On-site Labor Productivity Estimation Using Neural Networks

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Abstract

On-site Labor Productivity Estimation Using Neural Networks

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This thesis presents a study of on-site labor productivity in building construction using the work sampling method. The study is based on a field investigation of a number of selected construction operations on three buildings in Montreal, Quebec, Canada. The developed models revealed related parameters' impact on labor productivity. Neural network was used as a method for the development of the models presented in this thesis.

The developed models are based on the data collected using work sampling and were developed using NeuralShell2 software. The network was trained and tested using 221 data points collected from real construction projects that were performed in Montreal in a 30-month period. The models' development and validation utilize real-world data from the projects. Three types of neural network-based models were developed. The first type of models is back propagation neural network (BPNN) models associated with different settings. The fifth model has shown the best results. General regression neural network (GRNN) model and group method of data handling (GMDH) models were developed as well. Afterwards, a regression model was developed and verified in

order to validate the neural network model. The validation indicates that the performance of the chosen model is reliable.

Based on the validated developed neural network model, the analysis was derived to reveal the impact of all involved parameters on labor productivity. The analysis of interrelations between labor productivity and the seven independent variables was plotted using Excel.

Through the study, it is proven that neural network-based models for estimating on-site labor productivity of formwork installation using work sampling method provides an insight into impacts of multiple variables on labor productivity.

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Chapter 1

Introduction

1.1 Labor Productivity in Construction

Construction industry is a major factor in the national economic development. As a labor-intensive industry, labor productivity is of central importance to the development of construction industry and it has significant influence on contractors' profit margin. Therefore, productivity research has been performed in order to figure out how to measure and improve labor productivity effectively in construction industry.

Generally, four parties are involved in construction project; they are owners, designers, constructors, and the labor force (Oglesby, 1989). This study focuses on labor productivity modeling based on neural networks. Statistically, construction productivity has increased 30% over the past 40 years according to a new analysis. In the same period, labor productivity in other non-farm industries increased by 1.7% annually. Haskell studied the effect of observable increases in labor productivity: machine excavation and trenching, power floating and troweling, concrete pumps, gang forms, power tools, computerized transits, lightweight materials and other factors. Haskell also pointed out that construction needs still more productivity to keep up with other industries (Haskell, 2001).

1.2 Scope and Objectives

This thesis focuses on studying labor productivity on a number of tasks in building construction using work sampling method and neural network. The data used in this study was collected from three construction projects in the Montreal area. The tasks concerned in this study include piling, excavation and earthmoving, blasting, shoring and lagging, reinforcing bars, formwork installation, and concrete pouring. A detailed study of labor productivity performance of formwork installation was carried out from September 2001 until June 2004. The data was used to develop neural network-based models for estimating productivity of formwork installation. The main objectives of the research were to identify the major factors impacting on building construction job sites. Subsequently, neural network models were developed to measure labor productivity performance of formwork installation based on the work sampling method.

1.3 Research Methodology

In this study, the research methodology used is based on the field observation of three construction projects in Montreal area. It consists of three steps: 1) understanding projects characteristics and on-site operations, 2) data collection and analysis of selected construction operations, 3) model development and validation.

In the first step, general information of selected construction projects was provided. The field investigation is performed to collect real data based on work-sampling method in the second step. Meanwhile, related parameters, such as crew size, completed quantity, etc. are collected by on-site observation and visits and a digital monitoring system. Then, the collected data is normalized in required worksheet 4.0 format for the next modeling step. Finally, the performance of developed models is evaluated through comparison to the validated regression model.

1.4 Thesis Organization

Figure 1.1 provides an overview of the thesis development and organization. Chapter 2 presents a literature review comprising: 1) labor productivity, and 2) neural networks. Some concepts about labor productivity, such as definition, measurement, only if necessary, are described. Neural networks are introduced as a useful tool to develop required models as well.

Chapter 3 describes the field investigation stage, including the data collection and organization, data preparation, analysis, and formulation. In this chapter, the impact of the different types of data on labor productivity is revealed as well. The objective of this chapter is to prepare formulated data for further model development.

Chapter 4 describes the developed neural networks models and regression model.

The formulated data sets in Chapter 3 were used to develop both a neural network models and a regression model in this chapter. The detailed explanation of proposed labor productivity models is described.

In Chapter 5, the developed regression model was verified through several tests. Then the best performance neural network-based productivity estimation model was validated by comparing to verified regression model. After this validation step, analysis of impact of involved parameters on labor productivity was derived.

Chapter 6 presents summary and conclusion with recommendation for future works.

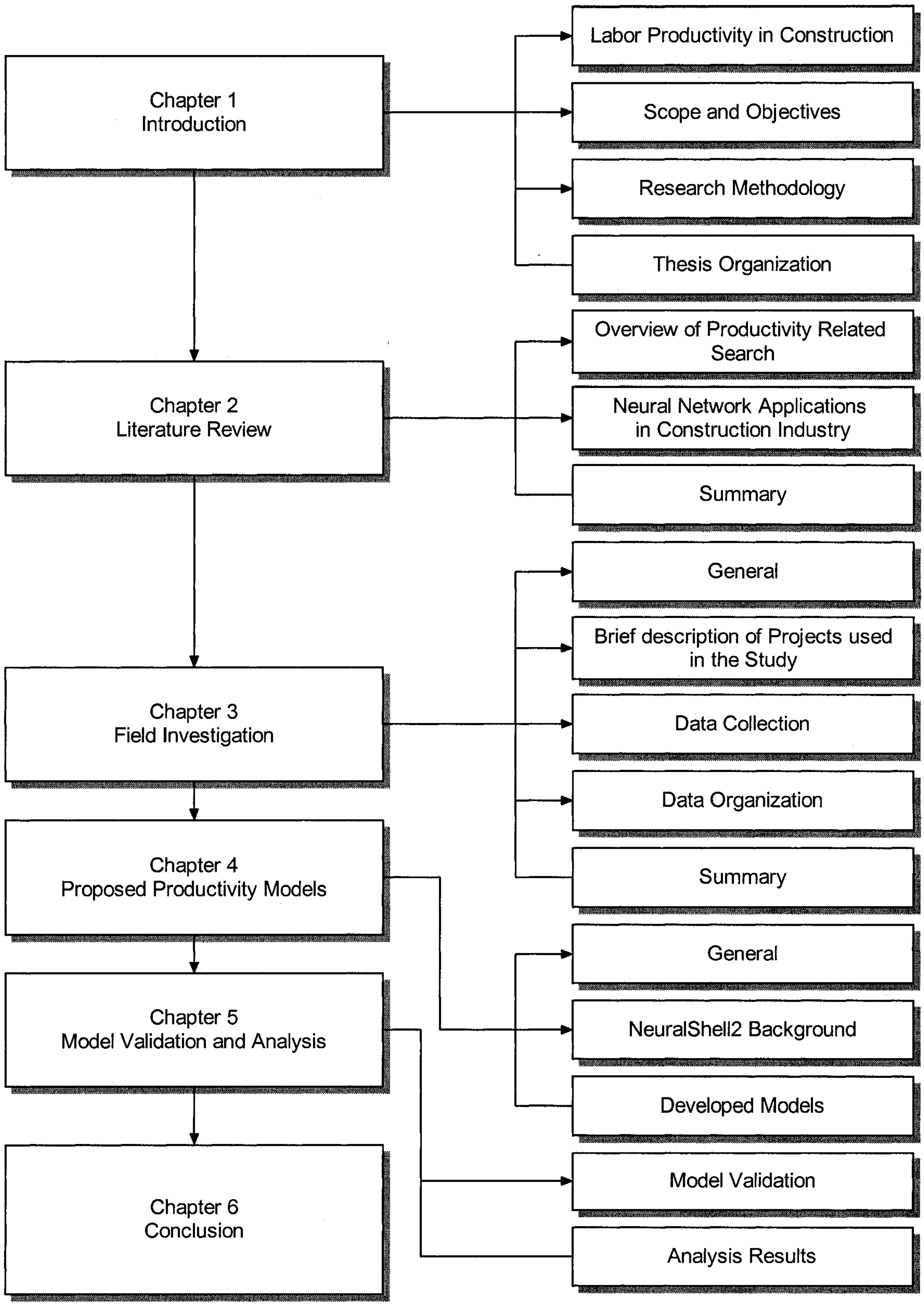

Figure 1.1 Thesis organizations

Chapter 2

Literature Review

2.1 Overview of Labor Productivity Research

Construction is a labor-intensive industry; therefore, labor productivity plays important role in the healthy development of construction industry. On-site labor activity and performance are often concerned by involved parties, both contractors and owners, in construction industry (Hendrickson, 2000). Considerable research has been carried out on labor productivity analysis and modeling.

2.1.1 Defining Labor Productivity

A comprehensive definition of productivity means the ratio of valuable output to input. However, definitions of productivity are varied from different view, i.e., productivity has a variety of meanings. For contractors, productivity is the amount or percentage which costs are below or above the payment received from the owner. For owners, it is the cost per unit of output produced. The Concise Oxford Dictionary (9^{th} Edition) defines productivity as the capacity to produce, the state of being productive; effectiveness of productive effort, especially in industry; production per unit of effort. Hence, three issues are involved in the definition: (1)

the capacity to produce, that is the force behind production itself, (2) effectiveness of productive effort is assessed to determine how well the resources of production are, (3) the production per unit of effort (or rate) used to measure output during a defined period (Olomolaiye, et al. 1998). Therefore, all definitions attempt to measure the effectiveness of construction activities to complete a project in support of labors, equipment, materials, tools and management to figure out potential improvement, i.e., to produce more with less. For the purpose of this study, productivity is defined as the quantity of output produced by a given quantity of labor input, i.e., labor productivity indicates the output per man-hour of labor.

2.1.2 Measuring Labor Productivity

Generally, productivity can be simply measured by the following expression (Alfeld, 1988):

$$\text{Productivity} = \text{Output}/\text{Input} \qquad \text{(Eq. 2.1)}$$

However, based on different considered factors of input part in productivity, productivity could be expressed as total-factor productivity and single-factor productivity (only one factor is involved) or partial productivity (Olomolaiye, et al. 1998).

Total-factor productivity = Total output/Total input (Eq. 2.2a)

Partial productivity = Total output/Partial input (Eq. 2.2b)

There are some factors that could influence measuring productivity and therefore increase the difficulty of measuring. Those factors could be changes of design, changes of demand, etc, and will be discussed later.

Simply, labor productivity could be expressed in terms of quantity of output per hour performed (Manser, 2001).

Labor productivity = Quantity of output/Hours (Eq. 2.3)

2.1.3 Trends in Labor Productivity

Governments and construction companies have realized the importance of construction productivity improvement, since construction industry plays an important role in national economic development. More companies use effectiveness of productivity as a competitive factor because less expense is more profit has been widely recognized. According to the research released in the United States, new-construction-put-in-place accounted for roughly 7% of the gross domestic product (GDP) in 1997, and if one includes remodeling and repair work the total rises over 10% of the GDP (Barry, 1998).

Statistics released by the Canadian Construction Association revealed that the gross output of construction in 2000 was up to total $119.2 billion. This is a 9.5% jump from the 1999 gross output of $108.8 billion. According to the forecast of Industry Canada, the Canadian construction industry is expected to record notable growth over the following two years. In 2004, the gross output of the construction industry increased by 4.5%, while in 2005 anticipated growth is in the range of 3.9 percent. Table 2.1 shows the excepted increase in the next seven years:

Table 2.1 National Gross Output Forecast (in millions of Canadian dollars)

Year	Gross Output	Change in %
2003	123,138	-0.3
2004	128,701	4.5
2005	133,708	3.9
2006	136,336	2.0
2007	137,301	0.7
2008	140,020	2.0
2009	142,068	1.5

Source: Informetrica

As a result, Canada had stronger construction growth in 2004 and continues to be a leader in other North American countries in this regard (Grant, 2003). According to Statistics Canada, the construction industry has a stronger multiplier effect on the national economic performance than the whole industries average and most individual industries in particular. Those data indicated the significance of construction industry in domestic economic development. Therefore, productivity improvement is necessary to meet the requirement of industry's increase. Labor productivity trends in Canada are as shown in Table 2.2, 1961 to 2000 (Statistics Canada, 2001).

Table 2.2 Productivity trends in Canada, 1961 - 2000

	1961-2000	1961-1973	1973-1981	1981-1989	1989-2000	1989-1995	1995-2000
Business sector	2.0	3.7	1.2	1.1	1.4	1.5	1.2[1]
Agriculture	4.4	5.9	3.6	1.8	5.2	4.3	6.3
Fishing and trapping	-0.2	2.7	-0.5	-3.0	-0.9	-1.4	-0.3
Logging and forestry	2.2	4.0	1.8	3.4	-0.2	-2.0	2.0
Mining, quarrying and oil well	1.6	6.1	-5.9	3.0	1.6	3.4	-0.6
Manufacturing	2.9	4.2	2.0	2.3	2.0	3.0	0.9
Construction	0.8	0.5	4.1	-0.6	-0.3	-0.5	-0.2
Transportation and storage	2.4	5.1	0.0	2.2	1.6	1.8	1.3
Communication and other utility industries	3.4	5.8	3.1	1.6	2.3	1.4	3.5
Wholesale trade	2.5	2.3	1.7	4.4	1.9	1.2	2.8
Retail trade	2.1	3.6	1.5	1.0	1.8	0.4	3.5

Source: Aggregate Productivity Measures, Statistics Canada, May 22, 2001.

In fact, productivity has being remained moderate, sustaining increase with the industry's development worldwide. Table 2.3 is an example of the trend of labor productivity in three European countries U.K., France, Germany and U.S from 1950 to 1996 (O'Mahony, 1999).

Table 2.3 Trend of productivity in U.K, France, Germany, and U.S from 1950 to 1996 (O'Mahony, 1999).

	1950-73	1973-96
UK	2.99	2.22
France	4.62	2.78
Germany[1]	5.18	2.56
US	2.34	0.77

However, this statistics discovered that the increase of labor productivity in these countries declined.

2.1.4 Factors Influencing Labor Productivity

All factors affect productivity, as summarized by Oglesby et al. (1989), could be divided into two categories, external and internal. External factors include changes of demand, weather, relationship among all involved parties, local politics, and so on. Weather is a significant external factor due to the character of construction activity. Productivity can be affected by adverse weather conditions because many on-site construction activities are performed outdoors. For example, some outdoors operations, such as formwork, concrete pouring, have to be stopped when it is too hot, cold, or rainy.

In regards to weather's influence, research also revealed that the labors perform most efficiently at temperatures between 10°C and 21°C with a moderate 30-80%

humidity (Oglesby et al. 1989) which is called the comfort zone. In the comfort zone, body temperatures remain normal since evaporative effects bring heat out of skin without much sweating. Either hot or cold climates hinder performance of labor. Humidity is significantly interrelated with productivity as well. Effect of cold weather on productivity shown in Table 2.4.

