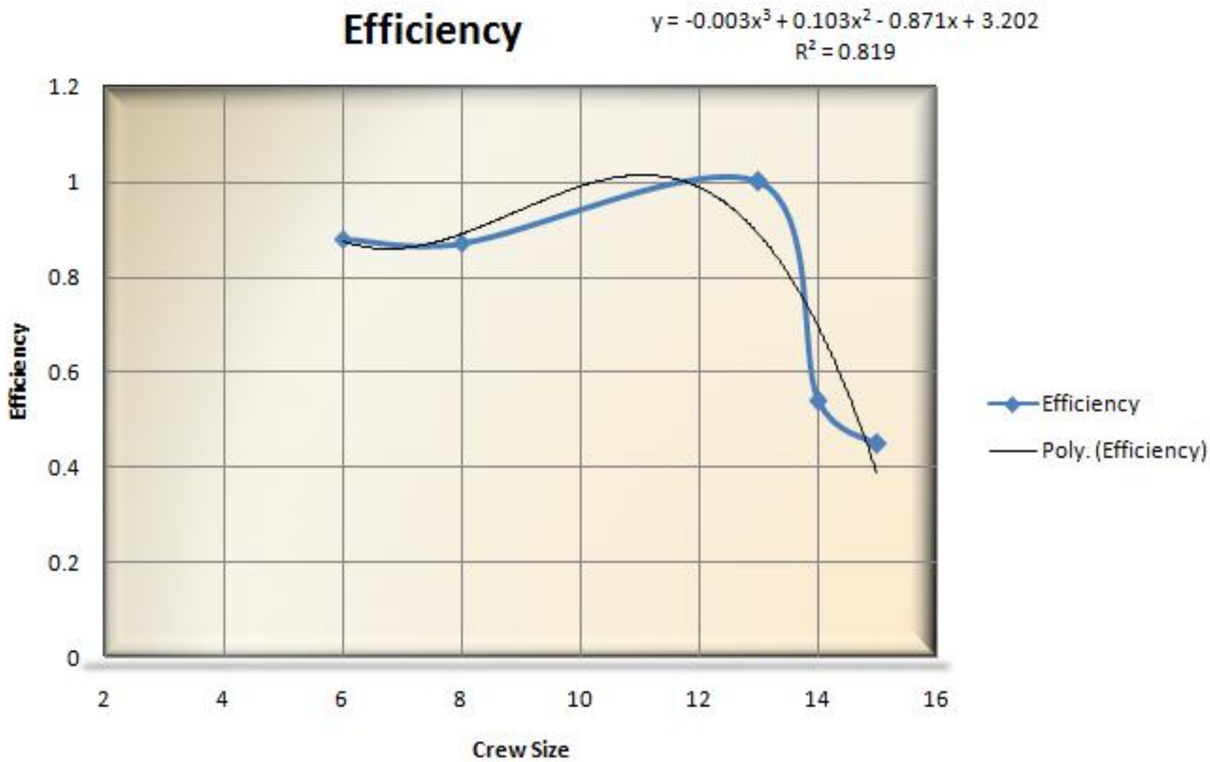


Graph2 Concrete productivity curve

2. Block Masonry

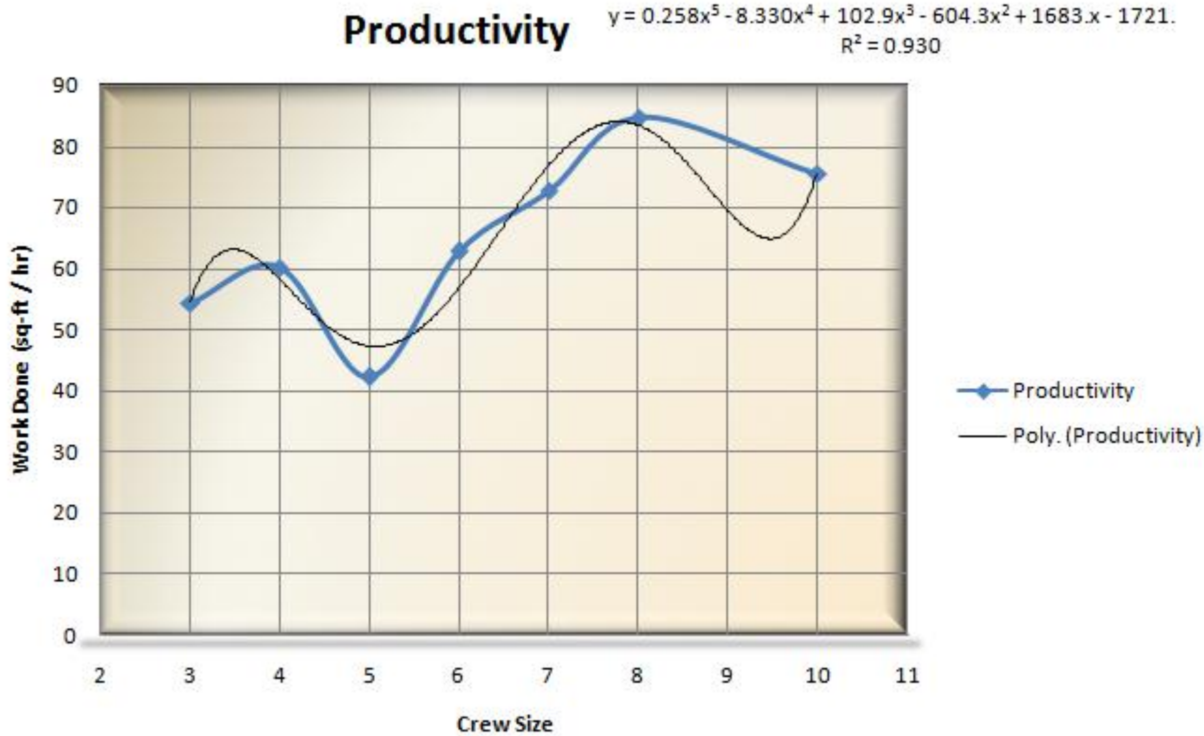


Graph3 block masonry productivity curve

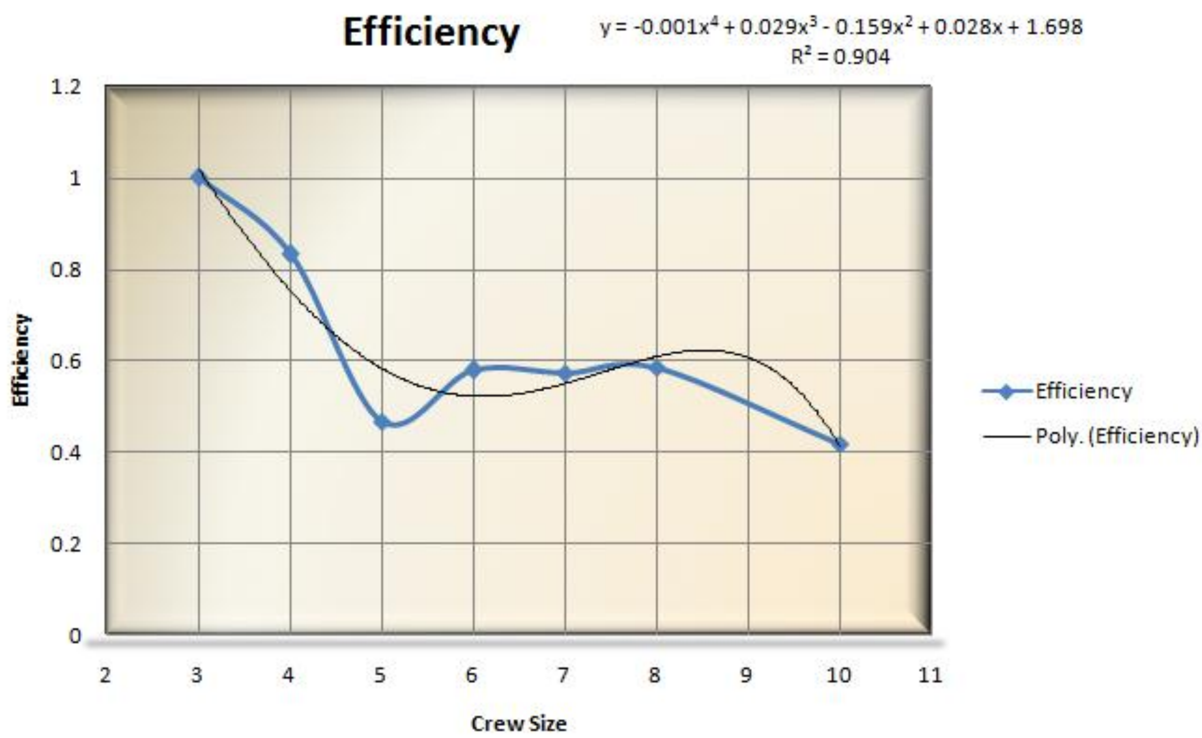


Graph4 block masonry efficiency curve

3. Plaster

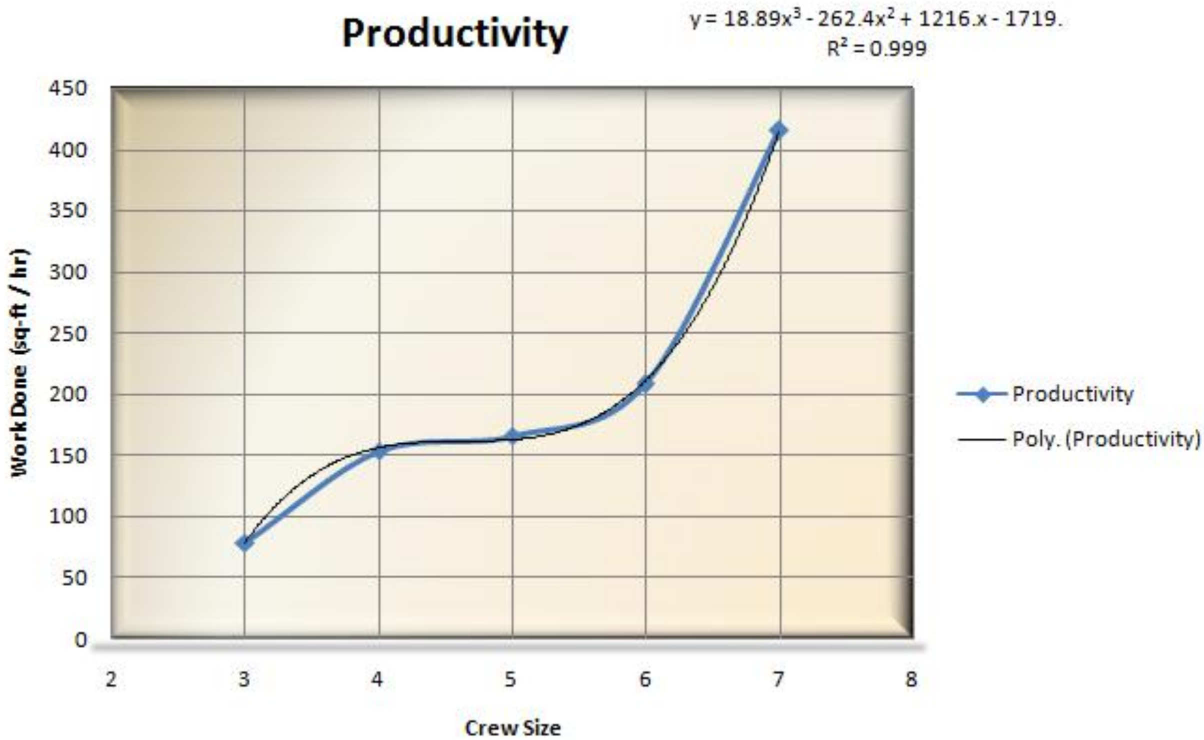


Graph 5 Plaster productivity Curve

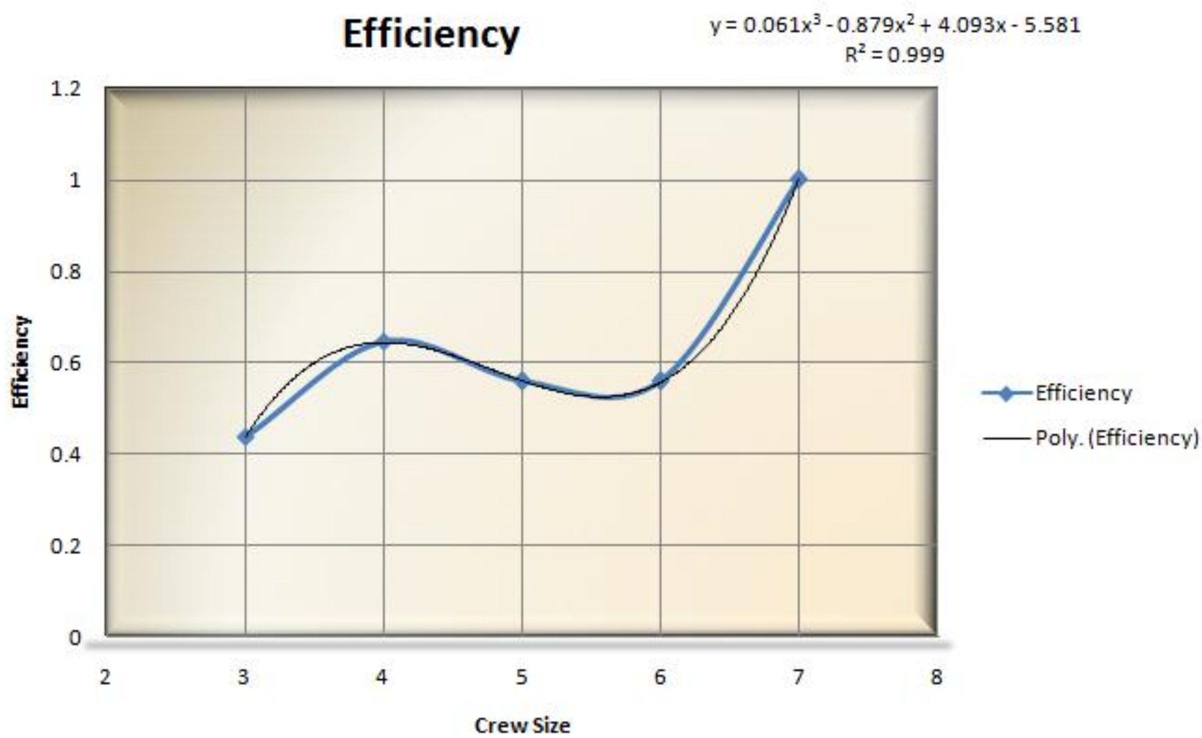


Graph6 Plaster efficiency curve

4. Paint



Graph 7 Paint productivity curve



Graph 8 Paint Efficiency curve

4.3 What do the graphs tell us

1. ***Concreting***

Concreting is a complex activity. It almost always involves an extent of mechanization in it. The extent of mechanization depends upon the type of project, finances, desired quality, and amount to be concreted etc. We have collected our data from mega projects as well as normal house construction sites. The trend that the plot shows is that while employing 9 labors in an activity, the amount of concreting done is very high. As far as our scope is concerned theoretically, this would hold true. As we move from the papers to the practical world at site, this becomes an anomaly because how can 9 labors ever produce more work than a group of 15 labors. To explain this behavior, it is to be noted that all of the other crew size readings have at least 3 or 4 data points which have been averaged to get their corresponding points on the plot. In case of 9 labors, however, we could gather only a single data point besides our best efforts. As far as concreting is concerned, the contractors normally apply a high number of labors and this particular crew size is hard to find at any construction site where normal methods are being used. The sites where 9 labors are working on a concreting job at a mega project, usually has abnormal working conditions therefore taking data from such a site will definitely cause a variation in the whole database. The extent of concreting may be less at such a place, or the availability of materials or equipment on such place is dependent on another concreting site which is of more importance, hence the collection of data from such a point would have been injurious to this project.

