MODELING AND PARAMETER RANKING OF CONSTRUCTION LABOR PRODUCTIVITY

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ABSTRACT

Modeling and Parameter Ranking of Construction Labor Productivity

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For having, both a qualitative as well as a quantitative analysis of various aspects of the topic, a field investigation spanning over eighteen months, for collecting actual data from on-going construction sites was carried out. The set of nine input parameters which is selected for this study is considered to be the one which causes short term or daily variations in productivity.

The entire analysis and experimentation can be divided into three main parts, those of modeling the phenomenon, ranking the independent variables in the order of their relative significance and determining and graphically depicting the exclusive influences of each variable on the output which is daily productivity of formwork installation operations.

Various neural network models under different paradigms and network settings were developed and compared for performances under the criteria of R^2, MSE and MAE. The best performing model of Back Propagation with modified learning rate and momentum was validated with data unexposed to the model.

Separate analyses for input parameter ranking were done by employing the fuzzy subtractive clustering, neural network analysis and stepwise selection procedure and their individual results were transformed into a final ranking

For representing productivity as a function of independent variables, one variable was varied at a time with others fixed at average value and predictions of out put obtained using neural network model. Mat lab was used for the two dimensional graphs and corresponding mathematical expressions.

AKNOWLEDGEMENTS

Numerous thanks are humbly offered to God who has made this possible.

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Lastly, I wish to deeply appreciate my wife and my two sons who stood besides me and endured hard times and inconveniences due to my involvement in this work as well as encouraged me to accomplish this goal.

Finally, I wish to dedicate this thesis to my parents whose perennial guidance and encouragement has always been a source of inspiration and initiation for me.

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NOMENCLATURE OF ABBREVIATIONS AND SYMBOLS

A_J^K	=	FUZZY MEMBERSHIP FUNCTION FOR INPUT VARIABLE 'J' IN THE RULE 'K'
A/E	=	ARCHITECT / ENGINEER
ADOPE	=	AUTOMATED DAILY ON-JOB PRODUCTIVITY ESTIMATION
AI	=	ARTIFICIAL INTELLIGENCE
ANN	=	ARTIFICIAL NEURAL NETWORK
ANOVA	=	ANALYSIS OF VARIANCE
Bldg.	=	BUILDING
BPNN	=	BACK PROPAGATION NEURAL NETWORK
BRT	=	BUSINESS ROUND TABLE
DF	=	DEGREE OF FREEDOM
d_f	=	DEGREE OF FREEDOM
DP	=	DAILY PRODUCTIVITY
E & O'	=	ERRORS AND OMISSIONS
Engg.	=	ENGINEERING
F	=	F-STATISTICS
F	=	FLOOR LEVEL
$F_{1-\gamma}$	=	CUMULATIVE F-STATISTICS
FL	=	FUZZY LOGIC
FRF	=	FOREMAN'S RESPONSE Form
F_α	=	CRITICAL VALUE OF F-STATISTICS TO REFUSE NULL HYPOTHESIS
G	=	GANG SIZE
GMDH	=	GROUP METHOD OF DATA HANDLING
GRNN	=	GENERAL REGRESSION NEURAL NETWORK
H	=	NULL HYPOTHESIS
H	=	PERCENT HUMIDITY
H_a	=	ALTERNATE HYPOTHESIS
IRC	=	INSTITUTE FOR RESEARCH IN CONSTRUCTION
k	=	NUMBER OF INDEPENDENT VARIABLES IN THE MODEL
kms / hr	=	KILOMETERS PER HOUR
L	=	PERCENT LABOR

M	=	WORK METHOD
m^2 / man-hr	=	METER SQUARE PER MAN HOUR
MAE	=	MEAN ABSOLUTE ERROR
MDI	=	MANAGEMENT DISRUPTION INDEX
MS	=	MEAN SQUARE
MSE	=	MEAN SQUARE ERROR
$MSE_{S+1(J)}$	=	MEAN SQUARE ERROR OF THE MODEL AT $(S+1)^{TH}$ STAGE WHEN 'J' PREDICTOR VARIABLE IS ADDED.
n	=	TOTAL NUMBER OF DATA POINTS OR INPUT PATTERNS
NECA	=	NATIONAL ELECTRICAL CONTRACTOR'S ASSOCIATION
NN	=	NEURAL NETWORKS
P	=	PRECIPITATION
p	=	NUMBER OF PREDICTOR VARIABLES
PF	=	PROJECT PERFORMANCE INDEX
PINN	=	PROBABILITY INFERENCE NEURAL NETWORK
Ppt.	=	PRECIPITATION
PR	=	PARAMETER RANKING
R^2	=	COEFFICIENT OF MULTIPLE DETERMINATION
r_a	=	HYPERSPACE CLUSTER RADIUS IN DATA SPACE
r_b	=	HYPERSPACE PENALTY RADIUS IN DATA SPACE
r_n	=	N^{TH} ORDERED RAW RESIDUAL
s	=	STANDARD DEVIATION ERROR
s	=	NUMBER OF PARAMETERS ALREADY IN THE REGRESSION ANALYSIS
SR	=	STATISTICAL REGRESSION
SS	=	SUM OF SQUARES
SSE	=	SUM OF THE SQUARED ERRORS
$SSE_{S+1(J)}$	=	SUM OF THE SQUARED ERROR OF THE MODEL AT $(S+1)^{TH}$ STAGE WHEN 'J' PREDICTOR VARIABLE IS ADDED.
SSR	=	REGRESSION SUM OF SQUARES
SST	=	TOTAL SUM OF SQUARES
SW	=	STEP WISE PROCEDURE
T	=	TEMPERATURE
t	=	T-STATISTICS

$t_{\alpha/2}$	=	CRITICAL VALUE OF T-STATISTICS FOR TWO TAILED TEST
TW	=	WORK TYPE
W	=	WIND SPEED
wh	=	WORK HOUR
y	=	VALUE OF INPUT VARIABLE
$\hat{y}$	=	PREDICTED VALUE OF OUTPUT
$\bar{y}$	=	AVERAGE VALUE OF OUTPUT
α	=	LEVEL OF SIGNIFICANCE
β	=	VALUE OF CO-EFFICIENT OF THE FIRST PARAMETER IN REGRESSION MODEL
β_k	=	VALUE OF COEFFICIENT OF THE K^{TH} PARAMETER IN THE MODEL
γ	=	SIGNIFICANCE LEVEL (STEP WISE PROCEDURE).
ε^{-}	=	ACCEPT RATIO
ε_{-}	=	REJECT RATIO.
η	=	SQUASH FACTOR
ϵ'	=	VALUE OF RESIDUAL
π_j	=	QUANTITATIVE INDEX

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CHAPTER 1

Introduction

1.1 Nature and Status of Construction Industry

Construction is one of Canada's largest industries. It is a huge engine that converts financial investments into physical assets such as houses, commercial buildings, industrial plants, roads, bridges, and other elements of general infrastructure.

Though construction industry is one of the largest industries of any country in the world, developed or developing; yet even in developed parts of the world like the USA, it is inevitable that the industry is troubled. Some of the reasons are outlined as under:

1) Construction industry's share of the gross domestic product has declined in the recent past.
2) Construction costs have increased more than inflation.
3) Construction industry accounts for a major portion of national fatal accidents.
4) Litigation expenses are increasing every year. (Michel, L. 1998).

Canadian situation isn't very different. The Canadian construction industry is highly fragmented and complex, marked with dwindling domestic market and declining productivity rates; it lags behind other industries in generating and adopting new technology (IRC 1986). Talking about developing countries, the situation is even worse. The construction industry with its complex and versatile nature when combined with a lack of appropriate techniques and technologies results in its inadequate performance of the industry.

Regarding the nature of construction industry it is found that variability has been a serious concern because of numerous reasons. These include the involvement of numerous activities interdependent to each other in a critical path, the involvement of various trades at the same place, unique requirements of each project with all of them to be executed in external conditions being exposed to weather.

Despite all the above, the construction industry has long been recognized for its immense competitiveness as well as for its numerous uncertainties. In an attempt to prosper and survive, many firms are beginning to explore alternative methods of increasing their competitiveness.

1.2 Construction Industry's Role in Economy

Changes in the construction activity affect other sectors of the economy through economic linkages, such as purchase of construction material and service industries, which are called backward linkages (IRC-1986). The changes in the construction activity will thus cause changes in output and employment levels in those industries producing construction materials and services. The impact of these changes will be amplified when they trickle down to those who supply raw or semi processed materials to the construction material manufacturer. The break up of overall construction cost is about 36% on material, 32% on labor, 17% on purchase of professional services, capital and other services, 5% on taxes; finally the profit /contingencies etc. account for the remaining 10% of the overall cost (IRC 1986).

Construction linkages can also mean the supply of its out put (buildings and structures) to those industries that use it as input. These types of linkages are called forward linkages (IRC 1986). Finally, linkages can be also be increased by investor and consumer spending induced by construction wage incomes .The total effect of these types of linkages is normally classified as the multiplier or ripple effect. Canadian input-output tables describing the interdependencies of various sectors of economy indicate that a dollar spent in the purchase of construction output will generate multiplier effect of worth of $1.83 in the whole economy (IRC 1986).

1.3 Labor Productivity – A Complex Variable

Over the past thirty years manufacturing has increased its productivity by more than 100% whereas construction is in decline (Briscoe 1988). Also, it is commonly acknowledged within the construction industry that labor productivity figures are highly variable, affected by such factors as the mode of employment, disruptions, overall task durations, length of the work day and labor composition. Owing to the above variability has been shown to be a key factor in the study of the behaviors of Construction Labor productivity (Lema & Price 1996).

Besides variability another attribute of construction projects is turbulence. This is caused by the number of variables involved, the labor intensive work, the unique character and the occurrence of unpredictable characters (Adriti 1985, Thomas et al. 1990 Horner & Talhouni 1995, Kaming et al.1996).

1.4 Labor Productivity in Construction

The vital importance of labor productivity in construction can be assessed through several criteria. For instance, contractors have often focused on labor productivity rates as the primary source of the overall success or failure of a project. Besides this, the contractors at the bid stage of the project are interested in knowing the site labor productivity figures, in order to estimate the likely labor cost for a particular task. Thereafter, if the contract is awarded to the contractor, the company needs to ensure that the estimated level of productivity is achieved

or bettered. Hence the more accurate the original data the more able the construction manager will be to:

1) Determine how effectively his or her projects are being managed.
2) Detect adverse trends quickly resulting in timely corrective action.
3) Determine the effects of the changed methods or conditions.
4) Identify both high and low areas of productivity and reason for the differences.
5) Compare the performance between sites.

Unfortunately, labor rates, though one of the largest and most important components of the estimate have also been historically the most inaccurate aspects of the estimating system. Therefore if a company wishes to reduce risk, increase profits or gain market share, there is a direct need within the firm to improve the efficiency and the accuracy of the methods used to gather this raw information.

1.5 Scope and Objectives

The principle objective of this thesis is to study on-site labor productivity of building construction through formwork installation operations and develop labor productivity models for formwork installation operations. The sub-objectives of this study are:

1) To review previous work on factors affecting construction labor productivity and the methods employed for modeling the phenomenon.

2) To develop structured forms for acquisition of data directly from project construction sites and to organize, analyse and prepare the collected data for later use in developing labor productivity models.

3) To identify the input parameters that significantly impact labor productivity on job sites and to rank these parameters based on their relative significance.

4) To study the impact of identified significant input parameters on labor productivity of form work installation operations and to depict their impact in graphical forms.

5) To develop labor productivity models of formwork installation operations using the data collected from construction sites, compare them and validate the one which performs the best.

1.6 Research Methodology

In order to achieve the above mentioned objectives the entire study that is conducted can be categorized into the following components;

1) Collection of actual site data through site visits as well as through accordingly designed data collection forms / templates. The data was collected throughout a period of eighteen months from two substantially large construction sites in downtown Montreal having the same attributes.

2) Transformation of data into formatted data points liable to be analyzed.

3) Data analysis and experimentation with the collected data for the purpose of determination of input parameter ranking according to their significance levels obtained through Artificial Intelligence as well as conventional techniques of

   - Artificial Neural Networks (ANN)
   - Fuzzy Logic (FL)
   - Statistical Regression (SR)

4) Evaluation of the effects of factors, influencing the productivity on short term or daily basis and giving graphical representation of the same for a qualitative illustration.

5) Development of productivity models using:

   - Artificial Neural Networks

   - Statistical Regression.

6) Comparison of the performances of various Neural Network Models under defined criteria, validation of the best one and comparison of the same with developed and tested regression model

1.7 Thesis Organization

Chapter 2 initially discusses some basic concepts and definitions, thereafter it is attempted to give a substantial review of the works and studies done so far on the concerned topics of factors affecting productivity. Following in the same chapter is a brief description of some of the conventional methods used for modeling labor productivity. The chapter concludes with a discussion on the applications of artificial intelligence techniques (AI) for productivity modeling with particular emphasis on neural networks.

Chapter 3 relates itself with data. The sources of data which are two under construction projects in the area of downtown Montreal are briefly described. The mechanism adopted for acquisition of data directly from site and its subsequent transformation and organization in sets of patterns to be analyzed, is explained thereafter.

Chapter 4 is the main core of the study. The daily labor productivity is modeled through two different theories, those of neural network and regression analysis. Various neural network models are developed apart from the one statistical regression model. After rigorous experimentation and trials with various neural network settings, the model found to be performing the best is validated through comparison with the regression model, which itself is validated with the data not exposed to it and later on its performance is compared with a developed and tested regression model. Further in this chapter, analysis is done for determining the parameter ranking (PR) of the involved input parameters influencing productivity is done. For more dependable and authentic findings, this analysis was done through three different approaches: those of neural network, fuzzy logic and statistical regression.

Chapter 5 is an attempt to extract out and represent the effects of the involved parameters on the daily productivity or to put it another way, the discounting of the effects of other than the parameter of interest is done through NN, thereby rendering the influence of only the studied parameter on labor productivity. Three

dimensional surfaces and two dimensional line and overlay plots of single or combinations of various parameters are presented to qualitatively represent the varying behavior of productivity as being their function.

Finally in chapter 6, the summary and concluding remarks are presented along with recommendations for further research.

CHAPTER 2

Literature Review.

2.1 Construction Labor Productivity

2.1.1 General

A multi aspect literature review was conducted focusing on the areas of interest i.e. labor productivity modeling and parameters influencing it. In this chapter, after discussing some basic concepts relating to labor productivity, an extensive review of the previous studies is done regarding the factors influencing productivity as well as the manner and extent to which they affect the output. This is followed by the review of productivity modeling techniques being employed and models developed so far.

2.1.2 Basic Concept.

Sometimes there are misunderstandings while interpreting the meanings of productivity. Analytically speaking it is neither a measure of production nor a measure of cost rather it is a component of cost. Also it doesn't measure the cost of a resource but the quantitative measure of the relationship between quantity of resources used and the quantity of output produced.

The basic formulation of productivity is very simple as it is the ratio of some measure of output to some measure of input. Again it is a measure of the

combined effect of the number of variables involved rather than the representation of efficiency in utilizing a particular resource.

Another misunderstanding arises when labor productivity is defined as the relationship between man-hours and work accomplished. Though it is a very useful and important approach yet only single output relates itself to a single measure of input and, therefore it doesn't equal performance (Alfeld, L. Edward 1988).

The perception of the concerned involved generates the different measures of productivity .The interpretation of productivity in terms of different ratios which relates output to any one of the inputs such as labor capital and material may vary to a wide extent. This is because each ratio is influenced by the volume and quality of other inputs employed and also upon how effectively they are being used.

Before turning towards the detailed definitions and the expositions of the techniques the most widely used formulations found in literature are stated below:

Productivity = Output ÷ Input ⇒ Output per unit of input.

An inverse form is also used:

Productivity = Input ÷ output ⇒ Unit Resource Requirements.

(Greenberg, L. 1973).

The above definitions were lately redefined more objectively as follows:

"Input divided by the output calculated over a finite time interval."

which is a Construction Industry Institute (Thomas and Kramer 1998) definition commonly called the unit rate and is more useful. The Business Round Table (BRT) defines productivity as:

"Out put divided by input",

this represents the owner's point of view (Chang 1991).

Different View Points Towards Productivity

Generally the following approaches are found when attempting to define productivity:

a) User Approach.

The user or developer tends to define productivity in terms of the value received for the dollars expended. This point of view seems to neglect besides the other things the time factor and other site conditions.

b) Designer Approach.

Designer tends to define productivity in terms of the man-hours required to complete a particular job. The definition neglects the cost factor and overlooks the quality of design which directly affects the site productivity.

c) Contractor Approach.

To a contractor, productivity should be measured as an out put of a piece of equipment or a crew of workers to complete a unit of construction.

d) Labor Approach.

Productivity is defined in terms of the wastages and inefficiencies on the job (Boyle, M.L. 1973).

2.1.3 Measurement Techniques.

The most widely used techniques found in literature, for productivity measurement directly through construction site involve the followings:

1) Field Ratings
2) Work Sampling
3) Five-Minute Ratings,
4) Field Surveys,
5) Foremen Delay Survey
6) Craftsmen's Questionnaire.

In addition to these, some other techniques more specified towards the certain aspects of productivity rate or comparison of productivity rates are:

THE METHOD PRODUCTIVITY DELAY MODEL.

Besides providing to the user, the measure of productivity, this model can also identify the sources of delay and their relative contribution to the lack of productivity (Dozzi 1993).

CHARTING TECHNIQUES — CREW BALANCE CHARTS.

It is a method of comparing the interrelationships between various crew members and equipments to carry out a task. This method is more suitably applied to cyclic tasks such as concrete pouring (Dozzi 1993).

2.1.4 Labor Productivity Standards.

Pertinent here is to mention the various standard labor productivity rates used as sources of making project cost estimates. Currently the following sources of standard rates are in practice.

1) RS Means—Building Construction Cost Data (For US & Canada).
2) Lansdowne's Construction Cost Hand book (For Canada.)
3) Hans comb's Yard sticks for Costing (For Canada)
4) Craftsman's Building Cost File (Basically for US but also concerns nine major Canadian cities).

Most of the above are based on the 16-Division Master Format System of Classification.

2.2 Factors Affecting Productivity.

Among numerous factors affecting construction labor productivity, some have long term effects, whereas others may only be influencing on short term and /or temporary basis. Apart from these some may not only be long term but may also have ripple effect.

Apart from the duration of effects criterion for a study, there is another criterion of the number of parameters studied. Many studies have focused on quantifying the effect of an individual factor on productivity. Weather conditions, overtime, learning curves, congestions of trades, over manning and change orders are the examples of such factors which will be explained with references in the pages to follow.

A few studies concentrated on the impact of multiple factors on productivity. The effects of six related variables on masonry productivity were included in the factor model (Sanders and Thomas 1993; Thomas and Sakarcan 1994). The effects of temperature, humidity and crew size were observed. The conclusion highlighted the relation between high productivity associated with relatively smaller gang sizes.

Since uncomfortable weather conditions negatively affect productivity, it has been the subject of study for several researchers. Koehn & Brown (1985)

reported that it is difficult to achieve efficient construction operations below -10°F and above 110° F (i.e. below -23.3 °C & above 43.3° C). They gave a tabular relationship to predict the construction productivity percentages as function of temperature and relative humidity. They also suggested that other factors such as task complexity, activity duration, labor skills involved and mental concentration should be considered when using the table. The productivity factors at a range of temperatures (-20 °F to 120 °F) at relative humidity of 60% is shown at Figure2.1.

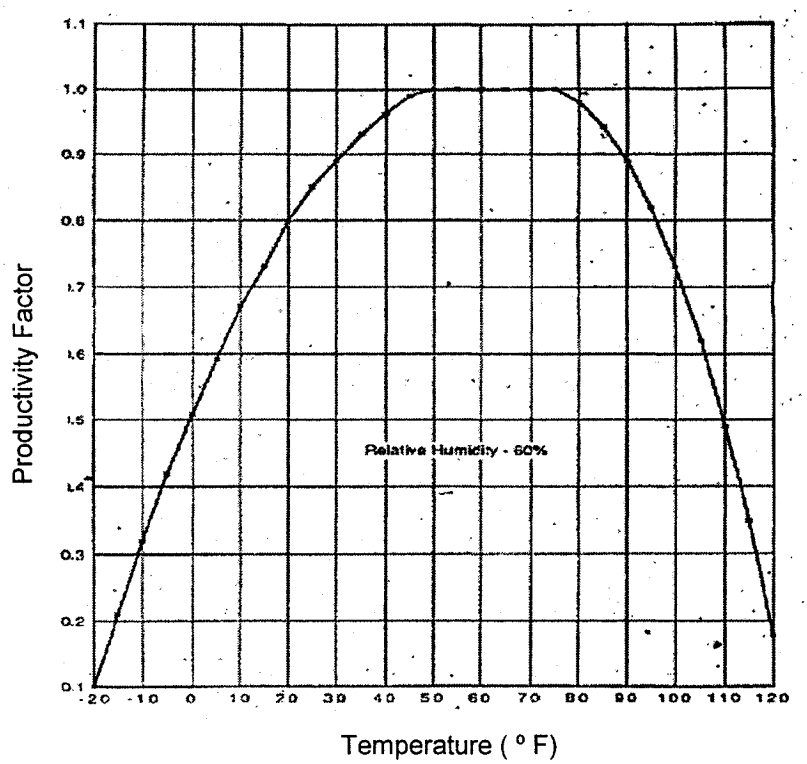


Fig: 2.1 Productivity Factors (Koehn's Model 1985)

In an another study, Thomas and Yiakoumis (1987) gathered data for the activities of masonry, formwork and structural steel tasks from three building

projects to model the effects of temperature and humidity on productivity. The conclusions of their study stated that changes of temperature from 13°C and humidity from 80% cause reductions in productivity.

The National Electrical Contractors Association (NECA) developed a table that shows the expected percentage of productivity for a corresponding temperature (°C) and relative humidity. (Dozzi 1993). Dozzi and AbouRizk (1993) stated that this table could be used for most construction tasks. They also reported that heat stress occurs between the following ranges:

- Temperatures over 120°F (49°C) at relative humidity 10%
- Temperatures around 88°F (31°C) at relative humidity 100%.

They also studied the effects of cold weather for gross and fine mason skills assuming 100% efficiency at 21°C.

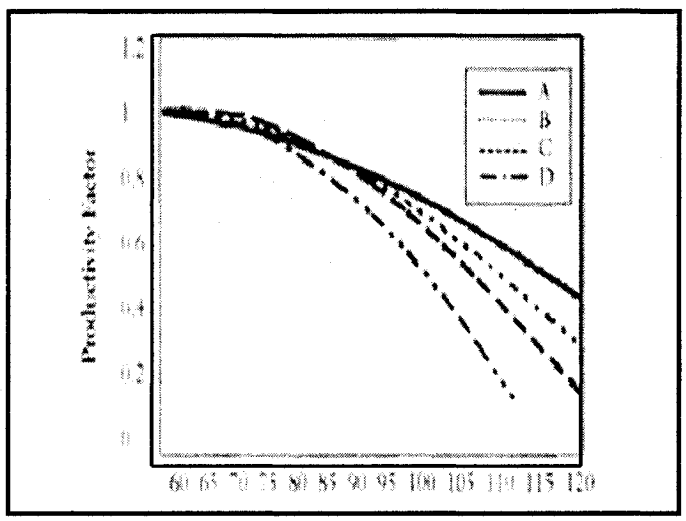
Hancher and Abd-Elkhalek (1998) also experimented to portray the effects of hot weather on construction labor productivity. First, they discussed the different types of heat indices used for studying the effects of heat strain on productivity. Thereafter some equations of productivity models for hot temperatures such as those of US Army Corps of Engineer's model, the Koehen and Brown Model and the Randolph Model were discussed.

Using the US Army Corps model they came up with the production factor curves for various tasks and degree of difficulties at a range of temperatures. The tasks

with their corresponding production curves are mentioned in Table 2.1, whereas the production factors for various production curves are given in Figure 2.2.

Table 2.1 Productivity Curves for Different Construction Processes (Hancher and Abd-Elkhalek 1998)

Construction Process	Prod. Curve	Construction process	Prod. Curve	Construction process	Prod. Curve
Excavation (manual)	D	Formwork (wood)	C	Masonry (external)	B
Excavation (Mech.)	A	Concrete reinforcement	C	Facade	C
Sheet Piling	B	Concrete Plac. (manual)	D	Painting (internal)	A
Water pumping	B	Concrete Plac. (mech.)	B	Painting (external)	C
Formwork (steel)	C	Masonry (internal)	C	Paving	C



Temperature in ° F

Fig: 2.2 Productivity Factors (Hancher and Abd-Elkhalek 1998)

Zayed (2004) has done a quantitative assessment for piles productivity factors where as Mohamed (2005) while emphasizing on the importance the affect of human thermal sensation on productivity has simulated the impact of thermal environment on labor productivity. A new regression model is introduced

reflecting the relationship between the thermal comfort index (PMV) and productivity. The above mentioned PMV index integrates the effect of all the main thermal environment variables, the nature of the construction task being performed; and the clothing ensembles worn by workers, into a single value.

Moselhi et al. (1988) while conducting a study on the major causes of impact on construction productivity due to delays and disruptions, listed on top, the factor of change orders. In a comprehensive field investigation during eighteen months, a total of ninety cases were studied, for two basic types of work. On the basis of the statistics obtained, the following ranking of the factors causing productivity losses related to change orders was established:

1) Timing of change order
2) Complexity of work
3) Processing time
4) Interdependencies
5) Intensity of work
6) Frequency of design E & O's
7) Contractor management.
8) Lack of A/E Supervision.

The histogram of the results is reproduced as under:

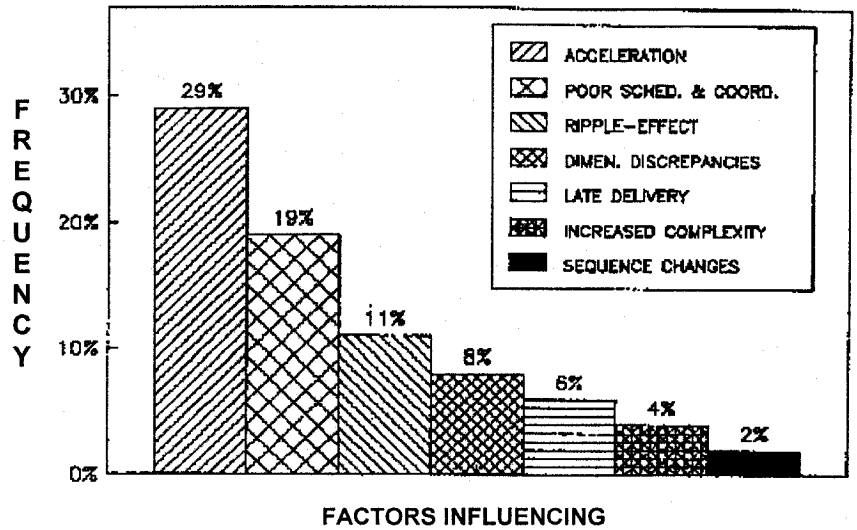


Fig: 2.3 Major Causes of Impact (Moselhi et al. 1988)

Investigating the effects of overtime also has been the core topic of research of a number of studies. It has been reported that a loss of productivity occurs when work is scheduled beyond eight hours per day or when it grosses more than 40 hour work per week. Overtime has also been found directly responsible for problems such as fatigue, demotivation, absenteeism, reduction of work space, increased accidents frequency and supervision problems (Thomas 1992). Leonard (1988) reported that the most commonly used indices to estimate the loss of productivity due to overtime are those prepared by User's Anti Inflation Round Table 1973.

As regards the theory of learning, a relatively older study states that when ever the production quantity of a crew doubles, the unit or cumulative average cost (hours, man-hours, dollars) declines by a certain percentage or by a cumulative average rate of the previous unit (Belakaoui et al. 1986). More recently Lam et al.

(2001) described the effects of both learning and forgetting in a repetitive construction activity. The learning and forgetting curves developed by them are reproduced in Figure 2.4.

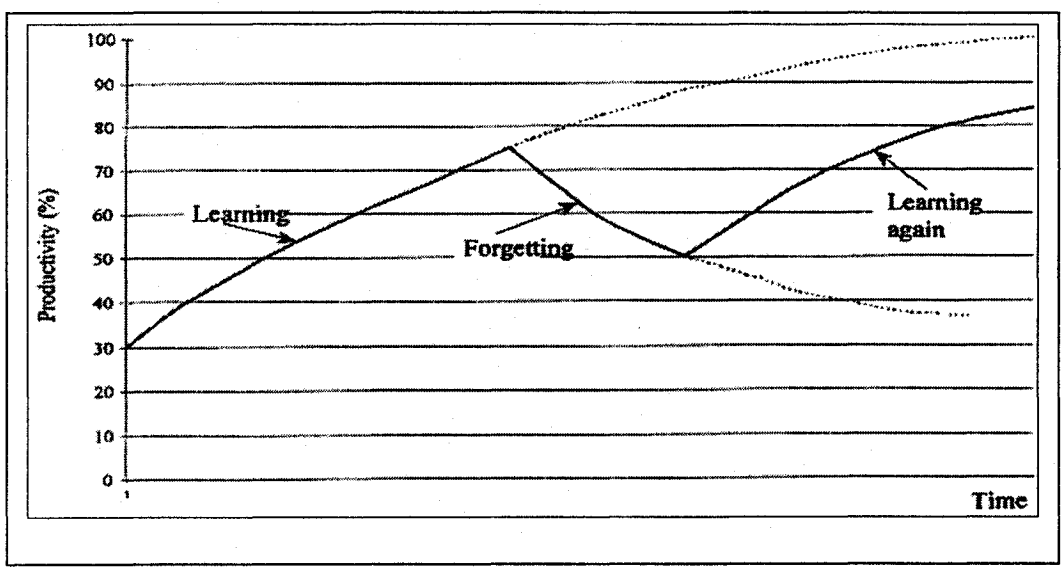


Fig: 2.4 Graphical representation of learning–forgetting–learning curve (Lam et al. 2001)

Congestion of trades also impact construction productivity when different trades that were supposed to be working sequentially are obliged to work simultaneously at the same limited workspace. The productivity loss due to congestion is described by the Modifications Impact Evaluation Guide developed by the US Army. Corp. of Engineers (1979).

Another bad scenario for productivity is the one in which the number of workers assigned to a certain task exceeds the optimum limit which causes the productivity also to shift from optimality. The effects are attributed to over manning. Dozzi & Abbu Rizk (1993) reported, over manning as the result of over staffing or the deployment of multiple crews.

Far earlier, in almost the same area Borcherding (1976) investigated the effective utilization of man-power. Again, Borcherding (1978) identified potential factors influencing productivity on large projects. The study was carried out through foremen and craftsmen questionnaires. Ten factors affecting productivity were investigated by sending questionnaires to foremen and craftsmen. Through the results obtained from foremen and craftsmen, two separate parameter ranking tables were prepared and thereafter the combined ranking was done, all three of them are reproduced at Table 2.2

Table 2.2 Factors that Affect Productivity According to Craftsmen and Foremen (Borcherding 1978)

Craftsmen Results	Foremen's Results	Combined Results
Material shortages	Material shortages	Material shortages
Change Orders	Change Orders	Change Orders
Labor shortages	Weather	Weather
Weather	Supervisory Changes	Labor shortages
Turn over	Turn over	Turn over
Supervisory Changes	Overtime	Overtime
Supervisory Capabilities	Labor shortages	Supervisory Changes
Overtime	Supervisory Capabilities	Supervisory Capabilities
Absenteeism	Scheduling	Scheduling
Scheduling	Absenteeism	Absenteeism

In connection with the craftsmen productivity in nuclear power plant construction in USA, Sebastian and Borcherding performed a study exploring the major influencing factors.

The area of relationship between management control and labor productivity was explained in a study by Horner et al. (1987).

Earlier in 1978, Tadros carried out a concise but equally objective study, categorizing the factors affecting productivity into six main categories. The categories along with their component members are reproduced at Table2.3.

Table 2.3 Groups and Their Factors Affecting Productivity (Tadros 1978)

Labor Factors	
Labor Disputes and Work Slow Downs	Shortage of Skilled Labor
Strikes	Project Size
Performance Restrictions	Site Location
Feather Bedding	Travel Time
	Political Factors
Human Capacities	Govt. Regulations
Personal Effects	Economic Conditions
Learning Abilities	Public Interface
Standard Work Day	
	Management Related
	Management and Supervision
Design Related	Planning and Scheduling
Quality of Design	Motivation
	Inspection and Rework
General Conditions	Expediting
Over Time	

Labor productivity can be impaired by numerous other factors, that have not been thoroughly mentioned so far, such as contractor management and material management practices. In this connection an approach has been described by Thomas et al. (1999). The purpose of their study was to explore the impact of material delivery practices and adverse winter weather conditions on labor performance using case studies of structural steel erection activities of three similar nature projects. Another objective of interest was illustrating the calculation of parameters that can be used to evaluate the effect of management

disruptions on overall project performance, including the ripple effect. The definition of productivity used in their study was work hours (wh) divided by the quantities executed, commonly referred to as the unit rate.

Figure 2.5 shows variations in productivities. The smoothly varying line is the base line productivity whereas the line with abrupt changes is the actual daily productivity. The reasons of the abruptions and delays in the actual productivity are represented through different symbols at the node points. Besides this the pie diagram at Figure 2.6 shows the proportions of various factors contributing towards productivity loss in terms of the hours allocation. For analyzing the influence of managerial techniques which include material handling and delivery schedules some project performance parameters were devised in this study namely;

PF = Project Performance Index, to evaluate the efficacy of management skills

MDI = Management Disruption Index, for knowing the extent to which the project was affected due to managerial disruptions.

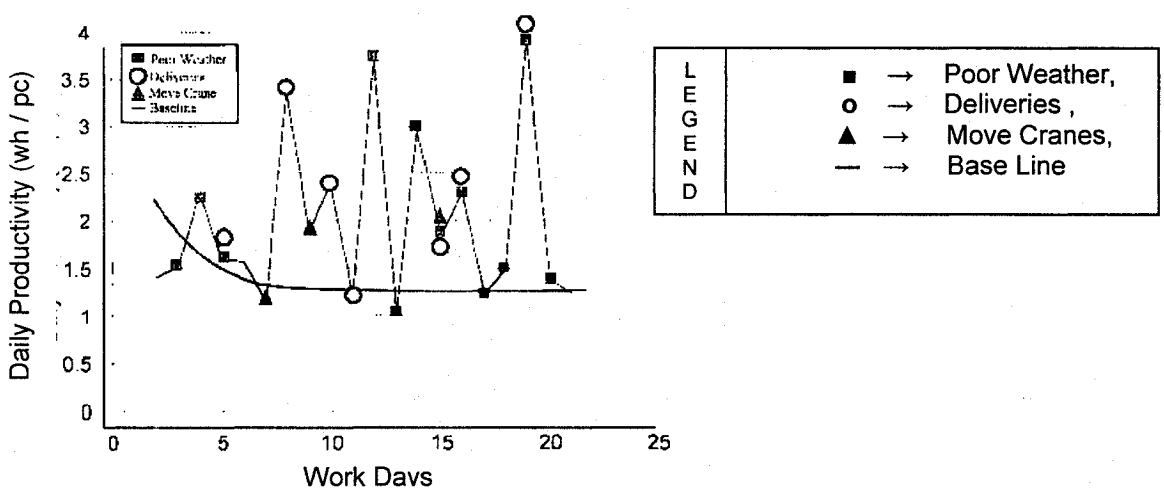


Fig: 2.5 Daily and Base Line Productivity (Thomas et al. 1999)

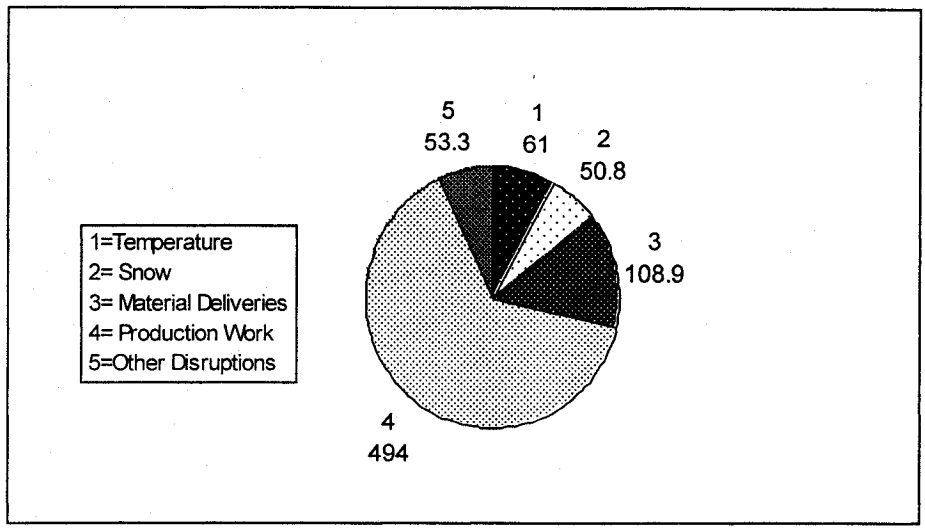


Fig: 2.6 Summary of Work Hour Distribution (Thomas et al.1999)

The relationship found between MDI and PF for three different projects as shown in the Figure 2.7 is defined as, the higher the disruption occurred due to managerial reasons the worse is the performance.

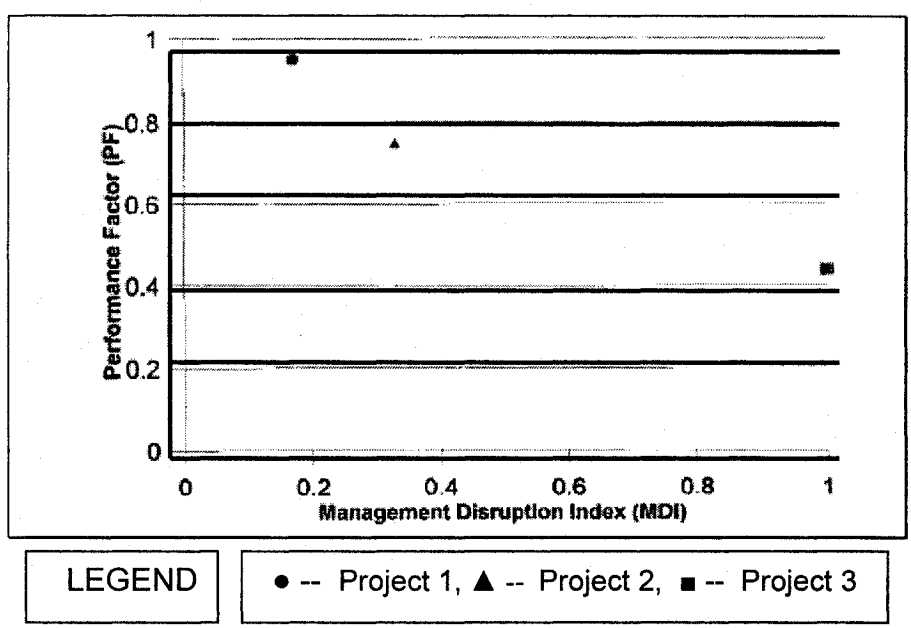


Fig: 2.7 Comparison of Project Performance Parameters (Thomas et al.1999)

In a relatively recent study AbouRizk and Knowles (2001), with the intention of identifying all possible factors influencing productivity came up with 33 items grouped into nine categories. These categories included: General project characteristic, site, labor, equipment, overall project difficulty general activity conditions, quantity, design, & activity difficulty

General project characteristics cover factors that impact the entire project such as who the designer was, and who the superintendent was and where the project was located. Site indicates how restricted the work area may be and the extent of prefabrication and modularization. Labor characteristics include crew size and whether or not the project is unionized. Equipment and material refer to the proportion of the cost of these items to that of labor. Difficulty of work is self-explanatory whereas quantity of work and design details captures repetition and ease of work on the project (AbouRizk & Knowles 2001).