Table 2.4 Effect of cold weather (Dozzi and AbouRizk, 1993)

Temperature (^{0}C)		4	-2	-7	-13	-18	-23	-28	-34
Loss of Efficiency (%)	Gross Skills	0	0	0	5	10	20	25	35
	Fine Skills	15	20	35	50	60	80	90-95	----

Note: skill classification (Mackenzie, 1997):

Gross skills: involve large muscle movements, where the major muscle groups are involved. The movements are not very precise, and include many fundamental movement patterns such as walking, running and jumping. The shot putt is an example of a primarily gross skill.

Fine skills: involve intricate movements using small muscle groups, tend to be precise and generally involve high levels of hand-eye coordination. A snooker shot or playing the piano are examples fine skills.

Internal factors include technology, management, organization, financial issues, and so on.

Horner et al. (1987) divided all factors affecting productivity into two categories: management controlled, and project related and environmental related, as shown in Table 2.5.

Table 2.5 Factors affecting productivity (Horner et al. 1987)

Management Controlled	**Project Related and Environmental**
Skill of labor force	Skill of labor force
Size of labor force	Size of project
Balance of labor force	Absenteeism
Morale of labor force	Unemployment rate
Motivation of labor force	Lack of motivation
Union attitudes	Union attitudes
Working hours	Weather
Welfare provisions	National/Local politics
Continuity of management	Continuity of work for trades
Working methods	Complexity
Mechanization	Constructability
Availability of resources	Availability of resources
Quality of finished work	Quality specification
Performance of subcontractors	Holidays
Relationships with client	Type of contract
Degree of management control	Variations (change orders)

Generally, there are five main causes of productivity losses. They are inadequate selection, training and motivation of the labor force, interruptions and disruptions, working overtime, planned and unplanned increase in the size of the labor force, and inadequate site management (Horner and Duff, 2001).

2.1.5 Current Methods in Labor Productivity Research

Currently, there are three major construction productivity measurement methods in use. These are work sampling, field surveys and photographic or video methods (Oglesby et al. 1989).

2.1.5.1 Work Sampling Method

Work sampling is a system to indirectly measure on-site construction labor productivity, which has been used for almost 70 years (Barnes, 1957). Work sampling measures how time is utilized by the labor force. In other words, it is a statistic method that measures the effective utilization of labor time. Labors spend time on various on-site activities, both productive and non-productive. The work sampling method is used to estimate the percentage of labor's time spent on both activities. A work sampling study consists of a large number of observations taken at random intervals (Heiland and Richardson, 1957). The procedure of work sampling consists of activity classification and observation. Generally, the method classifies the labor activities into three categories: direct work (DW), support work (S), and delays (D) (Borcherding, 1979).

Direct Work (DW) is the activities that the involved labor performed by using their tools, including productive actions, picking up tools, inspecting fitness, cleanup and holding materials at the working place. For example, a concrete finisher is using a trowel for concrete surface finishing, or a welder is welding a pipe connection. Support work (S) is to support other labors as a kind of assistant work, such as moving the required materials to the location where the work will be performed, including moving and handling materials or tools, instruction of operation and maintenance, and planning. Delays (D) are non-productive activities that totally unrelated with both direct work and support work, such as waiting for materials or equipment, any non-action like sitting, chatting, and late starts or early finish. In other words, delays result in wasted time.

After classification, observers go to the construction site and randomly select a specific group of labors to observe. The percentage of wasted time of the selected group is the ratio of the delays to the total observations in the period of time observed. The sample of observation form is shown in following Table 2.6 (Obtained from the Construction Site of Loyola Campus of Concordia University, Jan.18, 2002). In this sample, the observation time is in ten minutes interval.

Table 2.6 Work sampling observation form

Crew Size: 6 Acitvity: concrete

Time	DW	D	S
7:20-7:30	1,2,4	3,6	5
7:30-7:40	1,2,4,5	3	6
7:40-7:50	2,3,5,6	4	1
7:50-8:00	1,2,6	3	4,5
8:10-8:20	2,3,5,6	1	4
8:20-8:30	1,2,4	3,6	5
8:30-8:40	1,3,4	2	5,6
8:40-8:50	2,3,4	1,6	5
8:50-9:00	1,2	3,5	4,6

Labor description: 1 to 6 – Workers 1 to 6.

After observation, the percentage of each category for observed crew will be calculated. Table 2.7 is an observation result.

Table 2.7 An observation result for Jan 18, 2002, Loyola Campus project

Jan.10, 2002		Activity: Pouring concrete
Number of Laborers	Work	Percentage (%)
6	DW	43.5
	S	19.2
	D	37.3

Work sampling gives essential information about time spent on activities and therefore gives indirect information about productivity performance. However, direct work time does not necessarily correlate with unit rate productivity. In other words, a high percentage of direct work time would not always indicate an equally high level of unit rate productivity because of variation in skill levels of the sampled workers, working methods, and types of tools and equipment used. For example, a skilled worker will produce more than an unskilled worker performing the same task even though both have the same direct work time. A carpenter utilizing a skill saw will out-produce a carpenter with a handsaw even though the direct work percentage may be the same. Even considering these constraints, work sampling can be useful as a diagnostic tool for productivity improvement programs (Tucker et al. 1999).

2.1.5.2 Field Surveys

Craftsman questionnaire and foreman delay survey are very common methods adopted in field surveys. Craftsman questionnaire was developed for performance measurement and productivity improvement at construction sites using a questionnaire to collect data (Chang and Borcherding, 1986). Craftsman questionnaire (CQ) attempts to identify and quantify as much as possible related problems that adversely affect productivity. Craftsmen are experienced to provide direct, detailed and important information on productivity improvement. The procedure of this method includes preparation of written questionnaires and interviews. A classic craftsman questionnaire is shown in Appendix 1.

The questionnaire can comprise up to 50 short questions to show the areas of concern such as material availability and site layout, equipment and tool availability, rework items and causes of rework, management interference and inspection, and suggestions improvement. In addition, the questionnaire asks for the hours lost per week per craftsman on concerned field. It is often supplemented with personal interviews with some of the craftsmen to validate the responses and test the level of accuracy and seriousness. Table 2.8 shows a sample result (Dozzi and AbouRizk, 1993).

Table 2.8 Results from a CQ

Problem/Cause	Person-hours lost per week	Percentage per week
Material not available or poorly located	5.2	13
Tools not available or suitable	3.2	8
Equipment not available or down for repair	2	5
Work redone	4.8	12
Management interference	2.1	5.3
Other	2.5	6.3
Total	19.8	49.5

The results in Table 2.8 imply that material availability (13%) and redoing work (12%) are factors of major concern: they contribute to 25% of the time lost by a craftsman in a week. From the answers in the questionnaire itself, the reasons for the time loss could probably be identified.

Another format of field survey is foreman delay form (FDS) which is used is to identify the number of hours lost in a certain day due to delays. Most FDSs are divided into two categories, rework and delay. Once a form has been filled out, the information is extracted in the form of percentages and actions are taken to ensure that sources of delays are properly dealt with. Table 2.9 is a typical FDS form (Dozzi and AbouRizk, 1993)

Table 2.9 Sample of foreman delay survey

Problem Causing Area	Person-Hours Lost		
	No. of Hours Lost	No. of Workers	Total Person-Hours
Redoing work (design error or change)			
Redoing work (prefabrication error)			
Redoing work (field error or damage)			
Waiting for materials (warehouse)			
Waiting for materials (vendor furnished)			
Waiting for tools			
Waiting for construction equipment			
Construction equipment breakdown			
Waiting for information			
Waiting for other crews			
Waiting for fellow crew members			
Unexplained or unnecessary move			
Other			
Comments			
Made by:			
Date:			

The results of the survey are converted from person-hours into equivalent percentages and reported on a form as shown in Table 2.10, for example (Dozzi and AbouRizk, 1993). The example reveals that too much time has been spent on redoing work due to design errors – 2.3% of the time – and waiting for construction equipment – 1.1% of the time.

Table 2.10 Sample FDS results

Problem-Causing Area	Person-hours Lost	Percentage
Redoing work (design error or change)	122	2.3
Redoing work (prefabrication error)	24	0.5
Redoing work (field error or damage)	52	1
Waiting for materials (warehouse)	33	0.6
Waiting for materials (vendor furnished)	22	0.4
Waiting for tools	12	0.2
Waiting for construction equipment	56	1.1
Construction equipment breakdown	15	0.3
Waiting for information	12	0.2
Waiting for other crews	14	0.3
Waiting for fellow crew members	10	0.2
Unexplained or unnecessary move	20	0.4
Other	70	1.3
Total	462	8.9
Total work in person-hours	5210	

Both questionnaires could provide valuable information for the study to identify direct problems hindering labor productivity.

2.1.5.3 Photographic or Video Methods

Photographic or video methods can carry out two functions: 1) permanently record certain field operations for later analysis and other uses, and 2) compress that record so that the viewing times involved in scanning operations or for sorting out operations to be studied in detail is minimized (Oglesby et al. 1989).

a) Real-Time Photographic or Video

This method could be applied to record consecutive activities and movements of individual, crew, or machine and could be viewed repetitively for further detail study. However, this method may be time-consuming since the recording time is equal to the real operation time. Another disadvantage is that this method is more costly.

b) Photographic Time-Lapse Method

Time-lapse photography is more frequently used to record working activities (Oglesby et al. 1989). This method takes still pictures at selected intervals by camera. Generally, shorter intervals are used to record detailed activities, such as hand movements; longer intervals are applied to record overall body or equipment movements in construction. Figure 2.1 presents a sample of time-lapse photography technique that was taken on the construction site of SGW Campus of Concordia University, 2003; interval between images is 10 seconds.

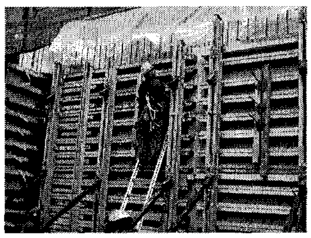

Figure 2.1 (a)

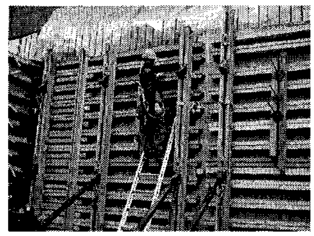

Figure 2.1 (b)

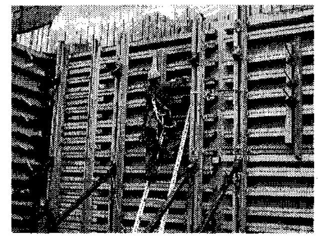

Figure 2.1 (c)

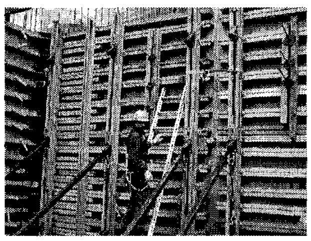

Figure 2.1 (d)

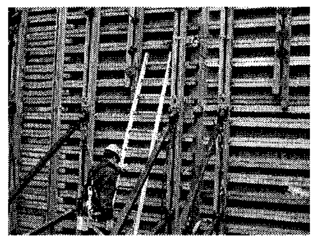

Figure 2.1 (e)

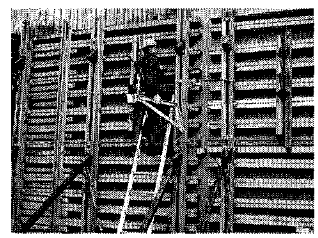

Figure 2.1 (f)

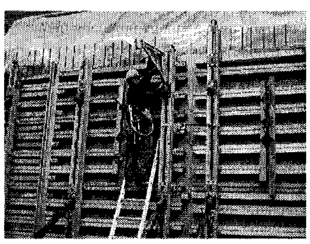

Figure 2.1 (g)

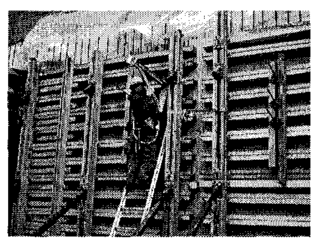

Figure 2.1 (h)

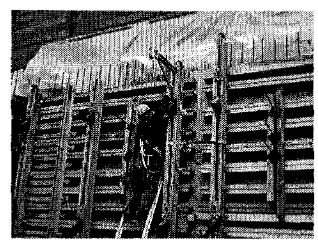

Figure 2.1 (i)

Figure 2.1 Time-lapse photograph of bracket installation. The interval between the photo images is 10 seconds.

2.2 Neural Networks Applications in Construction Industry

2.2.1 Neural Networks in Practice

Neural networks have broad applicability to real world business problems. Since neural networks are best at identifying patterns or trends in data, they have already been successfully applied in many industries. Generally, they are well suited for prediction or forecasting needs including: sales forecasting, industrial process control, customer research, data validation, risk management, target marketing (Stergiou and Siganos, 1996).

ANN are also used in the following specific paradigms: recognition of speakers in communications; diagnosis of hepatitis; recovery of telecommunications from faulty software; interpretation of multimeaning Chinese words; undersea mine detection; texture analysis; three-dimensional object recognition; hand-written word recognition; and facial recognition (Stergiou and Siganos, 1996).

2.2.2 Applications of Neural Networks in Construction

Neural networks are being successfully used in the construction industry across a large arrange of problem domains due to its power and ease of use. For example, neural networks are adaptive in the following fields:

2.2.2.1 Construction Cost Estimating

Cost estimating in a construction project is an important task in the management of construction projects. The quality of construction management depends on accuracy of estimation of the construction cost. One of the most common applications of neural networks in construction is to develop parametric estimates of construction projects or specific construction operations (Nassar, 2003). Neural networks are utilized for cost estimation to provide valuable predictive information of the cost of construction projects. For example, the study performed by Khaled. Nassar in 2003 presented a back-propagation Neural Network (NN) for the development of a parametric cost-estimating model of concrete forming and placement

2.2.2.2 Decision Making

Problems in construction management are various and complex with much uncertainty. There has been a rapidly growing interest in the application of neural network-based computing techniques which could be used as an intelligent supporting system for decision-making to solve manifold problems in construction management (Durmisevic and Sariyildiz, 1998). Sanja Durmisevic and Sevil Sariyildiz performed a study in 1998 to provide insight into understanding the important role of the technique in construction information technology and described the technique to construction information technology implementations.

2.2.2.3 Bidding Optimization

Competitive bidding is very important to bidders to obtain a project. Using neural networks, bidders could get valuable indicative information about how much that improvement in effectiveness remains (Seydel, 2003). Hence, price competitiveness could be enhanced as much as possible. In the study which is completed by John Seydel in 2003, bidding optimization models were developed to support bidding and provided an indicator of improvement level.

2.2.2.4 Labor Productivity Estimation and Improvement

Construction labor productivity is affected by multiple factors, such as weather conditions, resource availability, etc. Productivity improvement in construction is an important issue and most constructors have recognized that higher productivity means higher profits. The methodology based on neural network modeling techniques is used for quantitative evaluation of the impact of multiple factors on productivity. Neural network could be applied to develop productivity models for different construction activities, such as formwork, concrete pouring, etc. As an effective tool, neural network has been playing a significant role in the research since neural network provides powerful analysis and prediction on productivity research. For example, formwork labor productivity models were developed by NSERC (Alberta Construction Industry, 2003) to estimate labor productivity.