However the reason for such a steep peak of the curve at 9 labors is the mutual independence of their work. As already mentioned concreting is a complex activity and is simple to execute with a simpler crew rather than a large one for such sites which do not necessarily require a very large crew. Involving more and more people on such works would cause a troublesome scenario, where scarcity of equipment and tools, regular collision of workers, hindrance in reaching from the concrete supply point to the dropping point for the workers etc may cause a decrease in work being produced.

Moving past this peak at 9 labors, we can see that adding more people has resulted more net work being produced. It is clearly evident from the graph showing the productivity that more work is being accomplished when we increase the workers from 10 to 14. However we see a slight decrease on 14th man being added but again an increase for the 15th member proves that adding more people to it would cause more work done.

The second graph showing the efficiency of members clearly shows that 9 people working on a jab can work better than more people. This fact is again attributed to the disturbances caused by more people on the site. Concreting is the job where the workers have to work on the floor where they are standing and hence more workers standing are definite to cause more hindrance to the workers nearby. Moving on to the next crew sizes, we note that not much of increase in construction labor productivity is evident as we keep adding members to the optimum group. Hence we can safely say that fro this data, the optimum crew for concreting with maximum construction labor productivity is of 9 members with a construction labor productivity of 34 cubic meters per hour.

This is to be specially noted that adding more workers on a concreting job will definitely increase the per hour outcome of concreting as one can imagine. However what changes is that the work does not increase at the same rate that it should have been when another member of the group was added. The rate gradually declines with the addition of each next member to the optimum crew. Adding members into a group of 10 and taking it up to 13 members keeps the efficiency of the group somewhat in the same range. However as 14^{th} and 15^{th} members are added, the efficiency has again declined perhaps owing to the fact that addition of these people causes more hindrances in their own and other's work.

In the light of such graphs and the discussion above, it is advisable to use a crew of 9 members when concreting since it shows the maximum construction labor productivity for the group. The labor cost will be decreased following this instruction. However, adding more people will definitely accomplish more work at a slightly lower rate and the costs related to time will shorten. Depending on one's relation between time and cost, one can decide which size of crew is optimum for him, given the prevailing conditions for concreting.

2. *Block Masonry*

A CMU (Concrete Masonry Unit) also called a block is a relatively new technology in Pakistan. Mortar is used to join these blocks same as bricks, however the size of blocks is usually larger than a brick causing its handling and placing to be difficult and thus causing a decrease in productivity as compared to brick masonry. On the other note, since the blocks are larger than bricks, a certain wall can be made using less number of block layers than that of brick layers. Similarly lesser joints will be needed in case of blocks and causes the productivity to be more than that of the brick. The ultimate result depends on the size of the block used and seeing if the time is actually being saved or spent as compared to bricks.

A look at the graph of construction labor productivity for block masonry clearly establishes that a crew size of 13 is optimum for bringing about the maximum construction labor productivity for block masonry. However, again it is to be noted here that there is only one data point for a crew of 13 and this reading may not be as reliable as the other crew sizes. As has already been mentioned, finding different crew sizes was difficult for us hence only data point could be gathered for this crew. Other data points indicate that adding more workers into the crew will result into lesser work produced as compared to the optimum crew of 13 members.

As we see the efficiency of the crew in the second graph, it is clearly visible that a crew of 13 members has performed the best in this activity. It can be seen that subtracting a member from the optimum crew will result in a decreased productivity as will the addition of a member. It clearly shows that the optimum crew is the best to do a certain task with best productivity. However if time constraints demand a higher crew size, the work accomplished will be more per hour for this activity but the rate of increase of this work will not be the same as should have been with addition of a member.