The issue of low productivity is not in any way less serious and complicated in the under developed or the developing countries than it is in the developed world. Studies have been conducted in various parts of the world, some of them are referred here under:

SINGAPORE:

Lim and Alum (1995) carried out a remote survey of 130 registered top civil-engineering and building contractors in the year 1992.The survey pertained to

determining factors affecting construction productivity in Singapore. The respondents were asked if they had encountered any of a list of 17 problems, which were outlined by the researcher. The respondents were also asked to rank their answers. After analyzing the scores of the various factors according to some already assigned indices, the 17 problems were classified into 3 categories, those of management, manpower and environment. These along with their constituent components are tabulated below:

Table 2.4 Categories and Components of Productivity Problems (Lim and Alum 1995)

Management	
Materials shortages	Recruitment of workers
Delays in material deliveries at site.	Labor turnover
Disruption of power/water supplies	Absenteeism
Stop-work orders b /c of site accidents	Communication problems with foreign workers
Stoppages b /c of work being rejected by consultants	Alcoholism and similar problems among work force.
Stop-work orders b /c of infringements of Govt. regulations.	Labor disruptions
Stoppages b /c of insolvency of subcontractors/ Suppliers	
Stoppages b / c of disputes with owners/consultants.	**Environment**
Manpower	Health
	Inclement weather
Recruitment of supervisor	

INDONESIA:

Kaming et al. (1997) studied the intricacies of labor productivity in Indonesia focusing on three trades of craftsmen (brick layers, carpenters and steel fixers). A total of eleven factors or problems were investigated for each of the three trades. The ranking of the severity of the problems investigated was done

according to the criterion of the number of hours lost. The results of their study for each of the three trades are reproduced in the Table 2.5.

Table 2.5 Hours Lost and Problems Severity Ranking (Kaming et al. 1997)

	Brick Layer		Carpenters		Steel Fixers	
Productivity Problems	**Hours**	**Rank**	**Hours**	**Rank**	**Hours**	**Rank**
Lack of material	1.69	3	3.51	1	2.25	1
Lack of tools	0.23	8	0.32	5	1.21	3
Equipment breakdown	0.56	5	0.08	9	0.67	6
Rework	1.7	2	2.03	2	1	4
Changing of workers	0.38	6	0.11	7	0	10
Interference	0.62	4	0.37	4	2.04	2
Absenteeism	2.38	1	0.56	3	0.85	5
Supervision delays	0.2	10	0.19	6	0.02	9
Changing of foremen	0.03	11	0	11	0	10
Too much work	0.23	8	0.1	8	0.33	7
Overcrowded	0.24	7	0.03	10	0.09	8
Total hours lost	8.26		7.3		8.46	

An aggregate ranking of the problems was done thereafter, from the results of each trade. The same are reproduced at Table 2.6.

Employing the pre-1990s technique of investigation through task models, Olomolaiye et al. (1987) investigated factors influencing craftsmen's productivity in Nigeria; Parker et al. (1987) analyzed labor productivity in Tanzania, and Rahman et al. (1990) surveyed labor management problems in Malaysia.

Table 2.6 Overall Ranking of Productivity Problems (Kaming et al. 1997)

Productivity Problem		Mean Rank		Rank Order
Lack of material		1.67		1
Lack of tools		5.5		5
Equipment breakdown		6.67		6
Rework		2.67		2
Changing of workers		7.83		7
Interference		3.33		4
Absenteeism		3		3
Supervision delays		8.33		9
Changing of foremen		10.83		11
Too much work		7.83		7
Overcrowded		8.33		9
Cases	*W*	Chi-square	DF	Significance
3	0.07994	22.9818	10	0.00765

2.3 Productivity Modeling.

Productivity modeling has been done by many researchers, earlier through conventional methods and now mostly through artificial intelligence techniques. An overview of various models being developed, falling under the two main modeling categories is given below:

2.3.1 Conventional Modeling Techniques

2.3.1.1 Expectancy Model and Action-Response Model.

These models are proposed to explain variations in construction productivity. Expectancy model explains variations in performance by virtue of the effort that an individual is willing to exert (Maloney and McFillen 1985). The action-response model graphically depicts how a number of factors may interact to cause a loss of productivity (Halligan et al. 1994).

The expectancy model and action-response model both help in understanding the qualitative aspects of the phenomenon such as variations in productivity but have limitations while quantifying influences of multiple factors on construction productivity. (Sonmez 1998).

2.3.1.2 Statistical Models.

Like every other domain where data is being analyzed for the purposes of deducing results, drawing conclusions, viewing trends and requiring predictions, productivity studies too have enormously used regression analysis.

Simon (1999) developed a stepwise multiple regression model of earth moving operations using nine variables and seven interaction terms. Sonmez (1998) used regression analysis in combination with neural networks for the purpose of productivity modeling of concrete pouring, formwork and concrete finishing tasks.

Thomas et al (1999) utilized multiple regression technique for quantifying the differences in the labor productivity of two different projects, which employed different material delivery and handling methods.

Other statistical methods such as variance and ANOVA have also been commonly used for comparison and verification purposes. Elazouni et al. (1997) used regression for comparison of neural network models for estimating resource requirements whereas uses of variance and ANOVA were made by Thomas et

al. (1999) and Proverbs et al. (1997) respectively in connection with productivity modeling.

2.3.2 Artificial Intelligence Techniques.

2.3.2.1 Knowledge Based Expert Systems

Expert systems have also been used to estimate labor productivity. The expert system named "MASON" was developed to estimate activity durations of masonry construction (Hendrickson et al. 1987). In this study, the estimation of productivity, which was a part of the overall estimation process, was performed in two stages. First, the maximum expected productivity was estimated. Next, this rate was adjusted for various characteristics of job and site. The maximum productivity estimates and adjustments were based on the knowledge developed from interviews with professional masons and supporting labor.

The second expert system was developed more recently (Christian and Hachey 1995) to estimate the production rates for concrete pouring. The expert system led the user to an estimate, through a simple question-answer routine using the knowledge derived from experts and data gathered from seven construction sites. This expert system, like MASON, estimated productivity through previously defined decision rules. The task of identifying a mapping function for quantitative evaluation of the impact of multiple factors on productivity was not performed by both the expert systems. Generally, expert systems have limitations in regard to

identification of mapping functions and generalization of solutions (Wasserman 1989; Zahedi 1991).

2.3.2.2 Fuzzy Knowledge Based Systems

Though the use of fuzzy sets theory has been increasing in manufacture industry ever since its introduction by Zadeh in 1965 the construction industry has been lagging far behind in adopting it, contrary to what it has done, in cases of other artificial intelligence techniques. Rather the case of fuzzy logic has been one of the most unutilised.

Even by now, only few fuzzy logic applications can be seen in the areas of project scheduling (Ayub and Haldar 1984), resource strategies (Padilla 1991), resource constrained scheduling (Loterapong 1994) and project network analysis, (Loterapong and Moselhi 1996). There has been no worth mentioning literature found precisely on the subject of Labor Productivity Modeling.

2.3.2.3 Artificial Neural Network Modeling.

A number of neural network models have been successfully developed and used as an alternative to regression analysis ever since the back-propagation algorithm was proposed (Fletcher and Goss 1993; Karunanithi et al. 1994; Refenes et al. 1994; Goh 1995; Faghri and Hua 1995; Chua et al. 1997).

The applications of neural networks in Civil Engineering can be traced to the late 1980's. Moselhi et al.(1991) paved the way for the potential wide ranging use of neural networks in Civil Engineering. He also pointed out the possibility of modeling productivity through Neural Networks.

Karshenas and Feng (1992) analyzed earth-moving equipment productivity with a NN application. A modular NN structure was used to make it possible to add specifications of new equipment with only a brief training session. Each module represented a distinct type of equipment trained with two inputs, four hidden nodes, and one output within a back propagation training algorithm.

AbouRizk and Wales (1997) used NNs as a means of applying the effects of site environmental conditions to the labor production rate of an activity. Daily average temperature, precipitation and cumulative precipitation over the previous seven days were identified as three key site environmental conditions and were used as inputs into a feed forward back-propagation NN training algorithm. The output was a productivity factor such that a value > 1.0 indicates that site environmental conditions produce a greater than average productivity. On the other hand, productivity factor of < 1.0 indicates that the site environmental conditions result in below average productivity.

Chao and Skibniewski (1994) performed a case study in which a NN was used to predict the productivity of an excavator. They identified two main factors those of

job conditions and operation elements that affect an excavator's productivity.Two NN's were used for the purpose of this case study. The first was used to estimate the excavator cycle. The output of the first network was then incorporated into the second network, which examined the effect of the operational elements on the productivity.

Portas and AbouRizk (1997) developed a neural network model to estimate construction productivity for concrete formwork tasks.

In 1998 Sonmez & Rowings developed another productivity model with a combination of neural network and regression analysis. The methodology was designed to determine the significant variables through regression and those which were found not to improve the regression model were dropped for the final neural network model development. The model development schematic is shown in Figure 2.8.

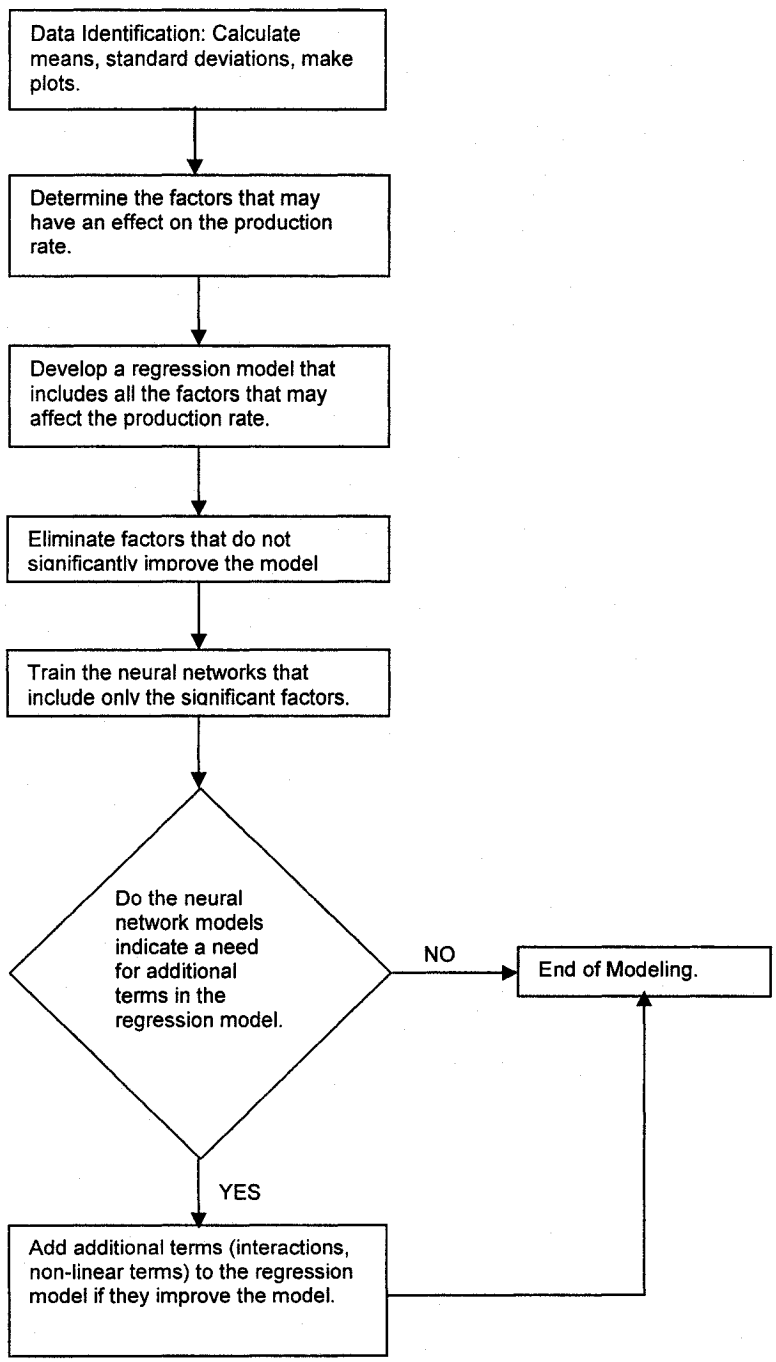


Fig: 2.8 Modeling Methodology (Sonmez 1998)

Abu Rizk (2000) developed a Probability Inference Neural Network-PINN for estimating industrial labor productivity rates.

Abu Rizk (2001) presented another methodology using neural networks for the estimation of industrial labor production rates. The distinct feature of this methodology is a two-stage model where both stages use different paradigms. The methodology followed is that the values of the variables to be involved in the project are determined by the estimator. The values are fed to the Kohonen network, which predicts whether the production rate will be typical or atypical. The appropriate back-propagation network (typical or atypical) is then invoked to predict the value of the production rate. The network architectures of both the models are shown at Figure 2.9 & Figure 2.10.

Moselhi (2005), as the result of a study conducted to investigate the impacts of change orders on construction labor productivity has introduced a new neural network model capable of quantifying this impact. The sources of data for this study is a through literature review and a field investigation spanning over six months, comprising of 33 actual cases of work packages and contracts, of projects constructed in Canada and the USA. The identification of factors adversely affecting labor productivity due to change order is done along with the development of a prototype soft ware to estimate the loss of labor productivity due to change orders, using the neural network model.

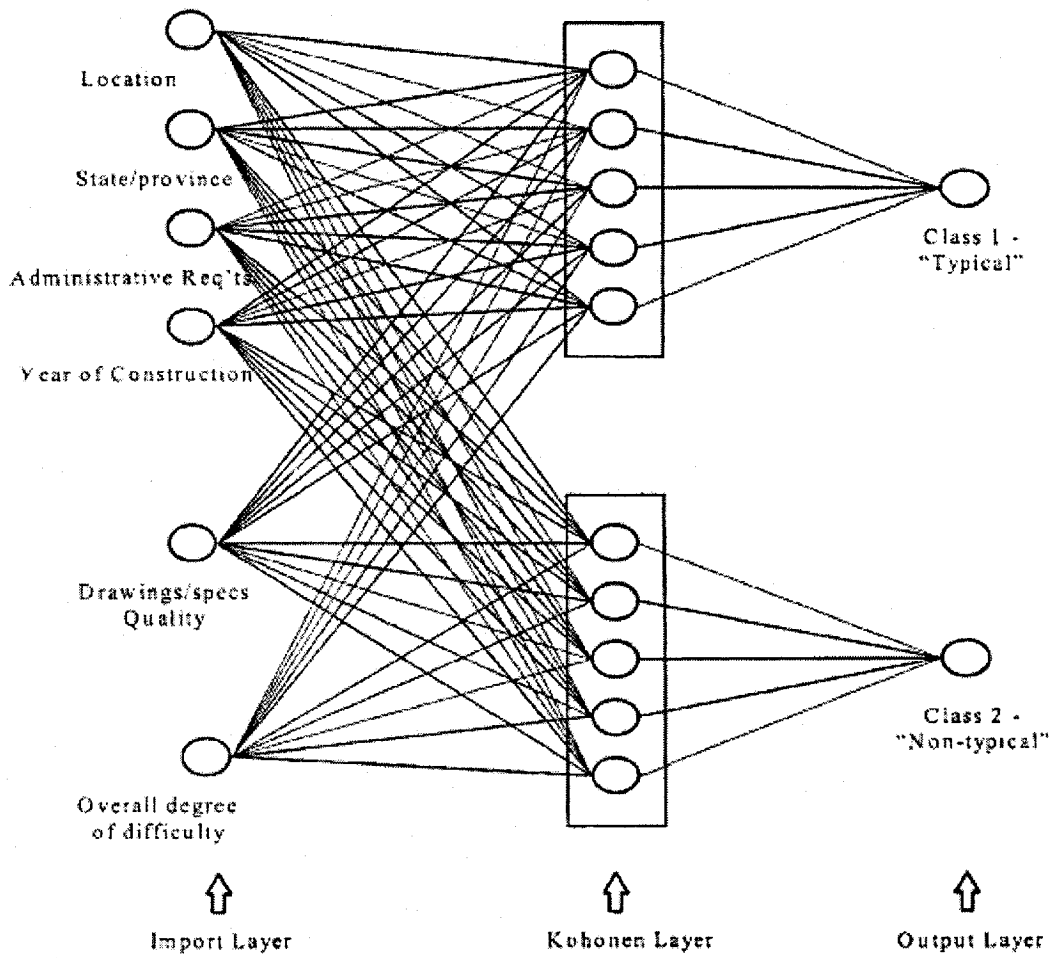


Figure 2.9 Kohonen Network For Classification (Abu Rizk et al 2001)

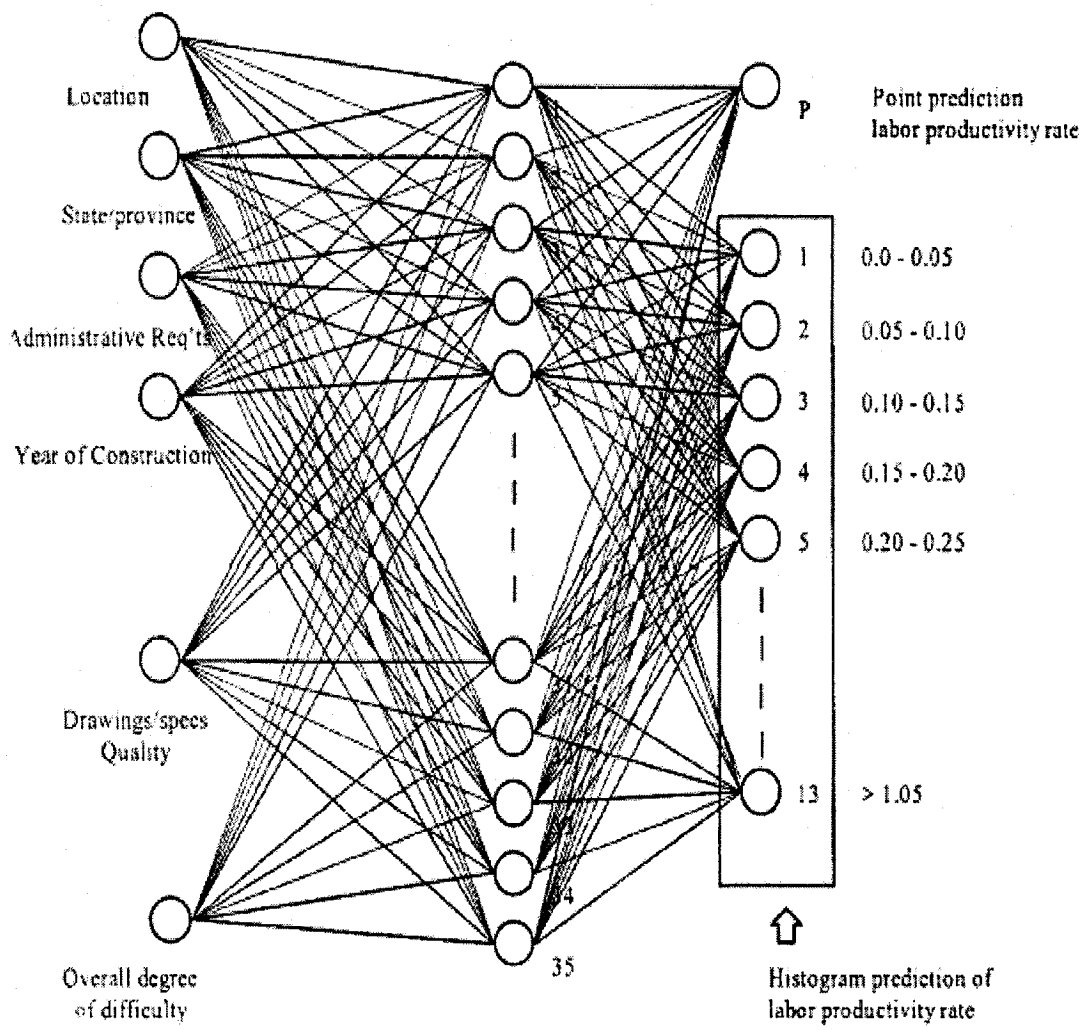


Figure 2.10 Feed forward Back propagation Neural Network for Prediction (Abu Rizk et al 2001)

2.4 Summary

Keeping in mind the preceding literature review it can be assumed that although a reasonable quantity of research work has been done in order to study construction labor productivity in its sub-domains of factors influencing and modeling, there are avenues where substantial work is still to be done, owing to the reasons referred under.

Most of the studies on the factors influencing productivity discussed variables that have persistent or in other terms mid or long-term effects on productivity or have a ripple effect.

Rarely are found studies, which have targeted factors causing variations in productivity on short term or daily basis. An influencing factor on a short term basis is taken as one that is likely to have a different value every day. Secondly its effect doesn't cumulate or trickle down to affect other activities, i.e. it doesn't have a ripple effect. It is therefore worthwhile to study the above referred type of variables. Consequently nine factors were selected grouped under three categories, given as under:

Weather Factors	**Crew Factors**	**Project Factors**
Temperature (T)	Gang Size (G)	Work Type (TW)
Humidity (H)	Labor Percentage (L)	Floor Level / Height (F)
Wind Speed (W)		Work Method. (M)
Precipitation (P)		

Although there are several other factors that come under the assumption of influencing productivity on a short term basis, the nine above mentioned are selected because they are the most common and are encountered all the time at every site. It is envisaged that exploring and explaining the effects of above factors on daily productivity of a particular gang will be helpful for the project supervisors in making short term or weekly performance plans correctly and realistically. In terms this will serve as a supportive tool for superintendents to remain on schedule.

Apart from the concept of studying the above mentioned type of input parameters, doing their ranking in the order of relative significance will also be helpful for supervisors and foremen at job sites in prioritizing, while giving focus to different aspects of day to day planning.

Furthermore, determining the behavior of productivity as function of a single parameter through discounting the effects of all the others is considered to be useful. After working out the exclusive effects of each factor on daily productivity, the graphical representations of the same, making three dimensional surfaces and two dimensional lines and overlay plots, may be given to crystallize the varying behavior of productivity as being their function. This is supposed to give a relatively clearer and direct idea to the concerned regarding the interrelationships of productivity and factors involved.

CHAPTER 3

Data Collection and Organization

3.1 General

There have been several approaches for on-site data collection, mostly for the purposes of productivity measurement and improvement. A very general grouping of the methods employed may be done on the basis of direct or indirect extraction of data from field.

Acquisition of data from historical records is usually a less cost involving and more convenient approach, but it doesn't assure quality data as it is often handled by different concerned quarters. The direct field extraction of data methods already referred in the section 2.1. 3, may also vary in accuracy, cost and effort involved but are preferred for specific needs.

Since this study is meant to employ an objective approach and is organized to perform quantitative analysis with specific sets of input and out put data, therefore a direct acquisition of data from the field instead from historical records was preferred. In this case the same method was possible due to two large building projects which had just started. Since formwork constitutes a substantial part of the overall labor component of any project, and since it is absolutely an outdoor activity subject to all of the above influencing factors, therefore the labor

productivity of formwork installation operations was selected as the dependent parameter of the model.

As mentioned earlier in section 2.4, this study is meant to investigate factors and input parameters that change on a daily basis and whose impacts vary on a short term or daily basis, thus it is concerned with the short term or daily plans of the foremen and supervisors. The factors selected for study are mentioned in the Table 3.1.

Table 3.1 Categories and Component Factors Selected For Study

Weather Factors	**Crew Factors**	**Project Factors**
Temperature (T)	Gang Size (G)	Work Type (TW)
Humidity (H)	Labor Percentage (L)	Floor Level / Height (F)
Wind Speed (W)		Work Method. (M)
Precipitation (P)		

As given above, the input parameters selected were classified into three categories necessitating the employment of three different means or methodologies for relevant raw data gathering.

Forms were designed for inputs from foremen and for data from internet sources regarding meteorological information. The inputs through these forms when combined with daily site visits constituted the overall data collection activity. Data was collected from both of the under study projects for a substantial period of eighteen months, thereby accumulating to a total of 221 data points. These data

points are also termed as "patterns" when used in analysis. A data point constitutes of the transformed values of all the nine parameters / independent variables affecting productivity treated as, inputs and the tenth element of data point, the daily productivity (DP) of the formwork installation activities, taken as output.

The information gathering stage was followed by the processing and transformation of the data to make it usable for analysis and experimentation. The schematic diagram given at Figure 3.1 illustrates all the steps involved and methods adopted right from the data collection phase up to the preparation of data spread sheet to be used for analysis.

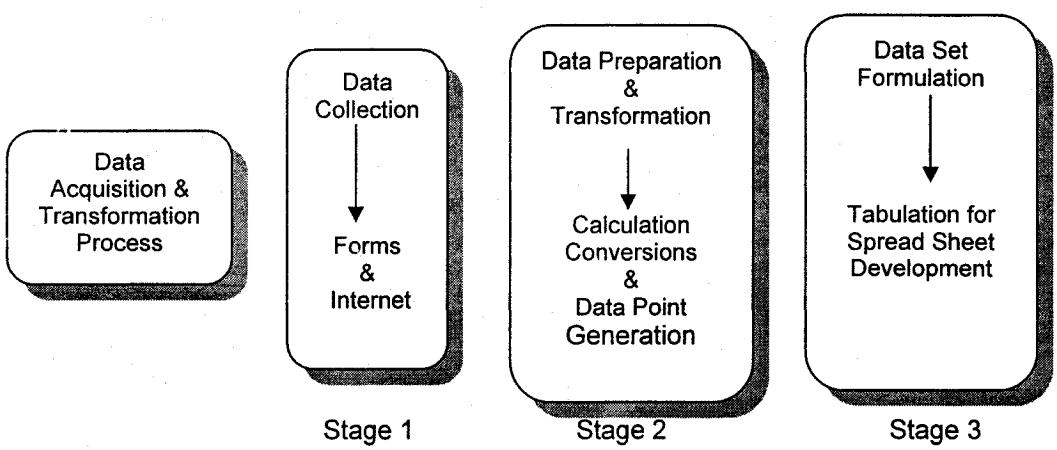


Fig: 3.1 Stages in Data point Development

3.2 Projects Studied.

The field observations and data collection were carried out for a period eighteen months from two under construction multistorey buildings located in down town Montreal, a brief introduction of which is as under:

ENGINEERING, COMPUTER SCIENCE AND VISUAL ARTS COMPLEX OF CONCORDIA UNIVERSITY

This 17 storey integrated educational complex of Concordia University built at its George William Campus is located on St. Catherine Street between Guy Street and Mackay Street. It is mainly a flat slab RCC construction with several typical levels having a surface area of 68,000 square meters. The project started in spring 2002 and the inauguration is expected in May 2005.

MULTI STOREY RESIDENTIAL BUILDING ON RENE- LEVESQUE WEST.

This residential project situated at Rene- Levesque West is constructed by Ma Gill Construction company. It is a 16 storey flat slab RCC construction with shear walls to cater for the lateral loads.

In the following pages some of the photographs taken at these two projects during the phase of data collection for formwork installation activities are shown:

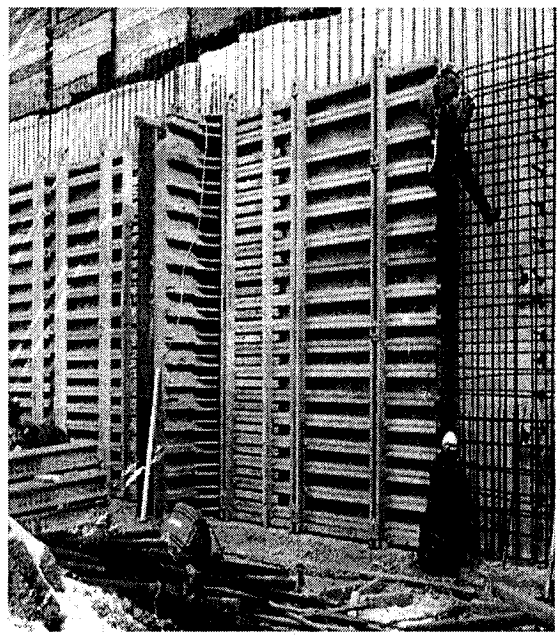


Fig.3.2.1 Wall Form Installation- Site 1

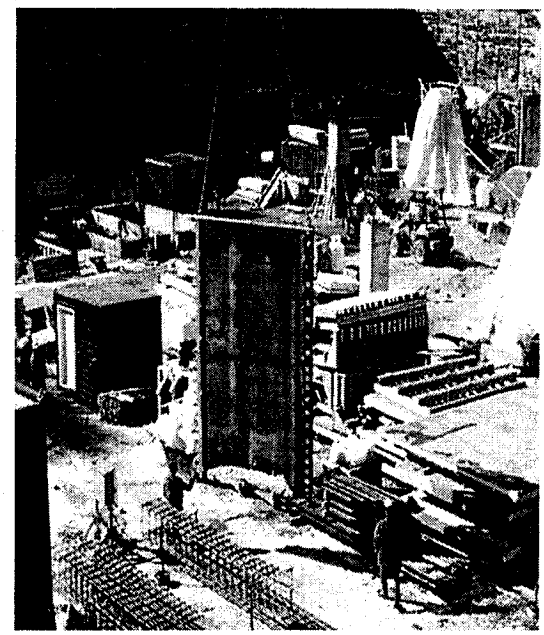


Fig.3.2.3 Wall Form Panel Handling Site 1

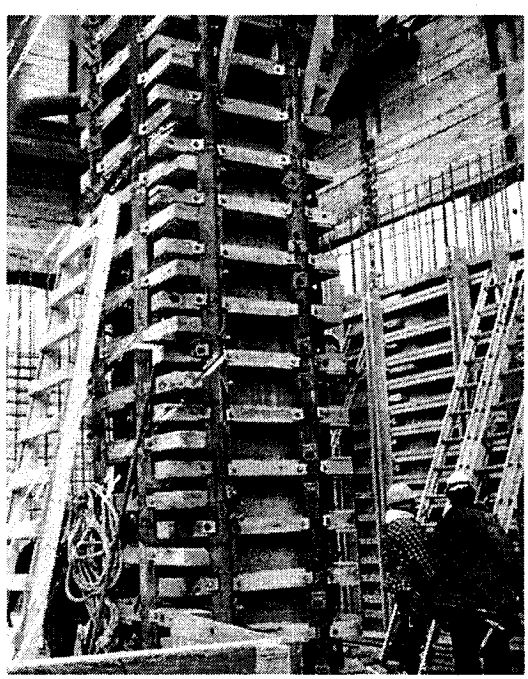


Fig.3.3.2 Column Form Installation Site 1

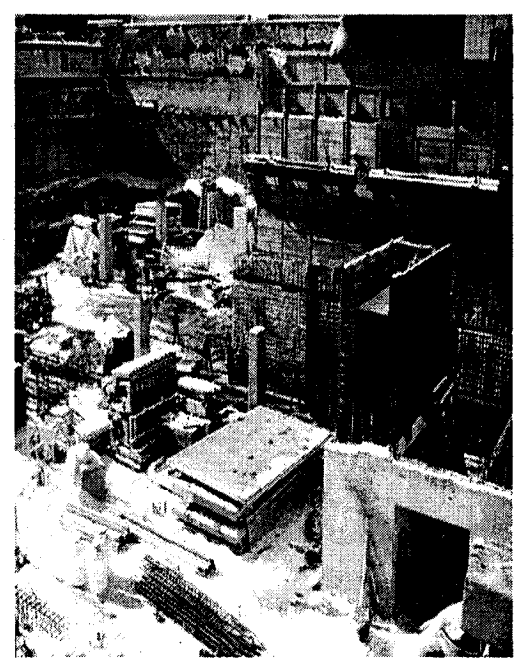


Fig.3.2.4 An Over view of Form work Operations Site 1

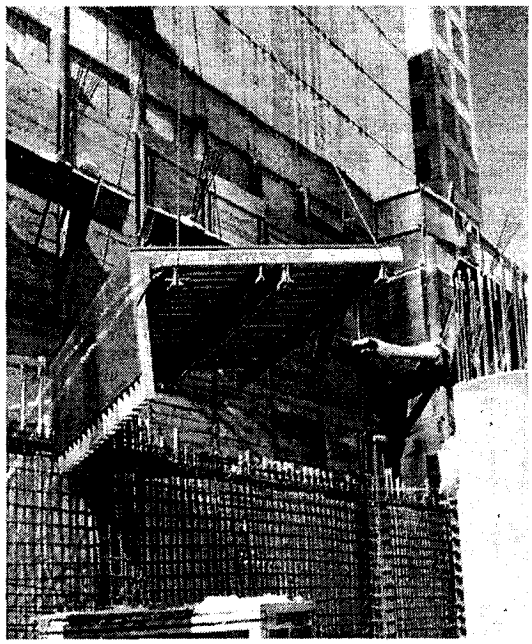


Fig.3.2.5 Wall Panel Handling Site 1

Fig.3.2.7 Flying Form Under Installation Site 1

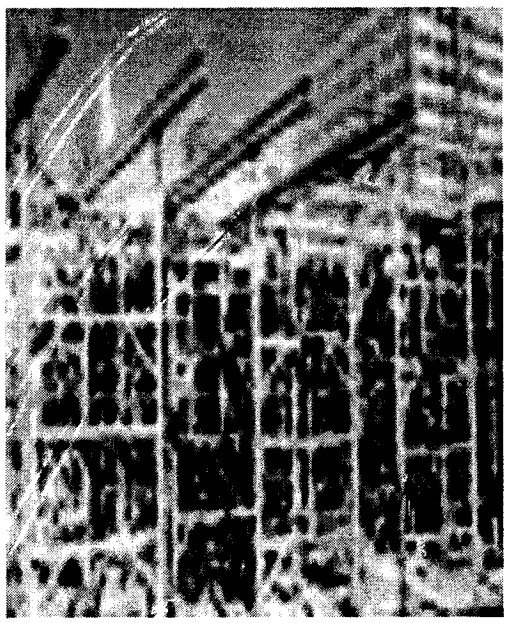


Fig.3.2.6 Support for Slab Site

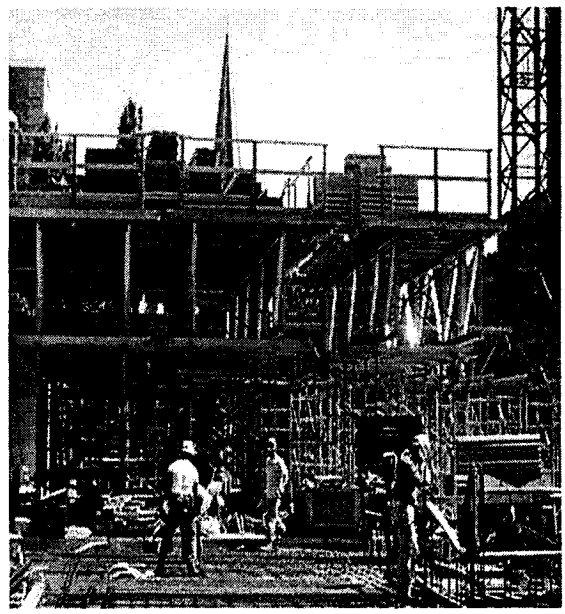


Fig.3.2.9 Flying Form Under Installation- Site 1

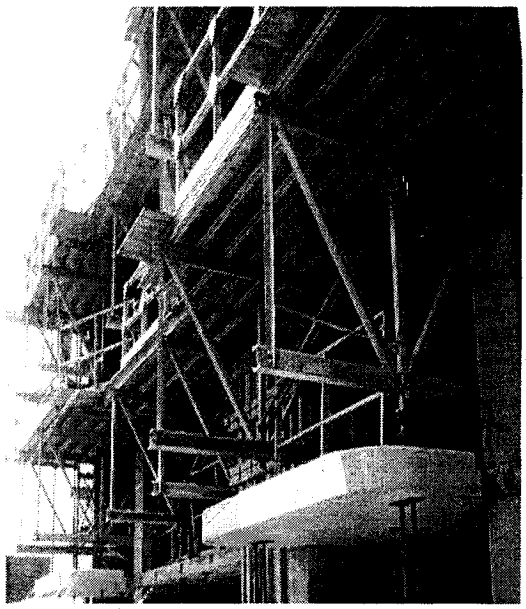


Fig.3.2.8 Flying Form Installed- Site 2

Fig.3.2.11 Façade- Site 1

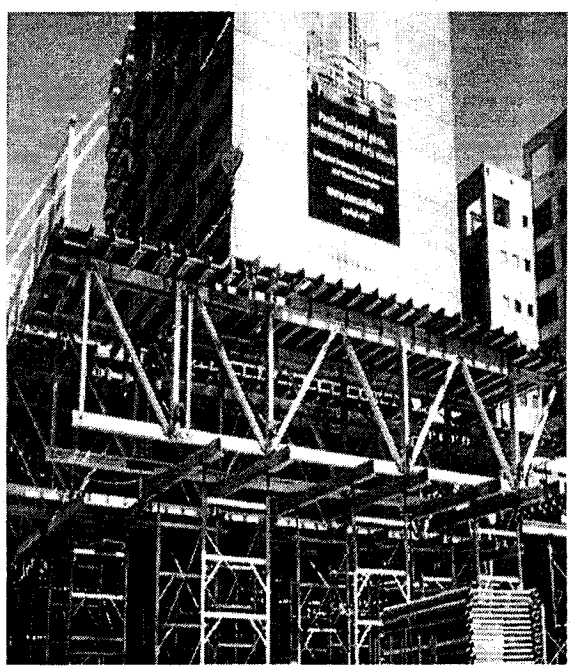


Fig.3.2.10 Another view of Flying Forms- Site 1

Fig.3.2.12 Façade Site 2

3.3 Data Collection Process.

The acquisition of data in a smooth manner is subject to many factors. Keeping in view the possible hindrances a very flexible and adaptable approach was employed. For the purpose of data collection through the site personnel, a very simplified and brief form was prepared in French as well as in English, termed here as Foreman's Response Form (FRF) annexed at appendix 10. Foremen were provided with those forms, which were meant to fetch out the crew related details. As regards the daily-executed quantities, the foremen furnished the required information in two different ways, depending upon their daily work load.

Situation 1 Quantities of work executed given directly in sq.m or sq. ft

Situation 2 Quantities of work executed given in terms of markings of gridlines on formwork plans.

The schematic diagram at Figure 3.2 illustrates the overall approach adopted for the development of data points to be used in analysis which comprised of ten elements of information gathered through different ways.

3.4 Transformation and Preparation of Data Points.

After collecting all the basic elements of data, the next step was to transform the same into a form compatible with the artificial intelligence techniques to be employed to it later. Processing was done to various elements to transform them:

Temperature : Average of eight working hours of the day (° C).

Relative Humidity : Average of eight working hours of the day (%)

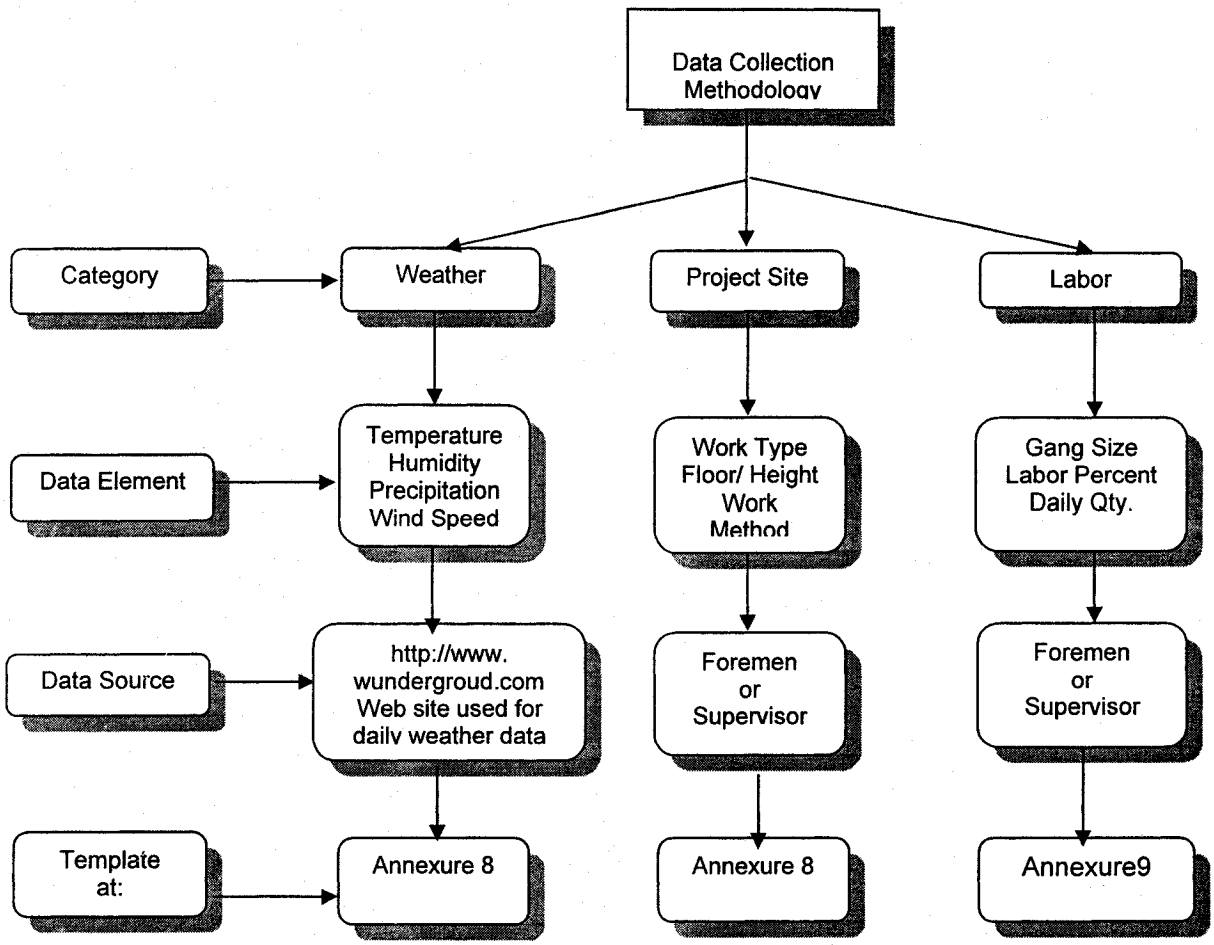


Fig. 3.2: Data Collection Process

Precipitation : Incorporated in terms of four numerical values assigned as:
No precipitation = 0,Light Rain =1,Snow =2, Rain=3

Wind Speed : Averaged for the eight working hours of the day. It was incorporated in calculations in terms of kms / hr.