2.3 Summary

In this chapter, the background and trends of labor productivity research was introduced. This introduction provided brief information about research methods and development of labor productivity. Meanwhile, the importance of improvement of productivity was outlined. Secondly, neural network was outlined as an accessorial tool to perform productivity research.

Chapter 3

Field Investigation

3.1 General

This chapter introduces the procedure of field investigation through three stages: 1) data collection, 2) data organization, 3) data preparation and analysis in three construction projects in the Montreal area. In the data collection stage, the method and procedure of data collection are introduced. Data organization stage outlines how data is organized for later stages. Data preparation and analysis stage presents how the data is prepared and normalized.

3.2 Projects Considered

In this study, the data used is collected form three construction sites in the Montreal area from September 2001 to September 2004, based on work-sampling method. These projects are located on Concordia Loyola Campus, Concordia SGW Campus, and 1700 Rene-Levesque West, respectively.

3.2.1 Richard J. Renaud Science Complex of Concordia University

This building is located on Loyola Campus of Concordia University, 7141 Sherbrooke Street, West, Montreal (Figure 3.1). It started using on September 22, 2003 with 33,000 square meters of space ---- five above-ground stories, two basement levels and a mechanical penthouse.

Figure 3.1 Richard J. Renaud Science Complex

3.2.2 Engineering, Computer Science and Visual Arts Complex of Concordia University

This is a 17-storey integrated educational facility with a surface area of 68,000 square meters, as shown in Figure 3.2, includes a 2 storey underground Fitness and Wellness Centre component as well, is being built on the university's Sir George Williams Campus on St. Catherine Street between Guy Street and Mackay Street. The inauguration is scheduled for May 2005. The project commenced in May 2002, and its concrete framework was fully completed in spring, 2004.

Figure 3.2 Engineering, Computer Science and Visual Arts Complex

3.2.3 Residential Building on Rene-Levesque West

This is a 16-storey residential building located on 1700 Rene-Levesque West, Montreal. It is constructed by MaGil Construction (Figure 3.3).

Figure 3.3 Residential building on 1700Rene-Levesque, West

3.3 Data Collection

In this stage, data collection methods and organization are introduced.

3.3.1 Work Sampling Data Collection

In this study, the data has been collected through both on-site observation and digital camera monitoring system from above three project sites based on work sampling method. The field investigation that focused on formwork was performed in a period over 30 months in Montreal area, from September 2001 to June 2004.

As description of working sampling method, the involved workers were firstly grouped into three classifications at the observation moment on site, i.e. direct work (DW), support work (S), and delay (D). The observation time interval for the observed workers was ten minutes. Usually, the total observation time could last at least three hours, or until the specific trade is completed on a working day.

On-site observation was performed in all involved construction projects. Meanwhile, a part of work-sampling data of Engineering, Computer Science and Visual Arts Complex Project of Concordia University was obtained by Genetec Omnicast V2.2 monitoring system, which is a computer-based digital monitoring system developed by Genetec Information Systems Inc.

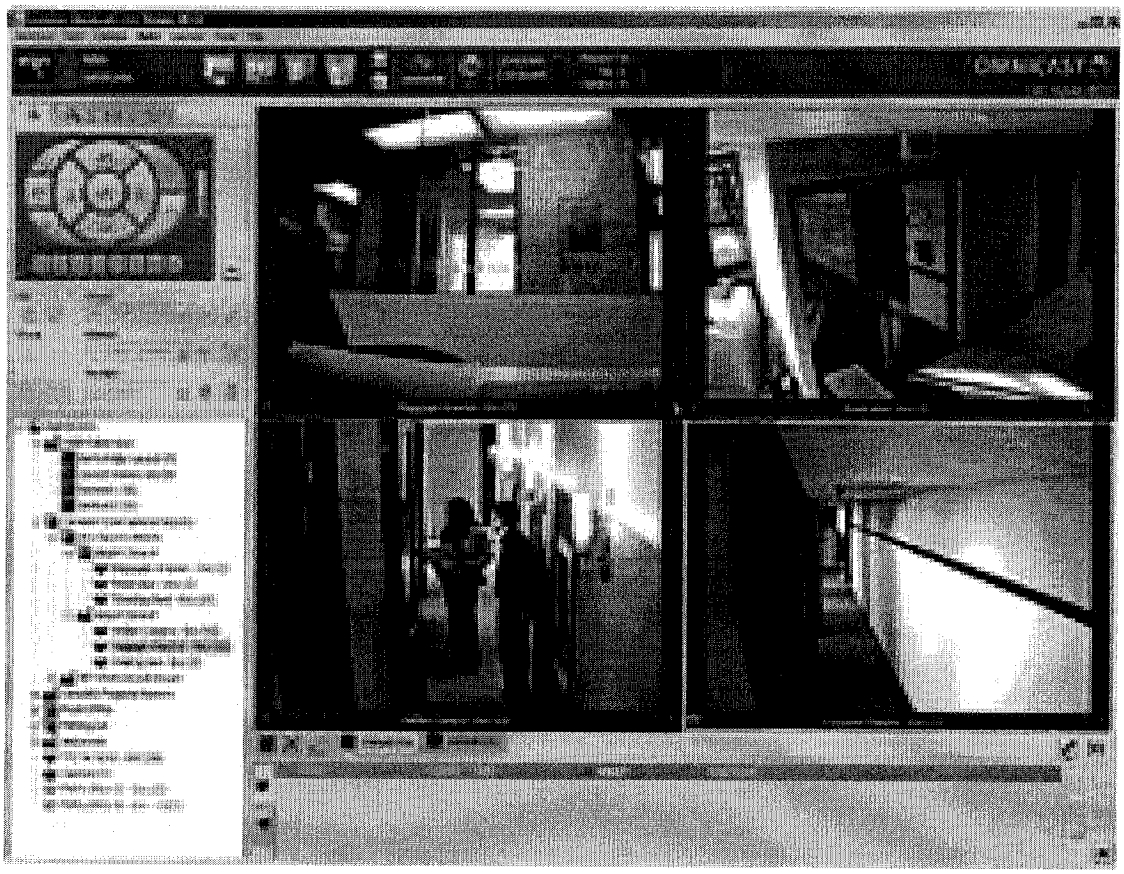

Figure 3.4 Omnicast V2.2 monitoring system interface

As mentioned in Chapter 2, the identifications of three classifications have been identified already. This is the prerequisite to commence the work-sampling observation. According to the definitions of classifications, in the following picture of concrete pouring, for example, worker A is working directly, worker B is in support work, worker C is idle.

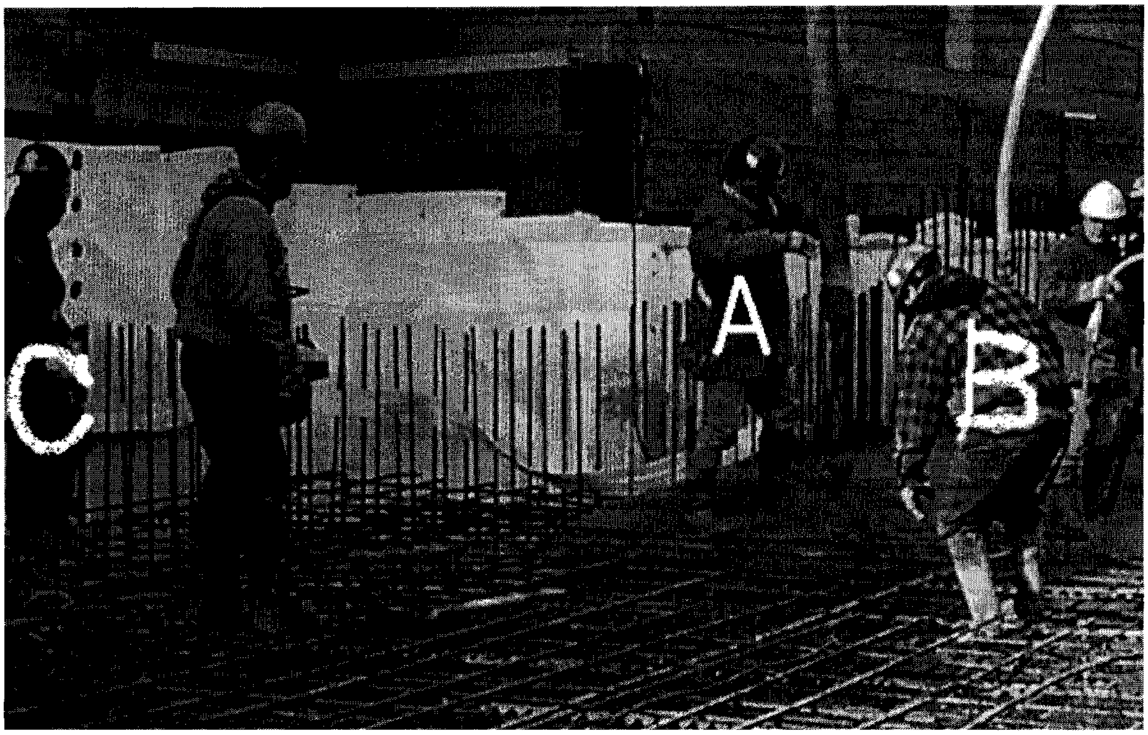

Figure 3.5 Concrete pouring in SGW Campus Site

As a result of observation, the excel-format observation form, as shown example in Table 3.1, is filled out row by row until the end of observation.

Table 3.1 Excel format work-sampling data sheet

Site visit to Loyola Campus			**Oct.25, 2001**
Pouring concrete			
Labourers:	1-5.Raking 6. Vibrator 7.Chord holder 8.Guiding pump 9.Finishing		
Time	DW	S	D
9:50-11:10			Pause(heavy rain)
11:20	1.2.3.5.6.8	7	4.9
11:30	1.2.3.4.5.8	7	6.9
11:40	1.2.3.4.5.8		6.7.9
11:50	1.2.3.4.6	7	5.8.9
12:00			1.2.3.4.5.6.7.8.9
12:10			1.2.3.4.5.6.7.8.9
12:20			1.2.3.4.5.6.7.8.9
12:30	6.8	7	1.2.3.4.5.9
12:40	1.3.5.6	7	2.4.8.9
12:50	1.2.3.4.5.6.8	7	9
13:00	1.2.3.6.8	7	4.5.9
13:10	1.2.3.4.5.6.8	7	9
13:20	6.8	7	1.2.3.4.5.9
13:30	4.5.6.8	1.7	2.3.9
13:40	2.3.5	1	4.6.7.8.9
13:50	1.2.5.9	3.4	6.7.8
14:00	1.2.3.4.9		5.6.7.8
14:10	9	1.2.3.4	5.6.7.8
14:20	1.2.3.4.8.9		5.6.7
14:30	1.2.3.6.8.9	7	5
14:40	1.2.3.4.5.6.8.9	7	
14:50	1.2.3.4.5.6.8.9	7	
15:00	1.2.3.4.5.6.8.9	7	
15:10	1.2.3.4.5.6.8.9	7	
15:20	1.3.5.9		2.6.7.8
15:30	1.2.3.4.5.8.9		6.7
15:40	1.2.3.4.8.9		5.6.7

Note: DW - Direct Work, S - Support Work, D - Delay

During the period of 13:20 to 14:20, concrete work paused due to temporary concrete supply problem.

3.3.2 Other Related Data Collection

Meanwhile, other related data was collected as well. This data includes gang size and the percentage of skilled labor, work type, work method, and completed quantity resulted from observed group.

1) Gang size: The numbers of labors who directly work in the group, exclude instructor(s), machine operator(s), etc.

2) Percentage of labor: % of Labor = (Skilled Labor/Gang Size) x100

3) Work type: the study focuses on three different types of formwork installation, the recorded coded as follows:

Columns =1, Walls =2, Slab =3.

4) Work method: what kind of method has been used to perform the work. For example, two methods were observed in formwork installation: flying forms and traditional forms. For concrete pouring, work methods included placement using pumps and using basket and crane. In this study, traditional wooden forms with steel support accessories for columns and walls were coded as 1. Flying forms

were coded as 2 for slabs.

5) Completed quantity: the quantity produced by the observed group at the end of observation. This data set will be converted into the value of productivity which is the quantity produced by each worker in the group observed. For formwork, its unit could be square metre/manhour/man.

3.4 Data Organization

In this stage, all collected raw data will be organized into one Excel sheet for further utilization. The following steps will explain the work in detail.

3.4.1 Work Sampling Data Analysis

The percentages of three classifications were calculated for each group member (Table 3.2). From this table, a direct view of individual labor performance was displayed.

Table 3.2 Percentage for each group member

Oct.25, 2001 Activity: Concrete

Labors	Work	Percentage (%)
1	DW	54
	S	9
	D	37
2	DW	51
	S	3
	D	46
3	DW	54
	S	5
	D	41
4	DW	39
	S	5
	D	56
5	DW	42
	S	0
	D	58
6	DW	39
	S	0
	D	61
7	DW	0
	S	46
	D	54
8	DW	47
	S	0
	D	53
9	DW	34
	S	0
	D	66

The percentage of the observed labor force could be calculated as used time of each classification divided by total working man-hours (Table 3.3).

Table 3.3 Example of final result of the percentage for the observed group

Oct.25, 2001		Activity: Pouring concrete
Number of Labors	Work	Percentage (%)
9	DW	40
	S	7.6
	D	52.4

3.4.2 Formatting Data Sets

Through above stages, all related data is obtained for further analysis. This data is converted into Excel data sheet before the next step. In this study, all data sets were organized in the data sheet by following the sequence as follows: gang size (GS), percentage (%), work type (type), work method (method), direct work (DW), support work (S), delay (D), and productivity (Produc.). Table 3.4 is an example of a data sheet for formwork. In Table 3.4, each row represents one observation cycle; productivity (Produc.) value is calculated according to real quantity pf completed work.