The second peak in the efficiency depicts that a crew of 16 will work better than a crew of 14 or 15. This change can be attributed to the type of worker added in the crew. For example, addition of a helper into an already stable group is not going to improve the work being done per hour. This may be case for crew sizes of 14 and 15 where the additional worker added might be helper. In such a case, it will be the number of masons that will bottleneck the construction labor productivity for block masonry. However, as the next mason is added to the crew the bottleneck of masons may be eased and the mason's addition may result into a greater amount of work produced. It is a viable philosophy for the fact that addition of 14th and 15th addition of member has resulted into lesser amount of work produced, however the 16th man has boosted up the work done. As the group has the ratio of masons and helpers stabled, the bottleneck of the absence of a mason has improved widely and the result is much better.

3. ***Plaster***

A short look on the graph of construction labor productivity of plaster shows that a group of 3 or 4 masons is a good group to carry plastering of a surface. Addition of a helper or a mason will result into bottlenecking the construction labor productivity and yield a lesser amount of work done. However as the group increase in size, the ratio of masons against helper loses its significance as the pool goes wide and the ratio does not change significantly with the change of a single man. Addition of the 6th man results in an increased work done owing to the more number of people doing the work.

This trend continues till the addition of 10th man. Construction labor productivity for plaster keeps on increasing with the increase of crew members. However the loss of work done by the addition of 10th member in the team may be attributed to the increased dependency of the crew on each other's movements, the hindrances in carrying out one's work, reduction of working space or simply overcrowding. Plastering is an activity usually done with a lesser number of workers as compared to concreting. Scaffolds have to be put in place where plastering is being done on a height where one's hand can't reach. Making the formwork and constantly changing it with the work done poses more dependency on other's work.

The efficiency graph clearly shows that a group of 3 and 4 members is ideal for plaster when the job suits these crew members. However if a greater number of crew members is required, the crew should not be avoided to have more than 8 members. A group of 6, 7 and 8 members has the second best construction labor productivity. Keeping the mason and helper ratio same is an issue in this activity also where one has to lookout how the group is composed. Otherwise the plaster activity shows a linear growth trend in general as long as overcrowding is not happening and the workers are independent of what other members of any group are doing.

4. ***Paint***

Paint is a very simple activity and generally shows a linear trend as the number of people is added. The efficiency also changes a little with changing a crew size. It is due to the fact that being a simple activity, the interdependence of the workers is the least of all the above mentioned activities. They only need one paint bucket and have to work on a site where all the other works of construction have completed. Hence adding more workers to the group will without a doubt increase the work being done. As far as the efficiency is concerned, adding more workers will increase it also since the factors that adversely affect the construction labor productivity are negligible here. No hindrance in work is to be expected when everyone has his area demarcated and no significant movements are required back and forth to carry the materials or the equipment. The only effects that increased number of people can bring are the building up of team spirit and adding more passion among the workers. Team work spirit is greatly enhanced as the group works together at only one job as compared to concreting where some part of the group prepares the material, other part handles and conveys material to the site and the masons that use it appropriately. Based on this discussion and the graphical trends shown, the maximum number of people, which in this case is 7 people, yields the best result for construction labor productivity regarding paint being a simple activity. Considering other factors, adding so many people which may cause overcrowding or any other such factors will yield poor construction labor productivity.

4.4 Predictive Models

4.4.1 Concreting

a. Productivity

$$y = 0.154x^4 – 7.881x^3 + 150.0x^2 - 1257.x + 3932.$$

$$R^2 = 0.991$$

b. Efficiency

$$y = -0.014x^3 + 0.548x^2 – 6.862x + 28.87$$

$$R^2 = 0.954$$

4.4.2 Block Masonry

c. Productivity

$$y = 0.232x^4 - 10.1x^3 - 0.159x^2 + 1026.x + 2405.$$

$$R^2 = 0.981$$

d. Efficiency

$$y = 0.003x^4 + 0.151x^3 + 2.353x^2 - 15.44x – 36.98$$

$$R^2 = 0.973$$

4.4.3 Plaster

a. Productivity

$$y = 0.258x^5 - 8.330x^4 + 102.9x^3 - 604.3x^2 + 1683.x - 1721.$$

$$R^2 = 0.930$$

b. Efficiency

$$y = -0.001x^4 + 0.029x^3 - 0.159x^2 + 0.028x + 1.698$$

$$R^2 = 0.904$$

4.4.4 Paint

a. Productivity

$$y = 18.89x^3 - 262.4x^2 + 1216.x - 1719.$$

$$R^2 = 0.999$$

b. Efficiency

$$y = 0.061x^3 - 0.879x^2 + 4.093x - 5.581$$

$$R^2 = 0.999$$

4.5 What are the limitations of study

Firstly all of the external factors were not considered in our study and were kept as same throughout our study. Some of the factors that can affect our productivity but were neglected are as follows