Height : Employed in terms of the floor worked at. This was incorporated in terms of the number of floors.

Work Type : This study encompassed three different types of formwork installation activities which, for the purpose of analysis are coded as Slabs=1 Walls =2

Columns=3,

Work Method : Basically two different forming techniques were employed at both sites. For columns and walls the traditional wooden forms with steel interface layer, supports and accessories were coded as 1. For slabs mostly flying forms were used which were coded as 2.

Gang Size : No transformation or coding was required for gang size. It was used in terms of number of persons.

Percent Labor : It was obtained after the simple arithmetic:

%age Labor = [(Gang Size–Skilled Labor) ÷ GangSize]x100

Daily output : The calculations for transforming the output depended upon the format of the raw data received

Situation 1: When having the total quantities executed, there were no meticulous calculations required, simply the total quantities were divided by the total man-hours to get the daily output in terms of m^2 / man-hr ,where total man-hr = Gang Size x hours worked

Situation 2. When instead of direct quantities the grid line references were given. In this case, first the quantities executed were worked out from formwork plans and then the same procedure was followed as in situation 1.

The template prepared after all the transformations and thereby reflecting complete data point is shown in Table 3.2.

Table 3.2 Final Template for Data Point.

DATA POINT TEMPLATE.					
Project: New Engg. Bldg. (Formwork Installation Activity)		New Engineering Building Concordia University			**Dated:**
					Notes
Weather Data	Temperature	% age Humidity	Precipitation	Wind speed	
	-17.5	75	2	17.3	
Crew Data	Gang Size		%age Labor		
	14		29		
Site Data	Work Type	Floor Level	Work Method		
	2	1	1		
Daily Executed Quantities	**93.1 sq.m**				

3.5 Data Set Formulation

As the result of the eighteen-month long observation and data collection phase there were 221 data points in all, collected from both of the sites. The last step before the analysis could be initiated was to formulate a data set containing data points as patterns to be presented to various AI and statistical analysis techniques. A sample portion of the final spreadsheet utilized for the analysis is shown at Table 3.3.

Table 3.3 Sample Portion of the Data Spread Sheet Used In Analysis

Temperature	Humidity	Ppt.	Wind Speed	Gang Size	Labor % age	Work Type	Floor	Work Method	Productivity
-17.5	75	2	17.3	14	29	2	1	1	0.95
-18	72	2	6.6	14	36	1	3	1	1.12
-18	72	2	6.6	18	33	2	3	1	1.01
-8	87	2	14.2	22	36	1	3	1	1.27
-8	87	2	14.2	23	30	2	3	1	1.14
-12.5	54	0	5.2	21	38	1	3	1	1.17
-12.5	54	0	5.2	20	30	2	3	1	1.04
-16	55	0	6	23	35	1	3	1	1.16
-15	51	2	18.7	17	29	2	4	1	1.99
-15	51	2	18.7	20	40	1	4	1	1.1
-8.5	58	0	26.5	18	33	2	4	1	1
-8.5	58	0	26.5	19	47	1	4	1	1.12
-4	87	2	3.6	22	36	1	4	1	1.55
-14	42	0	10	23	35	2	4	1	1.26
-14.5	42	0	7.5	19	33	2	4	1	1.14
-14.5	42	0	7.5	16	37	1	4	1	1.27
1 5	85	0	9.4	21	33	1	5	1	1.45
-0.5	53	0	7.5	20	30	1	5	1	1.51
-0.5	53	0	7.5	22	36	2	5	1	1.37
-3.5	47	0	20	17	29	1	5	1	1.38
-3.5	47	0	20	22	36	2	5	1	1.25
-4	81	1	11.9	22	36	1	5	1	1.49
-4	81	1	11.9	16	38	2	5	1	1.34
3	97	0	8	22	36	1	5	1	1.36

CHAPTER 4

Model Development and Input Parameter Ranking

4.1 General

This chapter encompasses the development of labor productivity models as well as the ranking of the input parameters involved according to their significance and importance in causing productivity variations. Following are the variables used in the study. The reasons for the use of this set of input parameters have already been discussed in the section 2.4.

Inputs: Temperature, relative humidity, precipitation, wind speed, Gang size, labor percentage, height worked at / floor level, work type, work method.

Output: Daily labor productivity of formwork installation operations in terms of m^2 / man-hr.

Figure 4.1, is presented to give the overview of the entire chapter as well as to schematically express the steps of the various analyses conducted, as regards model development and input parameter ranking.

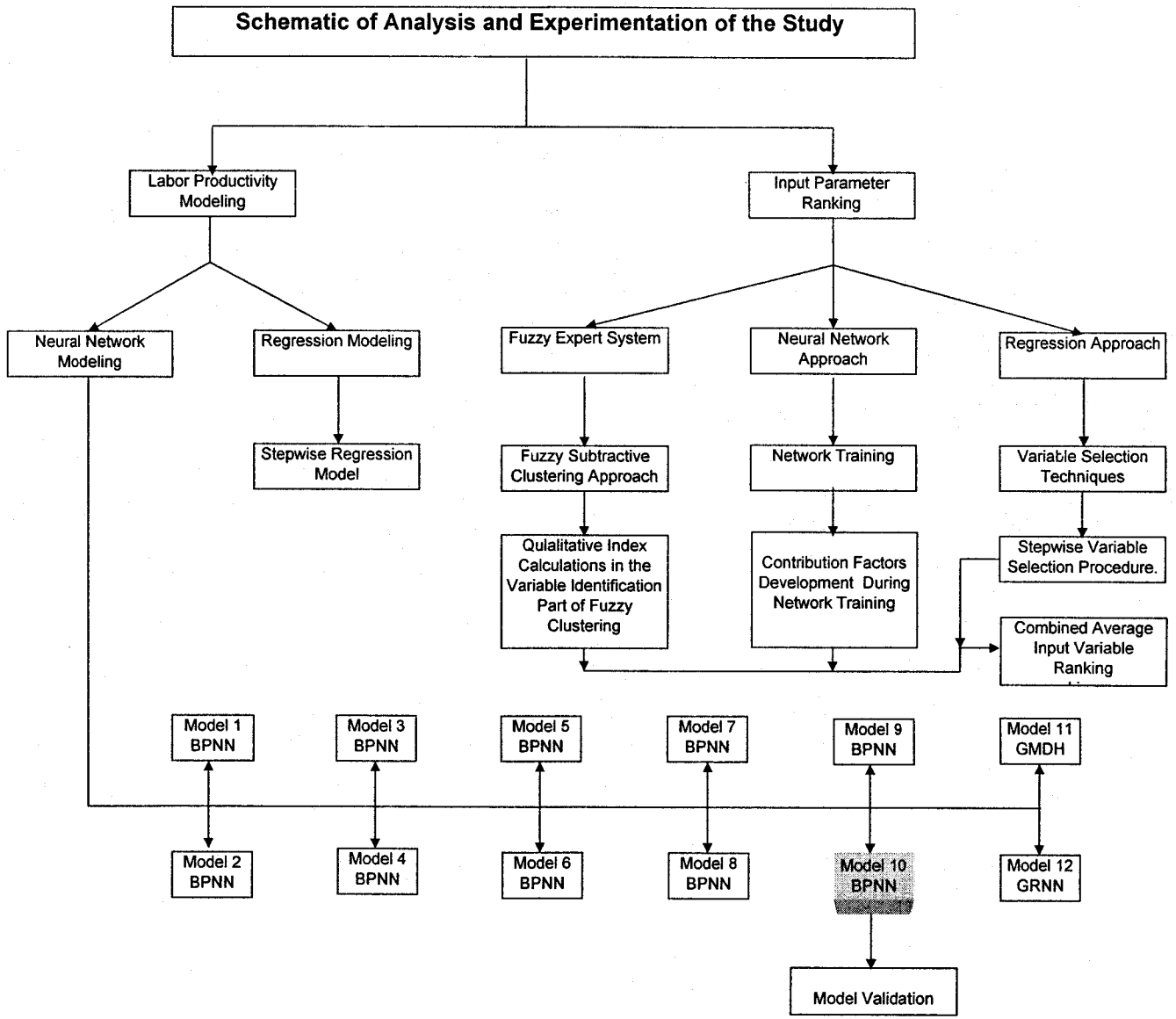


Fig: 4.1 Schematic Diagram of Model Development And Input Parameter / Variable Ranking Analysis.

4.2 Fuzzy Logic Approach.

4.2.1 General

As already mentioned, the ranking of the involved input parameters is intended to be done through different theoretical approaches with a goal of arriving at some authentic conclusion, the first of which is fuzzy logic. Figure 4.2 is the schematic diagram showing the various intermediate steps and the methods employed.

4.2.2 Fuzzy Expert Systems.

The potential of fuzzy expert systems lies in their ability to handle imprecise, uncertain and vague information used by human experts. Fuzzy Knowledge based expert systems are of two types, subjective and objective. The objective models are constructed from input and output data of the system by using a systematic process with a specific objective function. In either case a set of Fuzzy IF–THEN rules forms the fuzzy knowledge based body of the system.

The fuzzy knowledge based system identification and modeling process is composed of two parts:

- Variable Identification
- Parameter Identification

In variable identification, the significant variables of the system are identified among the set of possible variables.

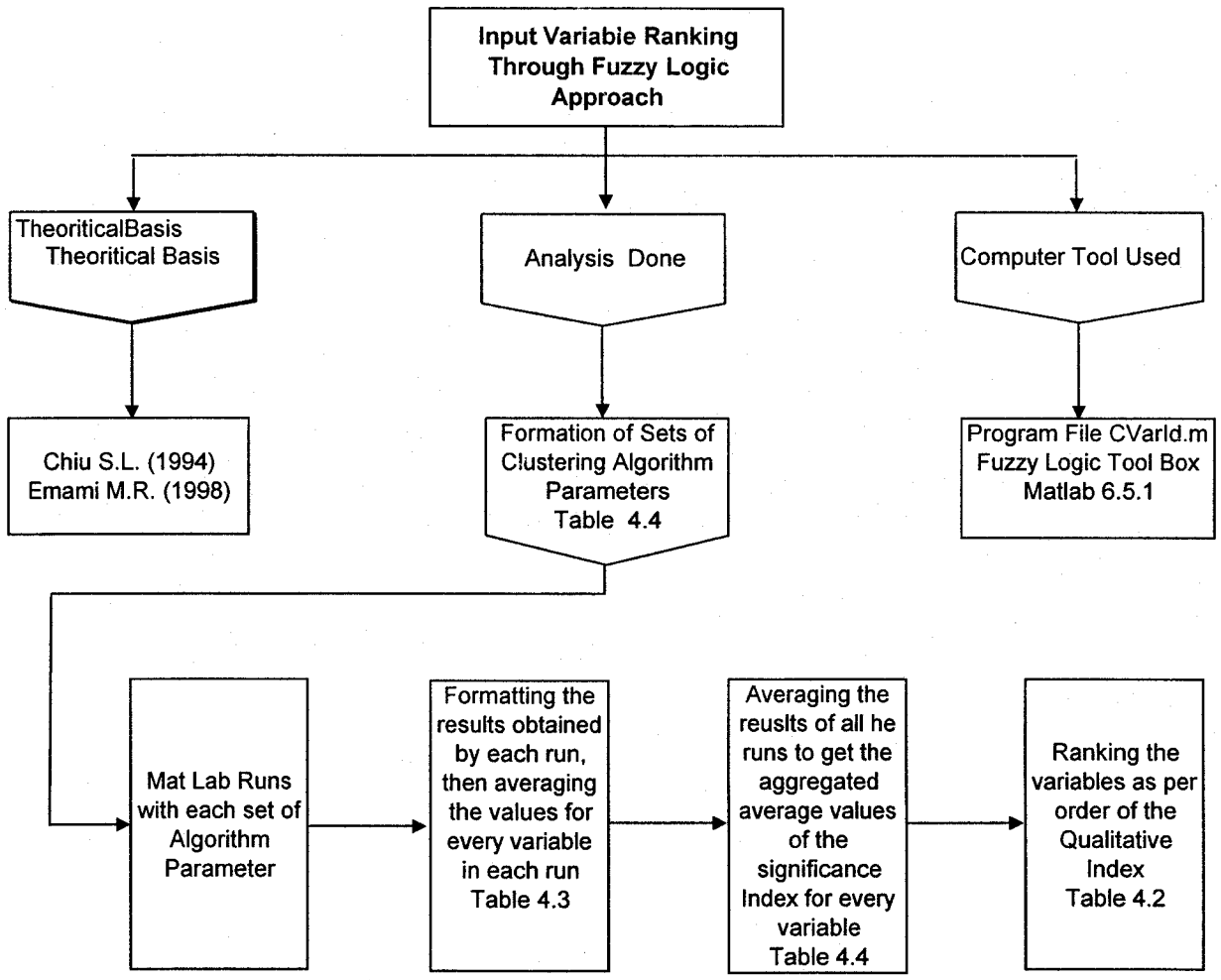


Fig: 4.2 Schematic Diagram For Input Variable Ranking Analysis Through Fuzzy Clustering

In parameter identification, the parameters of the knowledge based systems that describe the relationship between input and output variables are identified. These are the parameters of the membership functions, i.e. the parameters describing the rules.

For variable identification and modeling a problem, fuzzy clustering is done. Fuzzy clustering is a process to obtain a partition Z of a set A of N objects x_i =(1, 2,3,.....N) using a resemblance or dissemblance measure such as distance measure 'd' between x_i and x_j where i , j =1,2,3,...N. A partition Z is normally a set of disjoint or partially overlapping subsets of A, and the elements Z_C of Z are regarded as clusters centers. The intended purpose of clustering is to segregate the data into its natural grouping sets so as to produce a concise representation of a system's behavior.

Among various methods of fuzzy clustering, the one widely used is the Subtractive Clustering Method. The steps involved in model development or for rule base development can be referred at Chui (1994). While doing variable identification using the subtractive clustering method, different models (rule bases) are created with various cluster radii by doing clustering in the output space only.

In each model, relative significance of variables is identified by applying the significance test in each dimension of the data space. In this test a quantitative

index as proposed by Emami et al., (1998) is used to measure the significance of a variable. The said quantitative index πj is defined as:

$$\pi j = \prod_{k=1}^{n} \frac{\left|core\ A_j^k\right|}{\left|\sup A_J^K\right|}, \quad \text{where } j = 1,2,3,\ldots\ldots m$$

The $|\text{core}\ A_J^K|$ represents the width of the core of the membership function for input variables j in the rule k and the $|\text{supp}\ A_J^K|$ represents the width of its support.

While clustering the output space, cluster formation depends only on the output data and is not influenced by any insignificant input data. When the clusters are projected onto the input space, the membership function of the variable are expected to have the lengths of their cores according to their relative significance. The smaller the quantitative index πj, the more significant the variable is considered (Emami 1998). Thus the input variables which consistently score high πj value in different models are identified as less or insignificant variables.

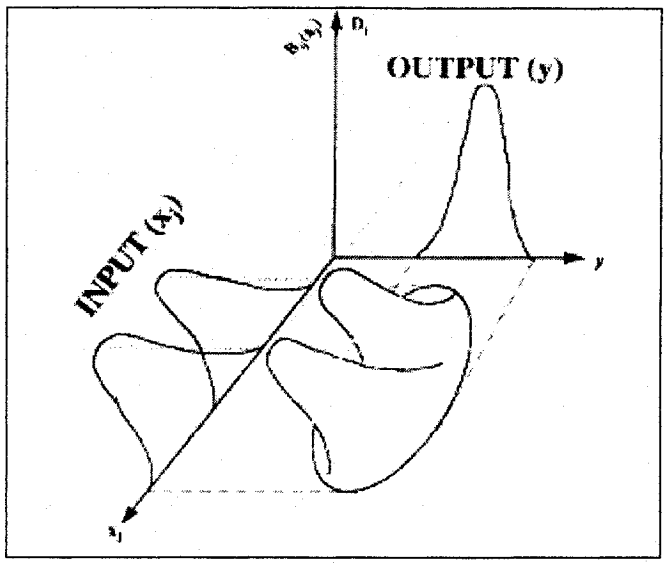


Fig: 4.3 Projection of Output Space on Input Space (Cheng 1999)

The parameters governing the cluster algorithm are:

r_a = Hyperspace cluster radius in data space

r_b = Hyperspace penalty radius in data space

η = Squash factor

ε^- = Accept ratio

ε_- = Reject ratio.

The function of the squash factor 'η' is that it is used to multiply the radii values to determine the neighborhood of a cluster center within which the existence of other cluster centers are to be discouraged. For each data point, a measure of its potential as a cluster center is computed. The data point with the highest potential is selected as the first cluster center. Accept ratio ε^- sets the potential as a fraction of the potential of the first cluster center, above which another data point will be accepted as a cluster center. Reject ratio ε_- sets the potential as a

fraction of the potential of the first cluster center, below which a data point will be rejected as a cluster center. For values in between the accept and reject ratio some further test are done.

Using the above theoretical basis, an extensive variable identification analysis was carried out to determine the input parameter significance ranking (PR) of the labor productivity variables under study. Numerous trials of varying combinations of the clustering algorithm parameters were employed to cluster the available data through numerous possible ways. With each combination of the clustering algorithm parameters, clusters of radii varying from r_a = 1.0 to r_a = 0.05 were formed. Table 4.1 below, shows the sets of parameters employed.

Table: 4.1 Set of Clustering Algorithm Parameters

VARIABLE IDENTIFICATION:					23	0.4	0.9	0.2
Clustering Algorithm Parameters					24	0.4	1	0.2
					25	0.4	0.7	0.4
					26	0.4	0.8	0.4
No. of Run	Squash Factor	Accept Ratio	Reject Ratio		27	0.4	0.9	0.4
1	0.5	0.7	0		28	0.4	1	0.4
2	0.5	0.8	0		29	0.4	0.7	0.6
3	0.5	0.9	0		30	0.4	0.8	0.6
4	0.5	1	0		31	0.4	0.9	0.6
5	0.5	0.7	0.2		32	0.4	1	0.6
6	0.5	0.8	0.2		33	0.3	0.7	0
7	0.5	0.9	0.2		34	0.3	0.8	0
8	0.5	1	0.2		35	0.3	0.9	0
9	0.5	0.7	0.4		36	0.3	1	0
10	0.5	0.8	0.4		37	0.3	0.7	0.2
11	0.5	0.9	0.4		38	0.3	0.8	0.2
12	0.5	1	0.4		39	0.3	0.9	0.2
13	0.5	0.7	0.6		40	0.3	1	0.2
14	0.5	0.8	0.6		41	0.3	0.7	0.4
15	0.5	0.9	0.6		42	0.3	0.8	0.4
16	0.5	1	0.6		43	0.3	0.9	0.4
17	0.4	0.7	0		44	0.3	1	0.4
18	0.4	0.8	0		45	0.3	0.7	0.6
19	0.4	0.9	0		46	0.3	0.8	0.6
20	0.4	1	0		47	0.3	0.9	0.6
21	0.4	0.7	0.2		48	0.3	1	0.6
22	0.4	0.8	0.2					

The computer program 'Varld.m' embedded in the fuzzy logic tool box of Mat lab 6.5.1 computing software based on the subtractive clustering theory, already referred to, is used for the said purpose. The copy of this Mat lab script file (M-file) is annexed in appendix 1. The mat lab run results are tabulated after necessary synthesis in the templates appended at appendix 2. A sample is reproduced at table 4.3.

4.2.3 Input Parameter Ranking by Fuzzy Logic Approach

It can be seen that each mat lab run provided us with an order of significance according to the associated (πj) value. Table 4.4 is the consolidated summary, giving besides the corresponding sets of algorithm parameters, the aggregated average value of the quantitative index πj. Thus it enables us to assign a significance ranking to the variables. The final ranking of the significance of labor productivity parameters is at Table 4.2 :

Table: 4.2 Input Parameter Ranking By Fuzzy Clustering

Order of Influence	Parameters	Quantitative Index (pi).
1	Work Type	6.36
2	Floor Level	8.68
3	Temperature	9.14
4	Wind Speed	9.76
5	Humidity	10.06
6	Labor percent	11.74
7	Gang Size	14.99
8	Precipitation	15.00
9	Method	16.44

Table: 4.3 Qualitative Index Values (Mat Lab Run # 1)

Cluster Radius (r_a)	Number of Fuzzy Rules	Qualitative Index Values								
		Temp.	Humidity	Ppt.	Wind	Gang Size	%age Labor	W-Type	Floor Level	W-Method
1	1	0.8451	0.7722	1	0.9	1	1	0.5	0.875	1
0.95	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.9	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.85	2	0.3529	0.4608	1	0.5	0.75	0.5556	0.5	0.375	1
0.8	2	0.7451	0.7597	1	0.511	0.75	0.7222	0.5	0.6964	1
0.75	2	0.7451	0.5962	1	0.535	0.75	0.8333	0.5	0.6964	1
0.7	3	0.7843	0.452	1	0.649	0.8203	0.8333	0.5	0.6964	1
0.65	3	0.7843	0.7597	1	0.667	0.8203	0.8333	0.5	0.6964	1
0.6	3	0.7843	0.7597	1	0.63	0.8203	0.787	0.5	0.6094	1
0.55	3	0.7843	0.7597	1	0.647	0.8789	0.787	0.5	0.6563	1
0.5	3	0.549	0.7223	1	0.647	0.8789	0.7346	0.5	0.3281	1
0.45	4	0.3173	0.3841	0	0.518	0.7324	0.5142	0	0.375	1
0.4	4	0.2266	0.3145	0	0.457	0.9375	0.5651	0	0.25	1
0.35	4	0.1976	0.4532	1	0.287	0.625	0.242	0.25	0.1667	1
0.3	5	0.407	0.4242	0	0.319	0.7031	0.5617	0	0.426	1
0.25	6	0.0032	0.0359	0	0.07	0.0148	0	0	0	0
0.2	7	0.0832	0.0341	0	0.239	0.4219	0	0	0.1202	0
0.15	9	0.0308	0.0421	0	0.047	0.2093	0.0835	0	0.2518	0
0.1	15	0	0	0	0	0	0	0	0	0
0.05	22	0	0	0	0	0	0	0	0	0
Summation	9.3303	9.2748	12	9.4	13.11	11.0528	5.75	8.8441	15	

Table: 4.4 Summary Showing Average Values of Qualitative Index (π_j) of Selected Trials Along with Corresponding Clustering Algorithm Parameters

Run No.	Clustering Parameters (sf, ar , rr)	Qualitative Index Values π								
	At Cluster Radius ra = 1.0 : 0.0	Temperature	Humidity	Ppt.	Wind Speed	Gang Size	Labor percent	Work Type	Floor level	Method
1	(0.5, 0.7, 0.0)	9.3303	9.2748	12	9.4214	13.113	11.0528	5.75	8.8441	15
4	(0.5, 1.0, 0.0)	9.3303	9.2748	12	9.4214	13.113	10.9722	5.25	8.891	15
5	(0.5 ,0.7 , 0.2)	9.7154	10.1016	14	10.0227	13.963	11.734	6.75	8.8794	15
8	(0.5 , 1.0 , 0.2)	9.7154	10.1016	14	10.0227	13.963	11.734	6.75	8.8794	15
9	(0.5, 0.7 , 0.4)	10.7174	12.0567	18	11.1257	15.222	12.7925	8.75	9.7444	18
12	(0.5 , 1.0 , 0.4)	10.7174	12.0567	18	11.1257	15.222	12.847	9.25	9.7541	18
13	(0.5 ,0.7 , 0.6)	11.5202	13.0414	18	12.5871	16.887	13.7263	10.25	10.66	19
16	(0.5 , 1.0 , 0.6)	11.5202	13.0414	18	12.5871	16.887	13.7263	10.25	10.66	19
33	(0.3 , 0.7 , 0.0)	7.2215	7.3734	11	7.5997	13.253	10.1762	3.25	6.9542	14
36	(0.3 , 1.0 , 0.0)	7.2284	7.4421	11	7.7618	13.253	10.1762	3.25	6.9542	14
37	(0.3 , ,0.7 , 0.2)	7.3699	7.6681	11	7.9949	14.438	10.7334	3.25	7.1775	14
40	(0.3 , 1.0 , 0.2)	7.3887	7.7368	11	8.1935	14.475	10.7633	3.25	7.2504	14
41	(0.3 , 0.7 , 0.4)	8.5543	10.3218	18	9.3882	16.146	11.7451	6.5	8.3296	18
44	(0.3 , 1.0 , 0.4)	8.5662	10.3218	18	9.4337	16.182	11.8027	6.5	8.4025	18
45	(0.3 , 0.7 , 0.6)	8.6367	10.5707	18	9.7287	16.848	11.1099	6.5	8.1642	18
48	(0.3 , 1.0 , 0.6)	8.6575	10.5707	18	9.82	16.917	12.7789	6.25	9.3727	19
Average		**9.1369**	**10.0597**	**15**	**9.7646**	**14.993**	**11.7419**	**6.3594**	**8.6824**	**16.4375**

4.3 Neural Network Approach.

4.3.1 General

Neural Network Technology mimics the brain's own problem solving process. Similar to the human thinking and decision making ability, a neural network takes previously solved examples to build a system of neurons that makes new decisions, classifications and forecasts. Neural network learns patterns that are being presented to it during the training or learning phase. During the course of training, it develops in itself the ability to generalize, thereby becoming able to correctly classify new patterns or to make forecasts and predictions.

NETWORK STRUCTURE: The basic building bloc of neural network technology is the simulated neuron. An independent neuron is interconnected into a network. The neuron processes a number of inputs fed into it, to produce an output in terms of the network classification and predications.

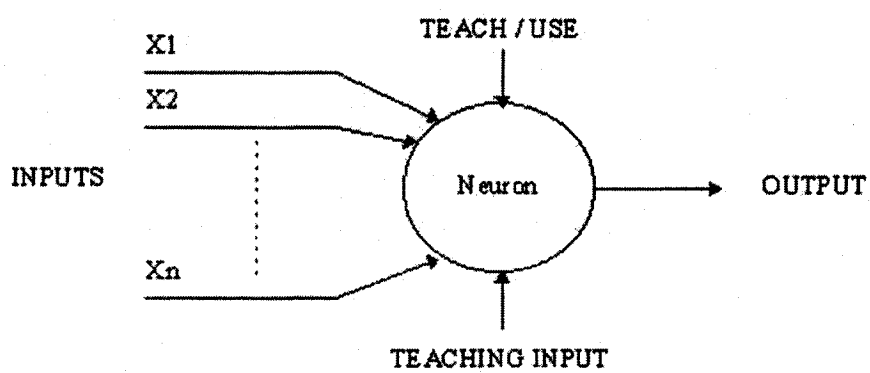


Fig: 4.4 Neuron –The information processing Unit (Christos & Dimitrois 1997)

The neurons have weights associated with them which are applied to the values passed from one neuron to the next. A group of neurons is called a slab.

Neurons are also grouped into layers by their connection to the outside world. There are three types of layers as shown in the figure 4.5. The first input layer takes the inputs from the user whereas the last layer, as it is named the output layer shows the network output. Neurons in between the input and output layer are in the hidden layer(s). A layer may contain one or more than one slabs of neurons.

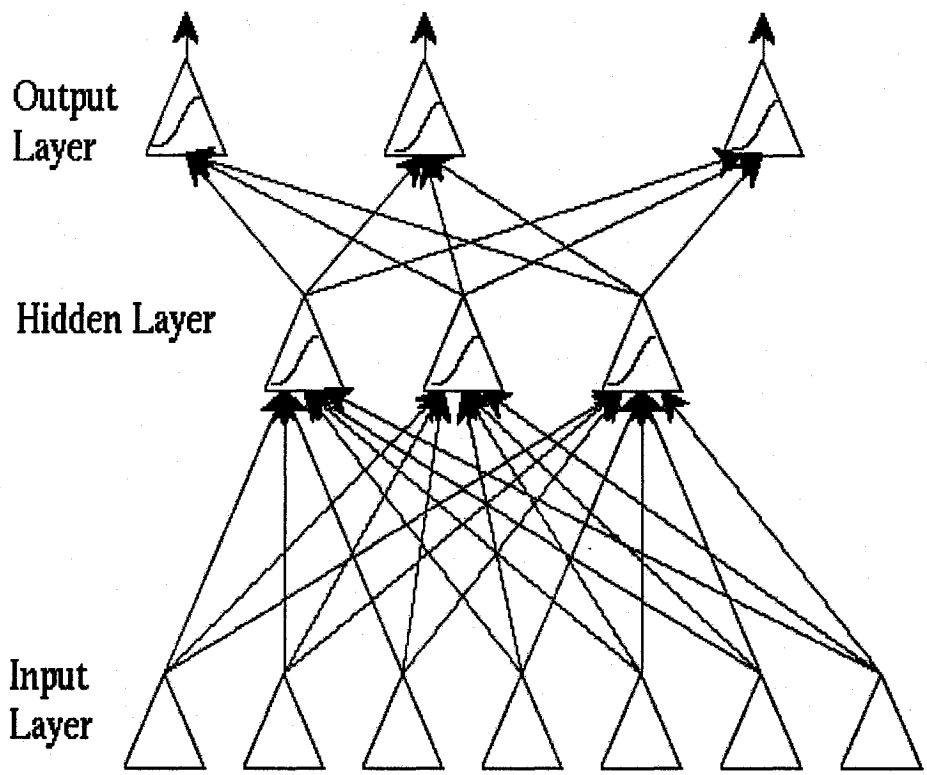


Fig: 4.5 A Typical Back Propagation Neural Network Architecture (Christos & Dimitrois 1997)

4.3.2 Network Learning.

A typical neural network is a back propagation network which normally has three layers of neurons. Input values in the first layer are weighted and passed to the second hidden layer. Neurons in the hidden layer fire or produce outputs that are

based upon the sum of the weighted values passed to them. The hidden layers passes values to the output layer in the same fashion and the output layer produces the desired results. *The network learns by adjusting the interconnection weights between the layers.* The answers the network is predicting are repeatedly compared with the correct answers, and each time the corresponding weights are adjusted slightly in the direction of the correct answer depending upon the settings of learning rate and momentum. Eventually, if the problem can be learned a stable set of weights adaptively evolves and produces good answers for all of the sample decisions and predictions.

In this study, Neuro Shell 2, which is a software developed by the Ward Systems Group Inc., is used for the neural network related analysis. Models are developed through various paradigms such as BPNN, GRNN and GMDH. In case of BPNN, which is regarded as the most salient NN paradigm, various experimentations were considered to be worthy of interest.

Regarding the input parameter significance, the contribution factors derived from the contribution factor module of the software formed the basis of establishing the ranking. The contribution factors are developed from an analysis of the weights of the trained neural network. The higher the number, the more that variable is contributing to the prediction or classification. Contribution factors of different networks can't be mutually compared. Obviously, if a certain variable is highly correlated with the answer, the variable will have a high contribution factor.

The prediction performance of the developed models is measured through the statistical terms of mean square error MSE and mean absolute error MAE and coefficient to multiple determination R^2 .The schematic diagram at Figure 4.6 illustrates the overall methodology adopted in case of the neural network analysis.

4.3.3 BPNN Model Development.

Most of the preceding discussion done about the architecture and learning of NN's implies to back propagation, and therefore the analysis now follows directly. As already mentioned, in the case of the BPNN, several trials were made either by making changes in the network architecture, or by varying the number of hidden neurons or activation functions. The aim was to find out the learning and the prediction performance of the neural network under various possible settings. The criteria for measuring the learning capability are coefficient of determination R^2 and those of prediction are the mean square error MSE & mean absolute error MAE. The consolidated summary of all the network setting employed and their corresponding results is placed at Appendix 3 whereas each model is also described individually here under:

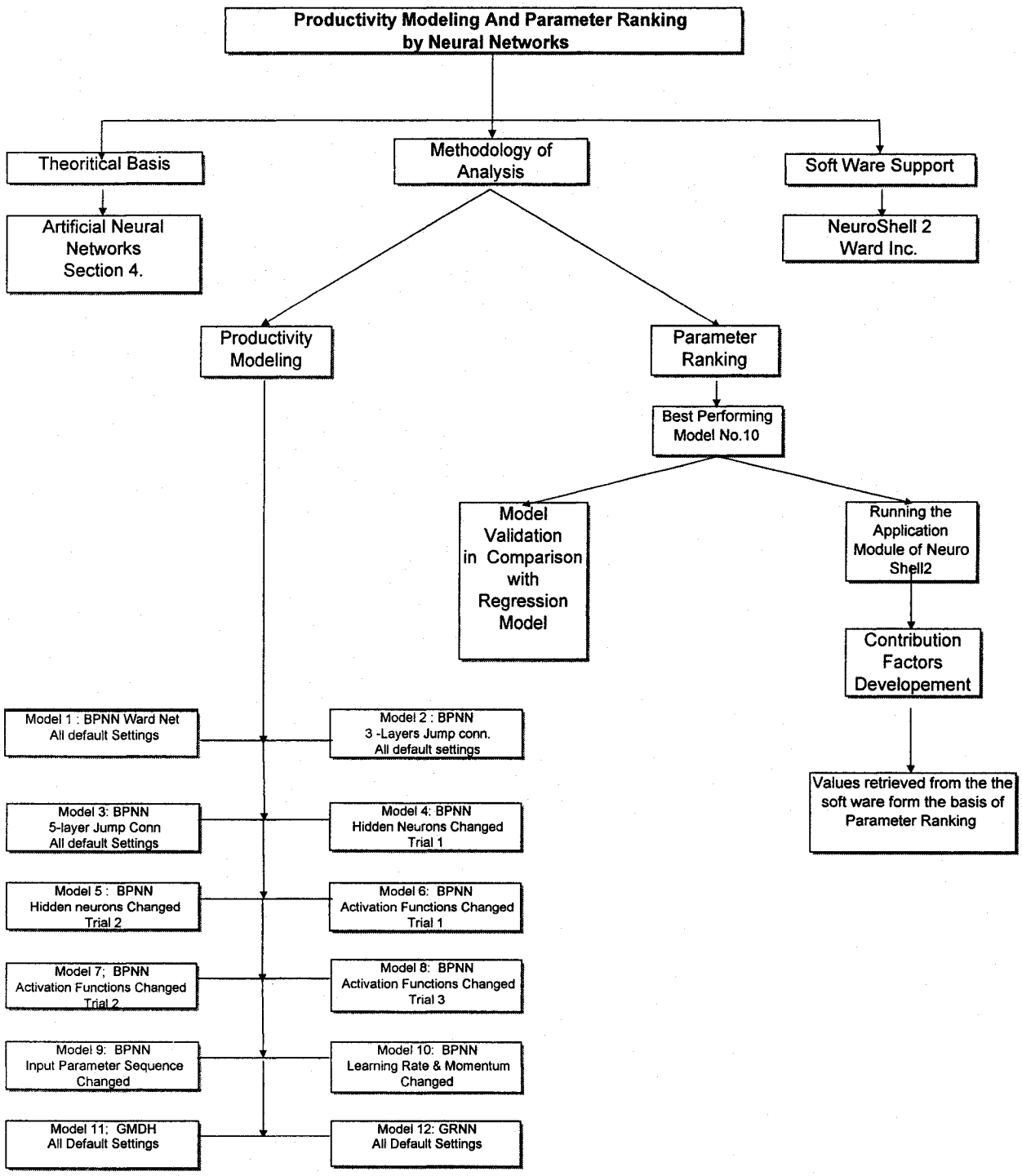


Fig: 4.6 Schematic Diagram for Neural Network Analysis

4.3.3.1 Model 1: ---- BPNN Ward Net

The network architecture is shown in the Figure 4.7

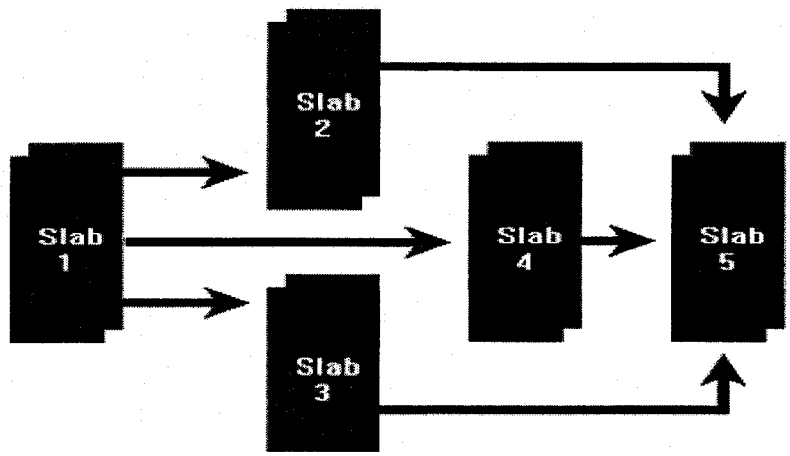


Fig: 4.7 Architecture of BPNN Ward Networks (Neuro Shell 2 1996)

The network settings which include scaling details, number of hidden neurons, activation functions employed, the learning rate and momentum applied are given in the Table 4.5.

Table: 4.5 Network Settings For BPNN Ward Network

Model	Settings	Performance Parameters	Values
BPNN Ward Net.	All Default Settings	**R squared:**	0.7667
	No .Of Neurons:	r squared:	0.7758
	Input = 9	**Mean squared error:**	0.0100
	1st hidden layer = 5 each slab	**Mean absolute error:**	0.0710
	2nd hidden =10	Min. absolute error:	0.0000
	Out put =1	Max. absolute error:	0.4450
	Scaling =None (Data normalized)	Correlation coefficient r:	0.8808
		Percent within 5%:	24.4340
		Percent within 5% to 10%:	16.7420
		Percent within 10% to 20%:	24.8870
		Percent within 20% to 30%:	14.9320
		Percent over 30%:	18.5520

4.3.3.2 Model 2 & Model 3 : ---- BPNN Jump Connection Networks

The difference between jump connection networks and the ward networks is that the former have jump links directly from the input to the hidden layers as well as to the out layers. Two BPNN jump connection networks developed are presented.

MODEL 2: (3-LAYERS JUMP CONNECTION NETWORK): The network architecture is shown in the Figure 4.8.

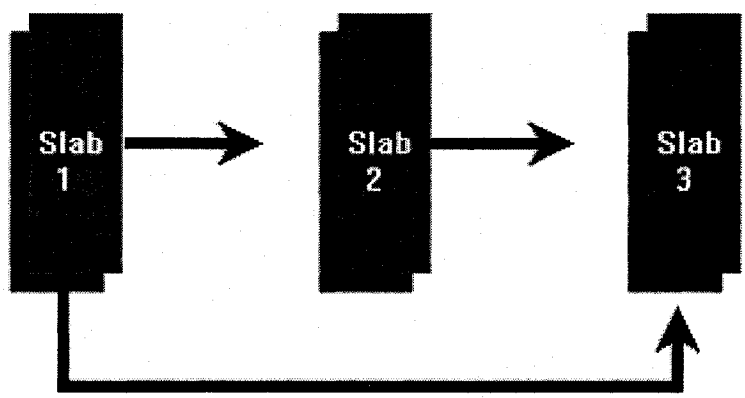


Fig: 4.8 Architecture of Three Layers Jump Connection Networks (Neuro Shell 2 1996)

Table: 4.6 Network Settings Three Layers Jump Connection Networks

Model	Settings	Performance Parameters	Values
BPNN: 3 Layer Jump Conn.Net	All Default Settings No. of Neurons =Default Scaling = None	**R squared:**	0.4236
		r squared:	0.4425
		Mean squared error:	0.0250
		Mean absolute error:	0.1280
		Min. absolute error:	0.0030
		Max. absolute error:	0.4710
		Correlation coefficient r:	0.6652
		Percent within 5%:	6.7870
		Percent within 5% to 10%:	9.9550
		Percent within 10% to 20%:	19.0050
		Percent within 20% to 30%:	21.7190
		Percent over 30%:	42.0810

MODEL 3: (5-LAYERS JUMP CONNECTION NETWORK): The network architecture is shown in the Figure 4.9

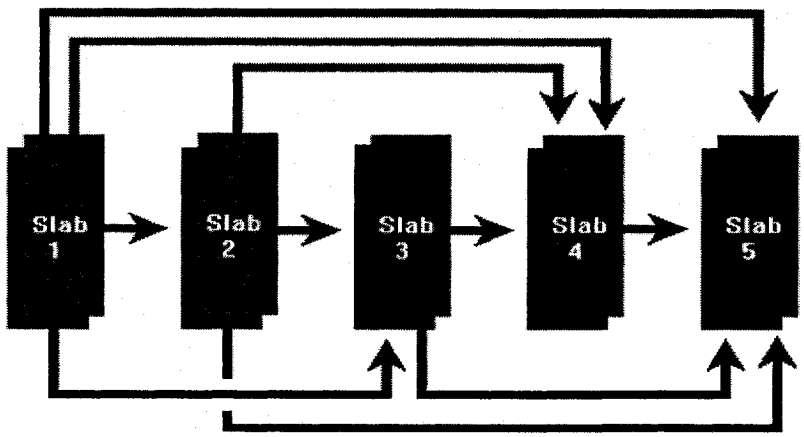


Fig: 4.9 Architecture of Five Layers Jump Connection Networks (Neuro Shell 2 1996)

The network settings employed are given in the Table 4.7.