Table 3.4 An example of data sheet (formwork)

G.S	%	Type	Method	DW	S	D	Produc.
14	29	2	1	55	6	39	0.95
14	36	1	1	59	6	35	1.12
18	33	2	1	57	6	37	1.01
22	36	1	1	63	6	31	1.27
23	30	2	1	60	6	34	1.14
21	38	1	1	62	6	32	1.17
20	30	2	1	59	3	38	1.04
23	35	1	1	61	6	33	1.16

17	29	2	1	84	7	9	1.99
20	40	1	1	60	4	36	1.1
18	33	2	1	56	7	37	1
19	47	1	1	58	6	36	1.12
22	36	1	1	74	4	22	1.55
23	35	2	1	68	5	27	1.26
19	33	2	1	61	4	35	1.14
16	37	1	1	64	4	32	1.27
21	33	1	1	72	2	26	1.45
20	30	1	1	72	4	24	1.51
22	36	2	1	70	5	25	1.37
17	29	1	1	71	4	25	1.38
22	36	2	1	69	4	27	1.25
22	36	1	1	74	3	23	1.49
16	38	2	1	68	5	27	1.34
22	36	1	1	69	6	25	1.36
15	40	2	1	66	5	29	1.22
19	42	1	2	69	5	29	1.34
18	33	2	1	65	5	30	1.2
24	38	1	2	73	5	22	1.39
24	38	1	2	75	3	22	1.41
22	36	2	1	70	4	26	1.26
23	35	1	2	75	2	23	1.48
19	33	1	2	70	4	26	1.36
20	30	2	1	63	7	30	1.21
20	30	1	2	68	4	28	1.34
21	33	2	1	58	4	38	1.09
18	33	1	2	62	10	28	1.21
19	47	2	1	73	3	24	1.47
20	30	1	2	65	6	29	1.32
20	30	2	1	72	3	25	1.37
19	33	1	2	67	6	27	1.23
20	30	1	2	73	4	23	1.47
20	30	2	1	69	5	26	1.34
21	33	1	2	78	2	20	1.49
18	33	2	1	70	3	27	1.35
22	36	1	2	77	3	20	1.54
21	33	2	1	72	4	24	1.38
24	38	1	2	74	4	22	1.52
24	38	2	1	71	3	26	1.37

24	38	1	2	79	4	17	1.67
21	33	2	1	71	9	20	1.51
22	36	1	2	75	6	19	1.65
19	33	2	1	74	4	22	1.48
20	30	1	2	74	6	20	1.57
18	33	2	1	74	4	22	1.41
19	33	1	2	77	5	18	1.56
19	33	2	1	73	5	22	1.4
19	33	1	2	73	7	20	1.63
18	33	2	1	71	9	20	1.46
16	31	1	2	79	5	16	1.73
17	35	1	2	83	3	14	1.89
16	31	2	1	80	4	16	1.71
18	33	1	2	81	4	15	1.74
19	33	2	1	73	6	21	1.55
20	30	1	2	82	5	13	1.8
18	39	2	1	72	7	21	1.62
16	31	1	2	82	3	15	1.87
15	33	2	1	75	7	18	1.68
16	31	1	2	78	3	19	1.67
16	31	2	1	70	8	22	1.52

Note: GS - Gang Size, % - Labor Percentage, Type - Work Type, Method - Work Method, DW - Direct Work, S - Support Work, D - Delay, Produc. - Productivity

According to observation, work sampling average value of observed formwork is outlined in Table 3.5.

Table 3.5 Average value of work sampling of observed formwork

Observation	Work	Percentage (%)
Formwork	DW	71.1
	S	5.8
	D	23.1

3.4.3 Data Preparation

In this stage, the collected data will be normalized for modeling stage. Data normalization is based on the formula:

$$X_n = (X_o - X_{min}) / (X_{max} - X_{min}) \qquad \text{(Eq. 3.1)}$$

Where: X_n is normalized data point

X_o is original value of collected data point

X_{min} is minimum value of all collected data

X_{max} is maximum value of all collected data

According to this formula, the value of normalized data is between 0 and 1. For example, the collected data for 5 days is as shown in Table 3.6.

Table 3.6 An example of data sets to be normalized (formwork)

G.S	%	Type	Method	DW	S	D	Produc.
18	33	3	1	61	4	35	1.1
19	32	1	1	73	9	19	1.76
19	37	1	1	78	6	16	1.98
21	33	1	1	71	5	24	1.58
20	35	2	1	68	4	28	1.45

Note: GS - Gang Size, % - Labor Percentage, Type - Work Type, Method - Work Method, DW - Direct Work, S - Support Work, D - Delay, Produc. - Productivity

The normalized data point for G.S would be:

$X_{n1} = (18 - 18)/(21 - 18)$

$X_{n1} = 0$

$X_{n2} = (19 - 18)/(21 - 18)$

$X_{n2} = 0.333$

$X_{n3} = (19 - 18)/(21 - 18)$

$X_{n3} = 0.333$

$X_{n4} = (21 - 18)/(21 - 18)$

$X_{n4} = 1$

$X_{n5} = (20 - 18)/(21 - 18)$

$X_{n5} = 0.667$

Similarly, all data points could be normalized. Table 3.7 is an example of a part of normalized data sheet for formwork (data was collected from Concordia University SGW project site).

Table 3.7 An example of normalized formwork data

G.S	%	Type	Method	DW	S	D	Produc.
0.000	0.000	1.000	0.000	0.000	0.500	1.000	0.000
0.000	0.389	0.000	0.000	0.138	0.500	0.867	0.163
0.400	0.222	1.000	0.000	0.069	0.500	0.933	0.058
0.800	0.389	0.000	0.000	0.276	0.500	0.733	0.308
0.900	0.056	1.000	0.000	0.172	0.500	0.833	0.183
0.700	0.500	0.000	0.000	0.241	0.500	0.767	0.212
0.600	0.056	1.000	0.000	0.138	0.125	0.967	0.087
0.900	0.333	0.000	0.000	0.207	0.500	0.800	0.202
0.300	0.000	1.000	0.000	1.000	0.625	0.000	1.000
0.600	0.611	0.000	0.000	0.172	0.250	0.900	0.144
0.400	0.222	1.000	0.000	0.034	0.625	0.933	0.048
0.500	1.000	0.000	0.000	0.103	0.500	0.900	0.163
0.800	0.389	0.000	0.000	0.655	0.250	0.433	0.577
0.900	0.333	1.000	0.000	0.448	0.375	0.600	0.298
0.500	0.222	1.000	0.000	0.207	0.250	0.867	0.183
0.200	0.444	0.000	0.000	0.310	0.250	0.767	0.308
0.700	0.222	0.000	0.000	0.586	0.000	0.567	0.481
0.600	0.056	0.000	0.000	0.586	0.250	0.500	0.538
0.800	0.389	1.000	0.000	0.517	0.375	0.533	0.404
0.300	0.000	0.000	0.000	0.552	0.250	0.533	0.413
0.800	0.389	1.000	0.000	0.483	0.250	0.600	0.288
0.800	0.389	0.000	0.000	0.655	0.125	0.467	0.519
0.200	0.500	1.000	0.000	0.448	0.375	0.600	0.375
0.800	0.389	0.000	0.000	0.483	0.500	0.533	0.394

Note: GS - Gang Size, % - Labor Percentage, Type - Work Type, Method - Work Method, DW - Direct Work, S - Support Work, D - Delay, Produc. - Productivity.

3.5 Other Observed Construction Activities

In this stage, other activities including piling, excavation, shoring, blasting, reinforcing bars, and concrete pouring, were observed as well.

3.5.1 Piling

There were a total of 117 piles driven in the SGW construction site.

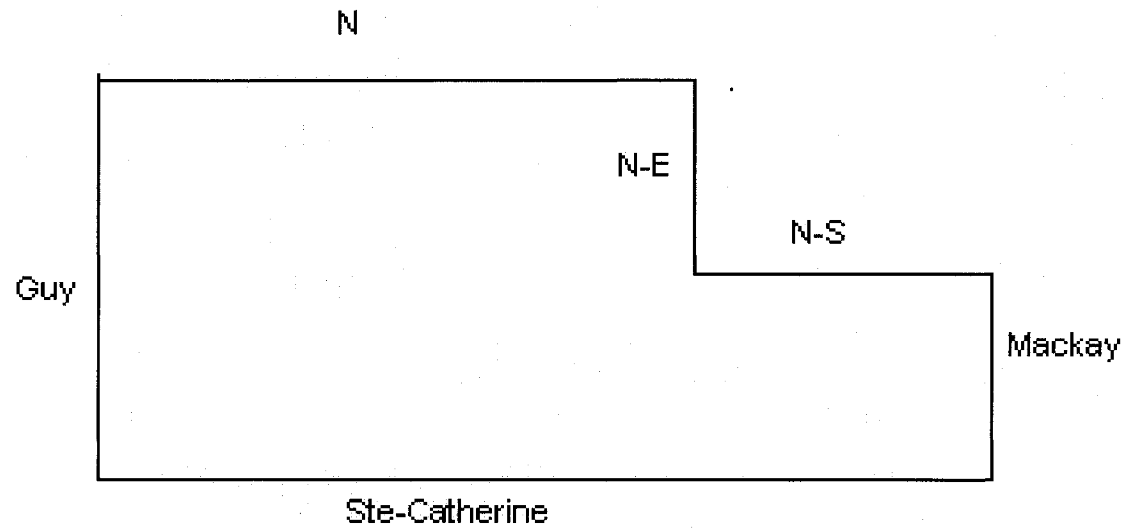

Figure 3.6 Plan of SGW Site

Table 3.8 shows the number of piles of each side.

Table 3.8 The number of piles

Location	Number of piles
N-E	18
N-S	17
Mackay Street	19
Ste-Catherine Street	34
Guy Street	29

There were no piles along the N side because there is a concrete foundation wall of subway along this side.

Figure 3.7 Link-Belt LS-98 pile driver

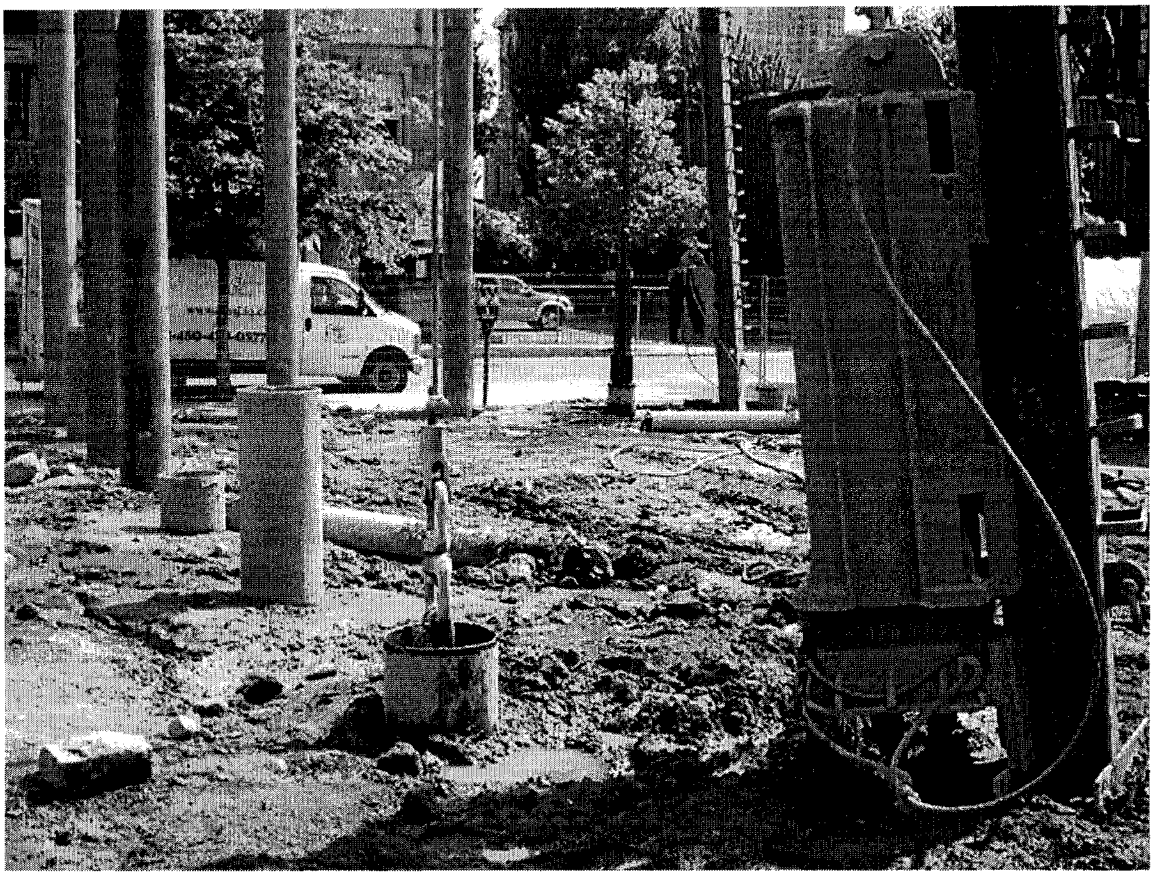

Figure 3.8 Pile driving

Usually, there were 3 pile drivers that were equipped with 3-ton hammer for steel-pipe piles and 1 pile driver with 4 tons hammer for H piles. Figure 3.7 shows a driver that is model Link-Belt LS-98 with 3-ton hammer for driving steel-pipe piles. The crew includes 1 pile driver operator, 1 pipe guider, and 2 welders who re-sharpen the aiguilles' teeth, worn due to the rock-grinding work.

Figure 3.9 Checking verticality

Figure 3.10 Sharpening aiguilles' teeth

Figure 3.11 Worn teeth

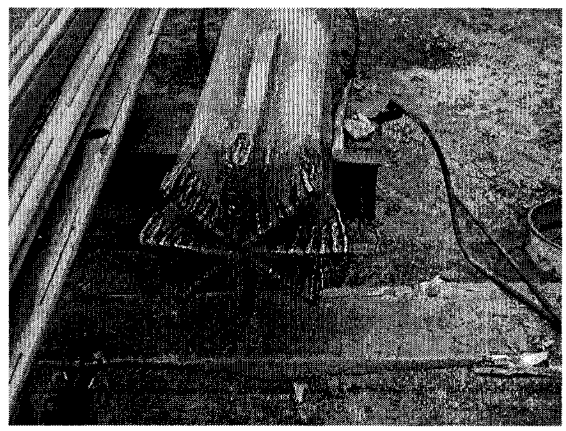

Figure 3.12 Re-sharpened teeth

The average time for driving the H pile to the required depth along Guy Street is only 25 minutes. However, driving time for the steel-pipe piles along the other 4 sides is much longer than the H pile driving time due to tough soil conditions, i.e. underground rocks. Each pile driver usually completes 2 steel-pipe piles daily. According to on-site observation, minimum driving time to complete one steel-pipe pile is 3 hours and 10 minutes. Average values of work sampling of piling are shown in Table 3.9.

Table 3.9 Average values of work sampling of observed piling

Number of Labors	Work	Percentage (%)
4	DW	48
	S	31
	D	21

3.5.2 Excavation and Earthmoving

The observation of this activity was performed in downtown Montreal SGW site.

Figure 3.13 Earthmoving

The total volume of earth moved from this site is approximately 32182 tons. The dumping locations are between 20 kilometers and 100 kilometers from the site. Usually, 15 trucks work with two excavators and one loader on any working day. One truck needs 1 to 4 hours for one return trip. Table 3.10 is equipment information of the fleet.

Table 3.10 Information of earthmoving equipment

Equipment	Quantity	Model	Capacity
Loader	1	Volvo L90C	2.2m3
Excavator	1	CAT 330BL	1.7m3
	1	CAT 365BL	3.75m3
Truck	7 - 25	Associated	19 – 21m3

Table 3.11 is loading information of the fleet based on on-site observation.