1. Working space => this refers to the available space on a specific site for the activity

2. Temperature and humidity => this refers to the external temperature and humidity of the surrounding's which varies from location to location. This can greatly affect the productivity of the work since the workers are directly affected by it. Also concrete setting depends on the external temperature and humidity.

3.Availability of funds => funds available vary from project to project. We assumed that we have funds available in all of our cases and study. Non availability of funds also on the site can vary the number of people deployed.

4.site location => site location can greatly effect the productivity as tough terrains where working is difficult can result in lesser productivity in those areas. Similarly a favorable terrain can result in higher productivity.

4.6 Problems

1. The number of sites available having the required stage of construction was quite difficult to find which were also in our locality
2. Sites of the same construction stage with variable number of labors were very difficult to find as we were unable to find sites nearby with varying laborers of the same construction stage
3. Also we faced difficulties in finding relevant links at those sites who would help us fill the data sheet regarding the activities since it was no possible to stay at the sites for many hours.

CHAPTER 5

5 Conclusions

From our graphs we observed different behaviours of each stage of construction. Thus we will have separate conclusions disccuesd for each stage of construction which will be related to the grapghs

Firstly we concluded that the optimum crew size for conrecting in our study came out to be off 9. This showed maximum productivity of 34 cubic meter/hour. The remaining trend showed an increase in productivity as our crew size was increased from 10 to 13 and onwards but from a lower value. Reason was that the 9 crew size was taken from a fast tracking project where shifts of labor are deployed so a higher productivity is achieved.

Secondly the block masonry showed an optimum productivity of 62 cubic meter/hour at a crew size of 13 after which the productivity decreased rapidly and it kept on decreasing on increasing crew size.

The plaster showed an increasing trend of productivity with an increasing crew size. In our research we had data up to a crew size of 8 and it showed the maximum productivity. Overall we concluded that the productivity increases with an increased crew size.

Paint also showed a similar trend of direct proportionality of the crew size with the the productivity.reason being the fact that it is an independent activity and does not get interrupted with an increased crew size. The more the crew size the more the productivity. In our case we got 410 square foot / hour with a crew size of 7.

5.1 Orientation of future study

For future study we would recommend the researchers to get more and more data from various sites so that the averaged value is more reliable.also we would recommend the factors effecting the productivity to be considered on the study of the producitivy since they exist in reality and are a very big factor being responsible for the producitivy

References

- Ameh, Oko John and Osegbo, Emeka Emmanuel (2011) *Study of Relationship between Time Overrun and Productivity on Construction Sites.* International Journal of Construction Supply Chain Management , 1 (1). pp. 56-67.
- Factors affecting labor productivity by Billal Malik (2016)
- Study of Factors Affecting Labor Productivity at a Building Construction Project in the USA: Web Survey by Gundecha, Mahesh Madan (2013)
- Understanding and quantifying the impact of changes on Construction labor productivity,Integration of productivity factors and quantification methods by Seulkee Lee
- Modeling the Variability of Labor Productivity in Masonry Construction by Rateb J. Sweis , Ghaleb J. Sweis, , Ayman A. Abu Hammad and Malek Abu Rumman (Jordan Journal of Civil Engineering, Volume 3, No. 3, 2009)
- Factors affecting labor productivity in gaza strip by, Adnan Enshassi, Sherif Mohamed, Ziad Abu Mustafa & Peter Eduard Mayer (Journal of civil engineering and management volume 13,issue 4,2007)
- “Labour Productivity Variability among Labour Force – A CaseStudy” by Anu V Thomas, J Sudhakumar. (The International Journal Of Engineering And Science (IJES)