Table: 4.7 Network Settings Five Layers Jump Connection Networks

Model	Settings	Performance Parameters	Values
BPNN: 5-Layer Jump Conn.Net	All Default Settings No. of Neurons= Default Scaling = None	**R squared:**	0.4620
		r squared:	0.4756
		Mean squared error:	0.0230
		Mean absolute error:	0.1220
		Min. absolute error:	0.0010
		Max. absolute error:	0.4850
		Correlation coefficient r:	0.6896
		Percent within 5%:	8.5970
		Percent within 5% to 10%:	9.9550
		Percent within 10% to 20%:	18.1000
		Percent within 20% to 30%:	23.0770
		Percent over 30%:	39.8190

4.3.3.3 Model 4 & 5: ---- Models With Changed Hidden Neurons

In Back propagation networks, the number of hidden neurons determines how well a problem can be learned. If a lot more than the optimum number of hidden neurons is used, the network will tend to memorize the problem, and thus will not generalize well later (although Calibration mitigates this effect to some extent). If too few than the optimum number is used the network will generalize well but may not have enough "power" to learn the patterns well. Getting the right number of hidden neurons is a matter or trial and error. The Ward Inc. manual for Neuro Shell 2 recommends the following formula for the default number of hidden neurons for a 3 layer network:

No. of hidden neurons = 1/2 (Inputs + Outputs) + square root of the number of patterns in the .PAT file if there is no .TRN file.

For more layers, the number computed above is divided by the number of hidden layers. If there are multiple slabs in a hidden layer, the hidden neurons are divided evenly among the slabs.

Two trials were done one each by decreasing and increasing the number of hidden neurons over the default one. The network settings employed and the performances achieved are given in the Tables 4.8 & 4.9.

Table: 4.8 Settings For Networks With Decreased Hidden Neurons

Model	Settings	Performance Parameters	Values
BPPN: Additional Neurons1	Ward Net All default settings No. of Neurons: 1st Layer = 8 2nd Layer = 8	**R squared:**	0.7789
		r squared:	0.7910
		Mean squared error:	0.0090
		Mean absolute error:	0.0640
		Min. absolute error:	0.0010
		Max. absolute error:	0.5150
		Correlation coefficient r:	0.8894
		Percent within 5%:	29.8640
		Percent within 5% to 10%:	18.5520
		Percent within 10% to 20%:	24.4340
		Percent within 20% to 30%:	10.8600
		Percent over 30%:	15.8370

Table: 4.9 Settings For Networks With Increased Hidden Neurons

Model	Settings	Performance Parameters	Values
BPNN: Additional Neurons 2	Ward Net All Default Settings No. of Neurons 1st Layer = 12 2nd Layer = 10	**R squared:**	0.7995
		r squared:	0.8113
		Mean squared error:	0.0090
		Mean absolute error:	0.0620
		Min. absolute error:	0.0000
		Max. absolute error:	0.3960
		Correlation coefficient r:	0.9007
		Percent within 5%:	31.2220
		Percent within 5% to 10%:	17.1950
		Percent within 10% to 20%:	23.5290
		Percent within 20% to 30%:	8.5970
		Percent over 30%:	19.0050

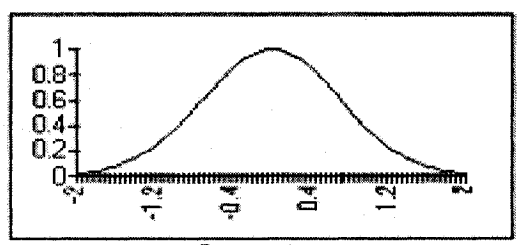
4.3.3.4 Model 6, Model 7 & Model 8: ---- Models With Changed Activation Functions

The way the neural networks work is that the hidden layers produce outputs based upon the sum of weighted values passed to them and so does the output layer.They produce their outputs by applying an "activation" function to the sum of the weighted values. The activation function, also called the squashing function, maps this sum into the output value, which is then "fired" on to the next layer. Though Logistic and the Gaussian Functions are the most widely used, there are other functions which may perform well in certain cases.

MODEL 6: ---- WITH GAUSSIAN, TAN H & LOGISTIC FUNCTION:

The horizontal and vertical axes represent 'X' and 'Y' values in the following figures:

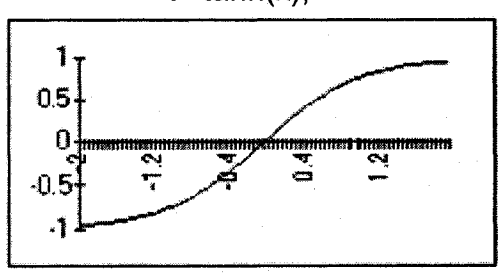
Y= exp(-x^2)



Gaussian

Source: Neuro Shell 2 1996

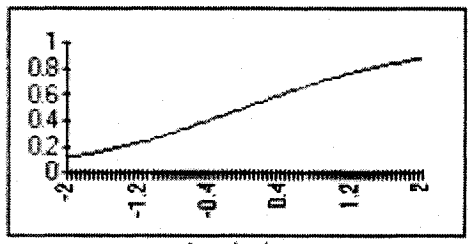
Y=tanh(x),



Tanh

Source: Neuro Shell 2 1996

Y=1/(1+exp(-x))



Logistic

Source: Neuro Shell 2 1996

The network settings employed are given in the Table 4.10.

Table: 4.10 Settings For Networks With Changed Activation Functions

Model	Settings	Performance Parameters	Values
BPNN: Activation Function 1	Ward Net	**R squared:**	0.7845
	All Default Settings	r squared:	0.7889
	Neurons No.= Default	**Mean squared error:**	0.0090
	Activation Functions :	**Mean absolute error:**	0.0690
	1st = Gaussian	Min. absolute error:	0.0000
	2nd = tan h	Max. absolute error:	0.5010
	output= logistic	Correlation coefficient r:	0.8882
		Percent within 5%:	23.0770
		Percent within 5% to 10%:	19.0050
		Percent within 10% to 20%:	24.8870
		Percent within 20% to 30%:	13.5750
		Percent over 30%:	19.0050

MODEL 7:---- WITH GAUSSIAN, GAUSSIAN & LOGISTIC FUNCTION:

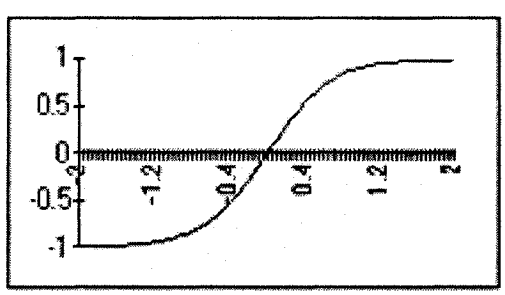
The network settings employed are given in the Table 4.11.

Table: 4.11 Settings For Networks With Changed Activation Functions

Model	Settings	Performance Parameters	Values
	Ward Net	**R squared:**	0.7945
	All Default Settings	r squared:	0.8022
	Neurons -	**Mean squared error:**	0.0090
	Recommended No.	**Mean absolute error:**	0.0640
	Activation Functions :	Min. absolute error:	0.0000
BPNN:	1st = Gaussian	Max. absolute error:	0.4880
Activation	2nd = Gaussian	Correlation coefficient r:	0.8956
Function 2	output= logistic	Percent within 5%:	26.2440
		Percent within 5% to 10%:	21.2670
		Percent within 10% to 20%:	23.9820
		Percent within 20% to 30%:	10.4070
		Percent over 30%:	17.6470

MODEL 8:----WITH TAN H & LINEAR FUNCTIONS:

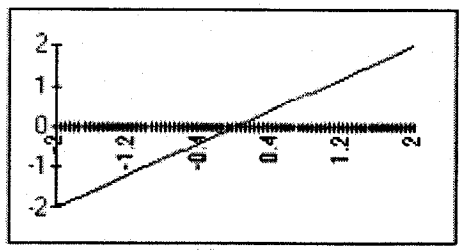
Y= tanh(1.5x)



Tanh15

Source: Neuro Shell 2 1996

Y=X



Linear

Source:Neuro Shell 2 1996

The network settings employed are given in the Table 4.12.

Table: 4.12 Settings For Networks With Changed Activation Functions

Model	Settings	Performance Parameters	Values
	Ward Net	**R squared:**	0.0876
	All Default Settings	r squared:	0.4257
	Neurons	**Mean squared error:**	0.0390
	Recommended No.	**Mean absolute error:**	0.1440
	Activation Functions :	Min. absolute error:	0.0010
BPNN:	1st = tanh1.5	Max. absolute error:	0.5820
Activation	2nd = tanh1.5	Correlation coefficient r:	0.6524
Function 3	Output= linear	Percent within 5%:	7.2400
		Percent within 5% to 10%:	10.4070
		Percent within 10% to 20%:	19.4570
		Percent within 20% to 30%:	18.5520
		Percent over 30%:	43.8910

4.3.3.5 Model 9:----With Pattern Presentation Arrangement Reversed

For all the models the input pattern presentation order was as under:

1	2	3	4	5	6	7	8	9
Temperature	Humidity	Precipitation	Wind Speed	Gang Size	Labor Percent	Work Type	Floor Level	Work Method

Now in the model 9 this order was reversed as under:

1	2	3	4	5	6	7	8	9
Work Method	Floor Level	Work Type	Labor Percent	Gang Size	Wind Speed	Precipitation	Humidity	Temperature

The network settings employed are given in the Table 4.13

Table: 4.13 Settings For Networks With Reversed Pattern Presentation Arrangement

Model	Settings	Performance Parameters	Values
BPNN: Input Presentation Arrangement Reversed	Ward Net All Default Settings Neurons= Recommended No. Data presentation Arrangement Reversed	**R squared:**	0.7953
		r squared:	0.8048
		Mean squared error:	0.0090
		Mean absolute error:	0.0660
		Min. absolute error:	0.0010
		Max. absolute error:	0.4470
		Correlation coefficient r:	0.8971
		Percent within 5%:	27.6020
		Percent within 5% to 10%:	18.1000
		Percent within 10% to 20%:	28.0540
		Percent within 20% to 30%:	7.6920
		Percent over 30%:	18.1000

4.3.3.6 Model 10 : ---- With Changed Learning Rate & Momentum

Each link in the network has its own learning rate and momentum that can be set individually. In case of predictive networks where the outputs are continuous values rather than categories, the Neuro Shell 2 manual recommends to use a smaller learning rate and momentum, such as 0.1.

The network settings employed in model 10 are given in the Table 4.14.

Table: 4.14 Settings For Networks With Decreased Learning Rate & Momentum

Model	Settings	Performance Parameters	Values
BPNN: Changed Learning Rate & Momentum	Ward Net Learning Rate = 0.05 Momentum = 0.05 Rest Default	**R squared:**	0.8316
		r squared:	0.8347
		Mean squared error:	0.0070
		Mean absolute error:	0.0580
		Min. absolute error:	0.0000
		Max. absolute error:	0.6040
		Correlation coefficient r:	0.9136
		Percent within 5%:	23.0770
		Percent within 5% to 10%:	23.0770
		Percent within 10% to 20%:	29.8640
		Percent within 20% to 30%:	11.3120
		Percent over 30%:	12.2170

4.3.4 GRNN Model

GRNN is a three-layer network where there must be one hidden neuron for each training pattern. There are no training criteria, such as learning rate and momentum, as in back propagation. GRNN applications are able to produce continuous valued outputs. GRNN can have multidimensional input, and it can fit multidimensional surfaces through data. The details of analysis carried out follows as under:

The network settings employed are given in the Table 4.15.

Table: 4.15 Settings For GRNN

Model	Settings	Performance Parameters	Values
GRNN	All Default	**R squared:**	0.8160
		r squared:	0.8166
		Mean squared error:	0.0080
		Mean absolute error:	0.0560
		Min. absolute error:	0.0000
		Max. absolute error:	0.5730
		Correlation coefficient r:	0.9037
		Percent within 5%:	35.2940
		Percent within 5% to 10%:	23.9820
		Percent within 10% to 20%:	19.0050
		Percent within 20% to 30%:	8.1450
		Percent over 30%:	13.1220

There was no scaling done as the data was already normalized, whereas the smoothing factor was 0.158203. Network predictions are annexed at Appendix 4.

4.3.5 GMDH Model.

The technique called Group Method of Data Handling works by building successive layers with complex links or connections that are the individual terms of a polynomial. These polynomial terms are created by using linear or non-linear regression. The initial layer is simply the input layer. The first layer is made by comparing regressions of the values of the first layer along with the initial input variables. Again, only the best are chosen by the algorithm. This process continues until the network stops getting better according to prescribed criteria. The features of the analysis carried out are as under:

The network settings employed are given in the Table 4.16.

Table: 4.16 Settings For GMDH

Model	Settings		Performance Parameters	Values
GMDH	Network type Settings No. of inputs: No. of outputs: No. of training patterns: No. of test patterns: Layers constructed: Best criterion value:	GMDH All default 9 1 177 0 7 0.28471		
			R squared:	0.7166
			r squared:	0.7166
			Mean squared error:	0.0121
			Mean absolute error:	0.0862
			Min. absolute error:	0.0007
			Max. absolute error:	0.4189
			Correlation coefficient r:	0.8465
			Percent within 5%:	12.6700
			Percent within 5% to 10%:	17.1950
			Percent within 10% to 20%:	28.0540
			Percent within 20% to 30%:	15.8370
			Percent over 30%:	25.7920

The network algorithm also gives the most significant variables found during the course of training which are reproduced below:

Table: 4.17 Most Significant Variables According To GMDH Model

Ranking	1	2	3	4	5	6
Parameter	Work Type	Temperature	Floor level / Height	Precipitation	Wind Speed	Humidity.

The best formula describing the model, retrieved from the network is:

Y=1.4*X8+0.47*X7-0.62+X2+0.13*X4-0.43*X3-3.5*X1+6*X1^2-1.1*X7^22.2*
X8^2-3.6*X1^3-0.51*X1*X7+2.6*X1*X8+1.4*X3^2-1.5*X3*X8-0.73*X2^2-0.45*X4^3

Legend:

X1	Temperature	X5	Gang Size	X9	Method
X2	Humidity.	X6	% Labor	Y	Productivity.
X3	Precipitation.	X7	Work Type		
X4	Wind Speed	X8	Floor Height		

The network predictions are annexed at Appendix 5.

4.3.6 Best performing Neural Network Model

The graphical comparison at Figure 4.10 gives a clear picture of the performance of all the developed neural network models with respect to the three given criteria. The best performing was Model No.10, both in terms of learning as well as prediction performance with highest value of R^2 and lowest values of MSE & MAE respectively.

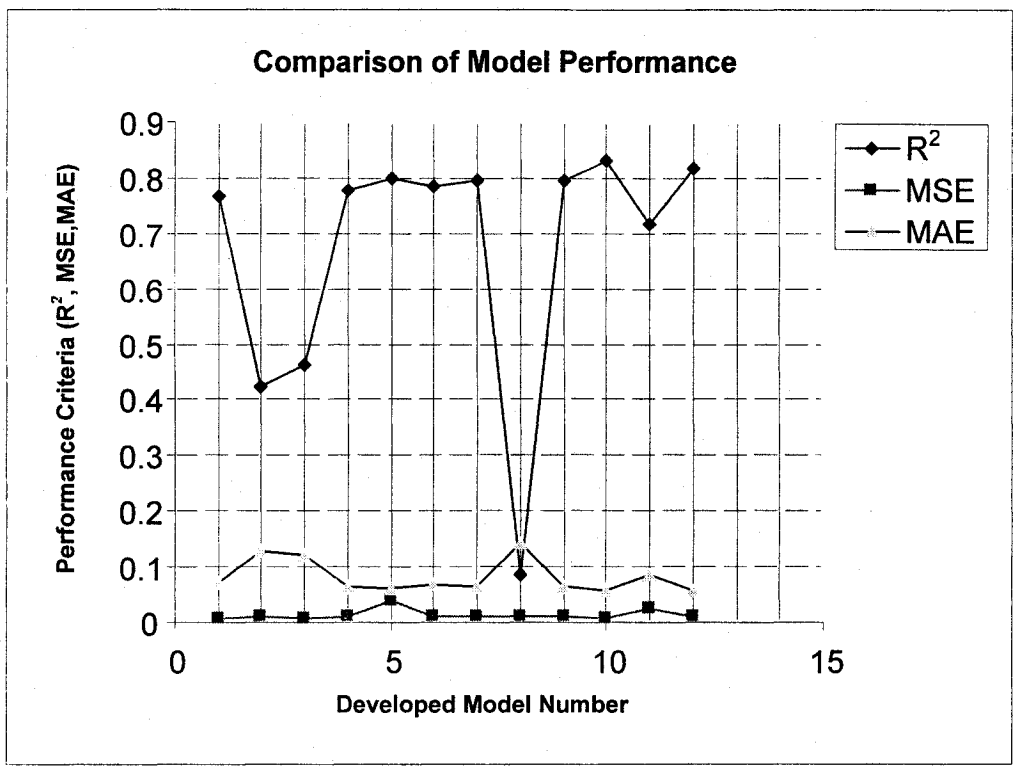


Fig: 4.10 Comparison of Neural Network Models Performances

Following are the relevant results extracted from the neural network analysis for Model No. 10. The Table 4.18 shows the weight values of all links in the network.

Table: 4.18 Weight Values of All Links in the Network For Model 10

LINK 1									
0.1947	-0.4326	0.6112	-0.2914	-0.3577	-0.0597	0.4291	0.8148	0.0263	0.1313
-0.0953	0.3302	0.0048	-0.2192	-0.4286	0.2204	0.1545	0.5545	-0.2682	-0.1870
-0.3634	0.0276	0.3970	0.8394	-0.0330	0.3129	-0.1041	-0.1431	-0.0131	-0.4960
-0.1234	1.0731	0.3733	-2.2861	-0.2177	-1.2692	-0.1864	-0.1855	-0.1678	-0.1733
0.9919	-1.6067	-0.1852	0.3861	-0.1773	-0.8398	-0.5658	-0.2047	1.8855	-0.2228
-0.4422	-0.6871	0.1512	-1.3733	0.0115	0.9999	-0.1650	-0.3799	1.6507	-0.3969
LINK 2									
-0.0059	0.8292	0.6487	-0.8172	-1.5909	1.5440	-1.7228			
LINK 3									
0.8595	-1.1087	-1.1497	0.2783	0.8250	-0.0829	0.1589	0.2694	0.5508	-0.2968
0.1275	0.0318	0.1475	-0.3906	0.2656	-0.0063	0.1869	-0.1333	0.2635	-0.0973
0.2080	-0.1791	0.0867	-0.7703	-0.0040	-0.0880	0.0355	0.3629	0.1492	0.0485
-0.0175	-0.7682	0.0451	0.1872	-0.1785	0.1191	-0.0736	0.3507	-0.9174	-0.1520
0.1991	0.4951	0.1805	0.1330	0.0559	0.2527	-0.2178	0.0168	0.0729	0.1596
-0.2891	0.8715	0.5408	-0.5237	-0.6936	-0.7314	0.6865	0.2976	1.2678	-0.2324
LINK 4									
0.0537	-0.8040	0.2924	0.6522	-0.7960	-0.0536	1.6289			
LINK 5									
0.1079	0.4480	0.3702	0.6765	0.0081	0.6455	-0.4024	0.5901	-0.9000	-0.0879
-0.2931	-0.1757	-0.2175	-0.0310	-0.2640	-0.1566	0.2461	0.1692	-0.2984	-0.3322
0.2508	0.4863	0.2858	0.2865	0.0693	0.1613	-0.1985	0.0900	0.1827	-0.2973
0.2679	-0.0414	0.0824	0.2635	-0.2268	-0.2008	-0.0840	0.1200	0.2160	0.0256
0.4739	-0.8322	-0.7963	-0.9451	0.1730	0.3551	0.0258	-0.3531	-0.7094	0.5572
0.2487	-0.2948	0.0880	0.5724	-0.0719	0.0372	1.2036	-0.1100	-0.9509	1.1937
LINK 6									
0.0946	-1.0911	-0.0082	-0.4414	-0.1362	-1.2409	-1.1770			

After training the network was applied on the entire pattern file having 221 data points and the predictions obtained are given at Table 4.19.

Table: 4.19 Output Predictions by NN Model # 10 (For Model Validation Purpose)

Pattern #	Actual	Network	Act-Net
1	0.9500	1.0203	0.0703
2	1.1200	1.2380	0.1180
3	1.0100	1.0512	0.0412
4	1.2700	1.2811	0.0111
5	1.1400	1.2019	0.0619
6	1.1700	1.3280	0.1580
7	1.0400	1.0785	0.0385
8	1.1600	1.2843	0.1243
9	1.9900	0.9570	-1.0330
10	1.1000	1.1125	0.0125
11	1.0000	1.0925	0.0925
12	1.1200	1.1837	0.0637
13	1.5500	1.5968	0.0468
14	1.2600	1.2129	-0.0471
15	1.1400	1.1805	0.0405
16	1.2700	1.3331	0.0631
17	1.4500	1.5229	0.0729
18	1.5100	1.4707	-0.0393
19	1.3700	1.2243	-0.1457
20	1.3800	1.1965	-0.1835
21	1.2500	1.1911	-0.0589
22	1.4900	1.4259	-0.0641
23	1.3400	1.4050	0.0650
24	1.3600	1.4013	0.0413
25	1.2200	1.2715	0.0515
26	1.3400	1.5042	0.1642
27	1.2000	1.3530	0.1530
28	1.3900	1.4704	0.0804
29	1.4100	1.4458	0.0358
30	1.2600	1.2745	0.0145
31	1.4800	1.3325	-0.1475
32	1.3600	1.4093	0.0493
33	1.2100	1.2829	0.0729
34	1.3400	1.3936	0.0536
35	1.0900	1.4583	0.3683
36	1.2100	1.2030	-0.0070
37	1.4700	1.4193	-0.0507
38	1.3200	1.3674	0.0474
39	1.3700	1.3190	-0.0510
40	1.2300	1.2550	0.0250
41	1.4700	1.3912	-0.0788
42	1.3400	1.3488	0.0088
43	1.4900	1.3919	-0.0981
44	1.3500	1.3951	0.0451
45	1.5400	1.7365	0.1965
46	1.3800	1.5014	0.1214
47	1.5200	1.7933	0.2733
48	1.3700	1.6180	0.2480
49	1.6700	1.6520	-0.0180
50	1.5100	1.4994	-0.0106
51	1.6500	1.7052	0.0552
52	1.4800	1.5653	0.0853
53	1.5700	1.6234	0.0534
54	1.4100	1.4212	0.0112
55	1.5600	1.6878	0.1278
56	1.4000	1.5279	0.1279
57	1.6300	1.6811	0.0511
58	1.4600	1.5307	0.0707
59	1.7300	1.6423	-0.0877
60	1.8900	1.9130	0.0230
61	1.7100	1.6804	-0.0296
62	1.7400	1.9369	0.1969
63	1.5500	1.5917	0.0417
64	1.8000	1.8582	0.0582
65	1.6200	1.6023	-0.0177
66	1.8700	2.0729	0.2029
67	1.6800	1.6353	-0.0447
68	1.6700	2.0421	0.3721
69	1.5200	1.4902	-0.0298
70	1.1000	1.1606	0.0606
71	1.7600	1.7676	0.0076
72	1.9800	2.0343	0.0543
73	1.5800	1.5442	-0.0358
74	1.4500	1.5089	0.0589
75	1.2600	1.2669	0.0069
76	2.0200	1.8851	-0.1349
77	1.5400	1.5701	0.0301
78	2.4000	2.2297	-0.1703
79	1.4900	1.6429	0.1529

80	2.2500	2.2067	-0.0433
81	2.2000	2.1125	-0.0875
82	1.6200	1.6253	0.0053
83	1.3300	1.5131	0.1831
84	2.2400	2.0779	-0.1621
85	1.7500	1.6047	-0.1453
86	1.9300	1.8332	-0.0968
87	1.4300	1.5158	0.0858
88	1.6500	1.7401	0.0901
89	1.6500	1.9398	0.2898
90	1.8500	1.9519	0.1019
91	1.8000	2.1071	0.3071
92	1.3200	1.4873	0.1673
93	1.5500	1.9955	0.4455
94	1.1000	1.2356	0.1356
95	1.4700	1.6087	0.1387
96	1.4200	1.4467	0.0267
97	1.4900	1.6560	0.1660
98	1.4500	1.4459	-0.0041
99	1.6100	1.6802	0.0702
100	1.5200	1.5376	0.0176
101	1.7600	1.7736	0.0136
102	1.7500	1.8005	0.0505
103	1.7300	1.8289	0.0989
104	1.9100	2.0292	0.1192
105	1.7900	1.5000	-0.2900
106	1.7700	1.8088	0.0388
107	1.8000	1.9095	0.1095
108	1.4200	1.4901	0.0701
109	1.4900	1.6139	0.1239
110	1.8700	1.9023	0.0323
111	2.0000	2.1959	0.1959
112	1.7800	1.6683	-0.1117
113	1.3600	1.3949	0.0349
114	2.4200	2.1797	-0.2403
115	2.3100	2.1811	-0.1289
116	2.0900	1.5594	-0.5306
117	1.8000	1.9076	0.1076
118	1.8500	1.9177	0.0677
119	1.8800	1.8926	0.0126
120	1.7800	1.9247	0.1447
121	2.3300	2.2528	-0.0772
122	1.7200	1.5746	-0.1454
123	1.7000	1.4947	-0.2053
124	2.0900	2.2311	0.1411
125	2.3200	2.3246	0.0046
126	2.3400	2.3343	-0.0057
127	1.8800	1.7958	-0.0842

128	1.9000	1.9195	0.0195
129	1.6500	1.5771	-0.0729
130	2.3300	2.2991	-0.0309
131	2.3500	2.2963	-0.0537
132	2.4000	2.3046	-0.0954
133	2.3800	2.2965	-0.0835
134	2.4000	2.3338	-0.0662
135	2.5300	2.3239	-0.2061
136	2.5000	2.2549	-0.2451
137	1.8000	1.6493	-0.1507
138	1.7000	1.7663	0.0663
139	2.3400	2.1901	-0.1499
140	1.9800	2.1377	0.1577
141	1.7400	1.7179	-0.0221
142	1.7800	1.6882	-0.0918
143	1.8000	1.6964	-0.1036
144	1.6800	1.7183	0.0383
145	1.5000	1.5030	0.0030
146	1.7400	1.8422	0.1022
147	1.8200	1.8658	0.0458
148	1.7300	2.0600	0.3300
149	2.1000	2.2936	0.1936
150	2.0200	2.1143	0.0943
151	1.9100	1.7361	-0.1739
152	1.9700	2.1069	0.1369
153	2.0000	2.0295	0.0295
154	2.0200	1.6511	-0.3689
155	1.7600	1.6883	-0.0717
156	1.7700	1.7218	-0.0482
157	1.8300	1.9069	0.0769
158	1.4200	1.4226	0.0026
159	1.2000	1.4002	0.2002
160	1.7800	1.6559	-0.1241
161	1.9600	1.9637	0.0037
162	1.5400	1.6302	0.0902
163	2.0300	2.0456	0.0156
164	1.9900	1.9954	0.0054
165	1.8900	1.8891	-0.0009
166	1.6900	1.6250	-0.0650
167	1.9600	1.8761	-0.0839
168	1.9800	1.9563	-0.0237
169	1.6400	1.6034	-0.0366
170	1.3300	1.2523	-0.0777
171	1.2400	1.1542	-0.0858
172	1.2200	1.2570	0.0370
173	1.6200	1.2005	-0.4195
174	1.1900	1.1455	-0.0445
175	1.2000	1.2759	0.0759

176	1.3100	1.4524	0.1424
177	1.7300	1.6350	-0.0950
178	1.2900	1.3580	0.0680
179	1.2600	1.3343	0.0743
180	1.3400	1.2248	-0.1152
181	1.3800	1.5061	0.1261
182	1.2300	1.3148	0.0848
183	1.3000	1.3289	0.0289
184	1.2800	1.2383	-0.0417
185	1.2100	1.1638	-0.0462
186	1.1600	1.0854	-0.0746
187	1.1000	1.1074	0.0074
188	1.0500	1.0751	0.0251
189	0.8800	1.0030	0.1230
190	1.2500	1.2242	-0.0258
191	1.2500	1.2491	-0.0009
192	1.3000	1.2880	-0.0120
193	1.4500	1.3621	-0.0879
194	1.2100	1.1284	-0.0816
195	1.1400	1.2005	0.0605
196	1.1100	1.2030	0.0930
197	1.1200	1.1194	-0.0006
198	1.0400	1.0746	0.0346
199	0.8200	1.1276	0.3076

200	1.4400	1.3730	-0.0670
201	1.3600	1.4615	0.1015
202	1.1500	1.2119	0.0619
203	1.5100	1.3737	-0.1363
204	1.4400	1.4718	0.0318
205	1.5100	1.3171	-0.1929
206	1.5800	1.4845	-0.0955
207	1.6500	1.5347	-0.1153
208	1.4900	1.5316	0.0416
209	1.3200	1.3719	0.0519
210	1.4700	1.4283	-0.0417
211	1.3000	1.2772	-0.0228
212	0.9900	1.1324	0.1424
213	1.3600	1.2920	-0.0680
214	1.1800	1.1654	-0.0146
215	1.2800	1.1562	-0.1238
216	1.2400	1.2151	-0.0249
217	1.6100	1.6496	0.0396
218	1.6500	1.8834	0.2334
219	1.5200	1.5552	0.0352
220	1.6700	1.6670	-0.0030
221	1.5000	1.6511	0.1511

4.3.7 Input Parameter Ranking By Neural Network Approach

The contribution factors of various input parameters obtained from selected model 10 are as under:

Table: 4.20 Input Parameter Ranking by Best Performing NN Model # 10

Ranking Order	Input Parameter	Contribution Factor
1	Work type	0.1827
2	Floor Level	0.1713
3	Temperature	0.1536
4	Gang Size	0.1072
5	Precipitation	0.0861
6	Humidity	0.0852
7	Work Method	0.0792
8	%age labor	0.0781
9	Wind Speed	0.0566

4.4 Regression Approach.

Regression analysis consists of a graphic and analytical method of exploring relationships between one variable, called the response variable and one or

more variables called the predictor variables. In regression analysis the response variable is expressed as a function of the predictor variable. Once such an expression is obtained the relationship can be utilized to have a quantified prediction of the response variable or to identify variables significantly affecting the response. The schematic diagram at Figure 4.11 shows the method employed for regression model development and input parameter ranking through regression.

The variable selection techniques in regression analysis can be divided into two main categories, those of:

Subset Selection Methods

Stepwise Selection Methods.

Stepwise Selection Methods are preferred over the subset methods category when the number of variables involved is large, because the former approach usually involves tedious analysis.

Stepwise regression procedures are selection techniques that sequentially add or delete single predictor variables to the prediction equation. Since a series of steps are involved before a final equation is obtained, and since each step directly leads to the next a lesser number of equations is to be evaluated through this process in comparison to the subset selection techniques.

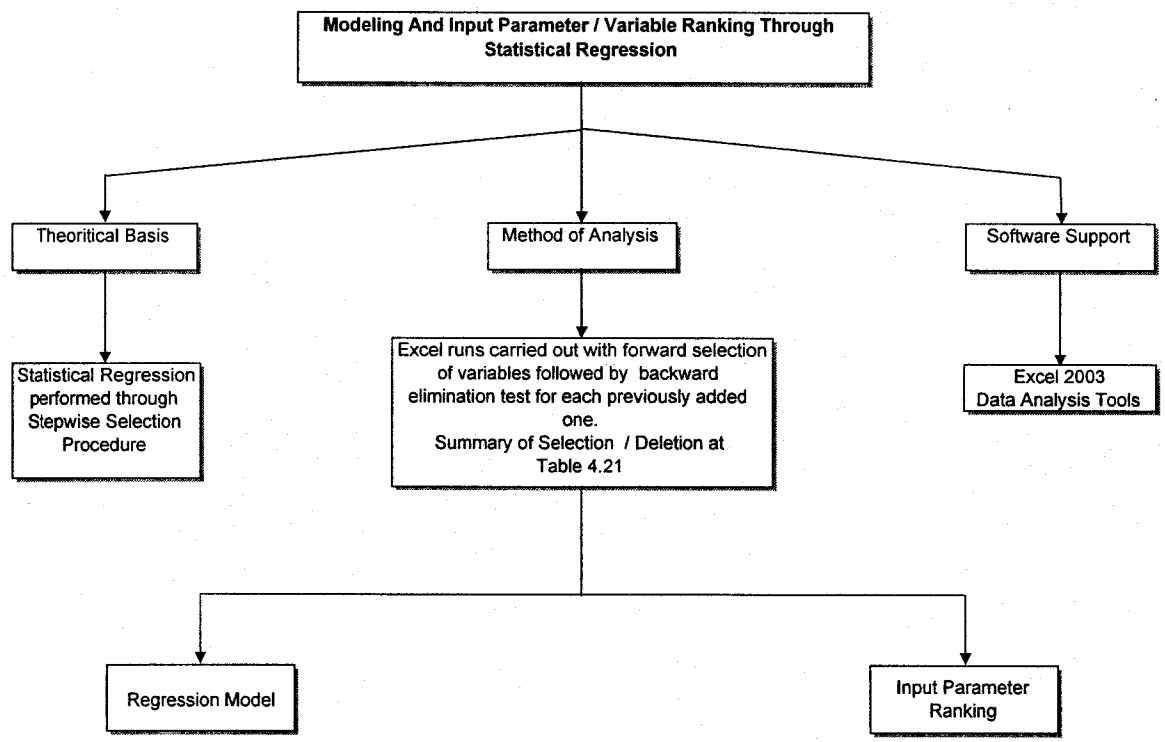


Fig: 4.11 Schematic Diagram for Statistical Regression Analysis.

4.4.1 Stepwise Procedure.

The Stepwise procedure (SW) is one of the three stepwise selection methods. It combines the plus points of both of its preceding stepwise techniques, i.e. the forward selection and the backward elimination. It is basically a forward selection procedure but at each step of the process the predictor variables in the chosen subset are re-examined for possible deletion, as in the back elimination method. Hence, after each predictor variable is added consideration is given to discarding one of the previously accepted variables. At each step of the SW technique a predictor variable is added to the predictor equation only if its F-statistics is the largest one as calculated by the equation 4.1 (Gunst & Mason 1985).

$$F_J = \frac{SSE - SSE_{s+1(J)}}{MSE_{s+1(J)}} \quad \text{and exceeds } F_{1-\gamma}(1, n-s-2), \ldots\ldots\ldots\ldots \quad \text{Eq. 4.1}$$

where:

γ = Significance Level for F-Statistics.

n= Total no. of data points

s= No. of parameters already in the analysis

$F_{1-\gamma}$ at γ (0.25) is $F_{0.75}$ (1,210)

=> $F_{0.75}$ = 1.33 (Cumulative F-Dist. Table at Appendix 6).

Next each predictor variable already chosen is reconsidered for possible elimination from the previously selected sub-set if its F-statistics , again calculated from the above equation 4.1, is the smallest one and doesn't exceed $F_{1-\gamma}$ (1, n-s-2).This process continues until all 'p' predictor variables are in the

equation or until the selection criteria is met. The advantage of this method is quite evident. At each step, this procedure allows one to judge the contribution of each predictor.

For establishing the input parameter / variable significance ranking, the order of their final entry and 'NOT' the first entry in the subset is recorded i.e., after which the variable under consideration wasn't eliminated during re-examination. The order of variables according to the time of their non exclusion from the subset is treated as their order of significance in this study.

Using $\gamma = 0.25$, the step wise selection procedure was carried out with nine input and one output data. Table 4.21 shows the summary of the selection procedure.

Table: 4.21 Tabulation of Variable Selection Steps

Step	Variables			F-stat
	In	Added	Deleted	
1	None	T		116.0808
1	None	H		1.7694
1	None	W		9.3640
1	None	P		6.0933
1	None	G		7.5577
1	None	L		0.6179
1	None	TW		31.2459
1	None	F		21.8639
1	None	M		26.3746
2	T	H		57.7755
2	T	W		62.3154
2	T	P		61.1036

2	T	G		58.4341
2	T	L		57.8575
2	T	TW		81.1684
2	T	F		57.8575
2	T	M		81.0154
3	T,TW		T	31.2459
4	T,TW	H		54.0127
4	T,TW	P		57.7122
4	T,TW	WS		55.7250
4	T,TW	G		55.7250
4	T,TW	L		54.0066
4	T,TW	F		55.8683
4	T,TW	M		56.2693
5	T,TW,P		TW	61.1036
5	T,TW,P		T	20.4389
6	T,TW,P	H		43.1646
6	T,TW,P	W		45.3373
6	T,TW,P	G		44.1212
6	T,TW,P	L		43.3055
6	T,TW,P	F		43.6692
6	T,TW,P	M		44.3906
7	T,TW,P,W		P	55.7250
7	T,TW,P,W		TW	57.7122
7	T,TW,P,W		T	16.6553
8	T,TW,P,W	H		36.1987
8	T,TW,P,W	G		38.7992
8	T,TW,P,W	L		36.2348
8	T,TW,P,W	F		37.5929
8	T,TW,P,W	M		37.6174
9	T,TW,P,W,G		W	45.3373
9	T,TW,P,W,G		P	44.1212
9	T,TW,P,W,G		TW	33.8129
9	T,TW,P,W,G		T	12.8510
10	T,TW,P,W,G	H		32.2415
10	T,TW,P,W,G	L		32.9524
10	T,TW,P,W,G	F		32.3604
10	T,TW,P,W,G	M		32.8490
11	T,TW,P,W,G,L		G	32.9524
11	T,TW,P,W,G,L		W	35.6898

11	T,TW,P,W,G,L		P	37.9257
11	T,TW,P,W,G,L		TW	26.9468
11	T,TW,P,W,G,L		T	10.6927
12	T,TW,P,W,G,L	H		28.1188
12	T,TW,P,W,G,L	F		28.2835
12	T,TW,P,W,G,L	M		28.7293
13	T,TW,P,W,G,L,M		L	32.8490
13	T,TW,P,W,G,L,M		G	31.4078
13	T,TW,P,W,G,L,M		W	30.1860
13	T,TW,P,W,G,L,M		P	32.3949
13	T,TW,P,W,G,L,M		TW	31.2033
13	T,TW,P,W,G,L,M		T	9.5583
14	T,TW,P,W,G,L,M	H		25.0510
14	T,TW,P,W,G,L,M	F		25.0916
15	T,TW,P,W,G,L,M,F		M	28.2835
15	T,TW,P,W,G,L,M,F		L	28.0965
15	T,TW,P,W,G,L,M,F		G	27.5646
15	T,TW,P,W,G,L,M,F		W	25.7559
15	T,TW,P,W,G,L,M,F		P	27.9624
15	T,TW,P,W,G,L,M,F		TW	26.6591
15	T,TW,P,W,G,L,M,F		T	13.7424
16	T,TW,P,W,G,L,M,F,H			22.2173

4.4.2 Input Parameter Ranking by Regression Analysis Approach.

The ranking of input parameters according to the criteria of their order of final entry in the parameter selection test summarized above, is given as follows:

Table: 4.22 Input Parameter Ranking by Regression Analysis Approach

Ranking	1	2	3	4	5	6	7	8	9
Parameter	Temp.	Work Type	Precipitation	Wind Speed	Gang Size	Labor Percent	Work Method	Floor Height	Humidity

4.4.3 Regression Model .

Subsequent to the parameter selection step the following linear regression model was developed:

$$DP = 2.1908 + 0.0165\,T - 0.0004\,H - 0.0525\,P - 0.0078\,W - 0.0111\,G - 0.0079\,L - 0.1597\,WT + 0.0036\,F + 0.0816\,WM.$$

The performance parameters of the regression model are given in the Table 4.23 & 4.24. where as the detailed regression analysis is placed at Appendix 8.