Table 3.11 Loading information of the observed fleet

Equipment	Model	Cycle Time (Second)	Cycles for 1 Full Truck	Total Time for 1 Full Truck (Minute)
Loader	Volvo L90C	30 - 45	7-8	5
Excavator	CAT 330BL	20 - 30	4-6	1.2 – 3
	CAT 365BL	30	3	1.5

According to observations, the maximum daily earthmoving ability is 120 trucks and occurred on August 7, 2002. However, loading equipment, including loader and excavators, sometimes have to wait for the trucks' return. Therefore, earthmoving productivity is negatively affected due to wasted waiting time. Table

3.12 shows average values of work sampling of observed earthmoving work (Observed data in Appendix 13).

Table 3.12 Average values of work sampling of observed earthmoving

Number of Observed Equipment	Work	Percentage (%)
3	DW	46
	S	22
	D	32

Note: Number of observed equipment includes two excavators and one loader.

Figure 3.14 Volvo L90C loader

3.5.3 Blasting

Blasting was done on the number of stages each followed by moving the blasted rock, i.e., blasting was performed between earthmoving in the SGW construction site. The blasting pattern used on site is shown as Figure 3.15.

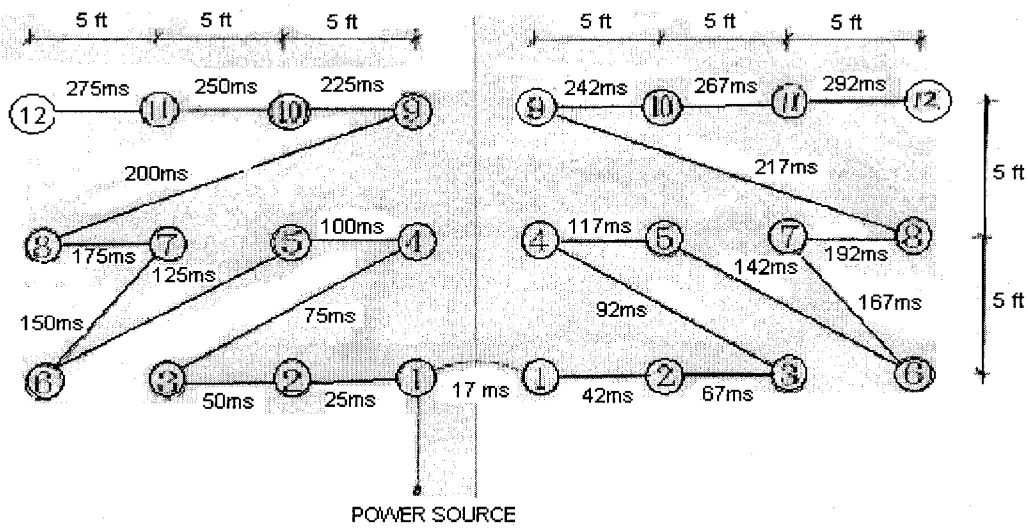

Figure 3.15 Blasting pattern

Blasting work was performed by a 2-person crew (1 helper, 1 blaster). The rock type in the site is limestone. General information of blasting work is listed as Table 3.13.

Table 3.13 Blasting information

Type of blasting circuit	Parallel series
Power source	6V battery (type: ICI 100)
Firing line	Size 14 copper wires
Buswire	5m-nonel handidet with 25 ms delay
Explosive	Amex dynamite
Primer	Powerditch
Drilling patterns	Square
Hole space	5 feet ´ 5 feet
Hole depth	1.1m to 4m
Hole diameter	2.75in
Number of caps per hole	1 or 2
Explosive load per hole	1.5kg
Drilling pressure	200-psi
Rock yield	4500 cubic feet

Usually, 24 holes were drilled in each blasting cycle. On any workday, up to 100 holes could be drilled by the drilling machine. In other words, 4 cycles of blasts could be done every workday. Two different explosive loading styles applied in blasting depend on various blasting areas (As shown in Figure 3.16). If the blasting area is far from existing buildings, explosive will be loaded as pattern 1; if the blasting area is near existing buildings, explosive will be loaded as pattern2.

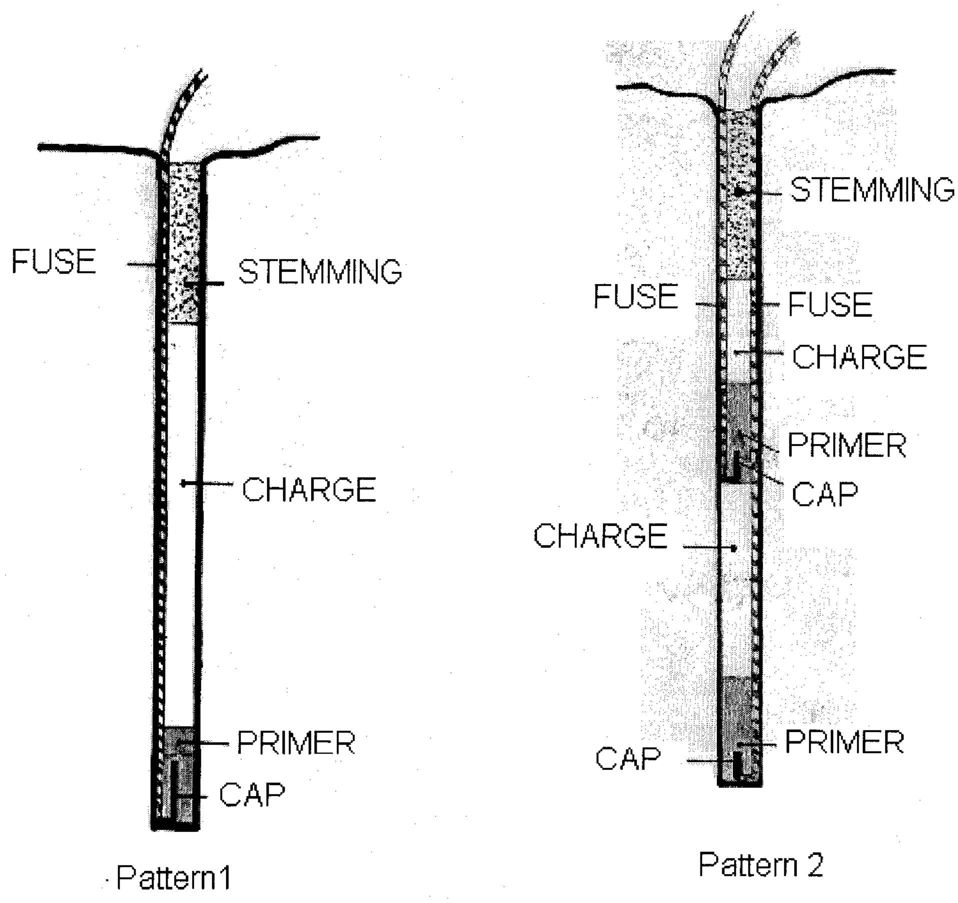

Figure 3.16 Charging patterns of explosive

The entire blasting procedure is illustrated below (Figure 3.17 to 3.37).

Step 1. Helper marks exact holes location with bright paint (Figure 3.17).

Figure 3.17 Locating

Step 2. Confirm the depth of every hole by using transmitter and laser detector (Figure 3.18 and 3.19).

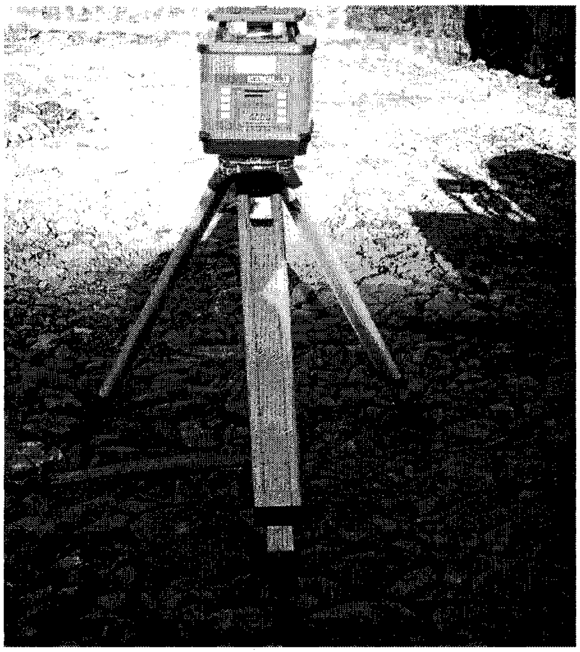

Figure 3.18 Eagle-3 transmitter

Figure 3.19 Laser detector

Step 3. Operator drills hole to required depth under 200-psi air pressure (Figure 3.20 to 3.23).

Figure 3.20 ROC 722HC-01 drilling machine


Figure 3.21 Button bit aiguilles

Figure 3.22 Locating aiguilles

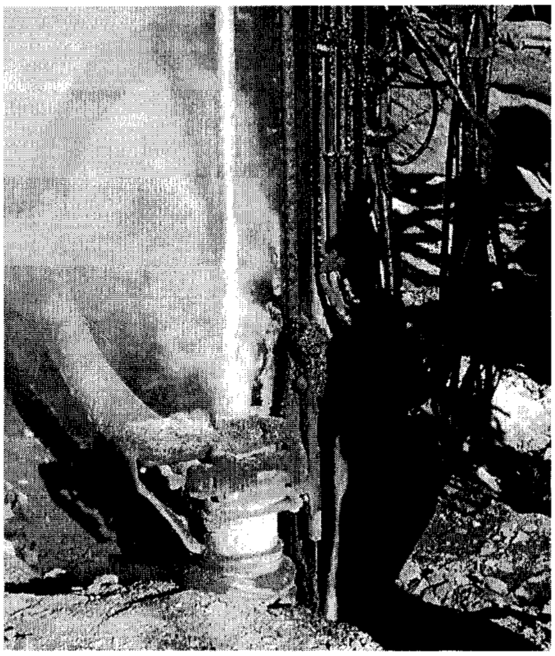

Figure 3.23 Drilling

Step 4. Before charging, every hole is covered by a plastic cap to prevent soil falls (Figure 3.24 and 3.25).