Table: 4.23 Regression Statistics

Multiple R	0.70954211
R Square	0.50345
Adjusted R Square	0.46518202
Standard Error	0.25932506
Observations	221

Table: 4.24 ANOVA

	d_f	SS	MS	F	Significance F
Regression	9	13.47377	1.497085	22.26166	0
Residual	211	14.18964	0.067249		
Total	220	27.66341			

4.5 Combined Average Parameter Ranking.

Since by now the parameter rankings from all three approaches employed, i.e. the fuzzy expert system, neural network analysis and regression analysis have been obtained, so in order to arrive at one final parameter significance ranking given at Table 4.25 the following approach was applied:

- First, equal weight age was given to the intermediate parameter rankings given by each of the above referred methodology.

- The values of the parameters establishing significance ranking (columns 1, 3, & 6) in all the three cases were normalized. In case of fuzzy logic a little adjustment had to be made because in this case the assumption was that the lower the value of qualitative index (column 3), the more significant the variable is. In the other two cases the relationship was straight forward, i.e. the more the criterion value the more important the variable. So in order to handle fuzzy logic values in the same manner as the other two, the column 4 normalized values were subtracted from 1 and were placed in column 5. In this way, all three normalized values were placed in columns 2, 5, & 7 respectively.

- The values in the column 8 are the combined average values of columns 2,5 & 7. The final rankling of the input parameters is done by arranging the column 8 values in descending order.

Table: 4.25 Calculations For Final Parameter Ranking

Parameter	Contribution Factor Neural Networks	Normalization of Column I	Qualitative Index Values Fuzzy Clustering	Normalization of Column III	Adjustment of Normalized Values of Col. IV = 1-(IV)	F-Statistics Regression Analysis	Normalization of Column VI	Average of Normalized Significance Values
	I	II	III	IV	V	VI	VII	VIII
Temperature	0.1536	0.7692	9.1369	0.2756	0.7244	116.0808	1.0000	0.8312
Humidity	0.0852	0.2268	10.0597	0.3672	0.6328	10.0597	0.0000	0.2865
Precipitation	0.0861	0.2339	15.0000	0.8574	0.1426	57.7122	0.4495	0.2753
Wind Speed	0.0566	0.0000	9.7646	0.3379	0.6621	45.3373	0.3327	0.3316
Gang Size	0.1072	0.4013	14.9927	0.8566	0.1434	38.7992	0.2711	0.2719
Labor Percant	0.0781	0.1705	11.7419	0.5341	0.4659	32.9524	0.2159	0.2841
Work Type	0.1827	1.0000	6.3594	0.0000	1.0000	62.3154	0.4929	0.8310
Floor Level	0.1713	0.9096	8.6824	0.2305	0.7695	25.0916	0.1418	0.6070
Work Method	0.0792	0.1792	16.4375	1.0000	0.0000	28.7293	0.1761	0.1184

Table:4.26 Overall Parameter Ranking

1	Temperature
2	Work Type
3	Floor Level
4	Wind Speed
5	Humidity
6	Labor Percant
7	Precipitation
8	Gang Size
9	Work Method

Table 4.26 gives the final significance ranking of the input parameters used in this study to model the labor productivity of Formwork installation activities

4.6 Model Validation.

4.6.1 Neural Network Model Validation

The developed best performing neural network model was validated by testing with the portion of the data not exposed to it during training. The set of data used for this purpose is called the Production Set and is extracted by the network during the design phase of network development. The new file with 221 data points (including 44 new production points) was applied to the trained / developed model to obtain anew, the predictions for the entire data set. The predicted out puts are shown in the Table 4.19 the R^2, MSE and MAE values of which are 0.8314, 0.0086 and 0.0701 respectively.

The following schematic shows the validation process of the Neural Network models, the performance verifications of the Regression models and the final comparisons of the two models on the basis of their of R^2, MSE and MAE values.

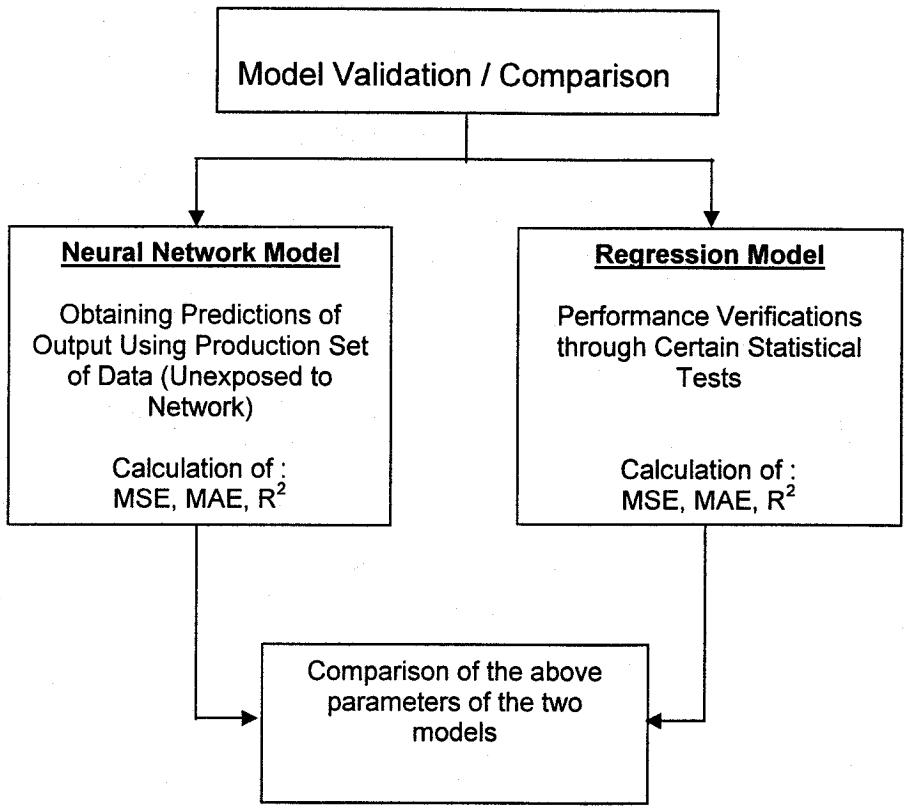


Fig: 4.12 Model Validation and Comparison Approach

where $MSE = \dfrac{\sum_{i=1}^{n} (P - \hat{P})^2}{n}$, $MAE = \dfrac{\sum_{i=1}^{n} \left| P - \hat{P} \right|}{n}$

and $R^2 = \dfrac{SST - SSE}{SST} = \dfrac{SSR}{SST}$,

where SSR = | SST | - [SSE] , $SSR = [\sum (P - \bar{P})^2] - [\sum (P - \hat{P})^2]$

where $\hat{P}$ = Predicted value of output $\bar{P}$ = Average value of output

4.6.2 Regression Model Verification.

As already mentioned, that before the regression model can be used for comparison with the selected neural network model, it is to be itself verified for being authentically representing and modeling productivity. To test its performance, four methods are recommended in literatures (Sincich et al. 1999) which are:

1) Overall model Test
2) Independent Variable Test
3) Statistical Parameters Test
4) Random Error Assumption Test

1) OVER ALL MODEL TEST

The purpose of the overall model test is to determine whether the multiple linear regression model is useful in predicting its dependent variable, i.e. the daily productivity. This is tested using the analysis of variance (ANOVA) (Sincich et al. 1999). The hypothesis test involves all the coefficients of the model, also called β parameters and is formulated as follows:

Null Hypothesis, H_0: $\beta_1 = \beta_2 = \ldots\ldots\beta_k = 0$

Alternative Hypothesis, H_a: At least one of $\beta_S \neq 0$

Here to refuse the null hypothesis we have to fulfill two conditions: 1) ANOVA F-test must be greater than the critical value of F ($F > F_\alpha$) and 2) the level of significance 'α' must be greater that the corresponding p-value (i.e. α>p-value).

There should be sufficient evidence to reject the null hypothesis and to conclude that at least one of the β factors is non zero. The significance level is defined as the probability of making a type I error for a hypothesis test. In hypothesis testing the type I error is the one that would occur when a null hypothesis is rejected when it is true, while type II error would occur when a null hypothesis is accepted when it is false. The value of 'α' is usually set to 0.05 (Evans and Olson, 2000). Here the F value is calculated using equation .

$$F = \frac{\text{Mean Square of Model}}{\text{Mean Square of Error}} = \frac{SS(Model)/k}{SSE/[n-(k+1)]} \qquad \text{Eq. 4.2}$$

Where:

SS= Sum of Squared ($\sum(y-\hat{y})^2$)

SSE= Sum of the Squared Errors

n = Number of Observations

k = No of parameters in the model (independent variables) excluding β_0.

F_α is driven from the corresponding statistical tables of the critical F values (see table at Appendix 6) as function of 1) numerator degrees of freedom (k), and (2) the denominator degrees of freedom [n-(k+1]. The p- values are given by Excel. The tabulation given at Table 4.27 illustrates that since the ANOVA F value is much more than Fα therefore, there is sufficient evidence to reject H_0 and to conclude that at least one of the independent variable coefficients (β_S) are non zero.

Table: 4.27 Over All Regression Model Test

n	k	α	F	F_α	p-value	Evaluation
221	9	0.05	22.26166	1.92	2.40643E-26	Pass

2) INDEPENDENT VARIABLE TEST.

The independent variable test checks whether or not the β coefficients are capable to represent the dependent variable. This hypothesis is tested through various tests on the coefficients. The number of test has to be limited to avoid the previously mentioned type I error. The hypothesis test is modeled as follows:

Null Hypothesis, $H_0 : \beta_k = 0$

Alternative Hypothesis, $H_a: \beta_k \neq 0$

If the data supports the alternative hypothesis, it can be concluded that the independent variable under investigation contributes to the prediction of the dependent variable using the straight line model. To reject the null hypothesis two conditions have to be fulfilled 1) the absolute value of the two tailed t-test must be greater than the critical value of t (i.e. $| t | > t_{\alpha/2}$), and 2) the level of significance α must be greater than the value of the corresponding p-value (i.e. α>p-value). The t value can be calculated through equation

$$t = \frac{\beta_k\left(\sum y^2 - \frac{\left(\sum y^2\right)}{n}\right)}{s}$$

where:

β_k = value of the coefficient (parameter)

s = standard deviation error of the factor

y = variable data

n = number of observations.

The critical value of t for the two tailed test ($t_{\alpha/2}$) is driven from the corresponding tables (see table at Appendix 7) and is a function of 1) $t_{0.025}$ (i.e. $t_{\alpha/2}$) and 2) the denominator degrees of freedom (n-(k+1).

As can be seen from the Table 4.28 the t-statistics of most of the independent variables are higher than $t_{\alpha/2}$. Therefore it can be concluded that they contribute towards the prediction of the dependent variable, i.e. daily labor productivity. It could also be stated that the overall model is robust and the independent variables are contributing towards the predictions of the dependent one.

Table: 4.28 Independent Variables Test For Regression Model

Input Parameter	Standard Error	N	k	α	T	$t_{0.025}$	p-value	Evaluation
Intercept	0.302920				7.232268		0.000000	Pass
X Variable 1(T)	0.002044				8.090219		0.000000	Pass
X Variable 2 (H)	0.001340				-0.257482		0.797057	Fail
X Variable 3 (P)	0.033591				-2.561861		0.019819	Pass
X Variable 4 (W)	0.002331	221	9	0.05	-3.339607	1.97	0.000992	Pass
X Variable 5 (G)	0.005266				-2.100946		0.036833	Pass
X Variable 6 (L)	0.005080				-2.545640		0.003690	Pass
X Variable 7 (TW)	0.057022				-2.800228		0.005581	Pass
X Variable 8 (F)	0.006566				1.543737		0.587196	Fail
X Variable 9 (M)	0.058428				2.396441		0.064049	Pass

3) Statistical Parameters Test

For assessing the strength of the model, there are several statistical parameter tests. The one most widely used is the coefficient of multiple determination (R^2) which can be calculated through the following equation

$$R^2 = \frac{SST - SSE}{SST} = \frac{SSR}{SST},$$

where:

$$SSR = |SST| - |SSE|, \quad SSR = [\Sigma(y-\bar{y})^2] - [\Sigma(y-\hat{y})^2]$$

$\hat{y}$ = Predicted value of output & $\bar{y}$ =Average value of output

The value of determination varies from 0 to+1. A regression model with a high R^2 (i.e. > 0.50) provides a better tool for predicting the dependent variable (McClave et al. 1997, Evans and Olson 2000). The developed model passes through the required criteria with a value of $R^2 = 0.503449998$.

4) Random Error Assumption Test

Among the random error assumption tests, the two employed here are:

a) The mean of 'Є' is 0

b) The probability plot of the residual is normal.

a) The mean of 'Є' equals zero: This assumption is violated if the model is misspecified. To detect the model misspecifications, the values of the independent values (x) are plotted against the corresponding residuals ($y - \hat{y}$).This plot is expected to vary randomly as x increases and not to give any specific shape or pattern (Sincich et al. 1999). The residual is simply the actual less the predicted values for the dependent values for each case. The residual plots of the regression model developed are shown in the Figures 4.13 to 4.20.

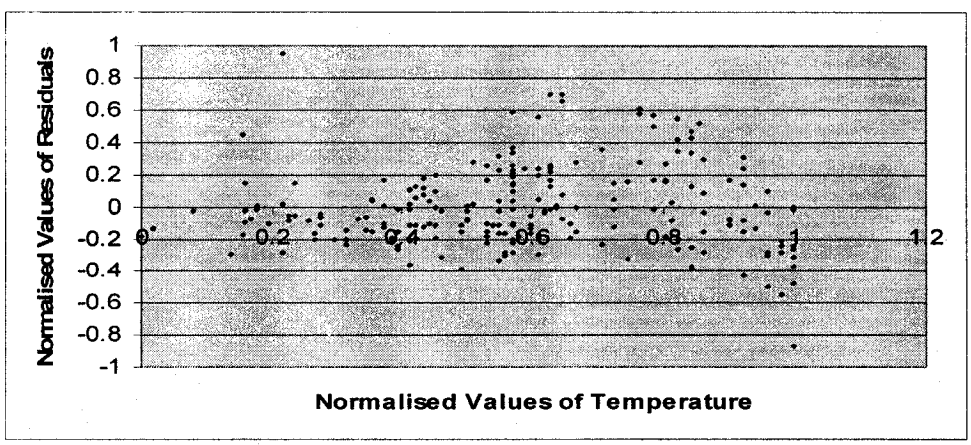


Fig: 4.13 Scatter of Residuals versus Temperature

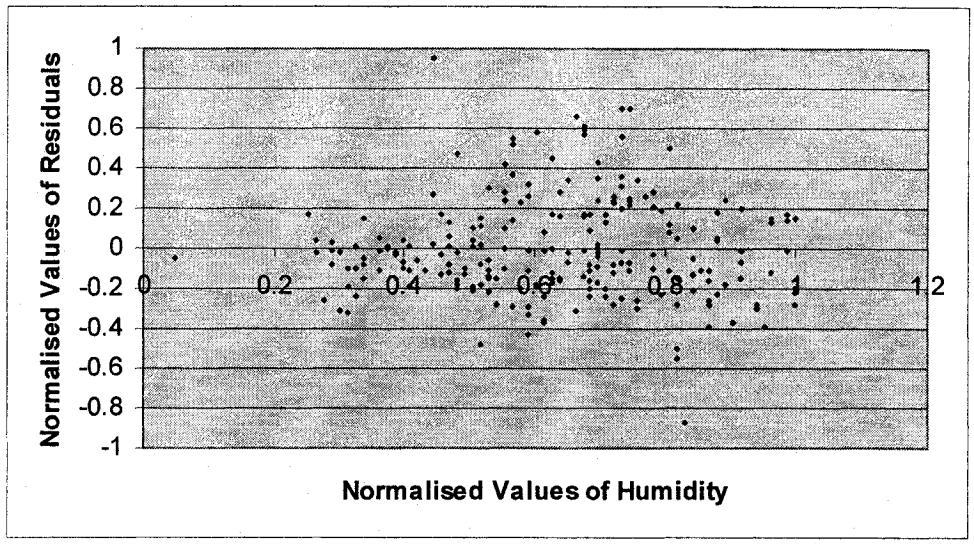


Fig: 4.14 Scatter of Residuals versus Humidity

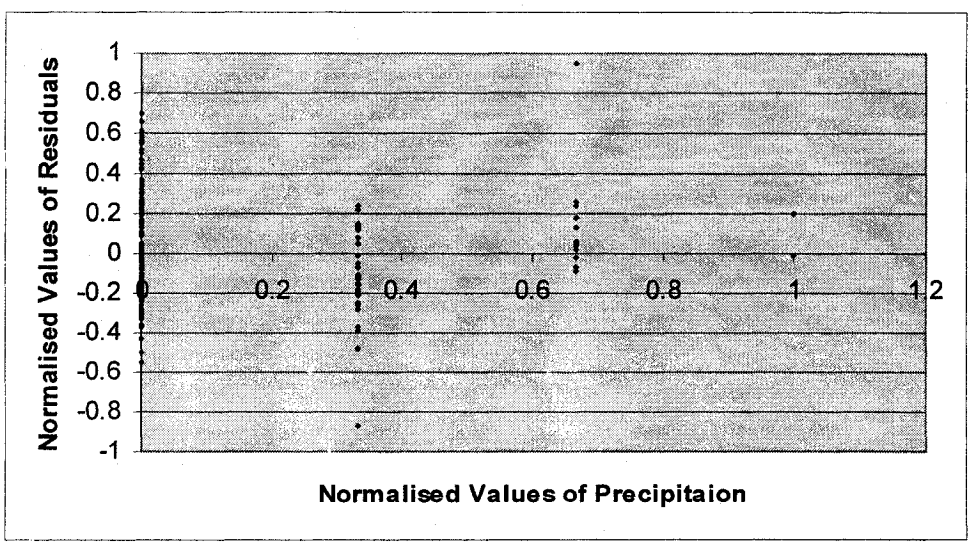


Fig: 4.15 Scatter of Residuals versus Precipitation

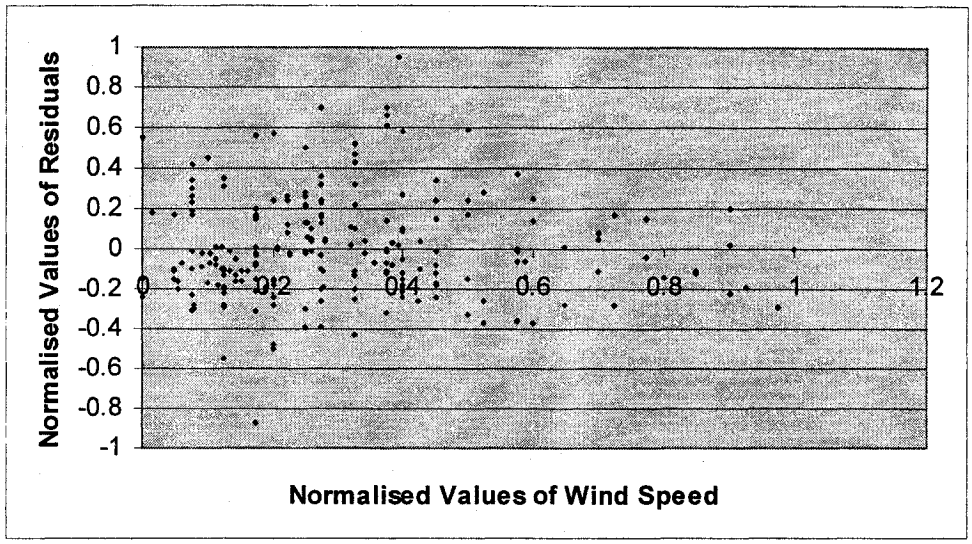


Fig: 4.16 Scatter of Residuals versus Wind Speed

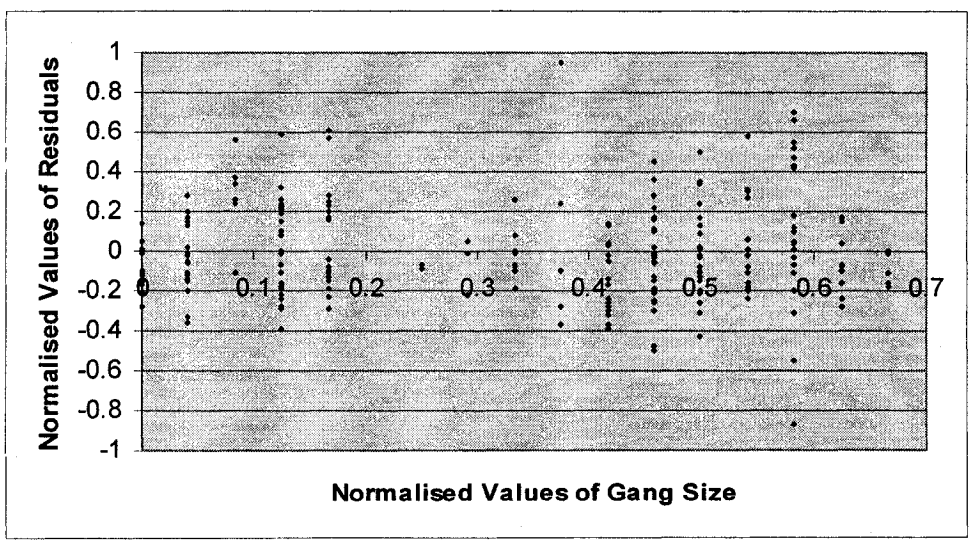


Fig: 4.17 Scatter of Residuals versus Gang Size

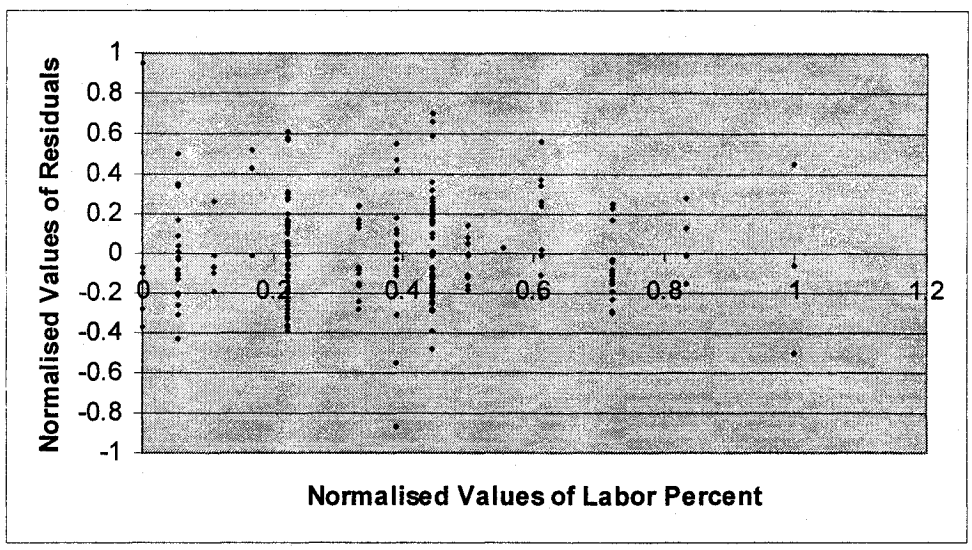


Fig: 4.18 Scatter of Residuals versus Labor Percentage

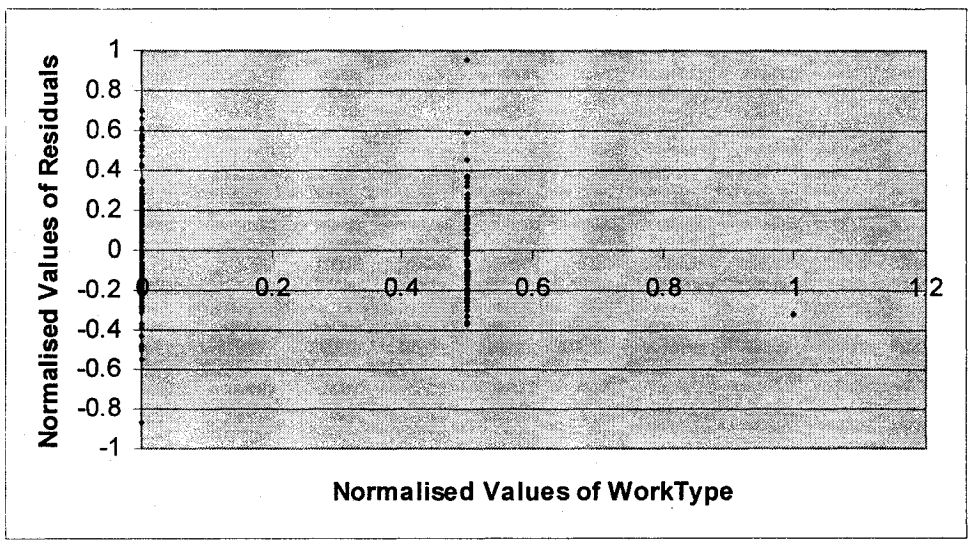


Fig: 4.19 Scatter of Residuals versus Work Type

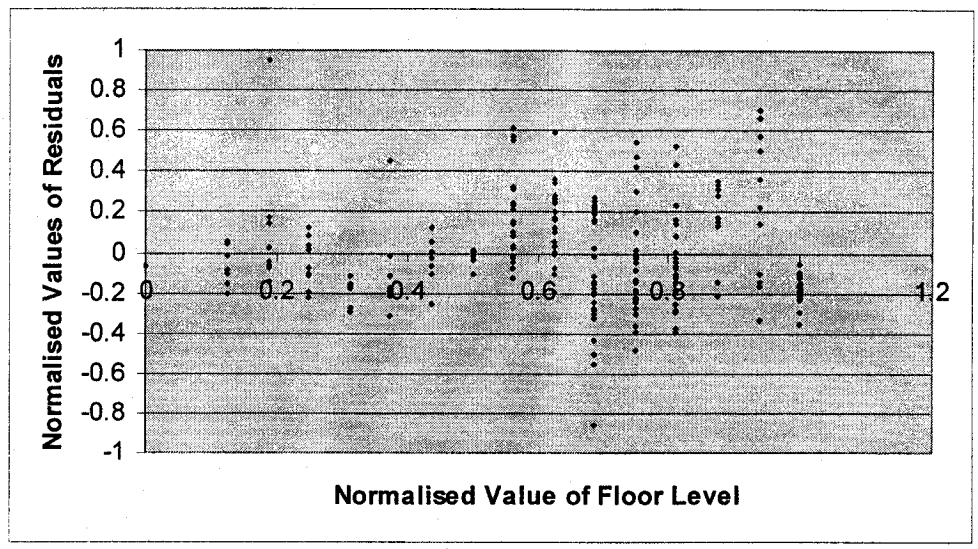


Fig: 4.20 Scatter of Residuals versus Floor Level

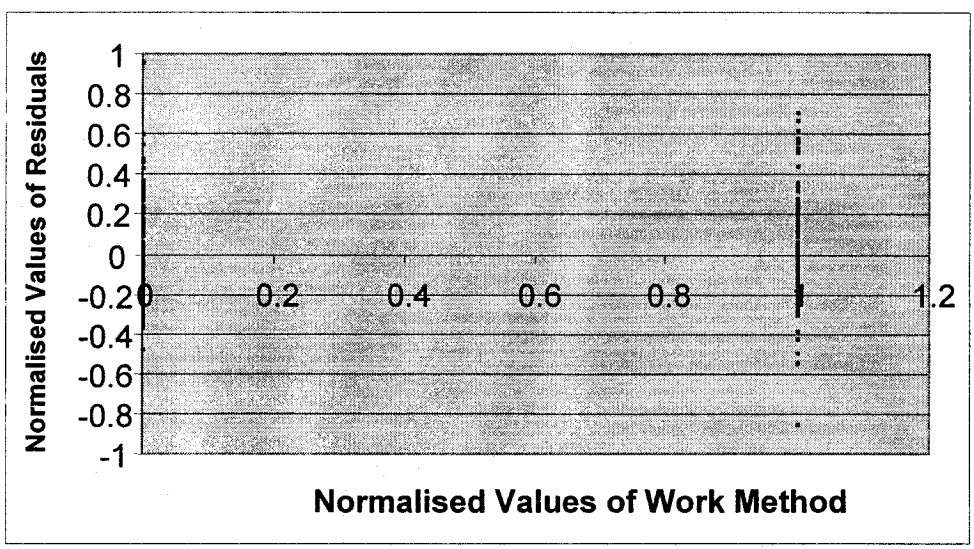


Fig: 4.21 Scatter of Residuals versus Work Method

An over view of the scatter plots above indicate that the distribution of residuals is random, and that there is no typical pattern found in the case of any independent variable. Therefore the means of the residuals can be taken as zero.

b) THE NORMAL PROBABILITY PLOT TEST:

Sincich et al (1999) state that the assumption that the distribution of 'Є' is normal, is least restrictive. The reasons being it is data dependent. To determine whether the developed model abides or violates this assumption, the actual data values of the output, i.e. the daily productivity values are plotted against the frequency of their occurrence and in case of following the assumption the distribution should acquire a bell like shape. Figure 4.21 drawn using Micro Soft Excel is the normal probability plot of data of this study which is not a bell shape. McClave et al (1997) and Sincich et al (1999) states that, this doesn't influence the relevancy of the model as it refers towards the need of more data and in certain cases the need of its further transformation

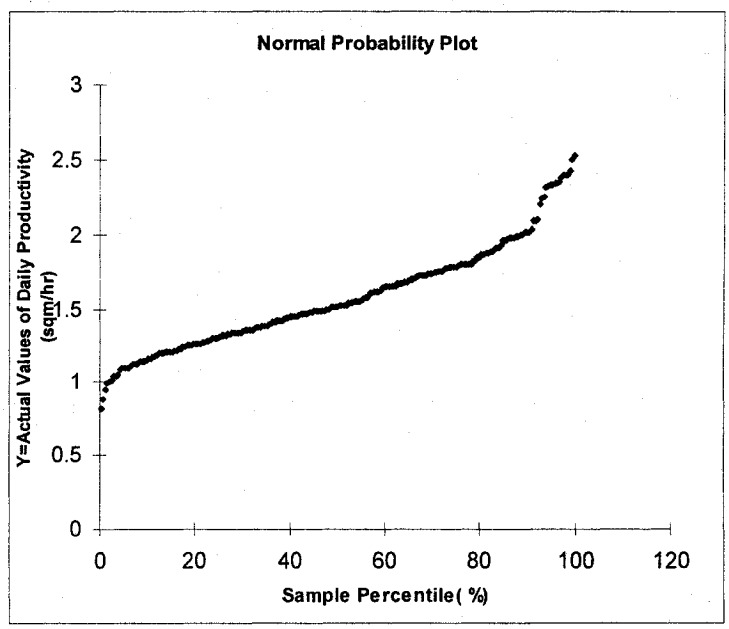


Fig: 4.22 Normal Probability Plot

Since the developed regression model has so far passed several tests of all four categories of model validation (Overall model Test , Independent Variable Test , Statistical Parameters Test, Random Error Assumption Test), it can be stated that, its goodness of fit has been tested and its performance has been verified.

4.6.3 Performance Comparison of Neural Network and Regression Model

As already mentioned, in order to evaluate the performance of the best neural network model, it is compared with the above regression model under the criteria of coefficient of determination, mean square error and mean absolute error.

The following Table 4.29 gives the comparison:

Table: 4.29 Comparison of Regression & Neural Network Model 10

Performance Measure	Neural Network Model (10)	Regression Model
R-Squared	0.8314	0.5034
MSE	0.0086	0.0642
MAE	0.0701	0.1954

It can be seen from the above table that the neural network model for formwork installation activities with modified learning rate and momentum learned the phenomenon and predicted the values satisfactorily, within the given limits of specified parameters and respective data ranges.

Chapter 5

Qualitative Analysis of Productivity Variations

5.1 General

The previous chapters illustrated how the actual data was collected directly from site and subsequently transformed and finally organized in the form of data points liable to be used in the analysis and experimentation. Thereafter, the various analyses done were described and the summarized results were reproduced. The analyses mainly comprised of input parameter significance ranking and development of various labor productivity models. Selection and validation of best performing model is the latest thing done so far.

As mentioned earlier the exclusive effects of individual parameters on productivity have also been explored. Stated alternatively, it is intended to qualitatively analyze the variations in daily productivity as a function of single / pair of input parameters. After determining these variations the same are represented through two dimensional line and over lay plots of productivity versus the input parameter under study. These are also observed through some three dimensional surface plots of productivity versus pair of input parameters belonging to a common category.

5.2 Method Adopted

The approach adopted to achieve the above is as under:

Firstly , for the expression of productivity variation trends as a function of single parameter, all the nine input variables were chosen and varied one at a time whereas for the functions as pair of factors, combinations of parameters belonging to a common category were made, which included, temperature-humidity, temperature-wind speed and gang size-labor percentage.

Second, in case of each of the analysis the target to be achieved was to have the output i.e. the daily labor productivity value as a function of only the input parameter observed. For this purpose effects of all the other input parameters on productivity were to be discounted. In other words only the effects of the factor studied on the output were to be extracted out from the combined behavior. For this purpose changes were made in the spread sheet containing the patterns to be used in analysis. The actual values of all the undesired parameters were replaced by the corresponding average values, leaving only the variations in the parameter of interest. This altered spread sheet was presented to the already trained best performing network for making the predictions. In other words the already trained model, capable of doing predictions, is applied on the altered spread sheet by using the application module of the neural network software Neuro Shell 2. .

The network is run and the predictions are obtained. Since the input values for output in every pattern were such that there were no variations in any factor that could cause any variation in productivity except the one, the effects of which

were to be worked out, therefore the variations in the behavior of the output so obtained are purely because of the single parameter studied. Alternatively the exclusive effects of studied parameter on productivity are extracted while the effects of all other parameter involved are discounted.

Subsequent to this the results were presented graphically as it gave a relatively clearer and direct qualitative idea to the concerned regarding the interrelationships of productivity and factors studied. Mat lab version 6.5.1 was used to develop the following graphics in which after plotting the basic polynomial fittings are also found out along with the relevant equations.

5.3 Two Dimensional Plots.

In the following section the behavior of productivity as a function of all the individual input parameters is presented one at a time in terms of two dimensional plots.

PRODUCTIVITY AS FUNCTION OF TEMPERATURE.

The overall trend of variations in productivity with respect to variations in temperature is directly proportional i.e. increases in temperature cause increases in productivity. At very low temperatures the productivity is relatively substantially low. There is a smooth increase in productivity upto about 80% of the data limit, after which the rate of increase drops drastically and becomes steady. At the few

last patterns the trend seems to be starting to reverse. The maximum value of temperature data was 25 °C which is the region just below which the optimality of productivity as a function of the sole parameter is achieved. The lowest polynomial relation found to be best fitting the prediction curve presented in figure 5.1 is of the 6th order, given as under:

$$y = 1.3*x^5 - 3.6*x^4 + 3*x^3 - 0.46*x^2 + 0.2*x + 0.28$$

Data Range on X & Y Axis.		
Normalized	Actual	
	Temperature	Productivity
0	-26	0.82
1	25	2.53

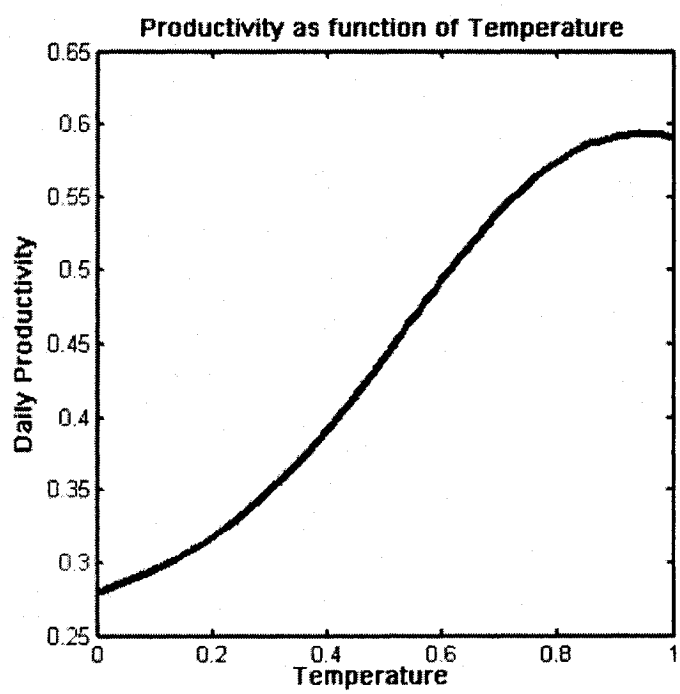


Fig: 5.1 Productivity presented as a Function of Temperature

PRODUCTIVITY AS FUNCTION OF HUMIDITY

The overall trend of variations in productivity with respect to variations in humidity is inversely proportional, i.e. increases in humidity cause decreases in productivity with the exception of approximately the first 25% low values of humidity. The description of the behavior found is that, at very low humidity the increase in its values causes an increase in productivity. After a certain optimum level of humidity, further increase is found to be negatively affecting productivity up till the maximum value of the data range. The lowest polynomial relation best fitting the prediction curve given in the figure 5.2, is of the 5th order given as under:

$$y = 0.029*x^5 - 0.1*x^4 + 0.15*x^3 - 0.17*x^2 + 0.069*x + 0.49$$

Data Range on X & Y Axis.		
Normalized	Actual	
	Percent Humidity	Productivity
0	18	0.82
1	97	2.53

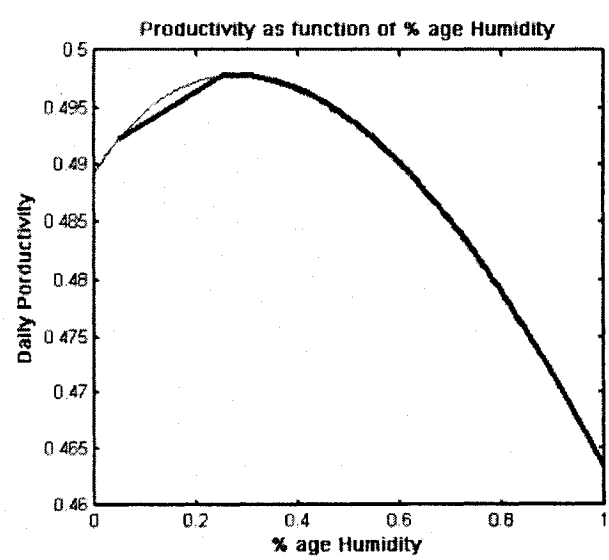


Fig: 5.2 Productivity presented as a Function of Humidity

PRODUCTIVITY AS FUNCTION OF PRECIPITATION

The overall trend of variations in productivity with respect to variations in precipitation is inversely proportional, i.e. increase precipitation causes decrease in productivity. At no precipitation, productivity is optimum. It suddenly drops when there is light precipitation, whether it is light rain or light snow. It is at its lowest at rain or snow, though in most cases the work is stopped. There is a linear relationship found in the variations of productivity as a function of precipitation as shown in figure 5.3.

Data Range on X & Y Axis.		
Normalized	Actual	
	Precipitation	Productivity
0	No Rain	0.82
1	Rain	2.53

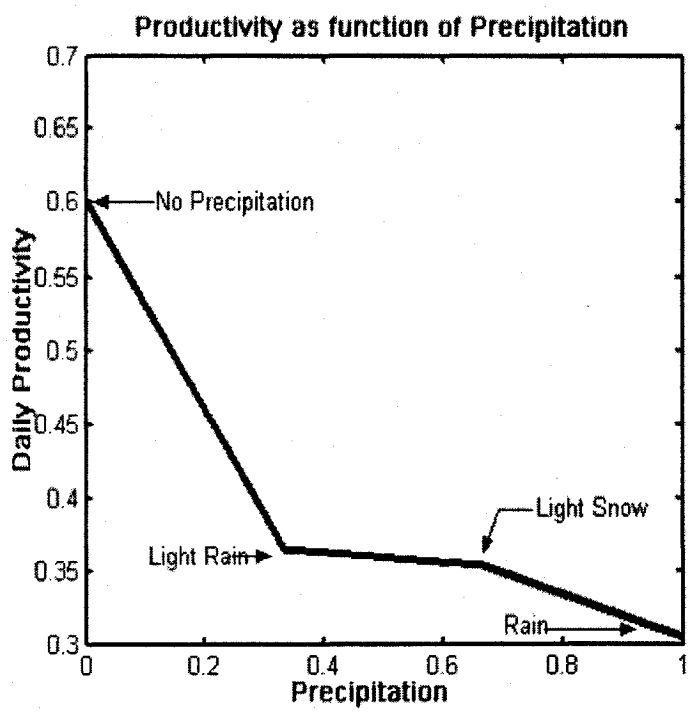


Fig: 5.3 Productivity presented as a Function of Precipitation

PRODUCTIVITY AS FUNCTION OF WIND SPEED.

There is a clear uniform inversely proportional trend of variations in productivity with respect to variations in wind speed, i.e. increase in wind speed causes decrease in productivity. The lowest polynomial relation found to be best fitting the prediction curve shown in figure 5.4 is of the 3rd order given as under:

$$y = 0.031*x^3 - 0.084*x^2 - 0.031*x + 0.51$$

Data Range on X & Y Axis.		
Normalized	Actual	
	Wind Speed	Productivity
0	3	0.82
1	43	2.53

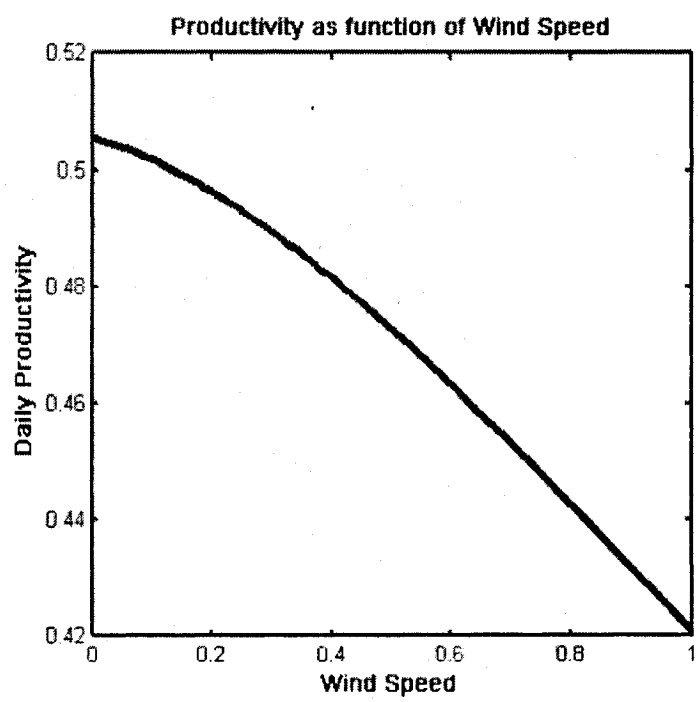


Fig: 5.4 Productivity presented as a Function of Wind Speed

PRODUCTIVITY AS FUNCTION OF GANG SIZE

In this data a directly proportional trend of variations in productivity with respect to variations in gang size is found, i.e. increase in gang size caused increase in productivity. The lowest polynomial relation found to be best fitting the prediction curve is presented in figure 5.5 and is of the 4th order given as under:

$$y = -0.53*x^4 - 0.095*x^3 + 0.86*x^2 + 0.14*x + 0.36$$

Data Range on X & Y Axis.		
Normalized	Actual	
	Gang Size	Productivity
0	8	0.82
1	24	2.53

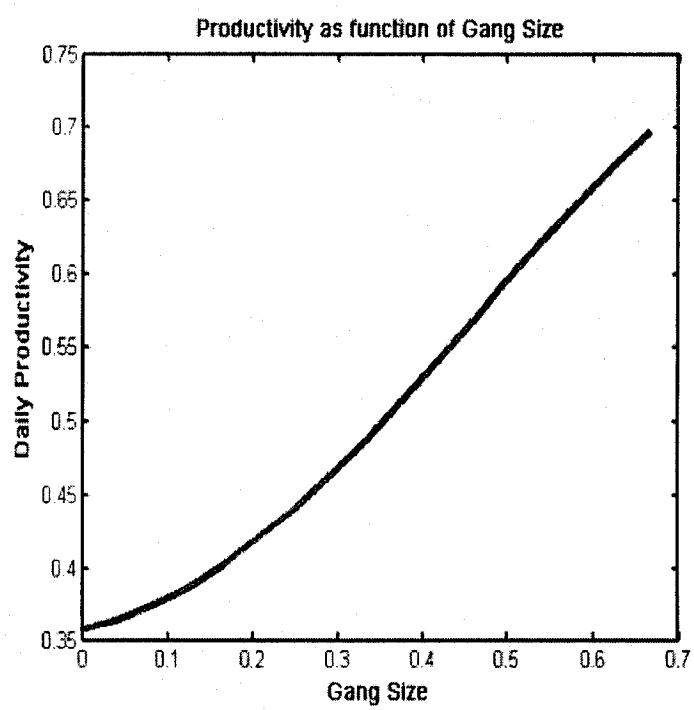


Fig: 5.5 Productivity presented as a Function of Gang Size

PRODUCTIVITY AS FUNCTION OF LABOR PERCENTAGE

There is a dual behavior of productivity with respect to labor percentage in the crew. Among approximately 30% of the initial labor content, the relationship is of directly proportional, and thereafter the productivity values start decreasing at a steady rate up till the end of the data range. The reason could be attributed to the fact that in order to have optimal productivity, it is necessary to have a balanced crew, i.e. there should be a certain optimum labor percentage in the crew to give the labor or unskilled support otherwise the overall productivity is negatively affected. Beyond this certain percentage, the relation ship becomes inversely proportional till the end of the data range, i.e. more than optimally required labor content, decreases the overall productivity. The lowest order polynomial relation found to be best fitting the data is given in figure 5.6 and is of the 4th order given as under:

$$y = -0.13*x^4 + 0.61*x^3 - 0.9*x^2 + 0.42*x + 0.43$$

Data Range on X & Y Axis.		
Normalized	Actual	
	Percent Labor	Productivity
0	29	0.82
1	47	2.53

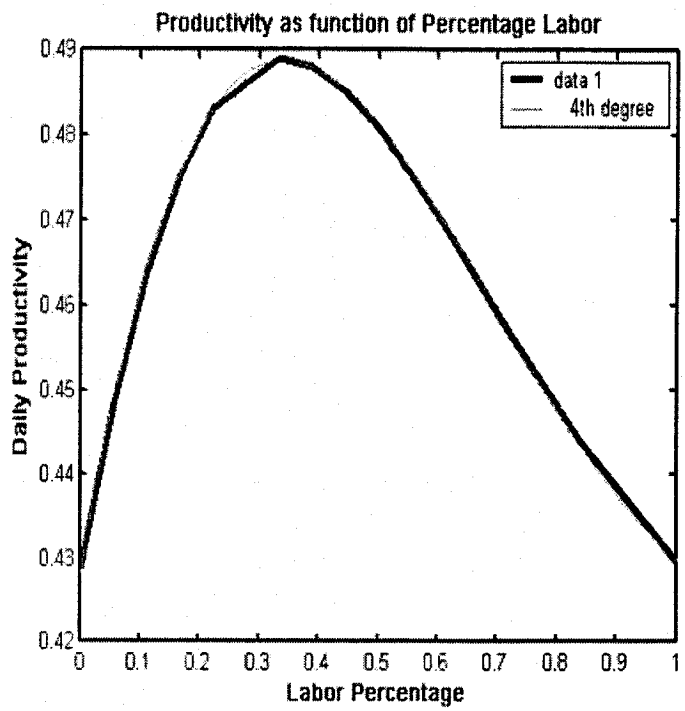


Fig: 5.6 Productivity presented as a Function of Labor Percentage

PRODUCTIVITY AS FUNCTION OF WORK TYPE

A linear relationship can define the variations in productivity as a function of work type. The relative productivity levels for the different work types studied are as under:

Productivity (Column) < Productivity (Wall) < Productivity (Slab)

The difference between walls and columns is much more than the corresponding difference between wall and slabs. Figure 5.7 explains how productivity varies within different items of work.

Data Range on X & Y Axis.		
Normalized	Actual	
	Work Type	Productivity
0	Slab	0.82
1	Columns	2.53

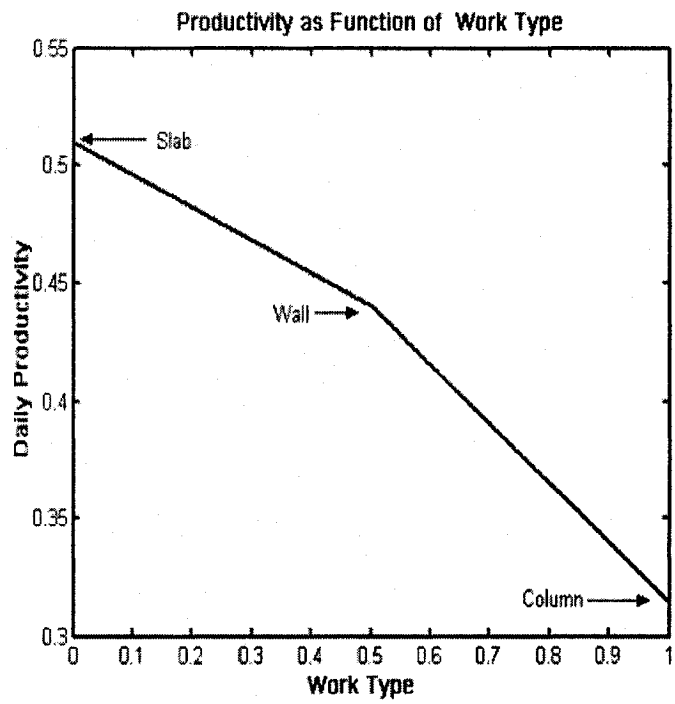


Fig: 5.7 Productivity presented as a Function of Work Type

PRODUCTIVITY AS FUNCTION OF HEIGHT WORKED AT / FLOOR LEVEL

During approximately the first 40% of the data points, the relationship between productivity and the height worked at (incorporated in calculations as floor level worked at), is that of directly proportional. Between 40% to 60% of the data range the rate of direct proportionality increase drops rapidly. After 60% the rate of increase is almost negligible.

The explanation for this apparently unexpected result is given through the following facts. First, the initial values of the data range correspond to the basement levels where the percentage of wall and column works is greater than the slab works. There are also normally congestions due to the presence of various other trades.

Secondly and more importantly, it is because, of the learning curve factor. Among the input parameters involved in this study, height / floor level is the only parameter which is synchronized with the time of start of the project and therefore it is the only factor which can unnoticeably encompass the effects of learning.

Keeping in mind that the above factors are active at the site, it can be understood that as the floor level increases and the project gets out of basement levels, and at the same time the manpower achieves learning, the productivity increases. But after a certain height perhaps there are negative effects of height on the crew as well as the rate of learning starts decreasing, resulting in a negative gradient in the rate of increase of productivity which becomes almost steady after 60%of the data range. The study of productivity beyond the numerical values of data of this study may quite possibly generate the graph on the other side. The behavior of productivity as a function of height / floor level is presented in figure 5.8. The lowest order polynomial relation found to be best fitting the data is of the 4th order given as under:

$$y = 1*x^4 - 1.7*x^3 + 0.24*x^2 + 0.89*x + 0.11$$

Data Range on X & Y Axis.		
Normalized	Actual	
	Height/ Floor Level	Productivity
0	1	0.82
1	17	2.53

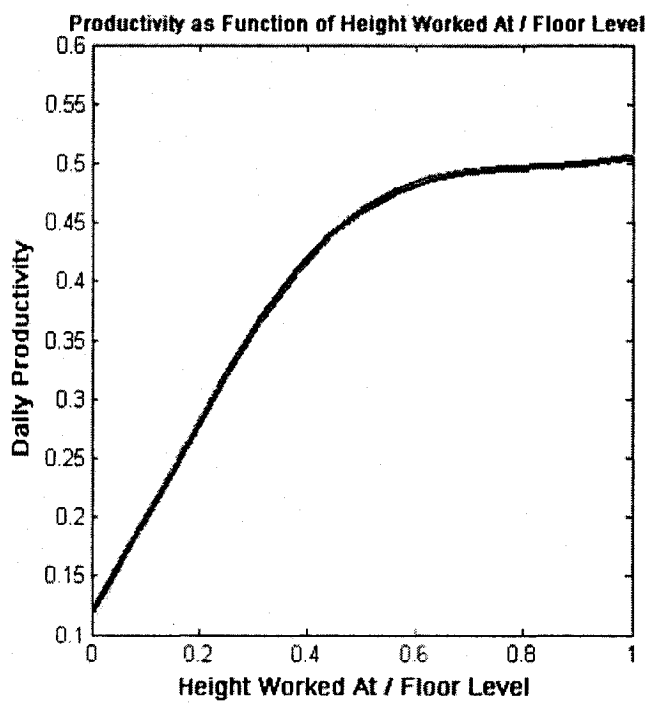


Fig: 5.8 Productivity presented as a Function of Height/ Floor Level

PRODUCTIVITY AS FUNCTION OF WORK METHOD

The relationship is quite straight forward. Even though this study is for formwork installation and not for formwork fabrication, the flying forms are found to be more

productive than the traditional forms. Pertinent here is that the difference found is not very substantial. The reason for this can be attributed to the fact that the use of flying forms is more productive when formwork fabrication is measured. In case of this study, the forms were prefabricated at contractor's workshop and at site only the installation of prefabricated forms was carried out. Figure 5.9 gives the different productivity levels with respect to the two work methods employed.

Data Range on X & Y Axis.		
Normalized	Actual	
	Work Method	Productivity
0	Traditional	0.82
1	Flying Forms	2.53

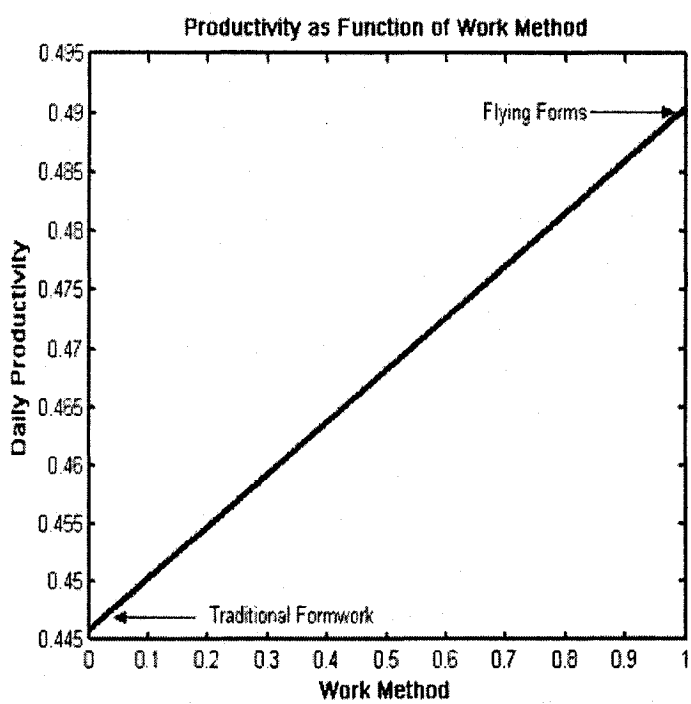


Fig: 5.9 Productivity presented as a Function of Work Method

5.4 Overlay Plot

The purpose of the overlay plots is to jointly present most of the already given line plots, in order to give the concerned a qualitative idea of the effects of each input parameter on productivity in relation to all the others. Since the description in case of each individual graph has already been given, therefore the overlay plot shown in figure 5.10 doesn't need any further description.

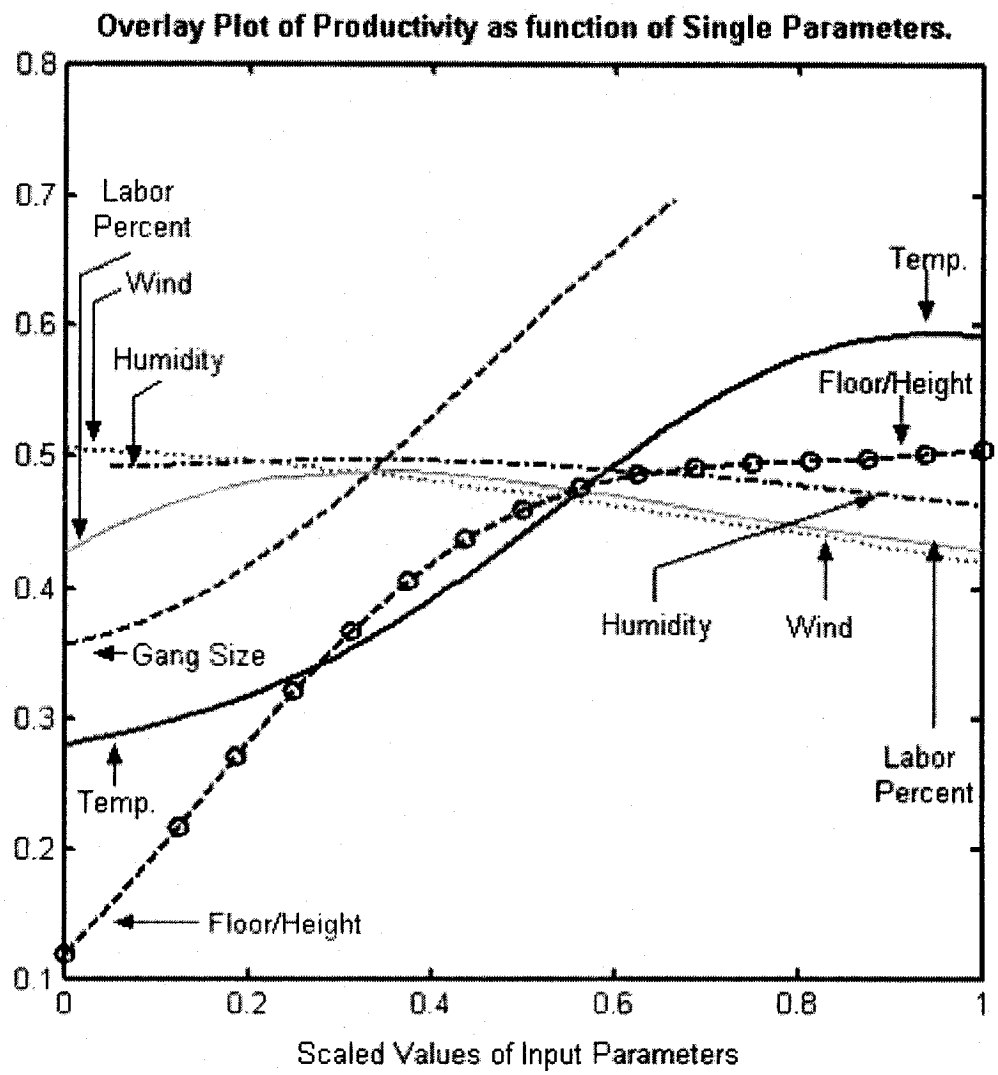


Fig: 5.10 Overlay plot of Productivity as Function of Single Parameters

5.5 Surface plots.

The approach adopted for developing the three dimensional surface plots showing the daily productivity as function of pair of input parameters belonging to same category is the same as that of the line plots for single parameters. The only exception in this case is that here instead of one, two input parameters had actual values and the other seven had average values in all the patterns. Also pertinent here is that since in this case there are two terms interacting to generate the output the results of these variations can't be compared with those of the individual ones. The surfaces developed for the pairs of temperature - humidity, temperature - wind speed and gang size - labor percentage are presented at figure 5.11, 5.12, and 5.13 respectively.

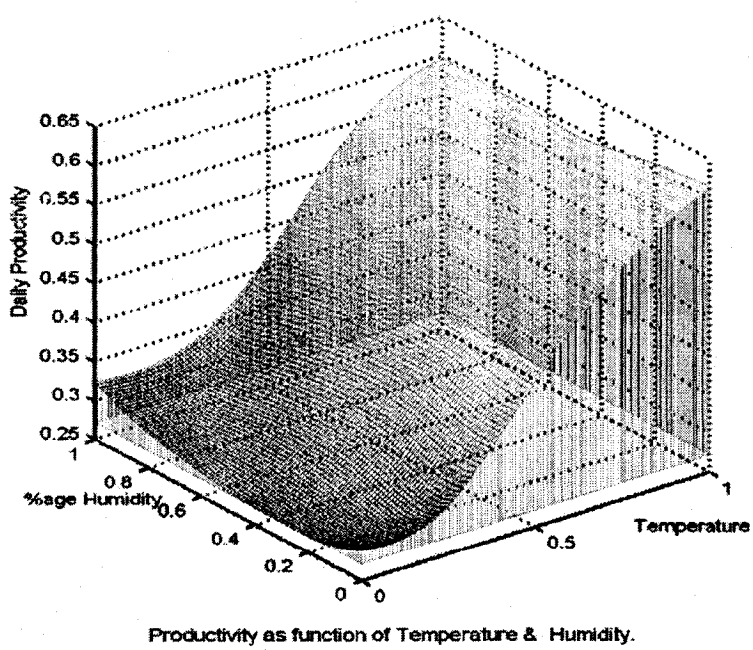
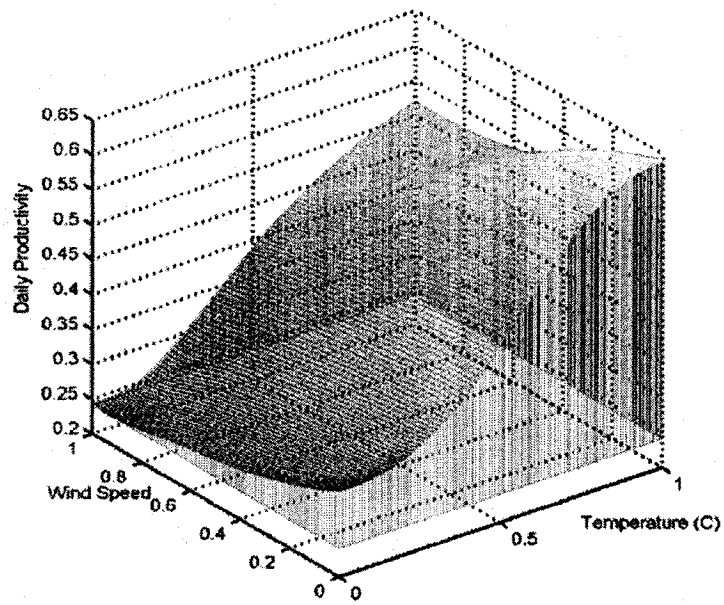
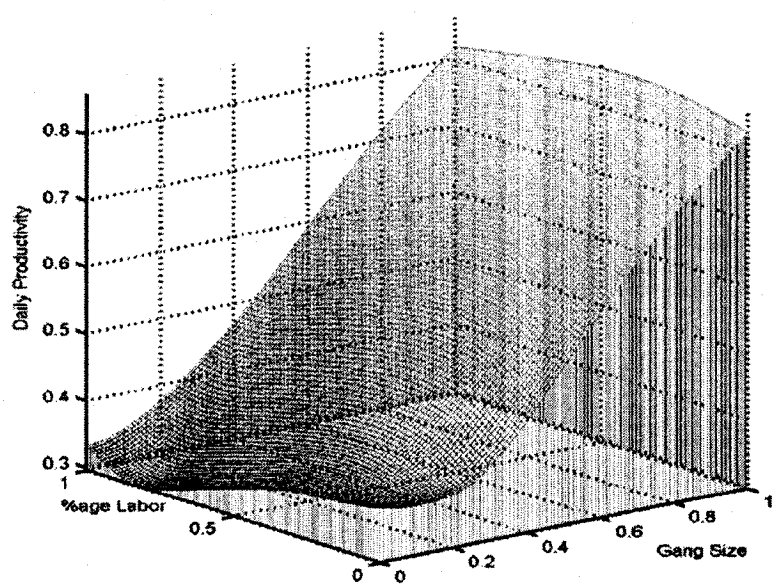


Fig: 5.11 Productivity as Function of Temperature & Humidity



Productivity as function of Temperture & Wind Speed.

Fig: 5.12 Productivity as Function of Temperature & Wind Speed



Productivity as function of GangSize & Labor %age.

Fig: 5.13 Productivity as Function of Gang Size & Labor Percentage

CHAPTER 6

Summary and Conclusions

6.1 Summary and Concluding Remarks.

A study of labor productivity of formwork installation operations at building construction sites has been carried out. This study involved a field investigation for on-site data collection. Experimentation with the collected data was carried out for the development of labor productivity models, input parameter significance ranking and for graphical representation of daily productivity variations as functions of individual or pairs of input parameters.

In all, a set of twelve productivity models was developed using artificial neural networks. In addition, a statistical regression model was also developed for the purpose of comparison with the best performing neural network model. The significance ranking of the involved parameters was also done in three different ways using neural networks, inferential statistics and fuzzy logic.

The data was obtained from two multistory building projects situated in down town Montreal. A total of 221 data points were collected jointly from both projects during an observation period of 18 months. A complete data point constituted of nine inputs, those of temperature, relative humidity, precipitation, wind speed, gang size, labor percentage, work type, height worked at and work method with the one output of daily labor productivity for

formwork installation, expressed in terms of m^2/ man-hr. The objective behind selecting these particular input parameters was to explore the short term or daily variations in labor productivity.

The data collection process comprised of the Foreman's Response Form (FRF) for crew related details and those of quantity of work executed. Internet sources were used for weather data and daily site visits enabled the capturing of the data elements and their characteristics such as floor height and work method employed.

Neural network analysis was carried out using Neuro shell 2, developed by Ward Inc., whereas statistical regression and fuzzy logic analyses were done using Excel (Data Analysis ToolPak) and Mat Lab (Fuzzy Logic Tool Box), respectively. Twelve models were developed using three different paradigms; general regression (GRNN), Group Method of Data Handling (GMDH) and Back propagation (BPNN). Ten models of Back Propagation paradigm were developed by varying the network architectures, the numbers of hidden neurons, the activation functions, the presentation arrangement of input patterns and the learning rate and momentum. Model 10, which had a decreased learning rate and momentum compared to the default settings, outperformed the others. It also outperformed the developed GRNN and GMDH models under the criteria of mean square error (MSE), mean absolute error (MAE) and the coefficient of multiple determination (R^2). The

contribution factors retrieved from the neural network model10 formed the basis of evaluating the significance ranking of the input parameters used. Element of work / work type was found to be the most important input parameter.

Not with standing, parameter ranking was also conducted using fuzzy subtractive clustering and stepwise selection procedure of statistical regression. In fuzzy clustering, the quantitative Index (π_j) of the parameters involved formed the basis of their significance ranking as per which the type of work and temperature were found the most influencing parameters. In the regression analysis however, temperature was found to be the most significant variable. A regression model was also developed and tested for the goodness for use by conducting the overall model Test, Independent Variable Test, Statistical Parameters Test and Random Error Assumption Test. The best performing neural network model 10 was then compared with this regression model and the neural network model was found to be outperforming the regression model under the criteria of R^2, MSE and MAE.

Individual parameters were studied and graphs were developed to depict the trends of variation in productivity. This was deemed useful for visual recognition of the sensitivity or the severity of impact of these parameters on productivity.

In summary the study made contribution towards the better understanding of construction labor productivity and the factors that impact it, specifically using neural networks.

6.2 Recommendations For Future Work

Future work may consider:

1) Development of productivity models for other activities such as form work fabrication, steel erection, concrete pouring and concrete finishing works.

2) The effects of other input parameters can also be investigated such as daily targeted quantities, congestion and overtime etc.

3) Model limits may be expanded. Ranges of input parameters may be increased to enhance model applicability, especially in respect of weather related parameters.

4) An Automated Daily On-job Productivity Estimation (ADOPE) System may be developed for predication and data base development purposes, by linking it with the company's already stored data, if any.

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Appendix – 1

Fuzzy Clustering Computer Program File
(Fuzzy Logic Tool Box,Mat Lab 6.5.1)

```
clear
D=[-17.50    75.00  2.00   17.30  14.00  29.00  2.00   1.00   1.00   0.95
-18.00  72.00  2.00   6.60   14.00  36.00  1.00   3.00   1.00   1.12
-18.00  72.00  2.00   6.60   18.00  33.00  2.00   3.00   1.00   1.01
-8.00   87.00  2.00   14.20  22.00  36.00  1.00   3.00   1.00   1.27
-8.00   87.00  2.00   14.20  23.00  30.00  2.00   3.00   1.00   1.14
-12.50  54.00  0.00   5.20   21.00  38.00  1.00   3.00   1.00   1.17
-12.50  54.00  0.00   5.20   20.00  30.00  2.00   3.00   1.00   1.04
-16.00  55.00  0.00   6.00   23.00  35.00  1.00   3.00   1.00   1.16
-15.00  51.00  2.00   18.70  17.00  29.00  2.00   4.00   1.00   1.99
-15.00  51.00  2.00   18.70  20.00  40.00  1.00   4.00   1.00   1.10
-8.50   58.00  0.00   26.50  18.00  33.00  2.00   4.00   1.00   1.00
-8.50   58.00  0.00   26.50  19.00  47.00  1.00   4.00   1.00   1.12
-4.00   87.00  2.00   3.60   22.00  36.00  1.00   4.00   1.00   1.55
-14.00  42.00  0.00   10.00  23.00  35.00  2.00   4.00   1.00   1.26
-14.50  42.00  0.00   7.50   19.00  33.00  2.00   4.00   1.00   1.14
-14.50  42.00  0.00   7.50   16.00  37.00  1.00   4.00   1.00   1.27
1.50    85.00  0.00   9.40   21.00  33.00  1.00   5.00   1.00   1.45
-0.50   53.00  0.00   7.50   20.00  30.00  1.00   5.00   1.00   1.51
-0.50   53.00  0.00   7.50   22.00  36.00  2.00   5.00   1.00   1.37
-3.50   47.00  0.00   20.00  17.00  29.00  1.00   5.00   1.00   1.38
-3.50   47.00  0.00   20.00  22.00  36.00  2.00   5.00   1.00   1.25
-4.00   81.00  1.00   11.90  22.00  36.00  1.00   5.00   1.00   1.49
-4.00   81.00  1.00   11.90  16.00  38.00  2.00   5.00   1.00   1.34
3.00    97.00  0.00   8.00   22.00  36.00  1.00   5.00   1.00   1.36
3.00    97.00  0.00   8.00   15.00  40.00  2.00   5.00   1.00   1.22
2.50    92.00  0.00   6.20   19.00  42.00  1.00   6.00   2.00   1.34
2.50    92.00  0.00   6.20   18.00  33.00  2.00   6.00   1.00   1.20
3.50    88.00  1.00   7.60   24.00  38.00  1.00   6.00   2.00   1.39
4.50    86.00  1.00   9.10   24.00  38.00  1.00   6.00   2.00   1.41
4.50    86.00  1.00   9.10   22.00  36.00  2.00   6.00   1.00   1.26
2.50    67.00  0.00   8.70   23.00  35.00  1.00   6.00   2.00   1.48
-4.50   48.00  0.00   14.10  19.00  33.00  1.00   7.00   2.00   1.36
-4.50   48.00  0.00   14.10  20.00  30.00  2.00   7.00   1.00   1.21
-6.50   56.00  0.00   10.50  20.00  30.00  1.00   7.00   2.00   1.34
-6.50   56.00  0.00   10.50  21.00  33.00  2.00   7.00   1.00   1.09
-18.10  66.00  0.00   7.00   18.00  33.00  1.00   7.00   2.00   1.21
-18.10  66.00  0.00   7.00   19.00  47.00  2.00   7.00   1.00   1.47
-2.50   39.00  0.00   10.00  20.00  30.00  1.00   7.00   2.00   1.32
-2.50   39.00  0.00   10.00  20.00  30.00  2.00   7.00   1.00   1.37
-6.00   37.00  0.00   19.90  19.00  33.00  1.00   8.00   2.00   1.23
-7.00   41.00  0.00   7.90   20.00  30.00  1.00   8.00   2.00   1.47
-7.00   41.00  0.00   7.90   20.00  30.00  2.00   8.00   1.00   1.34
-4.50   53.00  2.00   13.10  21.00  33.00  1.00   8.00   2.00   1.49
-4.50   53.00  2.00   13.10  18.00  33.00  2.00   8.00   1.00   1.35
-0.50   68.00  0.00   7.20   22.00  36.00  1.00   8.00   2.00   1.54
-0.50   68.00  0.00   7.20   21.00  33.00  2.00   8.00   1.00   1.38
3.00    63.00  0.00   8.30   24.00  38.00  1.00   9.00   2.00   1.52
3.00    63.00  0.00   8.30   24.00  38.00  2.00   9.00   1.00   1.37
6.50    45.00  0.00   11.30  24.00  38.00  1.00   9.00   2.00   1.67
6.50    45.00  0.00   11.30  21.00  33.00  2.00   9.00   1.00   1.51
5.50    46.00  0.00   12.00  22.00  36.00  1.00   9.00   2.00   1.65
5.50    46.00  0.00   12.00  19.00  33.00  2.00   10.00  1.00   1.48
4.50    84.00  1.00   8.70   20.00  30.00  1.00   10.00  2.00   1.57
4.50    84.00  1.00   8.70   18.00  33.00  2.00   10.00  1.00   1.41
-5.00   57.00  0.00   15.80  19.00  33.00  1.00   10.00  2.00   1.56
```

-5.00	57.00	0.00	15.80	19.00	33.00	2.00	10.00	1.00	1.40
2.00	36.00	0.00	16.60	19.00	33.00	1.00	10.00	2.00	1.63
2.00	36.00	0.00	16.60	18.00	33.00	2.00	10.00	1.00	1.46
7.00	90.00	1.00	5.40	16.00	31.00	1.00	10.00	2.00	1.73
6.00	74.00	2.00	11.90	17.00	35.00	1.00	11.00	2.00	1.89
6.00	74.00	2.00	11.90	16.00	31.00	2.00	11.00	1.00	1.71
3.00	56.00	0.00	13.40	18.00	33.00	1.00	11.00	2.00	1.74
3.00	56.00	0.00	13.40	19.00	33.00	2.00	11.00	1.00	1.55
15.50	38.00	0.00	18.30	20.00	30.00	1.00	11.00	2.00	1.80
15.50	38.00	0.00	18.30	18.00	39.00	2.00	11.00	1.00	1.62
11.00	44.00	0.00	13.40	16.00	31.00	1.00	11.00	2.00	1.87
11.00	44.00	0.00	13.40	15.00	33.00	2.00	11.00	1.00	1.68
7.50	40.00	0.00	8.00	16.00	31.00	1.00	11.00	2.00	1.67
7.50	40.00	0.00	8.00	16.00	31.00	2.00	11.00	1.00	1.52
12.00	40.00	0.00	18.00	18.00	33.00	3.00	12.00	1.00	1.10
14.00	38.00	0.00	18.00	19.00	32.00	1.00	12.00	1.00	1.76
15.00	35.00	0.00	10.00	19.00	37.00	1.00	12.00	1.00	1.98
15.00	54.00	1.00	11.00	21.00	33.00	1.00	12.00	1.00	1.58
18.00	59.00	0.00	23.00	20.00	35.00	2.00	12.00	1.00	1.45
18.00	59.00	1.00	29.00	18.00	33.00	2.00	12.00	1.00	1.26
15.00	51.00	0.00	19.00	21.00	33.00	1.00	12.00	1.00	2.02
16.00	73.00	1.00	14.00	21.00	33.00	1.00	12.00	1.00	1.54
16.00	61.00	0.00	3.00	22.00	36.00	1.00	13.00	1.00	2.40
15.00	64.00	1.00	19.00	19.00	37.00	1.00	13.00	1.00	1.49
16.00	60.00	0.00	6.00	22.00	36.00	1.00	13.00	1.00	2.25
18.00	58.00	0.00	6.00	21.00	33.00	1.00	13.00	1.00	2.20
20.00	57.00	0.00	10.00	23.00	35.00	2.00	13.00	1.00	1.62
17.00	75.00	1.00	16.00	19.00	37.00	2.00	13.00	1.00	1.33
17.00	54.00	0.00	16.00	22.00	36.00	1.00	13.00	1.00	2.24
22.00	56.00	0.00	10.00	22.00	36.00	2.00	13.00	1.00	1.75
23.00	52.00	0.00	14.00	20.00	30.00	1.00	13.00	1.00	1.93
25.00	57.00	1.00	11.00	19.00	37.00	1.00	13.00	1.00	1.43
22.00	55.00	0.00	8.00	19.00	37.00	2.00	13.00	1.00	1.65
25.00	77.00	0.00	24.00	20.00	30.00	1.00	14.00	1.00	1.65
20.00	50.00	0.00	8.00	20.00	30.00	1.00	14.00	1.00	1.85
20.00	47.00	0.00	10.00	23.00	35.00	1.00	14.00	1.00	1.80
17.00	89.00	1.00	27.00	18.00	33.00	1.00	14.00	1.00	1.32
21.00	63.00	0.00	16.00	20.00	30.00	1.00	12.00	2.00	1.55
25.00	83.00	1.00	10.00	22.00	36.00	1.00	12.00	2.00	1.10
24.00	82.00	0.00	8.00	22.00	36.00	1.00	12.00	2.00	1.47
23.00	82.00	0.00	11.00	19.00	47.00	1.00	12.00	2.00	1.42
23.00	77.00	0.00	13.00	18.00	33.00	2.00	12.00	1.00	1.49
23.00	86.00	0.00	11.00	23.00	35.00	2.00	12.00	1.00	1.45
24.00	82.00	0.00	8.00	17.00	29.00	2.00	12.00	1.00	1.61
24.00	65.00	0.00	19.00	18.00	33.00	2.00	12.00	1.00	1.52
24.00	73.00	0.00	11.00	23.00	35.00	1.00	13.00	2.00	1.76
25.00	69.00	0.00	6.00	22.00	36.00	1.00	13.00	2.00	1.75
25.00	71.00	0.00	21.00	21.00	33.00	1.00	13.00	2.00	1.73
21.00	71.00	0.00	10.00	21.00	33.00	1.00	13.00	2.00	1.91
23.00	60.00	0.00	19.00	22.00	36.00	2.00	13.00	1.00	1.79
25.00	66.00	0.00	18.00	16.00	38.00	2.00	13.00	1.00	1.77
25.00	65.00	0.00	13.00	15.00	40.00	2.00	13.00	1.00	1.80
25.00	65.00	0.00	24.00	17.00	29.00	2.00	13.00	1.00	1.42
17.00	86.00	1.00	13.00	18.00	33.00	1.00	14.00	2.00	1.49
18.00	79.00	0.00	10.00	19.00	42.00	1.00	14.00	2.00	1.87
18.00	71.00	0.00	19.00	20.00	30.00	1.00	14.00	2.00	2.00