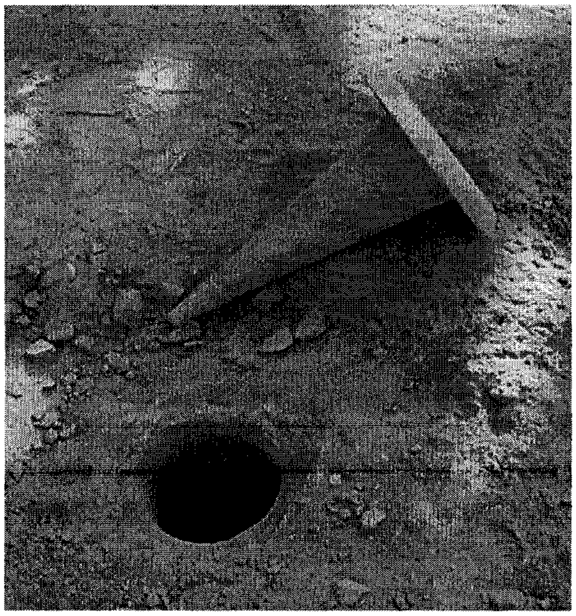

Figure 3.24 Plastic cap

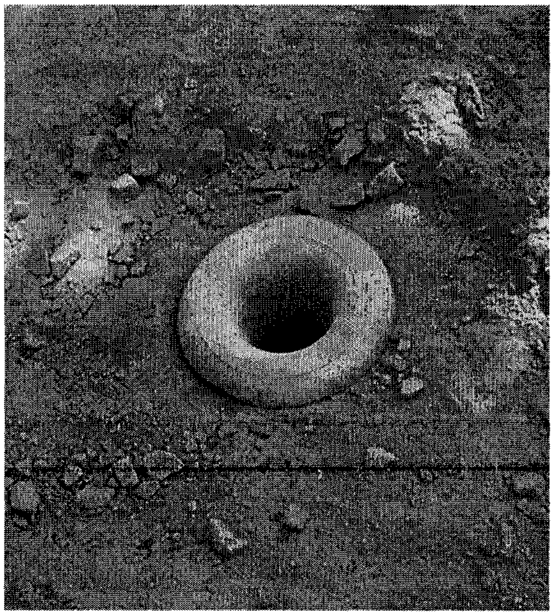

Figure 3.25 Covered hole

5. Blaster puts explosive in holes one by one (Figure 3.26 to 3.29).

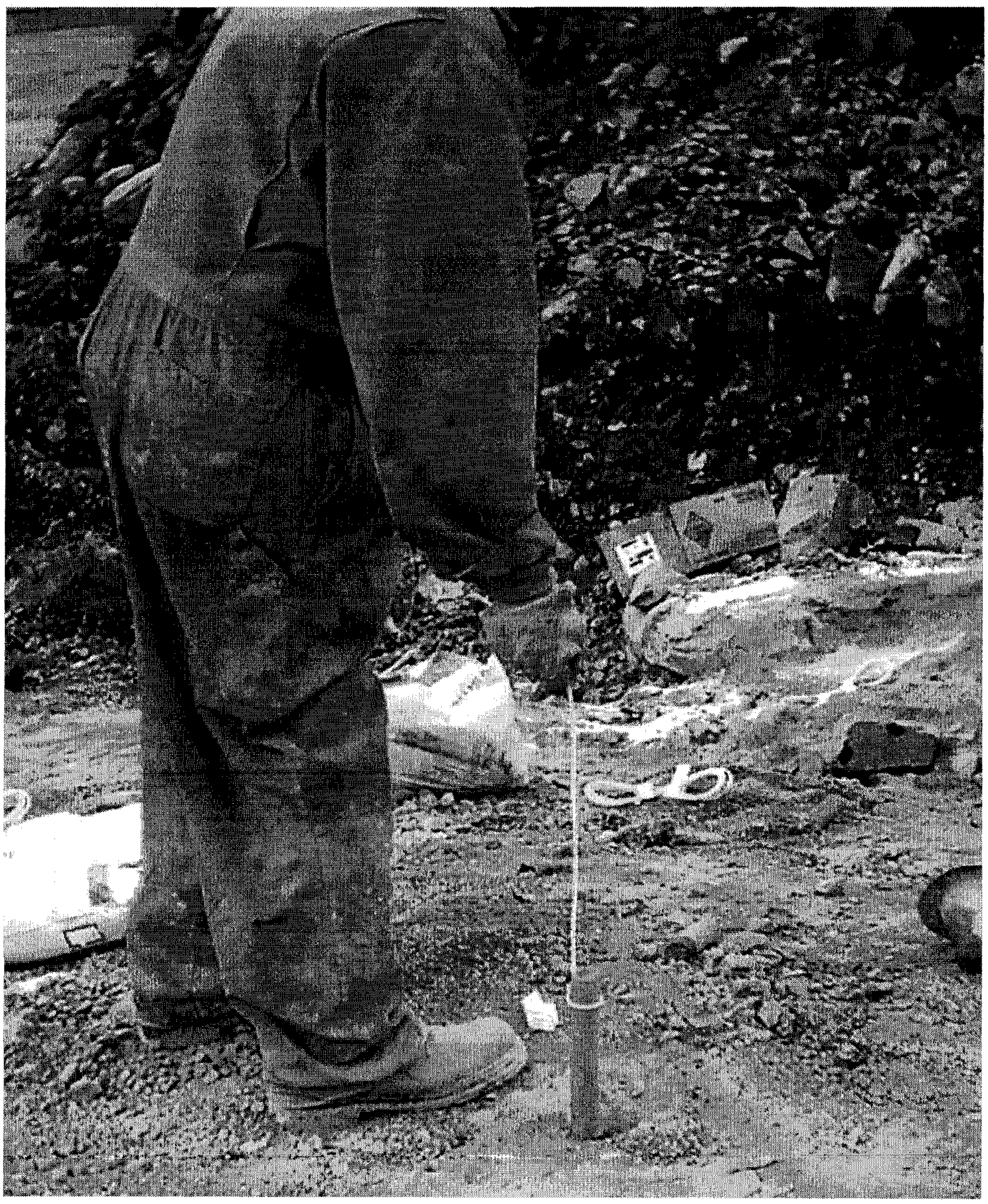

Figure 3.26 Placing cap and Powerditch primer

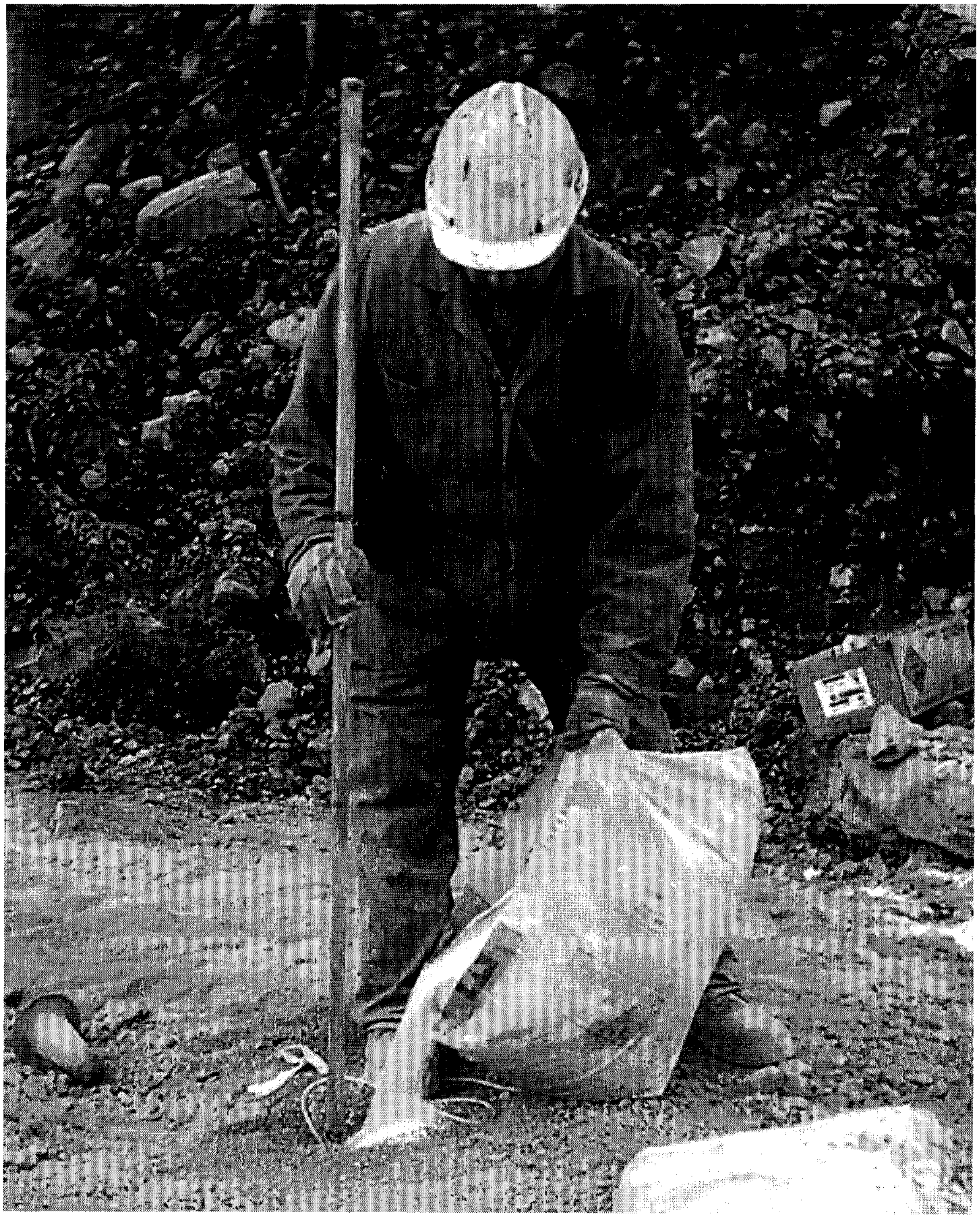

Figure 3.27 Placing dynamite and tamping

Figure 3.28 Stemming

Figure 3.29 Explosive to be placed

Step 6. Blaster connects every 12 caps together by series pattern, then connects these 2 12-cap via a 17 ms (millisecond) delay electric cap (green) (Figure 3.30 to 3.32).

Figure 3.30 Connecting caps (25 ms delay each)

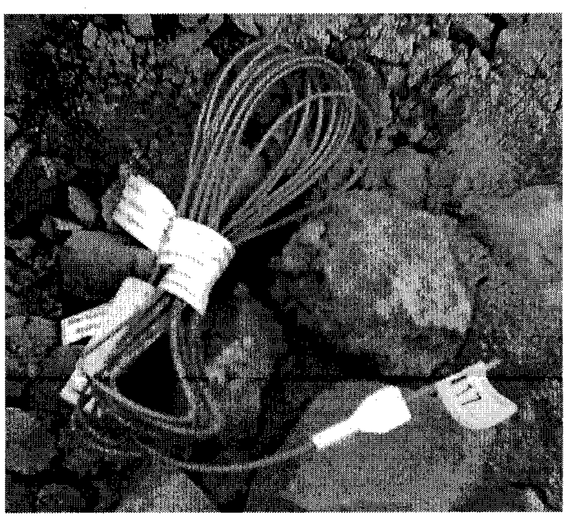

Figure 3.31 17 ms delay electric cap

Figure 3.32 Connected caps

Step 7. Power source will be connected to 17 ms cap via a 2.5 m length 0 ms delay electric cap (Figure 3.33 to 3.35).

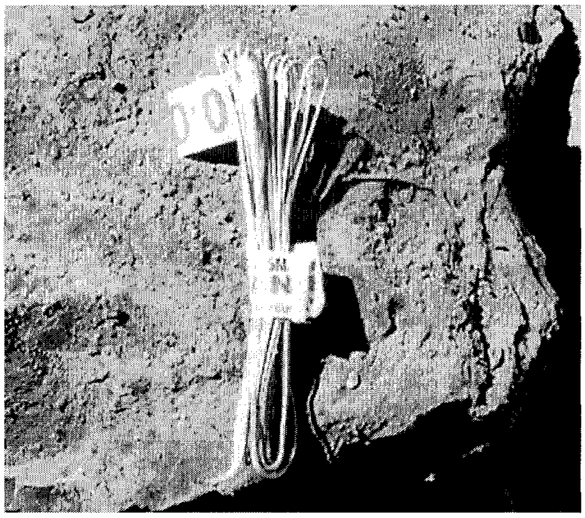

Figure 3.33 0 ms delay electric cap

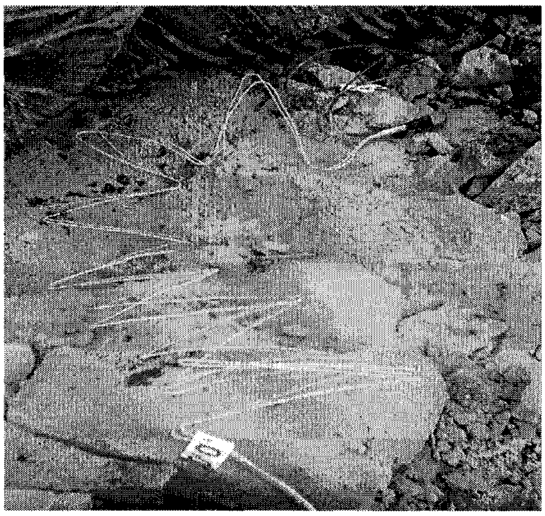

Figure 3.34 Connected electric cap

Figure 3.35 IC100 6V battery power source

Step 8. Blasting area is covered by rubber mats for safety reason (Figure 3.36).

Figure 3.36 Placing rubber mat

Step 9. Remove rubber mats after blasting (Figure 3.37).

Figure 3.37 Removing mats after blasting

Table 3.14 shows average values of work sampling of blasting according to observation.

Table 3.14 Average values of work sampling of blasting.

Number of Labors	Work	Percentage (%)
2	DW	58
	S	18
	D	24

DW: direct work, S: support work, D: Delay

3.5.4 Shoring and Lagging

Shoring takes many forms of construction techniques from supporting open trenches with shields to vertical cut shoring walls. The most flexible and widely used vertical shoring walls use soldier piles with lagging (Washington, 2001). Lagging can be wood, steel plate or pre-cast concrete panels. The additional tiebacks or pipe bracing is frequently used for walls over 15 feet in height. Other common shoring systems include soil nails, sheet piling, secant walls and tiebacks with concrete washers (no piles).

For the observed construction site, the shoring system is soldier piles with lagging and additional tiebacks, as shown in Figure 3.38.

Figure 3.38 Completed shoring system in SGW site

The productivity of shoring work is observed following work sampling method. Table 3.15 is an observation sample from SGW construction site where 41 square meters lagging completed on the observed workday.

Table 3.15 A sample of observation of lagging work

Date: Aug.9, 2002		Activity: Lagging
Number of Labors	Work	Percentage (%)
8	DW	31
	S	27
	D	42

DW: direct work, S: support work, D: delay

Average values of work sampling observations for SGW construction site are shown in Table 3.16 (Observed data in Appendix 14).

Table 3.16 Average values of work sampling of lagging

Observation	Work	Percentage (%)
Lagging	DW	38
	S	31
	D	31

DW: direct work, S: support work, D: delay

3.5.5 Reinforcing Bars

Reinforcing bars work in this study includes slabs' bars, columns' bars, and walls' bars assembly (Figure 3.39 to 3.41). In the observation, reinforcing bars work was observed using the work sampling method as well.

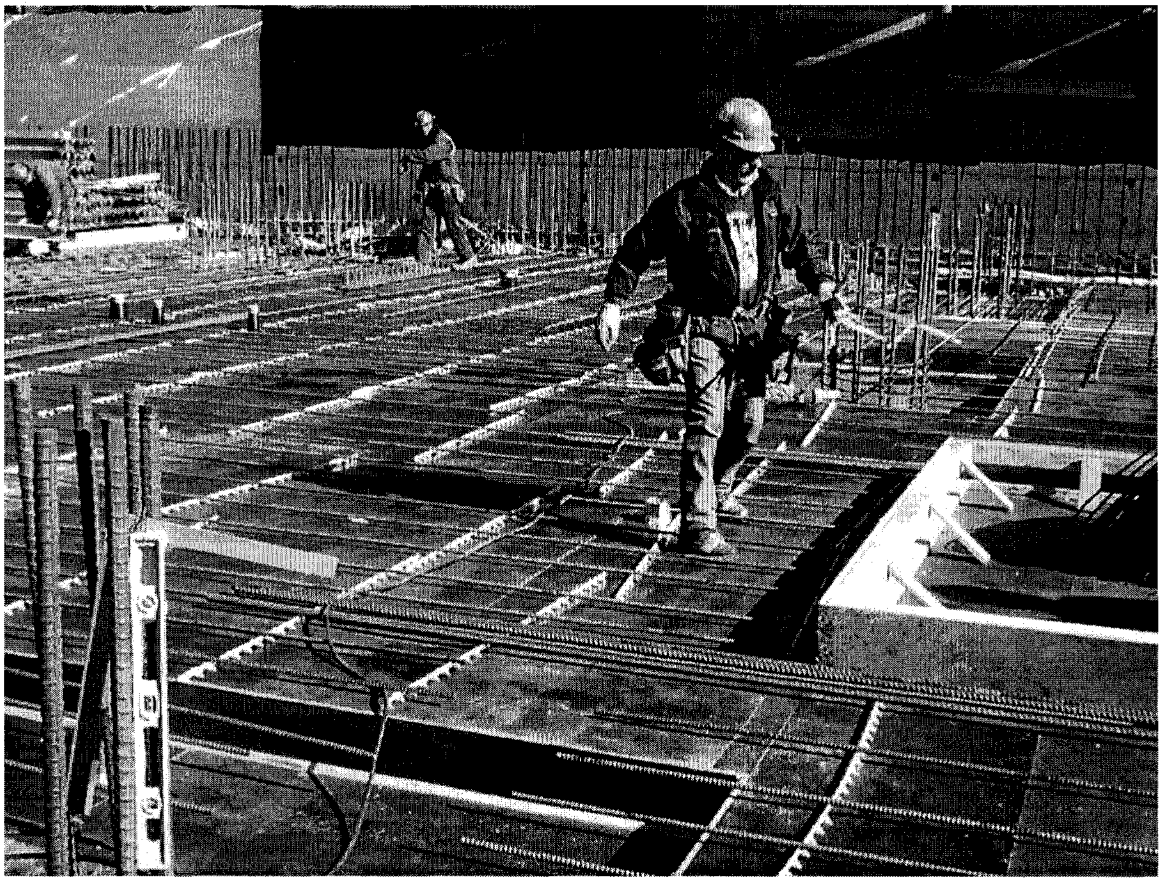

Figure 3.39 Reinforcing bars for slab (Concordia SGW site)

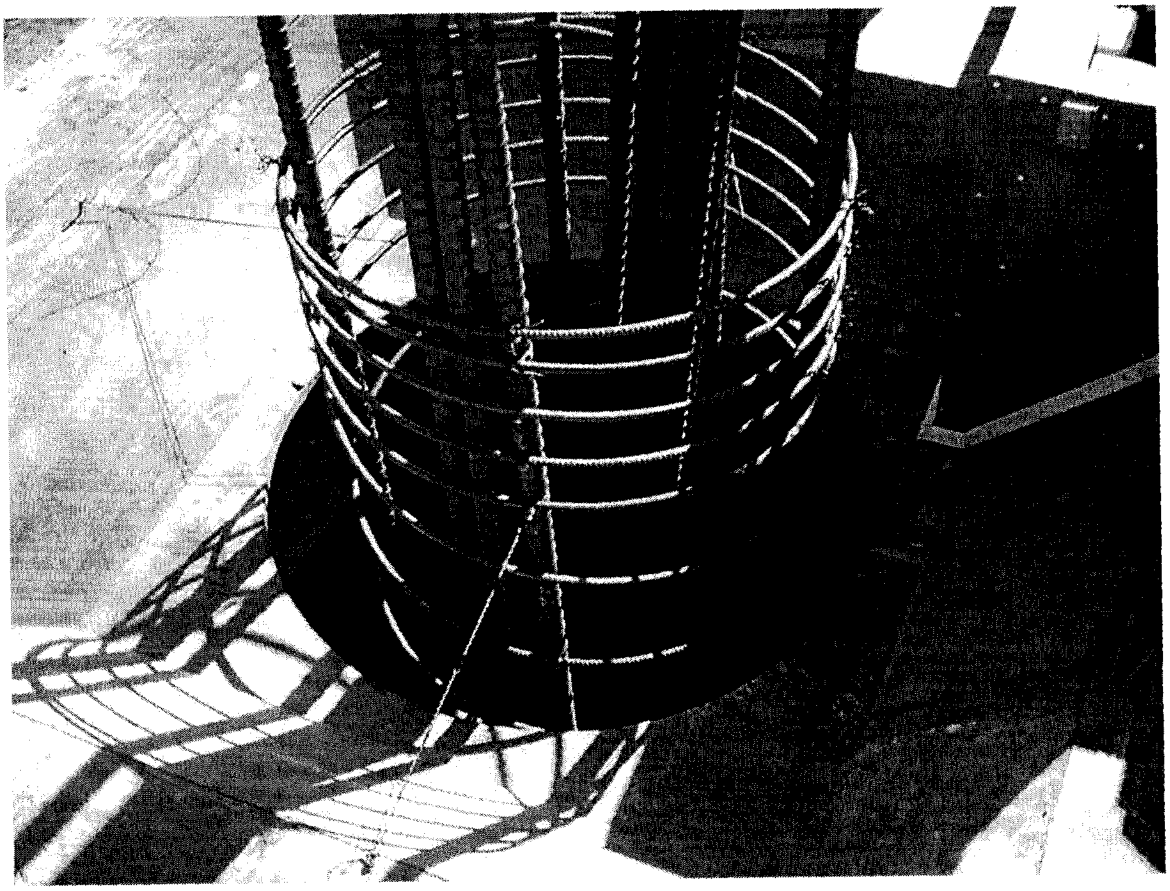

Figure 3.40 Reinforcing bars for column (Concordia SGW site)

Figure 3.41 Reinforcing bars for wall (Concordia SGW site)

Table 3.17 is an observation result derived from a reinforcing bars work in the SGW site on October 24, 2001.