14.00	70.00	0.00	14.00	23.00	30.00	2.00	14.00	1.00	1.78
16.00	86.00	1.00	14.00	18.00	33.00	2.00	14.00	1.00	1.36
17.61	61.00	0.00	16.00	22.00	32.00	1.00	14.00	2.00	2.42
17.00	72.00	0.00	16.00	22.00	32.00	1.00	14.00	2.00	2.31
21.00	72.00	1.00	21.00	20.00	35.00	1.00	14.00	2.00	2.09
17.00	73.00	0.00	13.00	20.00	35.00	2.00	15.00	1.00	1.80
14.00	71.00	0.00	5.00	20.00	35.00	2.00	15.00	1.00	1.85
13.00	60.00	0.00	13.00	19.00	37.00	2.00	15.00	1.00	1.88
15.00	67.00	0.00	14.00	19.00	37.00	2.00	15.00	1.00	1.78
21.00	75.00	0.00	8.00	21.00	33.00	1.00	15.00	2.00	2.33
21.00	82.00	1.00	19.00	19.00	37.00	1.00	15.00	2.00	1.72
24.00	84.00	1.00	19.00	19.00	37.00	1.00	15.00	2.00	1.70
20.00	73.00	0.00	23.00	20.00	30.00	1.00	15.00	2.00	2.09
16.00	72.00	0.00	8.00	20.00	30.00	1.00	15.00	2.00	2.32
17.00	68.00	0.00	6.00	20.00	30.00	1.00	15.00	2.00	2.34
21.00	61.00	0.00	18.00	18.00	33.00	2.00	16.00	1.00	1.88
10.00	75.00	0.00	14.00	19.00	37.00	2.00	16.00	1.00	1.90
6.00	82.00	1.00	13.00	19.00	37.00	2.00	16.00	1.00	1.65
7.00	69.00	0.00	18.00	22.00	37.00	1.00	16.00	2.00	2.33
6.00	75.00	0.00	18.00	22.00	37.00	1.00	16.00	2.00	2.35
7.00	76.00	0.00	14.00	22.00	37.00	1.00	16.00	2.00	2.40
13.00	64.00	0.00	19.00	21.00	33.00	1.00	16.00	2.00	2.38
14.00	81.00	0.00	13.00	20.00	30.00	1.00	16.00	2.00	2.40
14.00	70.00	0.00	11.00	12.00	33.00	1.00	10.00	2.00	2.53
13.00	70.00	0.00	18.00	12.00	33.00	1.00	10.00	2.00	2.50
11.00	94.00	1.00	34.00	11.00	37.00	1.00	10.00	2.00	1.80
7.00	65.00	1.00	31.00	11.00	37.00	1.00	10.00	2.00	1.70
5.00	75.00	0.00	10.00	10.00	40.00	1.00	10.00	2.00	2.34
4.00	76.00	0.00	14.00	10.00	40.00	1.00	10.00	2.00	1.98
3.00	96.00	1.00	27.00	8.00	38.00	1.00	10.00	2.00	1.74
2.00	63.00	0.00	16.00	11.00	37.00	2.00	10.00	1.00	1.78
2.00	63.00	0.00	14.00	11.00	37.00	2.00	10.00	1.00	1.80
4.00	60.00	0.00	23.00	11.00	37.00	2.00	10.00	1.00	1.68
6.00	96.00	1.00	6.00	9.00	44.00	2.00	10.00	1.00	1.50
6.00	76.00	0.00	16.00	11.00	37.00	2.00	10.00	1.00	1.74
6.00	94.00	1.00	14.00	9.00	44.00	1.00	11.00	2.00	1.82
8.00	72.00	0.00	26.00	11.00	37.00	1.00	11.00	2.00	1.73
12.00	70.00	0.00	10.00	12.00	33.00	1.00	11.00	2.00	2.10
5.00	75.00	0.00	10.00	12.00	33.00	1.00	11.00	2.00	2.02
0.00	67.00	0.00	24.00	12.00	33.00	1.00	11.00	2.00	1.91
6.00	96.00	0.00	14.00	12.00	33.00	1.00	11.00	2.00	1.97
3.00	78.00	0.00	13.00	11.00	37.00	1.00	11.00	2.00	2.00
3.00	70.00	0.00	23.00	11.00	37.00	2.00	11.00	1.00	2.02
3.00	61.00	0.00	26.00	10.00	40.00	2.00	11.00	1.00	1.76
3.00	77.00	0.00	21.00	10.00	40.00	2.00	11.00	1.00	1.77
8.00	79.00	0.00	13.00	9.00	44.00	2.00	11.00	1.00	1.83
5.00	82.00	1.00	31.00	8.00	38.00	2.00	11.00	1.00	1.42
-3.00	60.00	0.00	43.00	8.00	38.00	2.00	11.00	1.00	1.20
1.00	63.00	0.00	6.00	10.00	40.00	2.00	11.00	1.00	1.78
3.00	79.00	0.00	13.00	11.00	37.00	1.00	12.00	2.00	1.96
11.00	94.00	1.00	37.00	8.00	38.00	1.00	12.00	2.00	1.54
5.00	88.00	0.00	11.00	11.00	37.00	1.00	12.00	2.00	2.03
3.00	80.00	0.00	6.00	11.00	37.00	1.00	12.00	2.00	1.99
6.00	76.00	0.00	27.00	12.00	42.00	1.00	12.00	2.00	1.89
1.00	52.00	0.00	32.00	12.00	42.00	1.00	12.00	2.00	1.69
2.00	62.00	0.00	14.00	11.00	37.00	1.00	12.00	2.00	1.96

3.00	74.00	0.00	6.00	12.00	42.00	1.00	12.00	2.00	1.98
3.00	97.00	0.00	21.00	9.00	33.00	2.00	12.00	1.00	1.64
0.00	72.00	0.00	39.00	9.00	33.00	2.00	12.00	1.00	1.33
-7.00	53.00	0.00	19.00	9.00	33.00	2.00	12.00	1.00	1.24
-7.00	74.00	0.00	18.00	8.00	37.00	2.00	12.00	1.00	1.22
-7.00	66.00	0.00	6.00	9.00	33.00	2.00	12.00	1.00	1.62
-10.00	71.00	0.00	8.00	9.00	33.00	2.00	12.00	1.00	1.19
-6.00	67.00	0.00	10.00	9.00	44.00	2.00	12.00	1.00	1.20
-10.00	87.00	0.00	6.00	12.00	42.00	1.00	13.00	2.00	1.31
-3.00	84.00	0.00	16.00	11.00	37.00	1.00	13.00	2.00	1.73
3.00	97.00	1.00	29.00	11.00	37.00	1.00	13.00	2.00	1.29
-3.00	64.00	0.00	40.00	11.00	37.00	1.00	13.00	2.00	1.26
-5.00	90.00	3.00	26.00	11.00	37.00	1.00	13.00	2.00	1.34
-8.00	90.00	0.00	11.00	12.00	42.00	1.00	13.00	2.00	1.38
-1.00	93.00	1.00	14.00	11.00	37.00	1.00	13.00	2.00	1.23
-3.00	90.00	3.00	39.00	9.00	33.00	2.00	13.00	1.00	1.30
-6.00	75.00	0.00	26.00	8.00	37.00	2.00	13.00	1.00	1.28
-14.00	18.00	0.00	19.00	9.00	33.00	2.00	13.00	1.00	1.21
-17.00	70.00	0.00	21.00	9.00	33.00	2.00	13.00	1.00	1.16
-25.00	52.00	0.00	16.00	12.00	42.00	1.00	14.00	2.00	1.10
-26.00	57.00	0.00	19.00	11.00	37.00	1.00	14.00	2.00	1.05
-19.00	63.00	0.00	42.00	11.00	37.00	1.00	14.00	2.00	0.88
-12.00	81.00	0.00	31.00	11.00	37.00	1.00	14.00	2.00	1.25
-12.00	72.00	0.00	34.00	12.00	42.00	1.00	14.00	2.00	1.25
-13.00	74.00	0.00	21.00	12.00	42.00	1.00	14.00	2.00	1.30
-9.00	76.00	0.00	18.00	11.00	37.00	1.00	14.00	2.00	1.45
-18.00	57.00	0.00	34.00	9.00	33.00	2.00	14.00	1.00	1.21
-22.00	54.00	0.00	13.00	9.00	33.00	2.00	14.00	1.00	1.14
-17.00	48.00	0.00	29.00	8.00	37.00	2.00	14.00	1.00	1.11
-11.00	62.00	0.00	16.00	9.00	33.00	2.00	14.00	1.00	1.12
-10.00	70.00	0.00	35.00	9.00	33.00	2.00	14.00	1.00	1.04
-15.00	74.00	0.00	32.00	8.00	37.00	2.00	14.00	1.00	0.82
1.00	66.00	0.00	5.00	8.00	37.00	2.00	16.00	1.00	1.44
5.00	72.00	0.00	21.00	8.00	37.00	2.00	16.00	1.00	1.36
2.00	63.00	0.00	23.00	9.00	33.00	2.00	16.00	1.00	1.15
2.00	76.00	0.00	5.00	9.00	33.00	2.00	16.00	1.00	1.51
3.00	79.00	0.00	14.00	8.00	37.00	2.00	16.00	1.00	1.44
-3.00	58.00	0.00	18.00	10.00	40.00	1.00	17.00	2.00	1.51
-1.00	58.00	0.00	3.00	12.00	42.00	1.00	17.00	2.00	1.58
1.00	60.00	0.00	5.00	12.00	42.00	1.00	17.00	2.00	1.65
1.00	64.00	0.00	21.00	11.00	37.00	1.00	17.00	2.00	1.49
1.00	58.00	0.00	39.00	11.00	37.00	1.00	17.00	2.00	1.32
-6.00	41.00	0.00	3.00	11.00	37.00	1.00	17.00	2.00	1.47
-5.00	44.00	0.00	37.00	12.00	42.00	1.00	17.00	2.00	1.30
-5.00	65.00	0.00	26.00	9.00	33.00	2.00	17.00	1.00	0.99
-1.00	71.00	0.00	16.00	8.00	37.00	2.00	17.00	1.00	1.36
-12.00	49.00	0.00	26.00	9.00	33.00	2.00	17.00	1.00	1.18
-4.00	66.00	0.00	21.00	9.00	33.00	2.00	17.00	1.00	1.28
-5.00	58.00	0.00	10.00	8.00	37.00	2.00	17.00	1.00	1.24
2.00	71.00	0.00	11.00	11.00	37.00	1.00	17.00	2.00	1.61
10.00	80.00	0.00	6.00	12.00	42.00	1.00	17.00	2.00	1.65
5.00	48.00	0.00	19.00	12.00	42.00	1.00	17.00	2.00	1.52
8.00	42.00	0.00	11.00	12.00	42.00	1.00	17.00	2.00	1.67
5.00	61.00	0.00	8.00	12.00	42.00	1.00	17.00	2.00	1.50

];

```
unit            = [1 0.01 0.001]

y       = D(:,10);
x               = [D(:,1) D(:,2) D(:,3) D(:,4) D(:,5) D(:,6) D(:,7) D(:,8) D(:,9)],minY        =
min(y); maxY            = max(y);
rangeY          = maxY-minY;
PI              = [];

sf              = 0.5;
ar              = 0.8;
rr              = 0.0;

lowerBound      = 0.20;
upperBound      = 0.90


% for sf0=1:10
%       sf = sf0/10
for r=0:(20-1)
        ra = 1.0 - r/20;
        [C,S]   = subclust(y,ra,[],[sf,ar,rr,0]);
        pi=[];
        NumRule(r+1) = size(C,1);

        for j=1:size(C,1)
                row=0;
                for i=1:size(y,1)
                        row = row+1;
                        b = 1/(ra*rangeY)^2;
                        w(row,j) = exp(-4*b*(y(i)-C(j))^2);
                end
        end

        for k=1:size(x,2)
                for j=1:size(C,1)
                        cc=[0];
                        ss=[0];

                        row=0;
                        for i=1:size(y,1)
                                if w(i,j)>= upperBound
                                        row=row+1;
                                        c=x(i,k);
                                        cc(row,1)=c;
                                        cc(row,2)=w(i,j);
                                end
                        end

                        row=0;
                        for i=1:size(y,1)
                                if w(i,j)>= lowerBound
                                row=row+1;
                                s=x(i,k);
                                ss(row,1)=s;
                                ss(row,2)=w(i,j);
```

```
                end
            end

            maxcc = max(cc(:,1));
            mincc = min(cc(:,1));
            core  = maxcc-mincc;
            maxss = max(ss(:,1));
            minss = min(ss(:,1));
            supp  = maxss-minss;

            % this part is needed when support=0,
            % but not sure about the approach.
            if supp == 0
                supp = unit(k);
            end
            if core == 0
                core = unit(k);
            end

            pi(j,k)=core/supp;
        end  % for j
        PI(k)=prod(pi(:,k));
    end  % for k
    P=[ra,NumRule(r+1),PI]
end % for r
% end % for sf0
```

Appendix – 2

Mat Lab Runs For Qualitative Index of Parameters

Qualitative Index Values : Test Run # 1

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	1	0.8451	0.7722	1	0.9	1	1	0.5	0.875	1
0.95	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.9	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.85	2	0.3529	0.4608	1	0.5	0.75	0.5556	0.5	0.375	1
0.8	2	0.7451	0.7597	1	0.5108	0.75	0.7222	0.5	0.6964	1
0.75	2	0.7451	0.5962	1	0.5351	0.75	0.8333	0.5	0.6964	1
0.7	3	0.7843	0.452	1	0.649	0.8203	0.8333	0.5	0.6964	1
0.65	3	0.7843	0.7597	1	0.6666	0.8203	0.8333	0.5	0.6964	1
0.6	3	0.7843	0.7597	1	0.6296	0.8203	0.787	0.5	0.6094	1
0.55	3	0.7843	0.7597	1	0.6471	0.8789	0.787	0.5	0.6563	1
0.5	3	0.549	0.7223	1	0.6471	0.8789	0.7346	0.5	0.3281	1
0.45	4	0.3173	0.3841	0	0.5177	0.7324	0.5142	0	0.375	1
0.4	4	0.2266	0.3145	0	0.4567	0.9375	0.5651	0	0.25	1
0.35	4	0.1976	0.4532	1	0.2873	0.625	0.242	0.25	0.1667	1
0.3	5	0.407	0.4242	0	0.3188	0.7031	0.5617	0	0.426	1
0.25	6	0.0032	0.0359	0	0.0698	0.0148	0	0	0	0
0.2	7	0.0832	0.0341	0	0.2393	0.4219	0	0	0.1202	0
0.15	9	0.0308	0.0421	0	0.0465	0.2093	0.0835	0	0.2518	0
0.1	15	0	0	0	0	0	0	0	0	0
0.05	22	0	0	0	0	0	0	0	0	0
Avgerages	9.3303	9.2748	12	9.4214	13.1127	11.0528	5.75	8.8441	15	

Qualitative Index Values : Test Run # 4

r_a	No.of Rules	T	H	W	P	G	L	TW	F	M
1	1	0.8451	0.7722	1	0.9	1	1	0.5	0.875	1
0.95	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.9	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.85	2	0.3529	0.4608	1	0.5	0.75	0.5556	0.5	0.375	1
0.8	2	0.7451	0.7597	1	0.5108	0.75	0.7222	0.5	0.6964	1
0.75	2	0.7451	0.5962	1	0.5351	0.75	0.8333	0.5	0.6964	1
0.7	3	0.7843	0.452	1	0.649	0.8203	0.8333	0.5	0.6964	1
0.65	3	0.7843	0.7597	1	0.6666	0.8203	0.8333	0.5	0.6964	1
0.6	3	0.7843	0.7597	1	0.6296	0.8203	0.787	0.5	0.6094	1
0.55	3	0.7843	0.7597	1	0.6471	0.8789	0.787	0.5	0.6563	1
0.5	3	0.549	0.7223	1	0.6471	0.8789	0.5142	0	0.375	1
0.45	4	0.3173	0.3841	0	0.5177	0.7324	0.5142	0	0.375	1
0.4	4	0.2266	0.3145	0	0.4567	0.9375	0.5651	0	0.25	1
0.35	4	0.1976	0.4532	1	0.2873	0.625	0.242	0.25	0.1667	1
0.3	5	0.407	0.4242	0	0.3188	0.7031	0.5617	0	0.426	1
0.25	6	0.0032	0.0359	0	0.0698	0.0148	0	0	0	0
0.2	7	0.0832	0.0341	0	0.2393	0.4219	0.1398	0	0.1202	0
0.15	9	0.0308	0.0421	0	0.0465	0.2093	0.0835	0	0.2518	0
0.1	15	0	0	0	0	0	0	0	0	0
0.05	24	0	0	0	0	0	0	0	0	0
Averages:	9.3303	9.2748	12	9.4214	13.1127	10.9722	5.25	8.891	15	

Qualitative Index Values : Test Run # 5

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	1	0.8451	0.7722	1	0.9	1	1	0.5	0.875	1
0.95	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.9	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.85	2	0.3529	0.4608	1	0.5	0.75	0.5556	0.5	0.375	1
0.8	2	0.7451	0.7597	1	0.5108	0.75	0.7222	0.5	0.6964	1
0.75	2	0.7451	0.5962	1	0.5351	0.75	0.8333	0.5	0.6964	1
0.7	3	0.7843	0.452	1	0.649	0.8203	0.8333	0.5	0.6964	1
0.65	3	0.7843	0.7597	1	0.6666	0.8203	0.8333	0.5	0.6964	1
0.6	3	0.7843	0.7597	1	0.6296	0.8203	0.787	0.5	0.6094	1
0.55	3	0.7843	0.7597	1	0.6471	0.8789	0.787	0.5	0.6563	1
0.5	3	0.549	0.7223	1	0.6471	0.8789	0.7346	0.5	0.3281	1
0.45	3	0.5383	0.7105	1	0.6471	0.8789	0.7346	0.5	0.375	1
0.4	4	0.2266	0.3145	0	0.4567	0.9375	0.5651	0	0.25	1
0.35	4	0.1976	0.4532	1	0.2873	0.625	0.242	0.25	0.1667	1
0.3	4	0.4578	0.7474	1	0.3985	0.7031	0.5617	0.5	0.426	1
0.25	5	0.0166	0.0686	0	0.2569	0.0641	0.121	0	0	0
0.2	7	0.0832	0.0341	0	0.2393	0.4219	0.1398	0	0.1202	0
0.15	8	0.1256	0.1812	0	0.1965	0.5859	0.2714	0	0.2518	0
0.1	13	0.004	0.0021	0	0.0542	0.2692	0.0116	0	0.0071	0
0.05	18	0.0011	0.0033	0	0.0009	0.0087	0.0005	0	0.0282	0
Averages:	9.7154	10.1016	14	10.0227	13.963	11.734	6.75	8.8794	15	

Qualitative Index Values : Test Run # 8

r_a	No.of Rules	T	H	W	P	G	L	TW	F	M
1	1	0.8451	0.7722	1	0.9	1	1	0.5	0.875	1
0.95	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.9	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.85	2	0.3529	0.4608	1	0.5	0.75	0.5556	0.5	0.375	1
0.8	2	0.7451	0.7597	1	0.5108	0.75	0.7222	0.5	0.6964	1
0.75	2	0.7451	0.5962	1	0.5351	0.75	0.8333	0.5	0.6964	1
0.7	3	0.7843	0.452	1	0.649	0.8203	0.8333	0.5	0.6964	1
0.65	3	0.7843	0.7597	1	0.6666	0.8203	0.8333	0.5	0.6964	1
0.6	3	0.7843	0.7597	1	0.6296	0.8203	0.787	0.5	0.6094	1
0.55	3	0.7843	0.7597	1	0.6471	0.8789	0.787	0.5	0.6563	1
0.5	3	0.549	0.7223	1	0.6471	0.8789	0.7346	0.5	0.3281	1
0.45	3	0.5383	0.7105	1	0.6471	0.8789	0.7346	0.5	0.375	1
0.4	4	0.2266	0.3145	0	0.4567	0.9375	0.5651	0	0.25	1
0.35	4	0.1976	0.4532	1	0.2873	0.625	0.242	0.25	0.1667	1
0.3	4	0.4578	0.7474	1	0.3985	0.7031	0.5617	0.5	0.426	1
0.25	5	0.0166	0.0686	0	0.2569	0.0641	0.121	0	0	0
0.2	7	0.0832	0.0341	0	0.2393	0.4219	0.1398	0	0.1202	0
0.15	8	0.1256	0.1812	0	0.1965	0.5859	0.2714	0	0.2518	0
0.1	13	0.004	0.0021	0	0.0542	0.2692	0.0116	0	0.0071	0
0.05	18	0.0011	0.0033	0	0.0009	0.0087	0.0005	0	0.0282	0
Averages:	9.7154	10.1016	14	10.0227	13.963	11.734	6.75	8.8794	15	

Qualitative Index Values : Test Run # 9

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	1	0.8451	0.7722	1	0.9	1	1	0.5	0.875	1
0.95	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.9	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.85	2	0.3529	0.4608	1	0.5	0.75	0.5556	0.5	0.375	1
0.8	2	0.7451	0.7597	1	0.5108	0.75	0.7222	0.5	0.6964	1
0.75	2	0.7451	0.5962	1	0.5351	0.75	0.8333	0.5	0.6964	1
0.7	3	0.7843	0.452	1	0.649	0.8203	0.8333	0.5	0.6964	1
0.65	3	0.7843	0.7597	1	0.6666	0.8203	0.8333	0.5	0.6964	1
0.6	3	0.7843	0.7597	1	0.6296	0.8203	0.787	0.5	0.6094	1
0.55	3	0.7843	0.7597	1	0.6471	0.8789	0.787	0.5	0.6563	1
0.5	3	0.549	0.7223	1	0.6471	0.8789	0.7346	0.5	0.3281	1
0.45	3	0.5383	0.7105	1	0.6471	0.8789	0.7346	0.5	0.375	1
0.4	3	0.5383	0.7105	1	0.6851	0.9375	0.7346	0.5	0.5	1
0.35	3	0.4392	0.7472	1	0.6851	0.9375	0.5185	0.25	0.5	1
0.3	4	0.4578	0.7474	1	0.3985	0.7031	0.5617	0.5	0.426	1
0.25	4	0.3153	0.6974	1	0.5139	0.769	0.5243	0.5	0.2434	1
0.2	5	0.2021	0.3677	1	0.3736	0.5273	0.3595	0.5	0.1374	1
0.15	7	0.1256	0.4449	1	0.2418	0.5859	0.2714	0.5	0.2518	1
0.1	10	0.0326	0.0305	0	0.0944	0.4037	0.0008	0	0.0282	0
0.05	16	0.0036	0.0139	0	0.0009	0.0103	0.0008	0	0.0282	0
Averages:	10.7174	12.0567	18	11.1257	15.2219	12.7925	8.75	9.7444	18	

Qualitative Index Values : Test Run # 12

r_a	No of Rules	T	H	W	P	G	L	TW	F	M	
1	1	0.8451	0.7722	1	0.9	1	1	0.5	0.875	1
0.95	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.9	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.85	2	0.3529	0.4608	1	0.5	0.75	0.5556	0.5	0.375	1
0.8	2	0.7451	0.7597	1	0.5108	0.75	0.7222	0.5	0.6964	1
0.75	2	0.7451	0.5962	1	0.5351	0.75	0.8333	0.5	0.6964	1
0.7	3	0.7843	0.452	1	0.649	0.8203	0.8333	0.5	0.6964	1
0.65	3	0.7843	0.7597	1	0.6666	0.8203	0.8333	0.5	0.6964	1
0.6	3	0.7843	0.7597	1	0.6296	0.8203	0.787	0.5	0.6094	1
0.55	3	0.7843	0.7597	1	0.6471	0.8789	0.787	0.5	0.6563	1
0.5	3	0.549	0.7223	1	0.6471	0.8789	0.7346	0.5	0.3281	1
0.45	3	0.5383	0.7105	1	0.6471	0.8789	0.7346	0.5	0.375	1
0.4	3	0.5383	0.7105	1	0.6851	0.9375	0.7346	0.5	0.5	1
0.35	3	0.4392	0.7472	1	0.6851	0.9375	0.5185	0.25	0.5	1
0.3	4	0.4578	0.7474	1	0.3985	0.7031	0.5617	0.5	0.426	1
0.25	4	0.3153	0.6974	1	0.5139	0.769	0.5243	0.5	0.2434	1
0.2	5	0.2021	0.3677	1	0.3736	0.5273	0.3595	0.5	0.1374	1
0.15	7	0.1256	0.4449	1	0.2418	0.5859	0.2714	0.5	0.2518	1
0.1	10	0.0326	0.0305	0	0.0944	0.4037	0.0553	0.5	0.0379	0
0.05	16	0.0036	0.0139	0	0.0009	0.0103	0.0008	0	0.0282	0
Averages:	10.7174	12.0567	18	11.1257	15.2219	12.847	9.25	9.7541	18	

Qualitative Index Values : Test Run # 13

r_a	No.of Rules	T	H	W	P	G	L	TW	F	M
1	1	0.8451	0.7722	1	0.9	1	1	0.5	0.875	1
0.95	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.9	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.85	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.8	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.75	2	0.7451	0.5962	1	0.5351	0.75	0.8333	0.5	0.6964	1
0.7	2	0.7843	0.7597	1	0.7054	0.875	0.8333	0.5	0.6964	1
0.65	2	0.7843	0.7597	1	0.7054	0.875	0.8333	0.5	0.6964	1
0.6	3	0.7843	0.7597	1	0.6296	0.8203	0.787	0.5	0.6094	1
0.55	3	0.7843	0.7597	1	0.6471	0.8789	0.787	0.5	0.6563	1
0.5	3	0.549	0.7223	1	0.6471	0.8789	0.7346	0.5	0.3281	1
0.45	3	0.5383	0.7105	1	0.6471	0.8789	0.7346	0.5	0.375	1
0.4	3	0.5383	0.7105	1	0.6851	0.9375	0.7346	0.5	0.5	1
0.35	3	0.4392	0.7472	1	0.6851	0.9375	0.5185	0.25	0.5	1
0.3	3	0.4819	0.7597	1	0.5253	0.9375	0.5617	0.5	0.4615	1
0.25	4	0.3153	0.6974	1	0.5139	0.769	0.5243	0.5	0.2434	1
0.2	4	0.3514	0.6409	1	0.4925	0.8789	0.4494	0.5	0.3297	1
0.15	6	0.1322	0.4449	1	0.5395	0.8203	0.3131	0.5	0.3022	1
0.1	9	0.0539	0.0776	0	0.1222	0.5383	0.0691	0.5	0.091	0
0.05	12	0.0129	0.0344	0	0.0067	0.1112	0.0125	1	0.0493	1
Averages:	11.5202	13.0414	18	12.5871	16.8872	13.7263	10.25	10.6601	19	

Qualitative Index Values : Test Run # 16

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	1	0.8451	0.7722	1	0.9	1	1	0.5	0.875	1
0.95	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.9	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.85	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.8	1	0.8451	0.7722	1	0.9	1	1	0.5	0.8125	1
0.75	2	0.7451	0.5962	1	0.5351	0.75	0.8333	0.5	0.6964	1
0.7	2	0.7843	0.7597	1	0.7054	0.875	0.8333	0.5	0.6964	1
0.65	2	0.7843	0.7597	1	0.7054	0.875	0.8333	0.5	0.6964	1
0.6	3	0.7843	0.7597	1	0.6296	0.8203	0.787	0.5	0.6094	1
0.55	3	0.7843	0.7597	1	0.6471	0.8789	0.787	0.5	0.6563	1
0.5	3	0.549	0.7223	1	0.6471	0.8789	0.7346	0.5	0.3281	1
0.45	3	0.5383	0.7105	1	0.6471	0.8789	0.7346	0.5	0.375	1
0.4	3	0.5383	0.7105	1	0.6851	0.9375	0.7346	0.5	0.5	1
0.35	3	0.4392	0.7472	1	0.6851	0.9375	0.5185	0.25	0.5	1
0.3	3	0.4819	0.7597	1	0.5253	0.9375	0.5617	0.5	0.4615	1
0.25	4	0.3153	0.6974	1	0.5139	0.769	0.5243	0.5	0.2434	1
0.2	4	0.3514	0.6409	1	0.4925	0.8789	0.4494	0.5	0.3297	1
0.15	6	0.1322	0.4449	1	0.5395	0.8203	0.3131	0.5	0.3022	1
0.1	9	0.0539	0.0776	0	0.1222	0.5383	0.0691	0.5	0.091	0
0.05	12	0.0129	0.0344	0	0.0067	0.1112	0.0125	1	0.0493	1
Averages:	11.5202	13.0414	18	12.5871	16.8872	13.7263	10.25	10.6601	19	

Qualitative Index Values : Test Run # 33

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6563	1
0.95	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6094	1
0.9	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.85	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.8	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.7545	1
0.75	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.6602	1
0.7	3	0.6761	0.606	1	0.6166	1	0.8333	0.25	0.6602	1
0.65	3	0.5409	0.606	1	0.6166	1	0.7778	0.25	0.4062	1
0.6	3	0.4936	0.5962	1	0.5824	1	0.7778	0.5	0.4062	1
0.55	3	0.6151	0.5962	1	0.5824	1	0.8333	0.5	0.4062	1
0.5	4	0.2072	0.1955	0	0.3882	1	0.5342	0	0.2031	1
0.45	4	0.1777	0.2572	0	0.2437	0.8571	0.463	0	0.2321	1
0.4	4	0.3997	0.6492	1	0.3379	0.6875	0.5216	0.25	0.3929	1
0.35	5	0.1239	0.2407	0	0.2701	0.8789	0.3601	0	0.1741	1
0.3	6	0.0013	0.0166	0	0.0535	0.0156	0	0	0	0
0.25	7	0.0092	0.0326	0	0.2087	0.0641	0.0753	0	0	0
0.2	9	0	0	0	0	0	0	0	0	0
0.15	12	0	0	0	0	0	0	0	0	0
0.1	18	0	0	0	0	0	0	0	0	0
0.05	28	0	0	0	0	0	0	0	0	0
Averages:	7.2215	7.3734	11	7.5997	13.2532	10.1762	3.25	6.9542	14	

Qualitative Index Values : Test Run # 36

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6563	1
0.95	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6094	1
0.9	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.85	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.8	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.7545	1
0.75	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.6602	1
0.7	3	0.6761	0.606	1	0.6166	1	0.8333	0.25	0.6602	1
0.65	3	0.5409	0.606	1	0.6166	1	0.7778	0.25	0.4062	1
0.6	3	0.4936	0.5962	1	0.5824	1	0.7778	0.5	0.4062	1
0.55	3	0.6151	0.5962	1	0.5824	1	0.8333	0.5	0.4062	1
0.5	4	0.2072	0.1955	0	0.3882	1	0.5342	0	0.2031	1
0.45	4	0.1777	0.2572	0	0.2437	0.8571	0.463	0	0.2321	1
0.4	4	0.3997	0.6492	1	0.3379	0.6875	0.5216	0.25	0.3929	1
0.35	5	0.1308	0.3094	0	0.4322	0.8789	0.3601	0	0.1741	1
0.3	6	0.0013	0.0166	0	0.0535	0.0156	0	0	0	0
0.25	7	0.0092	0.0326	0	0.2087	0.0641	0.0753	0	0	0
0.2	9	0	0	0	0	0	0	0	0	0
0.15	11	0	0	0	0	0	0	0	0	0
0.1	17	0	0	0	0	0	0	0	0	0
0.05	28	0	0	0	0	0	0	0	0	0
Averages:	7.2284	7.4421	11	7.7618	13.2532	10.1762	3.25	6.9542	14	

Qualitative Index Values : Test Run # 37

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6563	1
0.95	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6094	1
0.9	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.85	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.8	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.7545	1
0.75	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.6602	1
0.7	3	0.6761	0.606	1	0.6166	1	0.8333	0.25	0.6602	1
0.65	3	0.5409	0.606	1	0.6166	1	0.7778	0.25	0.4062	1
0.6	3	0.4936	0.5962	1	0.5824	1	0.7778	0.5	0.4062	1
0.55	3	0.6151	0.5962	1	0.5824	1	0.8333	0.5	0.4062	1
0.5	4	0.2072	0.1955	0	0.3882	1	0.5342	0	0.2031	1
0.45	4	0.1777	0.2572	0	0.2437	0.8571	0.463	0	0.2321	1
0.4	4	0.3997	0.6492	1	0.3379	0.6875	0.5216	0.25	0.3929	1
0.35	5	0.1239	0.2407	0	0.2701	0.8789	0.3601	0	0.1741	1
0.3	5	0.0165	0.071	0	0.197	0.0781	0.0864	0	0	0
0.25	7	0.0092	0.0326	0	0.2087	0.0641	0.0753	0	0	0
0.2	8	0.0917	0.1855	0	0.2049	0.6759	0.2641	0	0.0936	0
0.15	11	0.0344	0.046	0	0.0397	0.3549	0.1499	0	0.0613	0
0.1	16	0.0071	0.0085	0	0.0066	0.0896	0.0284	0	0.0553	0
0.05	22	0	0.0003	0	0.0005	0.0023	0.0284	0	0.0131	0
Averages:	7.3699	7.6681	11	7.9949	14.4384	10.7334	3.25	7.1775	14	

Qualitative Index Values : Test Run # 40

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6563	1
0.95	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6094	1
0.9	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.85	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.8	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.7545	1
0.75	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.6602	1
0.7	3	0.6761	0.606	1	0.6166	1	0.8333	0.25	0.6602	1
0.65	3	0.5409	0.606	1	0.6166	1	0.7778	0.25	0.4062	1
0.6	3	0.4936	0.5962	1	0.5824	1	0.7778	0.5	0.4062	1
0.55	3	0.6151	0.5962	1	0.5824	1	0.8333	0.5	0.4062	1
0.5	4	0.2072	0.1955	0	0.3882	1	0.5342	0	0.2031	1
0.45	4	0.1777	0.2572	0	0.2437	0.8571	0.463	0	0.2321	1
0.4	4	0.3997	0.6492	1	0.3379	0.6875	0.5216	0.25	0.3929	1
0.35	5	0.1308	0.3094	0	0.4322	0.8789	0.3601	0	0.1741	1
0.3	5	0.0165	0.071	0	0.197	0.0781	0.0864	0	0	0
0.25	7	0.0092	0.0326	0	0.2087	0.0641	0.0753	0	0	0
0.2	8	0.0917	0.1855	0	0.2049	0.6759	0.2641	0	0.0936	0
0.15	10	0.0463	0.046	0	0.071	0.3785	0.2075	0	0.0996	0
0.1	15	0.0071	0.0085	0	0.0118	0.1024	0.0284	0	0.0899	0
0.05	22	0	0.0003	0	0.0005	0.0023	0.0007	0	0.0131	0
Averages:	7.3887	7.7368	11	8.1935	14.4748	10.7633	3.25	7.2504	14	

Qualitative Index Values : Test Run # 41

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6563	1
0.95	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6094	1
0.9	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.85	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.8	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.7545	1
0.75	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.6602	1
0.7	3	0.6761	0.606	1	0.6166	1	0.8333	0.25	0.6602	1
0.65	3	0.5409	0.606	1	0.6166	1	0.7778	0.25	0.4062	1
0.6	3	0.4936	0.5962	1	0.5824	1	0.7778	0.5	0.4062	1
0.55	3	0.6151	0.5962	1	0.5824	1	0.8333	0.5	0.4062	1
0.5	3	0.4921	0.5962	1	0.5824	1	0.6944	0.25	0.4062	1
0.45	3	0.4441	0.7472	1	0.6296	1	0.6944	0.25	0.4643	1
0.4	4	0.3997	0.6492	1	0.3379	0.6875	0.5216	0.25	0.3929	1
0.35	4	0.2943	0.699	1	0.5402	0.8789	0.4681	0.25	0.3482	1
0.3	4	0.3131	0.7223	1	0.4727	0.9375	0.3745	0.5	0.3297	1
0.25	6	0.1752	0.3315	1	0.4175	0.769	0.3265	0.5	0.213	1
0.2	7	0.0917	0.4553	1	0.2521	0.6759	0.2641	0.25	0.0936	1
0.15	10	0.0344	0.1129	1	0.0489	0.3549	0.1499	0.25	0.0613	0
0.1	15	0.0071	0.0254	0	0.0088	0.0896	0.0284	0.5	0.0553	1
0.05	20	0.0001	0.0012	0	0.0005	0.0027	0.0012	0.5	0.0131	0
Averages:	8.5543	10.3218	18	9.3882	16.146	11.7451	6.5	8.3296	18	

Qualitative Index Values : Test Run # 44

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6563	1
0.95	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6094	1
0.9	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.85	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.8	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.7545	1
0.75	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.6602	1
0.7	3	0.6761	0.606	1	0.6166	1	0.8333	0.25	0.6602	1
0.65	3	0.5409	0.606	1	0.6166	1	0.7778	0.25	0.4062	1
0.6	3	0.4936	0.5962	1	0.5824	1	0.7778	0.5	0.4062	1
0.55	3	0.6151	0.5962	1	0.5824	1	0.8333	0.5	0.4062	1
0.5	3	0.4921	0.5962	1	0.5824	1	0.6944	0.25	0.4062	1
0.45	3	0.4441	0.7472	1	0.6296	1	0.6944	0.25	0.4643	1
0.4	4	0.3997	0.6492	1	0.3379	0.6875	0.5216	0.25	0.3929	1
0.35	4	0.2943	0.699	1	0.5402	0.8789	0.4681	0.25	0.3482	1
0.3	4	0.3131	0.7223	1	0.4727	0.9375	0.3745	0.5	0.3297	1
0.25	6	0.1752	0.3315	1	0.4175	0.769	0.3265	0.5	0.213	1
0.2	7	0.0917	0.4553	1	0.2521	0.6759	0.2641	0.25	0.0936	1
0.15	9	0.0463	0.1129	1	0.0874	0.3785	0.2075	0.25	0.0996	0
0.1	14	0.0071	0.0254	0	0.0158	0.1024	0.0284	0.5	0.0899	1
0.05	20	0.0001	0.0012	0	0.0005	0.0027	0.0012	0.5	0.0131	0
Averages:	8.5662	10.3218	18	9.4337	16.1824	11.8027	6.5	8.4025	18	

Qualitative Index Values : Test Run # 45

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6563	1
0.95	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6094	1
0.9	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.85	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.8	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.7545	1
0.75	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.6602	1
0.7	3	0.6761	0.606	1	0.6166	1	0.8333	0.25	0.6602	1
0.65	3	0.5409	0.606	1	0.6166	1	0.7778	0.25	0.4062	1
0.6	3	0.4936	0.5962	1	0.5824	1				
0.55	3	0.6151	0.5962	1	0.5824	1	0.8333	0.5	0.4062	1
0.5	3	0.4921	0.5962	1	0.5824	1	0.6944	0.25	0.4062	1
0.45	3	0.4441	0.7472	1	0.6296	1	0.6944	0.25	0.4643	1
0.4	3	0.4441	0.7472	1	0.6162	1	0.6019	0.25	0.4643	1
0.35	4	0.2943	0.699	1	0.5402	0.8789	0.4681	0.25	0.3482	1
0.3	4	0.3131	0.7223	1	0.4727	0.9375	0.3745	0.5	0.3297	1
0.25	6	0.1752	0.3315	1	0.4175	0.769	0.3265	0.5	0.213	1
0.2	7	0.0917	0.4553	1	0.2521	0.6759	0.2641	0.25	0.0936	1
0.15	9	0.0597	0.1968	1	0.0833	0.5914	0.1873	0.25	0.1471	0
0.1	12	0.0154	0.0725	0	0.0324	0.2053	0.0403	0.5	0.1268	1
0.05	15	0.0045	0.0211	0	0.0047	0.0402	0.0142	1	0.0252	1
Averages:	8.6367	10.5707	18	9.7287	16.8482	11.1099	6.5	8.1642	18	

Qualitative Index Values : Test Run # 48

r_a	No. of Rules	T	H	W	P	G	L	TW	F	M
1	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6563	1
0.95	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6563	1
0.9	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6094	1
0.85	3	0.6628	0.5962	1	0.6166	0.9375	0.8333	0.25	0.6964	1
0.8	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.6964	1
0.75	3	0.6628	0.5962	1	0.6166	1	0.8333	0.25	0.7545	1
0.7	3	0.6761	0.606	1	0.6166	1	0.8333	0.25	0.6602	1
0.65	3	0.5409	0.606	1	0.6166	1	0.8333	0.25	0.6602	1
0.6	3	0.4936	0.5962	1	0.5824	1	0.7778	0.25	0.4062	1
0.55	3	0.6151	0.5962	1	0.5824	1	0.7778	0.5	0.4062	1
0.5	3	0.4921	0.5962	1	0.5824	1	0.8333	0.5	0.4062	1
0.45	3	0.4441	0.7472	1	0.6296	1	0.6944	0.25	0.4062	1
0.4	3	0.4441	0.7472	1	0.6162	1	0.6944	0.25	0.4643	1
0.35	4	0.2943	0.699	1	0.5402	0.8789	0.6019	0.25	0.4643	1
0.3	4	0.3131	0.7223	1	0.4727	0.9375	0.4681	0.25	0.3482	1
0.25	6	0.1752	0.3315	1	0.4175	0.769	0.3745	0.5	0.3297	1
0.2	7	0.0917	0.4553	1	0.2521	0.6759	0.3265	0.5	0.213	1
0.15	8	0.0805	0.1968	1	0.1491	0.6309	0.2641	0.25	0.0936	1
0.1	11	0.0154	0.0725	0	0.0579	0.2347	0.2594	0.25	0.2391	0
0.05	15	0.0045	0.0211	0	0.0047	0.0402	0.0403	0.5	0.206	1
Avereges:	8.6575	10.5707	18	9.82	16.9171	12.7789	6.25	9.3727	19	

Appendix – 3

Consolidated Summary of Neural Network Analysis

Summary--- Neural Network Analysis

Model #	Paradigms and Architecture	Settings Used	Measures Of Accuracy	Value	Parameter	Cont.Factor
1	**BPNN Ward Net.**	All Default Settings	R squared:	0.7667	Floor Level	0.1564
		No .Of Neurons:	r squared:	0.7758	Temperature	0.1516
		Input = 9	**Mean squared error:**	0.0100	Gang Size	0.1470
		1st hidden = 5 each	**Mean absolute error:**	0.0710	% age labour	0.1240
		2nd hidden =10	Min. absolute error:	0.0000	Precipitation	0.1135
		Out put =1	Max. absolute error:	0.4450	Work Type	0.1013
		Scaling =none (data normalised)	Correlation coefficient r:	0.8808	Wind Speed	0.0747
			Percent within 5%:	24.4340	Method	0.0675
			Percent within 5% to 10%:	16.7420	Humidity	0.0640
			Percent within 10% to 20%:	24.8870		
			Percent within 20% to 30%:	14.9320		
			Percent over 30%:	18.5520		
2	**BPNN 3-Layer Jump Conn. Net**	All Default Settings	R squared:	0.4236	Temperature	0.1671
		No.of Neurons = Recommended	r squared:	0.4425	Work Type	0.1476
		Scaling = None	**Mean squared error:**	0.0250	Precipitation	0.1250
			Mean absolute error:	0.1280	Floor	0.1148
			Min. absolute error:	0.0030	Gang Size	0.1082
			Max. absolute error:	0.4710	Method	0.0924
			Correlation coefficient r:	0.6652	%age Labour	0.0865
			Percent within 5%:	6.7870	Wind Speed	0.0843
			Percent within 5% to 10%:	9.9550	Humidity	0.0742
			Percent within 10% to 20%:	19.0050		
			Percent within 20% to 30%:	21.7190		
			Percent over 30%:	42.0810		

3	**BPNN 5-Layer Jump Conn.Net**	All Default Settings	R squared:	0.4620	Temperature	0.5192	
		No.of Neurons= Recommended	r squared:	0.4756	Wind Speed	0.4262	
		Scaling = None	**Mean squared error:**	0.0230	Precipitation	0.4151	
			Mean absolute error:	0.1220	%age Labour	0.4143	
			Min. absolute error:	0.0010	Floor	0.4035	
			Max. absolute error:	0.4850	Work Type	0.4032	
			Correlation coefficient r:	0.6896	Method	0.3948	
			Percent within 5%:	8.5970	Humidity	0.3806	
			Percent within 5% to 10%:	9.9550	Gang Size	0.3598	
			Percent within 10% to 20%:	18.1000			
			Percent within 20% to 30%:	23.0770			
			Percent over 30%:	39.8190			
4	**BPPN Additional Neurons1**	Ward Net	R squared:	0.7789	Gang SIZE	0.1528	
		All default settings	r squared:	0.7910	Temerature	0.1387	
		No. of Neurons:	**Mean squared error:**	0.0090	Precipitation	0.1361	
		1st Layer = 8	**Mean absolute error:**	0.0640	Floor	0.1356	
		2nd Layer = 8	Min. absolute error:	0.0010	% age Labour	0.1091	
			Max. absolute error:	0.5150	Work Type	0.0963	
			Correlation coefficient r:	0.8894	Humidity	0.0832	
			Percent within 5%:	29.8640	Method	0.0757	
			Percent within 5% to 10%:	18.5520	Wind Speed	0.0724	
			Percent within 10% to 20%:	24.4340			
			Percent within 20% to 30%:	10.8600			
			Percent over 30%:	15.8370			

5	**BPNN Additional Neurons 2**	Ward Net	R squared:	0.7995	Gang Size	0.1421	
		All Default Settings	r squared:	0.8113	Precipitation	0.1401	
		No. of Neurons	**Mean squared error:**	0.0090	Floor	0.1350	
		1st Layer = 12	**Mean absolute error:**	0.0620	Temperature	0.1209	
		2nd Layer = 10	Min. absolute error:	0.0000	% age Lbour	0.1119	
			Max. absolute error:	0.3960	Humidity	0.0922	
			Correlation coefficient r:	0.9007	Work Type	0.0914	
			Percent within 5%:	31.2220	Wind SPEED	0.0862	
			Percent within 5% to 10%:	17.1950	Method	0.0802	
			Percent within 10% to 20%:	23.5290			
			Percent within 20% to 30%:	8.5970			
			Percent over 30%:	19.0050			
6	**BPNN Activation Function 1**	Ward Net	R squared:	0.7845	Floor	0.1790	
		All Default Settings	r squared:	0.7889	%age Labour	0.1405	
		Neurons = Recommended No.	**Mean squared error:**	0.0090	Precipitation	0.1352	
		Activtion Functions :	**Mean absolute error:**	0.0690	Temperature	0.1258	
		1st = Gaussian	Min. absolute error:	0.0000	Gang Size	0.1170	
		2nd = tanh	Max. absolute error:	0.5010	Work Type	0.0924	
		output= logistic	Correlation coefficient r:	0.8882	Humidity	0.0821	
			Percent within 5%:	23.0770	Wind Speed	0.0755	
			Percent within 5% to 10%:	19.0050	Method	0.0526	
			Percent within 10% to 20%:	24.8870			
			Percent within 20% to 30%:	13.5750			
			Percent over 30%:	19.0050			

7	**BPNN Activation Function 2**	Ward Net	R squared:	0.7945	Temperature	0.1582	
		All Default Settings	r squared:	0.8022	Floor	0.1471	
		Neurons -Recommended No.	**Mean squared error:**	0.0090	Precipitaion	0.1419	
		Activtion Functions :	**Mean absolute error:**	0.0640	Gang Size	0.1395	
		1st = Gaussian	Min. absolute error:	0.0000	%age Labour	0.1075	
		2nd = Gaussian	Max. absolute error:	0.4880	Wind Speed	0.0861	
		output= logistic	Correlation coefficient r:	0.8956	Humidity	0.0841	
			Percent within 5%:	26.2440	Work Type	0.0776	
			Percent within 5% to 10%:	21.2670	Method	0.0580	
			Percent within 10% to 20%:	23.9820			
			Percent within 20% to 30%:	10.4070			
			Percent over 30%:	17.6470			
8	**BPNN Activation Function 3**	Ward Net	R squared:	0.0876	Temperature	0.1566	
		All Default Settings	r squared:	0.4257	Humidity	0.1353	
		Neurons = Recommended No.	**Mean squared error:**	0.0390	Floor	0.1323	
		Activtion Functions :	**Mean absolute error:**	0.1440	Wind Speed	0.1108	
		1st = tanh1.5	Min. absolute error:	0.0010	Method	0.1093	
		2nd = tanh1.5	Max. absolute error:	0.5820	% age Labour	0.1065	
		Output= linear	Correlation coefficient r:	0.6524	Precipitation	0.0986	
			Percent within 5%:	7.2400	Work Type	0.0973	
			Percent within 5% to 10%:	10.4070	Gang Size	0.0534	
			Percent within 10% to 20%:	19.4570			
			Percent within 20% to 30%:	18.5520			
			Percent over 30%:	43.8910			

9	**BPNN Changed Arrangement**	Ward Net	R squared:	0.7953	% age Labour	0.1467	
	of Input Parameters	All Default Settings	r squared:	0.8048	Temperature	0.1432	
		Neurons = Recommended No.	**Mean squared error:**	0.0090	Floor	0.1354	
		Data presentsation Arrangement	**Mean absolute error:**	0.0660	Gang Size	0.1077	
		Reversed	Min. absolute error:	0.0010	Precipitaion	0.1061	
			Max. absolute error:	0.4470	Humidity	0.0971	
			Correlation coefficient r:	0.8971	Work Type	0.0966	
			Percent within 5%:	27.6020	Method	0.0961	
			Percent within 5% to 10%:	18.1000	Wind Speed	0.0712	
			Percent within 10% to 20%:	28.0540			
			Percent within 20% to 30%:	7.6920			
			Percent over 30%:	18.1000			
10	**BPNN Changed Learning Rate**	Ward Net	R squared:	0.8316	Precipitaion	0.1827	
	And Momentum	Learning Rate = 0.05	r squared:	0.8347	Floor	0.1713	
	(Selected Network)	Momentum = 0.05	**Mean squared error:**	0.0070	Temperature	0.1536	
		Rest Default	**Mean absolute error:**	0.0580	Gang Size	0.1072	
			Min. absolute error:	0.0000	WorkType	0.0861	
			Max. absolute error:	0.6040	Humidity	0.0852	
			Correlation coefficient r:	0.9136	Method	0.0792	
			Percent within 5%:	23.0770	%age Labour	0.0781	
			Percent within 5% to 10%:	23.0770	Wind Speed	0.0566	
			Percent within 10% to 20%:	29.8640			
			Percent within 20% to 30%:	11.3120			
			Percent over 30%:	12.2170			

11	**GMDH**	All Default Settings					
			R squared:	0.7166	Most Significant Variables:		
			r squared:	0.7166	Work type		
			Mean squared error:	0.0121	Temperature		
			Mean absolute error:	0.0862	Floor Level		
			Min. absolute error:	0.0007	Precipitation		
			Max. absolute error:	0.4189	Wind Speed		
			Correlation coefficient r:	0.8465	Humidity		
			Percent within 5%:	12.6700			
			Percent within 5% to 10%:	17.1950			
			Percent within 10% to 20%:	28.0540			
			Percent within 20% to 30%:	15.8370			
			Percent over 30%:	25.7920			
12	**GRNN**	All Default	R squared:	0.8160			
		Smoothing Factor =0.1582031	r squared:	0.8166			
			Mean squared error:	0.0080			
			Mean absolute error:	0.0560			
			Min. absolute error:	0.0000			
			Max. absolute error:	0.5730			
			Correlation coefficient r:	0.9037			
			Percent within 5%:	35.2940			
			Percent within 5% to 10%:	23.9820			
			Percent within 10% to 20%:	19.0050			
			Percent within 20% to 30%:	8.1450			
			Percent over 30%:	13.1220			

Appendix – 4

GRNN Model Predictions

Predictions GRNN Model

Pattern #	Actual	Network	Act-Net
1	0.9500	1.0103	0.7597
2	1.1200	1.1209	0.8191
3	1.0100	1.0106	0.8194
4	1.2700	1.2682	0.8218
5	1.1400	1.0228	0.9372
6	1.1700	1.1878	0.8022
7	1.0400	1.1756	0.6844
8	1.1600	1.1855	0.7945
9	1.9900	1.0105	1.7995
10	1.1000	1.1006	0.8194
11	1.0000	1.2552	0.5648
12	1.1200	1.1949	0.7451
13	1.5500	1.2663	1.1037
14	1.2600	1.2255	0.8545
15	1.1400	1.1804	0.7796
16	1.2700	1.2521	0.8379
17	1.4500	1.3405	0.9295
18	1.5100	1.2975	1.0325
19	1.3700	1.3242	0.8658
20	1.3800	1.3703	0.8297
21	1.2500	1.2624	0.8076
22	1.4900	1.2675	1.0425
23	1.3400	1.3417	0.8183
24	1.3600	1.3601	0.8199
25	1.2200	1.4722	0.5678
26	1.3400	1.5461	0.6139
27	1.2000	1.3814	0.6386
28	1.3900	1.4014	0.8086
29	1.4100	1.4022	0.8278
30	1.2600	1.3488	0.7312
31	1.4800	1.4915	0.8085
32	1.3600	1.3667	0.8133
33	1.2100	1.3178	0.7122
34	1.3400	1.3661	0.7939
35	1.0900	1.2573	0.6527
36	1.2100	1.2277	0.8023
37	1.4700	1.4118	0.8782
38	1.3200	1.3779	0.7621
39	1.3700	1.3474	0.8426
40	1.2300	1.3373	0.7127
41	1.4700	1.3904	0.8996
42	1.3400	1.3147	0.8453
43	1.4900	1.3929	0.9171
44	1.3500	1.1068	1.0632
45	1.5400	1.5101	0.8499
46	1.3800	1.3483	0.8517
47	1.5200	1.5219	0.8181
48	1.3700	1.3757	0.8143
49	1.6700	1.5366	0.9534
50	1.5100	1.4561	0.8739
51	1.6500	1.5262	0.9438
52	1.4800	1.4759	0.8241
53	1.5700	1.7210	0.6690
54	1.4100	1.4792	0.7508
55	1.5600	1.4045	0.9755
56	1.4000	1.3969	0.8231
57	1.6300	1.5109	0.9391
58	1.4600	1.4616	0.8184
59	1.7300	1.8409	0.7091
60	1.8900	1.4796	1.2304
61	1.7100	1.4611	1.0689
62	1.7400	1.7033	0.8567
63	1.5500	1.4842	0.8858
64	1.8000	1.8149	0.8051
65	1.6200	1.6199	0.8201
66	1.8700	1.8576	0.8324
67	1.6800	1.5288	0.9712
68	1.6700	1.7045	0.7855
69	1.5200	1.4833	0.8567
70	1.1000	1.5274	0.3926
71	1.7600	1.8801	0.6999
72	1.9800	2.0035	0.7965
73	1.5800	1.6329	0.7671
74	1.4500	1.5892	0.6808
75	1.2600	1.2851	0.7949
76	2.0200	1.9816	0.8584
77	1.5400	1.5697	0.7903
78	2.4000	2.2818	0.9382
79	1.4900	1.5338	0.7762
80	2.2500	2.2380	0.8320
81	2.2000	2.1204	0.8996
82	1.6200	1.6898	0.7502
83	1.3300	1.4295	0.7205
84	2.2400	2.0992	0.9608
85	1.7500	1.6889	0.8811

86	1.9300	1.9269	0.8231
87	1.4300	1.4896	0.7604
88	1.6500	1.6820	0.7880
89	1.6500	1.6677	0.8023
90	1.8500	1.9450	0.7250
91	1.8000	2.1074	0.5126
92	1.3200	1.5498	0.5902
93	1.5500	1.9402	0.4298
94	1.1000	1.7734	0.1466
95	1.4700	1.9250	0.3650
96	1.4200	1.4654	0.7746
97	1.4900	1.5688	0.7412
98	1.4500	1.5181	0.7519
99	1.6100	1.5844	0.8456
100	1.5200	1.5836	0.7564
101	1.7600	1.9626	0.6174
102	1.7500	1.9575	0.6125
103	1.7300	1.9908	0.5592
104	1.9100	2.0660	0.6640
105	1.7900	1.6792	0.9308
106	1.7700	1.7106	0.8794
107	1.8000	1.7292	0.8908
108	1.4200	1.4749	0.7651
109	1.4900	1.6638	0.6462
110	1.8700	1.8294	0.8606
111	2.0000	2.0896	0.7304
112	1.7800	1.6729	0.9271
113	1.3600	1.4956	0.6844
114	2.4200	2.1511	1.0889
115	2.3100	2.1504	0.9796
116	2.0900	1.8961	1.0139
117	1.8000	1.7445	0.8755
118	1.8500	1.7591	0.9109
119	1.8800	1.7657	0.9343
120	1.7800	1.7676	0.8324
121	2.3300	2.1586	0.9914
122	1.7200	1.7760	0.7640
123	1.7000	1.7648	0.7552
124	2.0900	2.0901	0.8199
125	2.3200	2.2562	0.8838
126	2.3400	2.2593	0.9007
127	1.8800	1.7487	0.9513
128	1.9000	1.8155	0.9045
129	1.6500	1.6449	0.8251
130	2.3300	2.3170	0.8330
131	2.3500	2.3127	0.8573
132	2.4000	2.2914	0.9286
133	2.3800	2.2863	0.9137

134	2.4000	2.2795	0.9405
135	2.5300	2.2518	1.0982
136	2.5000	2.2375	1.0825
137	1.8000	1.7412	0.8788
138	1.7000	1.7786	0.7414
139	2.3400	2.1297	1.0303
140	1.9800	2.0883	0.7117
141	1.7400	1.7268	0.8332
142	1.7800	1.7189	0.8811
143	1.8000	1.7241	0.8959
144	1.6800	1.7082	0.7918
145	1.5000	1.7095	0.6105
146	1.7400	1.7304	0.8296
147	1.8200	1.8137	0.8263
148	1.7300	1.9353	0.6147
149	2.1000	2.2022	0.7178
150	2.0200	2.0701	0.7699
151	1.9100	1.8633	0.8667
152	1.9700	1.9908	0.7992
153	2.0000	1.9867	0.8333
154	2.0200	1.6837	1.1563
155	1.7600	1.7217	0.8583
156	1.7700	1.7149	0.8751
157	1.8300	1.7521	0.8979
158	1.4200	1.6387	0.6013
159	1.2000	1.2113	0.8087
160	1.7800	1.7435	0.8565
161	1.9600	1.9531	0.8269
162	1.5400	1.7423	0.6177
163	2.0300	1.9768	0.8732
164	1.9900	1.9893	0.8207
165	1.8900	1.8837	0.8263
166	1.6900	1.8096	0.7004
167	1.9600	1.9314	0.8486
168	1.9800	1.9281	0.8719
169	1.6400	1.5043	0.9557
170	1.3300	1.2755	0.8745
171	1.2400	1.2676	0.7924
172	1.2200	1.3661	0.6739
173	1.6200	1.2742	1.1658
174	1.1900	1.2304	0.7796
175	1.2000	1.7064	0.3136
176	1.3100	1.3715	0.7585
177	1.7300	1.7552	0.7948
178	1.2900	1.6817	0.4283
179	1.2600	1.0255	1.0545
180	1.3400	1.3400	0.8200
181	1.3800	1.4099	0.7901

182	1.2300	1.3769	0.6731
183	1.3000	1.2548	0.8652
184	1.2800	1.2544	0.8456
185	1.2100	1.2093	0.8207
186	1.1600	1.1540	0.8260
187	1.1000	1.0965	0.8235
188	1.0500	1.0575	0.8125
189	0.8800	0.8804	0.8196
190	1.2500	1.3271	0.7429
191	1.2500	1.2420	0.8280
192	1.3000	1.3430	0.7770
193	1.4500	1.5477	0.7223
194	1.2100	1.1392	0.8908
195	1.1400	1.1482	0.8118
196	1.1100	1.1095	0.8205
197	1.1200	1.2056	0.7344
198	1.0400	1.0773	0.7827
199	0.8200	0.9416	0.6984
200	1.4400	1.4233	0.8367
201	1.3600	1.3717	0.8083
202	1.1500	1.1951	0.7749

203	1.5100	1.4693	0.8607
204	1.4400	1.4185	0.8415
205	1.5100	1.5298	0.8002
206	1.5800	1.5926	0.8074
207	1.6500	1.5884	0.8816
208	1.4900	1.5804	0.7296
209	1.3200	1.3049	0.8351
210	1.4700	1.5949	0.6951
211	1.3000	1.3931	0.7269
212	0.9900	1.1330	0.6770
213	1.3600	1.3461	0.8339
214	1.1800	1.1531	0.8469
215	1.2800	1.1806	0.9194
216	1.2400	1.3096	0.7504
217	1.6100	1.6570	0.7730
218	1.6500	1.6193	0.8507
219	1.5200	1.5545	0.7855
220	1.6700	1.6081	0.8819
221	1.5000	1.5808	0.7392

Appendix – 5

GMDH Model Predictions

Predictions GMDH Model

Pattern #	Actual	Network	Act-Net
1	0.076023	0.275572	-0.19955
2	0.175439	0.355029	-0.17959
3	0.111111	0.316243	-0.20513
4	0.263158	0.2976	-0.03444
5	0.187135	0.227786	-0.04065
6	0.204678	0.172801	0.031878
7	0.128655	0.116949	0.011706
8	0.19883	0.200146	-0.00132
9	0.684211	0.265318	0.418892
10	0.163743	0.313413	-0.14967
11	0.105263	0.150766	-0.0455
12	0.175439	0.219028	-0.04359
13	0.426901	0.328153	0.098748
14	0.25731	0.149554	0.107756
15	0.187135	0.150456	0.036679
16	0.263158	0.200101	0.063056
17	0.368421	0.351828	0.016593
18	0.403509	0.32427	0.079239
19	0.321637	0.231186	0.090451
20	0.327485	0.291807	0.035679
21	0.251462	0.208031	0.043431
22	0.391813	0.266583	0.12523
23	0.304094	0.184358	0.119735
24	0.315789	0.334281	-0.01849
25	0.233918	0.230337	0.003581
26	0.304094	0.401872	-0.09778
27	0.222222	0.29948	-0.07726
28	0.333333	0.346246	-0.01291
29	0.345029	0.356512	-0.01148
30	0.25731	0.247915	0.009395
31	0.385965	0.423207	-0.03724
32	0.315789	0.376064	-0.06027
33	0.22807	0.295392	-0.06732
34	0.304094	0.370366	-0.06627
35	0.157895	0.295899	-0.138
36	0.22807	0.340067	-0.112
37	0.380117	0.301591	0.078526
38	0.292398	0.367063	-0.07467
39	0.321637	0.280185	0.041453
40	0.239766	0.348825	-0.10906
41	0.380117	0.348622	0.031495
42	0.304094	0.275706	0.028388
43	0.391813	0.370449	0.021364
44	0.309942	0.289776	0.020166
45	0.421053	0.482594	-0.06154
46	0.327485	0.38951	-0.06202
47	0.409357	0.556861	-0.1475
48	0.321637	0.452917	-0.13128
49	0.497076	0.560216	-0.06314
50	0.403509	0.445413	-0.0419
51	0.48538	0.554924	-0.06954
52	0.385965	0.475788	-0.08982
53	0.438596	0.468433	-0.02984
54	0.345029	0.359835	-0.01481
55	0.432749	0.451492	-0.01874
56	0.339181	0.372371	-0.03319
57	0.473684	0.507852	-0.03417
58	0.374269	0.407011	-0.03274
59	0.532164	0.482306	0.049858
60	0.625731	0.513229	0.112502
61	0.520468	0.399978	0.12049
62	0.538012	0.598368	-0.06036
63	0.426901	0.494425	-0.06752
64	0.573099	0.627492	-0.05439
65	0.467836	0.484764	-0.01693
66	0.614035	0.655837	-0.0418
67	0.502924	0.527072	-0.02415
68	0.497076	0.612187	-0.11511
69	0.409357	0.494282	-0.08492
70	0.163743	0.144274	0.019469
71	0.549708	0.668135	-0.11843
72	0.678363	0.65167	0.026692
73	0.444444	0.542797	-0.09835
74	0.368421	0.535172	-0.16675
75	0.25731	0.344217	-0.08691
76	0.701754	0.703546	-0.00179
77	0.421053	0.557866	-0.13681
78	0.923977	0.732387	0.191589
79	0.391813	0.567311	-0.1755
80	0.836257	0.735738	0.100519
81	0.807018	0.716585	0.090433
82	0.467836	0.534238	-0.0664
83	0.298246	0.415467	-0.11722
84	0.830409	0.727374	0.103035
85	0.54386	0.482745	0.061115
86	0.649123	0.613008	0.036115

87	0.356725	0.370493	-0.01377
88	0.48538	0.478499	0.006881
89	0.48538	0.592685	-0.1073
90	0.602339	0.701114	-0.09877
91	0.573099	0.695769	-0.12267
92	0.292398	0.531038	-0.23864
93	0.426901	0.644732	-0.21783
94	0.163743	0.347776	-0.18403
95	0.380117	0.551192	-0.17108
96	0.350877	0.588131	-0.23725
97	0.391813	0.42718	-0.03537
98	0.368421	0.417352	-0.04893
99	0.461988	0.382092	0.079897
100	0.409357	0.386979	0.022377
101	0.549708	0.602512	-0.0528
102	0.54386	0.559769	-0.01591
103	0.532164	0.563867	-0.0317
104	0.637427	0.684088	-0.04666
105	0.567251	0.459569	0.107683
106	0.555556	0.393209	0.162347
107	0.573099	0.3928	0.180299
108	0.350877	0.381406	-0.03053
109	0.391813	0.558301	-0.16649
110	0.614035	0.754382	-0.14035
111	0.690058	0.757442	-0.06738
112	0.561404	0.633612	-0.07221
113	0.315789	0.419038	-0.10325
114	0.935673	0.755485	0.180188
115	0.871345	0.767142	0.104203
116	0.74269	0.512442	0.230248
117	0.573099	0.631708	-0.05861
118	0.602339	0.630795	-0.02846
119	0.619883	0.628827	-0.00894
120	0.561404	0.638853	-0.07745
121	0.883041	0.73089	0.152151
122	0.526316	0.515244	0.011072
123	0.51462	0.44216	0.07246
124	0.74269	0.743409	-0.00072
125	0.877193	0.776809	0.100384
126	0.888889	0.770188	0.118701
127	0.619883	0.580318	0.039565
128	0.631579	0.605565	0.026014
129	0.48538	0.304917	0.180463
130	0.883041	0.674328	0.208712
131	0.894737	0.652982	0.241755
132	0.923977	0.675326	0.248651
133	0.912281	0.763149	0.149132
134	0.923977	0.772675	0.151302

135	1	0.657989	0.342011
136	0.982456	0.66318	0.319276
137	0.573099	0.438563	0.134536
138	0.51462	0.45891	0.05571
139	0.888889	0.617689	0.2712
140	0.678363	0.607648	0.070714
141	0.538012	0.407649	0.130363
142	0.561404	0.474065	0.087339
143	0.573099	0.473918	0.099182
144	0.502924	0.483465	0.019458
145	0.397661	0.347026	0.050635
146	0.538012	0.518586	0.019426
147	0.584795	0.48217	0.102625
148	0.532164	0.660842	-0.12868
149	0.748538	0.699524	0.049014
150	0.701754	0.64072	0.061034
151	0.637427	0.547985	0.089442
152	0.672515	0.628528	0.043987
153	0.690058	0.611689	0.07837
154	0.701754	0.500212	0.201542
155	0.549708	0.483461	0.066247
156	0.555556	0.504064	0.051491
157	0.590643	0.557716	0.032928
158	0.350877	0.333096	0.017782
159	0.222222	0.238801	-0.01658
160	0.561404	0.468634	0.092769
161	0.666667	0.62162	0.045047
162	0.421053	0.439373	-0.01832
163	0.707602	0.644118	0.063484
164	0.684211	0.613211	0.070999
165	0.625731	0.650159	-0.02443
166	0.508772	0.511286	-0.00251
167	0.666667	0.599352	0.067315
168	0.678363	0.615912	0.062451
169	0.479532	0.484311	-0.00478
170	0.298246	0.353036	-0.05479
171	0.245614	0.326935	-0.08132
172	0.233918	0.348594	-0.11468
173	0.467836	0.338907	0.128929
174	0.216374	0.298069	-0.08169
175	0.222222	0.361595	-0.13937
176	0.28655	0.32461	-0.03806
177	0.532164	0.487796	0.044368
178	0.274854	0.378933	-0.10408
179	0.25731	0.359399	-0.10209
180	0.304094	0.343377	-0.03928
181	0.327485	0.365745	-0.03826
182	0.239766	0.335095	-0.09533

183	0.280702	0.203827	0.076875
184	0.269006	0.331453	-0.06245
185	0.22807	0.065496	0.162574
186	0.19883	0.199708	-0.00088
187	0.163743	0.185953	-0.02221
188	0.134503	0.208659	-0.07416
189	0.035088	0.023397	0.01169
190	0.251462	0.223249	0.028213
191	0.251462	0.204229	0.047233
192	0.280702	0.249471	0.03123
193	0.368421	0.331441	0.03698
194	0.22807	0.072724	0.155346
195	0.187135	0.138658	0.048476
196	0.169591	0.093178	0.076412
197	0.175439	0.224429	-0.04899
198	0.128655	0.170911	-0.04226
199	0	0.123545	-0.12355
200	0.362573	0.417272	-0.0547
201	0.315789	0.516016	-0.20023
202	0.192982	0.439396	-0.24641

203	0.403509	0.443294	-0.03978
204	0.362573	0.47479	-0.11222
205	0.403509	0.357134	0.046375
206	0.444444	0.406454	0.037991
207	0.48538	0.472627	0.012753
208	0.391813	0.482239	-0.09043
209	0.292398	0.360827	-0.06843
210	0.380117	0.211545	0.168572
211	0.280702	0.168188	0.112514
212	0.099415	0.207153	-0.10774
213	0.315789	0.339295	-0.02351
214	0.210526	0.005926	0.204601
215	0.269006	0.249551	0.019455
216	0.245614	0.214657	0.030957
217	0.461988	0.518097	-0.05611
218	0.48538	0.702189	-0.21681
219	0.409357	0.568164	-0.15881
220	0.497076	0.621531	-0.12446
221	0.397661	0.589882	-0.19222

Appendix – 6

Table of Critical Values For F- Statistics

Cumulative F Distribution

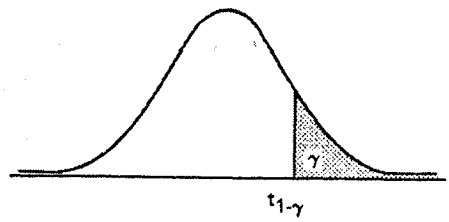
($\gamma = 0.05$)

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	161.00	200.00	216.00	225.00	230.00	234.00	237.00	239.00	241.00	242.00	244.00	246.00	248.00	249.00	250.00	251.00	252.00	253.00	254.00
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88

Cumulative F-Distribution
(Adopted from (Gunst / Mason 1985)

Appendix – 7

Table of Critical Values For t- Statistics



Cumulative Student *t* Distribution

d.f.	γ = .25	γ = .10	γ = .05	γ = .025	γ = .01	γ = .005
1	1.000	3.078	6.314	12.706	31.821	63.657
2	0.816	1.886	2.920	4.303	6.965	9.925
3	.765	1.638	2.353	3.182	4.541	5.841
4	.741	1.533	2.132	2.776	3.747	4.604
5	0.727	1.476	2.015	2.571	3.365	4.032
6	.718	1.440	1.943	2.447	3.143	3.707
7	.711	1.415	1.895	2.365	2.998	3.499
8	.706	1.397	1.860	2.306	2.896	3.355
9	.703	1.383	1.833	2.262	2.821	3.250
10	0.700	1.372	1.812	2.228	2.764	3.169
11	.697	1.363	1.796	2.201	2.718	3.106
12	.695	1.356	1.782	2.179	2.681	3.055
13	.694	1.350	1.771	2.160	2.650	3.012
14	.692	1.345	1.761	2.145	2.624	2.977
15	0.691	1.341	1.753	2.131	2.602	2.947
16	.690	1.337	1.746	2.120	2.583	2.921
17	.689	1.333	1.740	2.110	2.567	2.898
18	.688	1.330	1.734	2.101	2.552	2.878
19	.688	1.328	1.729	2.093	2.539	2.861
20	0.687	1.325	1.725	2.086	2.528	2.845
21	.686	1.323	1.721	2.080	2.518	2.831
22	.686	1.321	1.717	2.074	2.508	2.819
23	.685	1.319	1.714	2.069	2.500	2.807
24	.685	1.318	1.711	2.064	2.492	2.797
25	0.684	1.316	1.708	2.060	2.485	2.787
26	.684	1.315	1.706	2.056	2.479	2.779
27	.684	1.314	1.703	2.052	2.473	2.771
28	.683	1.313	1.701	2.048	2.467	2.763
29	.683	1.311	1.699	2.045	2.462	2.756
30	0.683	1.310	1.697	2.042	2.457	2.750
60	.679	1.296	1.671	2.000	2.390	2.660
90	.678	1.291	1.662	1.987	2.368	2.632
120	.677	1.289	1.658	1.980	2.358	2.617
∞	.674	1.282	1.645	1.960	2.326	2.576

Cumulative t- Distribution
(Adopted by Gunst / Mason 1985)

Appendix – 8

Results From Statistical Regression

Summary of Statistical Regerssion Analysis.

Regression Statistics		
Multiple R		0.709542
R Square		0.503450
Adjusted R Square		0.465182
Standard Error		0.259325
Observations		221.000000

ANOVA								
	df	SS	MS	F	Significance F			
Regression	9.000000	13.473765	1.497085	22.261656	0.000000			
Residual	211.000000	14.189642	0.067249					
Total	220.000000	27.663407						
	Coefficients	Standard Error	t-Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2.190796	0.302920	7.232268	0.000000	1.593660	2.787933	1.593660	2.787933
X Variable 1(T)	0.016538	0.002044	8.090219	0.000000	0.012508	0.020567	0.012508	0.020567
X Variable 2 (H)	-0.000345	0.001340	-0.257482	0.797057	-0.002986	0.002296	-0.002986	0.002296
X Variable 3 (Ppt)	-0.052464	0.033591	-1.561861	0.119819	-0.118681	0.013752	-0.118681	0.013752
X Variable 4 (W)	-0.007786	0.002331	-3.339607	0.000992	-0.012382	-0.003190	-0.012382	-0.003190
X Variable 5 (G)	-0.011064	0.005266	-2.100946	0.036833	-0.021446	-0.000683	-0.021446	-0.000683
X Variable 6 (L)	-0.007852	0.005080	-1.545640	0.123690	-0.017865	0.002162	-0.017865	0.002162
X Variable 7 (WT)	-0.159673	0.057022	-2.800228	0.005581	-0.272078	-0.047268	-0.272078	-0.047268
X Variable 8 (F)	0.003570	0.006566	0.543737	0.587196	-0.009373	0.016514	-0.009373	0.016514
X Variable 9 (WM)	0.081591	0.058428	1.396441	0.164049	-0.033586	0.196768	-0.033586	0.196768

RESIDUAL OUTPUT		
Observation	**Predicted Y**	**Residuals**
1	1.019098917	-0.069098917
2	1.207029001	-0.087029001
3	1.026652744	-0.016652744
4	1.219542953	0.050457047
5	1.09591497	0.04408503
6	1.326870846	-0.156870846
7	1.241075047	-0.201075047
8	1.263840415	-0.103840415
9	1.035339212	0.954660788
10	1.075451204	0.024548796
11	1.142146281	-0.142146281
12	1.180832339	-0.060832339
13	1.371797756	0.178202244
14	1.114152946	0.145847054
15	1.185310485	-0.045310485
16	1.346770651	-0.076770651
17	1.561404377	-0.111404377
18	1.588780019	-0.078780019
19	1.359868086	0.010131914
20	1.484954424	-0.104954424
21	1.214997463	0.035002537
22	1.365277025	0.124722975
23	1.256287332	0.083712668
24	1.558353037	-0.198353037
25	1.444724566	-0.224724566
26	1.637068769	-0.297068769
27	1.477533684	-0.277533684
28	1.567705741	-0.177705741
29	1.573254288	-0.163254288
30	1.369822306	-0.109822306
31	1.636930628	-0.156930628
32	1.549205905	-0.189205905
33	1.320432142	-0.110432142
34	1.553891102	-0.213891102
35	1.278007599	-0.188007599
36	1.384428012	-0.174428012
37	1.02217665	0.44782335
38	1.629799732	-0.309799732
39	1.388535567	-0.018535567
40	1.486604238	-0.256604238
41	1.574610658	-0.104610658
42	1.333346493	0.006653507
43	1.43178018	0.05821982
44	1.22370942	0.12629058
45	1.609004745	-0.069004745
46	1.402359919	-0.022359919
47	1.62578535	-0.10578535
48	1.384521185	-0.014521185
49	1.666518512	0.003481488
50	1.497705869	0.012294131
51	1.682017591	-0.032017591
52	1.501071995	-0.021071995
53	1.698410677	-0.128410677
54	1.455720578	-0.045720578
55	1.535306883	0.024693117
56	1.294042718	0.105957282
57	1.652086901	-0.022086901
58	1.421887205	0.038112795
59	1.79978614	-0.06978614
60	1.646792647	0.243207353
61	1.447999445	0.262000555
62	1.701276195	0.038723805
63	1.448947562	0.101052438
64	1.877482352	-0.077482352
65	1.587682512	0.032317488
66	1.875550629	-0.005550629
67	1.629647686	0.050352314
68	1.861093071	-0.191093071
69	1.619828906	-0.099828906
70	1.422452732	-0.322452732
71	1.772352012	-0.012352012
72	1.812955712	0.167044288
73	1.755428868	-0.175428868
74	1.598036235	-0.148036235
75	1.536687344	-0.276687344
76	1.746638839	0.273361161
77	1.742054285	-0.202054285
78	1.853256393	0.546743607
79	1.683983005	-0.193983005
80	1.830242925	0.419757075
81	1.898627877	0.301372123
82	1.703398547	-0.083398547
83	1.576949449	-0.246949449
84	1.770989083	0.469010917
85	1.740032058	0.009967942
86	1.955717086	-0.025717086
87	1.914065342	-0.484065342
88	1.781291066	-0.131291066
89	1.90587799	-0.25587799
90	1.957080537	-0.107080537
91	1.870091582	-0.070091582
92	1.692187149	-0.372187149

93	1.981295272	-0.431295272
94	1.965561652	-0.865561652
95	2.01740526	-0.54740526
96	1.92433453	-0.50433453
97	1.790210027	-0.300210027
98	1.73165218	-0.28165218
99	1.886424801	-0.276424801
100	1.764170434	-0.244170434
101	1.997508829	-0.237508829
102	2.057570022	-0.307570022
103	1.974707376	-0.244707376
104	1.994203473	-0.084203473
105	1.685114869	0.104885131
106	1.774590596	-0.004590596
107	1.809227461	-0.009227461
108	1.787818852	-0.367818852
109	1.883818853	-0.393818853
110	1.896864928	-0.026864928
111	1.912704278	0.087295722
112	1.611370919	0.168629081
113	1.61823069	-0.25823069
114	1.895230233	0.524769767
115	1.881347705	0.428652295
116	1.85467827	0.23532173
117	1.665241369	0.134758631
118	1.678606805	0.171393195
119	1.598935489	0.281064511
120	1.621810426	0.158189574
121	2.015536545	0.314463455
122	1.865732577	-0.145732577
123	1.914656255	-0.214656255
124	1.917515835	0.172484165
125	1.968501437	0.351498563
126	2.001991369	0.338008631
127	1.738003967	0.141996033

128	1.539931839	0.360068161
129	1.426687665	0.223312335
130	1.669314159	0.660685841
131	1.650706609	0.699293391
132	1.698044075	0.701955925
133	1.804950875	0.575049125
134	1.896960781	0.503039219
135	1.959866606	0.570133394
136	1.888825774	0.611174226
137	1.650086799	0.149913201
138	1.617297292	0.082702708
139	1.784254849	0.555745151
140	1.736227485	0.243772515
141	1.59693879	0.14306121
142	1.46329006	0.31670994
143	1.478862338	0.321137662
144	1.442897648	0.237102352
145	1.510622914	-0.010622914
146	1.524957161	0.215042839
147	1.693858156	0.126141844
148	1.726385739	0.003614261
149	1.938147323	0.161852677
150	1.820657571	0.199342429
151	1.631721919	0.278278081
152	1.798806952	0.171193048
153	1.742846565	0.257153435
154	1.426480597	0.593519403
155	1.393736315	0.366263685
156	1.427147833	0.342852167
157	1.551094316	0.278905684
158	1.36600536	0.05399464
159	1.20032193	-0.00032193
160	1.515693485	0.264306515
161	1.74607191	0.21392809
162	1.65921075	-0.11921075

163	1.791615368	0.238384632
164	1.800229936	0.189770064
165	1.637391797	0.252608203
166	1.524050576	0.165949424
167	1.727612039	0.232387961
168	1.751977042	0.228022958
169	1.489844987	0.150155013
170	1.308704622	0.021295378
171	1.355216421	-0.115216421
172	1.335416613	-0.115416613
173	1.451951898	0.168048102
174	1.385041301	-0.195041301
175	1.350632393	-0.150632393
176	1.536070844	-0.226070844
177	1.625331893	0.104668107
178	1.566390663	-0.276390663
179	1.445363525	-0.185363525
180	1.354932376	-0.014932376
181	1.529181019	-0.149181019
182	1.618411112	-0.388411112
183	1.099059549	0.200940451
184	1.292890703	-0.012890703
185	1.255094907	-0.045094907
186	1.171971725	-0.011971725
187	1.225785072	-0.125785072
188	1.234486638	-0.184486638
189	1.169100754	-0.289100754
190	1.364304219	-0.114304219
191	1.293727753	-0.043727753
192	1.377719807	-0.077719807
193	1.516862347	-0.066862347
194	1.062268684	0.147731316
195	1.160661019	-0.020661019
196	1.10049975	0.00950025
197	1.316459455	-0.196459455

198	1.18230108	-0.14230108
199	1.101248385	-0.281248385
200	1.585980054	-0.145980054
201	1.525483569	-0.165483569
202	1.483744279	-0.333744279
203	1.619410452	-0.109410452
204	1.544496186	-0.104496186
205	1.620519051	-0.110519051

206	1.732554673	-0.152554673
207	1.749368214	-0.099368214
208	1.673732778	-0.183732778
209	1.535651964	-0.215651964
210	1.706052093	-0.236052093
211	1.406503787	-0.106503787
212	1.347501249	-0.357501249
213	1.469102357	-0.109102357

214	1.237255418	-0.057255418
215	1.402624855	-0.122624855
216	1.45415209	-0.21415209
217	1.765717388	-0.155717388
218	1.883523828	-0.233523828
219	1.710653082	-0.190653082
220	1.824625463	-0.154625463
221	1.791816281	-0.291816281

Appendix – 9

Weather and Site Data Collection Form.

Weather and Site Information Form.

Project : _____ Dated: _____

Weather Related
(Mean Values)

Temperature	% Humidity	Wind Speed	Precipitation

Site Related

Work Type	Ret.Walls	Columns	Slab
Work Method	Conventional Formwork		Flying Forms
Floor Level			

Appendix – 10

Foreman's Response Form

Foreman's Response Form			
Project :New Engineering Bldg.			
			Dated:
Formwork Installation	Ret.Wall	Column	Slab
Gang Size			
No. Of Skilled Persons			
Hours Worked			
Quantity Executed (sq.m)			