Table 3.17 An observation result of reinforcing bars work

Oct.24 2001		Activity: Reinforcing bars for slab
Number of Laborers	Work	Percentage (%)
8	DW	39
	S	26
	D	35

DW: direct work, S: support work, D: delay

Table 3.18 shows average values of work sampling of reinforcing bars (Observed data in Appendix 15).

Table 3.18 Average values of work sampling of reinforcing bars

Observation	Work	Percentage (%)
Reinforcing Bars	DW	42
	S	31
	D	27

DW: direct work, S: support work, D: delay

3.5.6 Concrete Pouring

In the study, concrete pouring was performed by two methods, i.e. concrete pump and bucket. Figure 3.42 and 3.43 illustrated pump method concrete pouring performed on SGW site.

Figure 3.42 Concrete pump

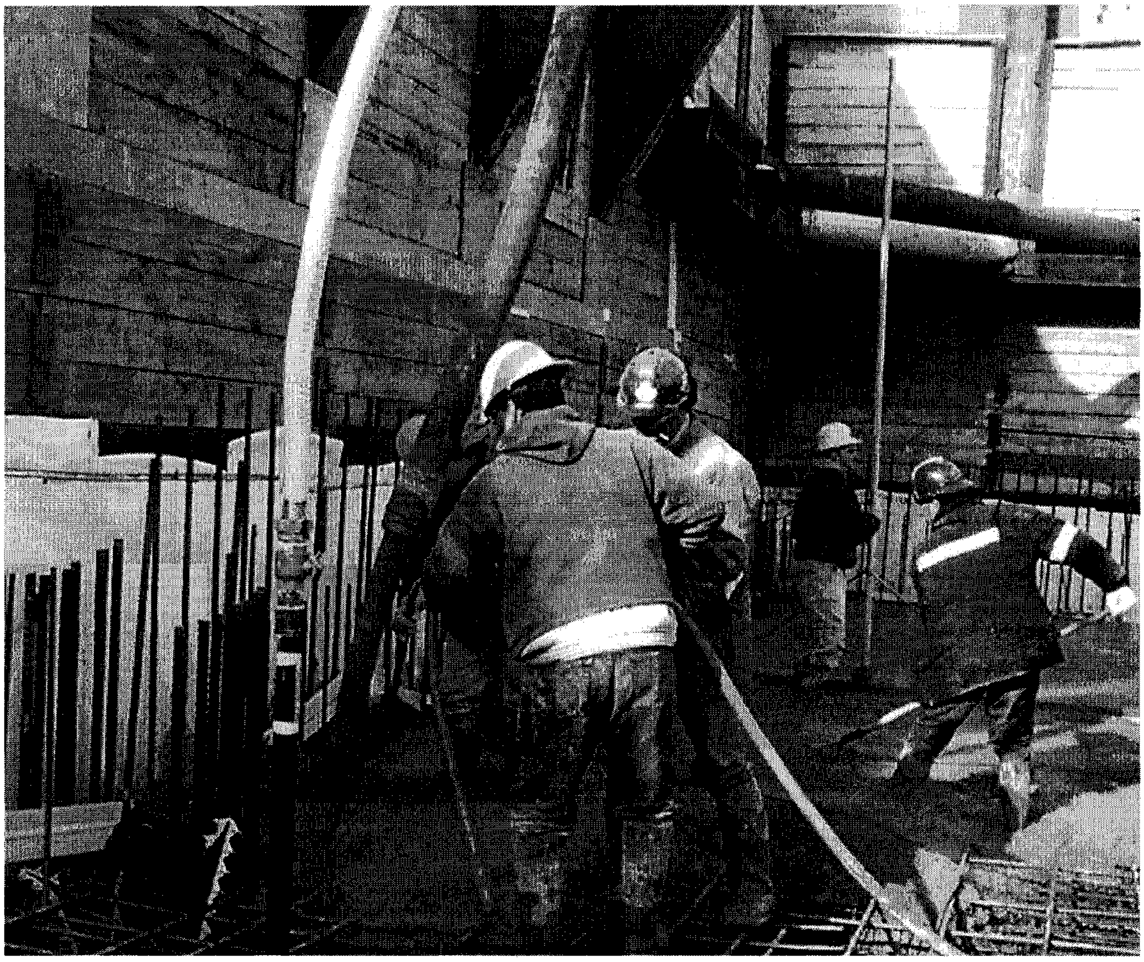

Figure 3.43 Pouring concrete by pump

Figure 3.44 and 3.45 are the pictures to show concrete pouring by concrete bucket.

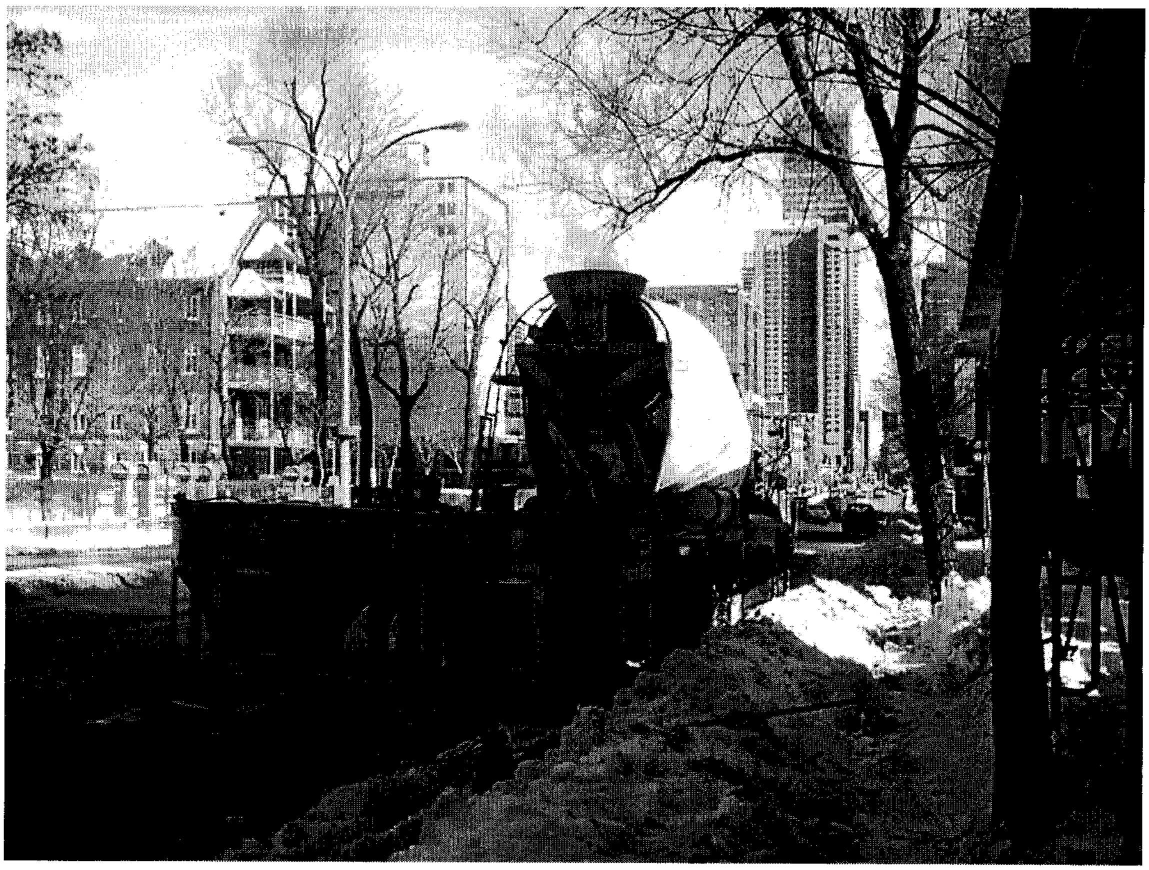

Figure 3.44 Concrete truck and buckets

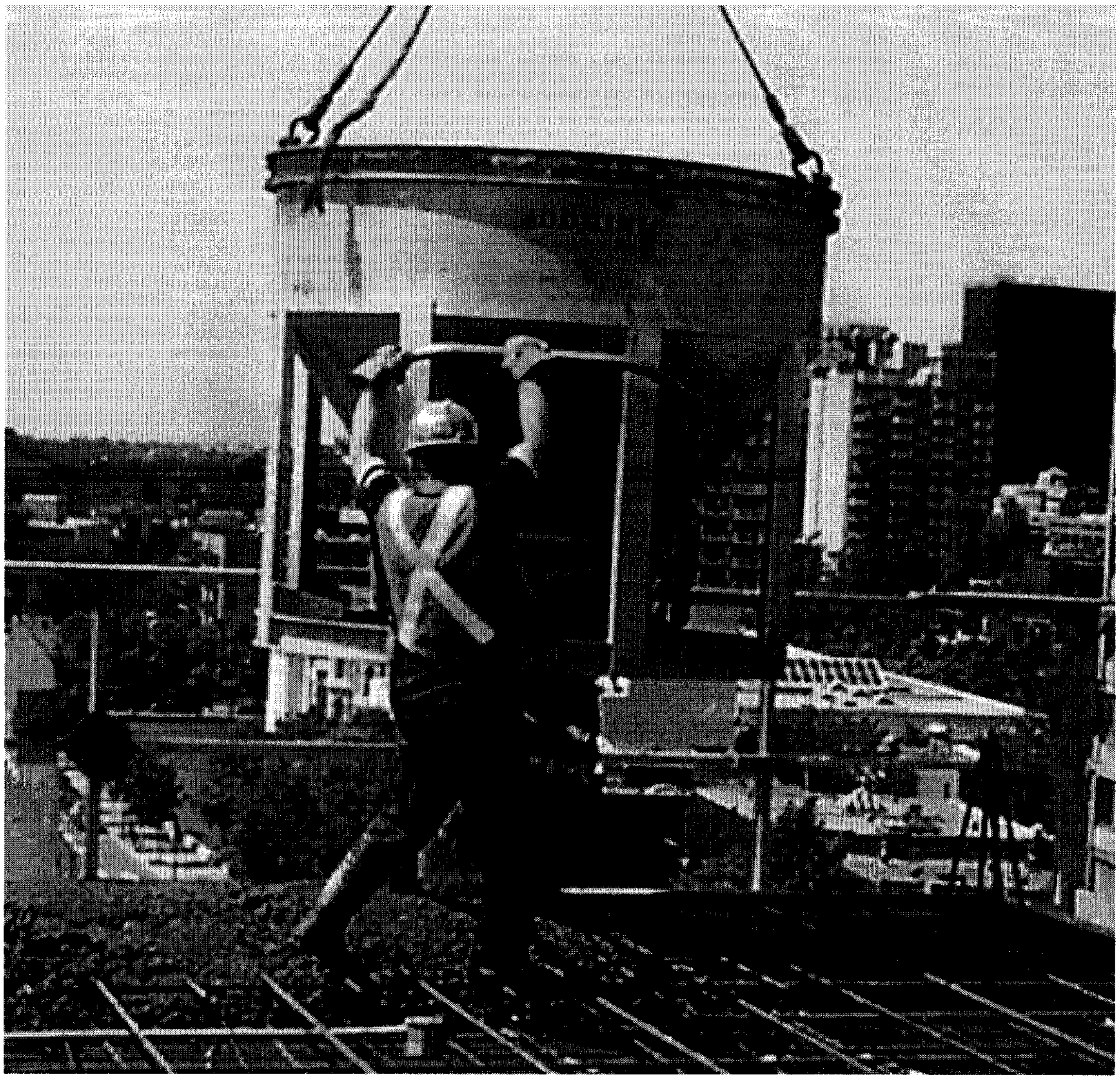

Figure 3.45 Pouring concrete by bucket

Table 3.19 is an on-site observation record of concrete pouring completed by pump on Loyola site observed on October 18, 2001.

Table 3.19 An observation result of concrete work completed by pump

Oct.18 2001		Activity: Pouring concrete
Number of Laborers	Work	Percentage (%)
9	DW	54
	S	11
	D	35

DW: direct work, S: support work, D: delay

Table 3.20 shows average values of work sampling of concrete pouring (Observed data in Appendix 16).

Table 3.20 Average values of work sampling of concrete pouring

Observation	Work	Percentage (%)
Concrete Pouring	DW	56
	S	15
	D	29

DW: direct work, S: support work, D: delay

3.6 Summary

In this chapter, the data collection and preparation has been introduced step by step. All necessary data was collected and then prepared for further modeling development which will be presented in the next chapter. Meanwhile, other construction activities, such as excavation, piling, shoring, concrete pouring etc, are reviewed as well.

Chapter 4

Proposed Productivity Models

4.1 General

The objective of this chapter is to develop the models by NeuralShell2 to reveal the impact of related parameters on on-site labor productivity. The neural network based models were developed using different settings in order to compare the results and increase the accuracy of the analysis. Afterwards, regression model was developed as well in order to perform model verification and validation in the next chapter.

In this chapter, NeuralShell2 was used. This software is developed by Ward Systems Group, Inc. As a general review, some important concepts in the software are outlined in Appendix 2. NeuroShell2 enables users to build sophisticated custom problem solving applications without programming. Users tell the network what they are trying to predict or classify, and NeuroShell2 will be able to "learn" patterns from training data. NeuroShell2 will also be able to make its own classifications, predictions, or decisions when presented with new data. Both NeuroShell2 and the brain are able to solve problems that cannot be solved by conventional computer software written in a step-by-step mode (NeuralShell2, 1996).

4.2 Brief Introduction of NeuralShell2

NeuralShell2 provides many different options of architecture to meet the users' demands. Generally, it includes back propagation neural network (BPNN), general regression neural network (GRNN), and group method of data handling network (GMDH), etc. (Figure 4.1)

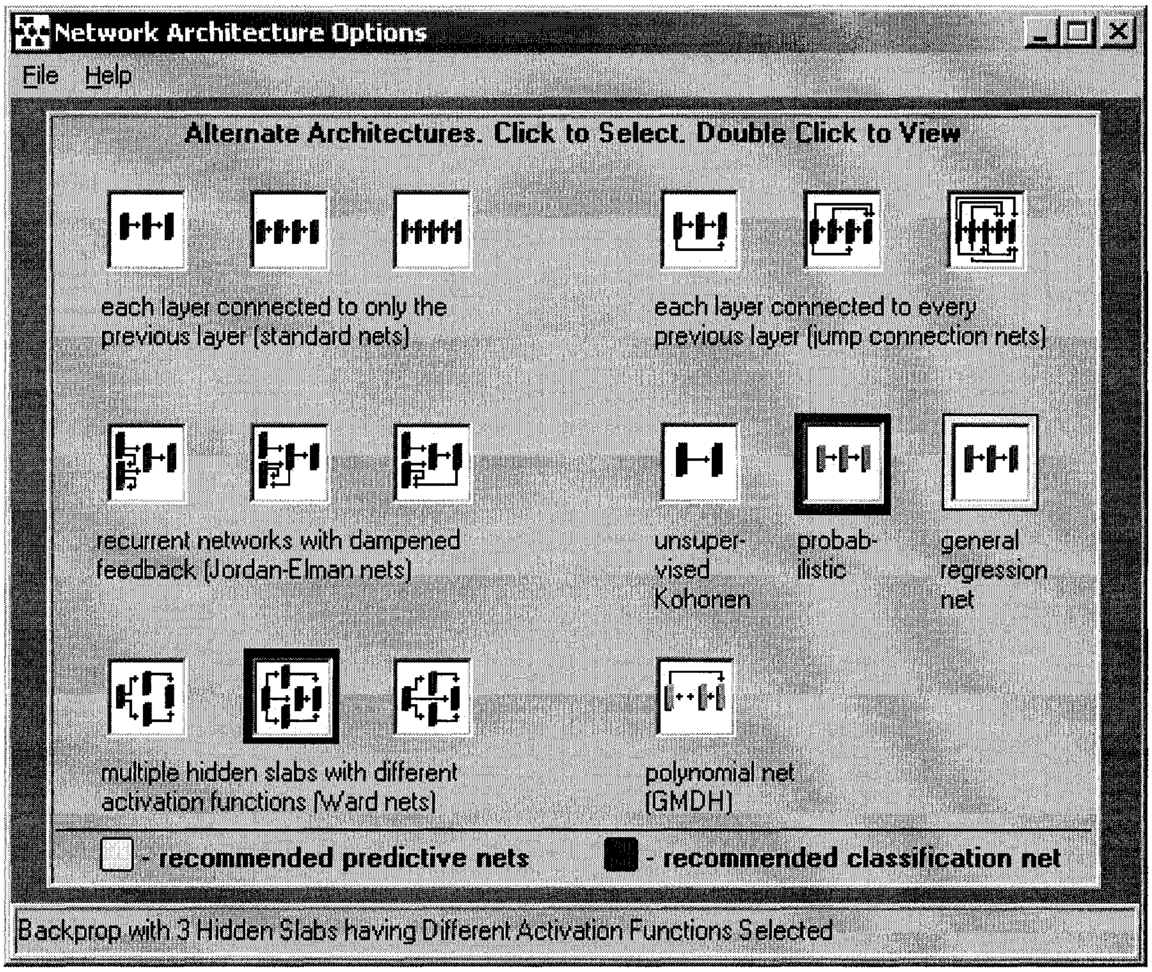

Figure 4.1 Network architecture options of NeuralShell2

4.2.1. Back Propagation Neural Network (BPNN)

Back propagation is the training algorithm most commonly used for the development of civil engineering, and more specially construction management applications (Moselhi and Siqueira, 1998). The networks are known for their ability to solve a wide variety of problems. Back propagation networks are a supervised type of network, e.g., trained with both inputs and outputs back propagation networks are used for the vast majority of working neural network applications. When using back propagation networks, you can increase the precision of the network by creating a separate network for each output. NeuroShell2 offers several different variations of back propagation networks (NeuralShell2, 1996):

1) Standard Connections: every layer is linked to the immediate previous layer (NeuralShell2 provides 3, 4, or 5 layers' option). Using more than 3 layers is rarely necessary if calibration is used. Using more than 5 layers should never be done because there is no known benefit to use more than 5 layers (NeuralShell2, 1996). According to the suggestion of the software, training time may be increased by as much as an order of magnitude when user applies more than one hidden layer (the layers between the input and output layers)

2) Jump Connections: each layer is connected to every previous layer (NeuralShell2 provides 3, 4, or 5 layers' option for jump connection network).

3) Recurrent networks: this type of back propagation network is usually applied for predicting financial markets because the network is excellent for time series data. There are three types of recurrent networks available in NeuralShell2:

a. Input layer fed back into input layer

The long-term memory remembers the new input data and uses it when the next pattern is processed.

b. Hidden layer fed back into input layer

The long-term memory remembers the hidden layer, which contains features detected in the raw data of previous patterns. This is the most powerful recurrent network.

c. Output layer fed back into input layer

Long-term memory remembers outputs previously predicted.

4). Ward networks: this type of network has multiple hidden layers. When the different hidden layers are given different activation functions, the output layer will display the different feature of the data. There are three options of ward networks in NeuralShell2:

a. 2 Hidden layers with different activation functions

This is a regular three-layer back propagation network with two hidden layers. Use a different activation function for each slab in the hidden layer to detect different features in the data.

b. 3 hidden layers with different activation functions

This is a type of back propagation network that adds a third slab to the hidden layer. It offers three ways to view the data when each slab in the hidden layers has a different activation function,

c. 2 hidden slabs, different activation functions + jump connection

This is a type of regular three-layer back propagation network with two slabs in the hidden layers and a jump connection between the input layer and output layer. The output layer receives two different views of the data's features as detected in the hidden slabs plus the original inputs.

4.2.2 Kohonen (Unsupervised)

The Kohonen Self Organizing Map network is a type of unsupervised network, which has the ability to learn without being shown correct outputs in sample patterns. These networks are able to separate data patterns into a specified number of categories.

4.2.3 Probabilistic Neural Network (PNN)

Probabilistic Neural Networks are a type of supervised network known for their ability to train quickly on sparse data sets. PNN separates data into a specified number of output categories, i.e., it classifies its input patterns into categories.

4.2.4 General Regression Neural Network (GRNN)

General Regression Neural Networks are known for the ability to train quickly on sparse data sets. GRNN is a type of supervised network. Rather than categorizing data like PNN, however, GRNN applications are able to produce continuous valued outputs (NeuralShell2 1996). This network is useful for continuous function approximation. GRNN networks may be more accurate than back propagation networks when there are multiple outputs because GRNN evaluates every output independently of the others.

4.2.5 Group Method of Data Handling or Polynomial Nets (GMDH)

GMDH builds successive layers with links that are simple polynomial terms that are created by applying linear and non-linear regression. The initial layer is simply the input layer. The first layer created is made by computing regressions of the input variables and then choosing the best ones. The second layer is created by computing regressions of the values in the first layer along with the input variables. The algorithm chooses the best. These are called survivors. This process continues until the net stops getting better (according to a prespecified selection criterion).

The result can be represented as a complex polynomial (i.e., a familiar formula) description of the model which contains the most significant input variables. It is similar to using regression analysis, but it is far more powerful than regression analysis.

4.3 Developed Models

4.3.1 Structures of Developed Models

In the twelve developed BPNN models of this study, the model No. 5 that changes the activation function with two hidden layers has the best result. Figure 4.2 is a flow chart of the sum of the developed neural network-based models.

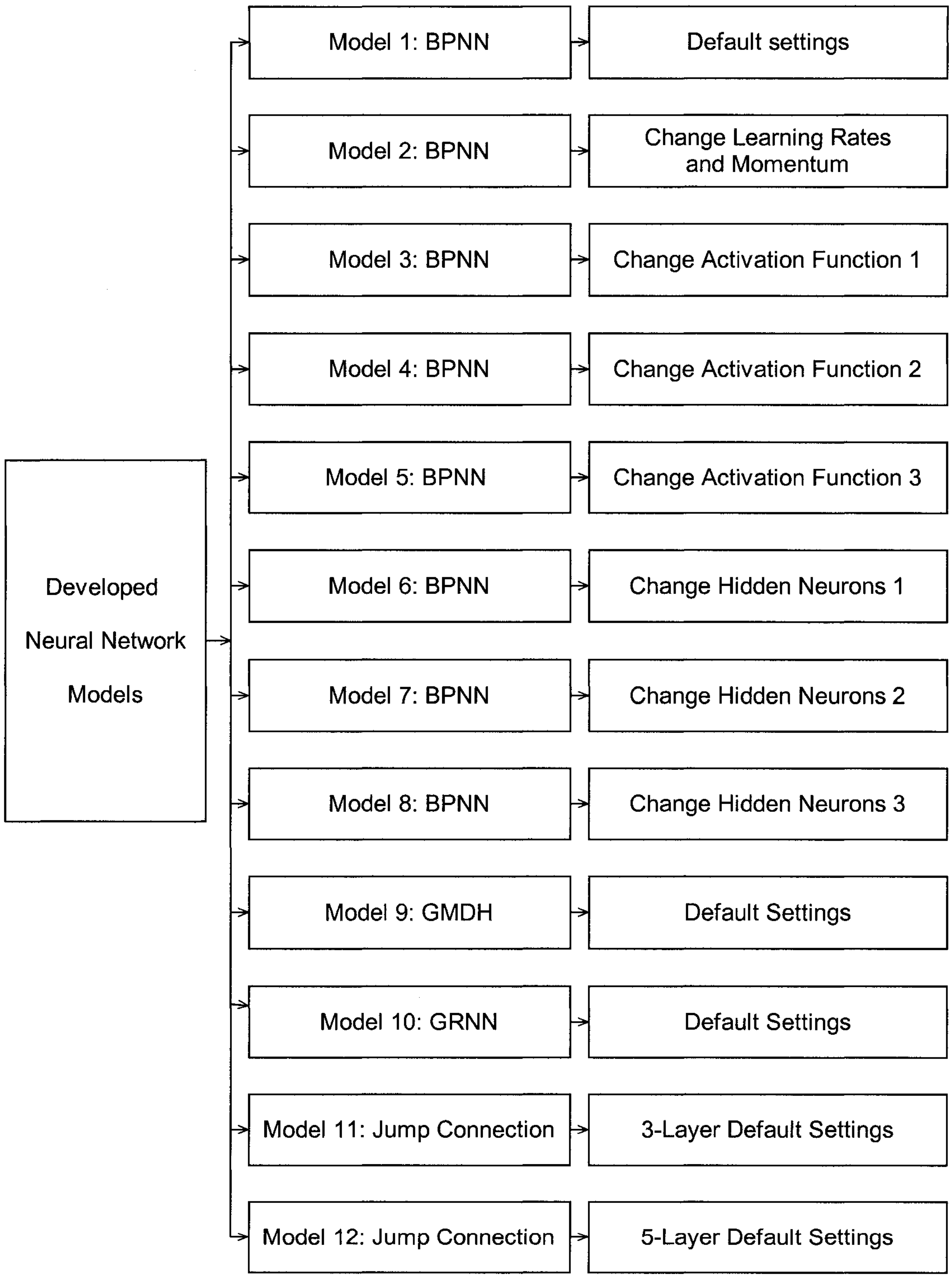

Figure 4.2 Developed neural network-based models

Figure 4.3 shows the structure of selected BPNN models from Model 1st to Model 8th.

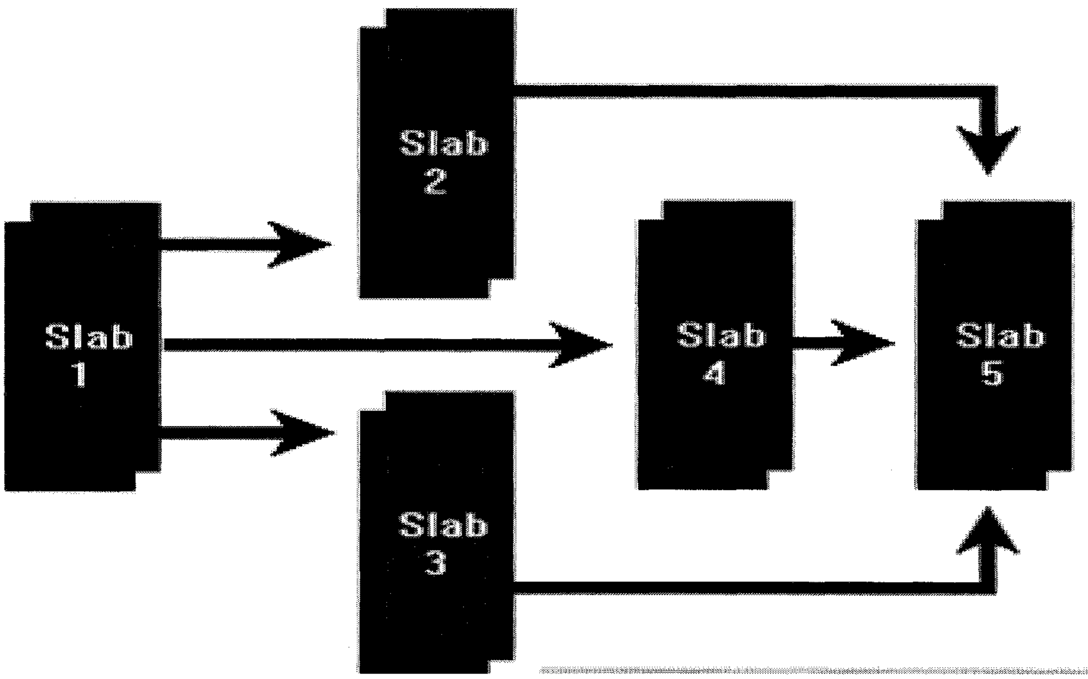

Figure 4.3 The structure of BPNN paradigm in NeuralShell2

Figure 4.4 is the structure of the Model 9th in neural network.

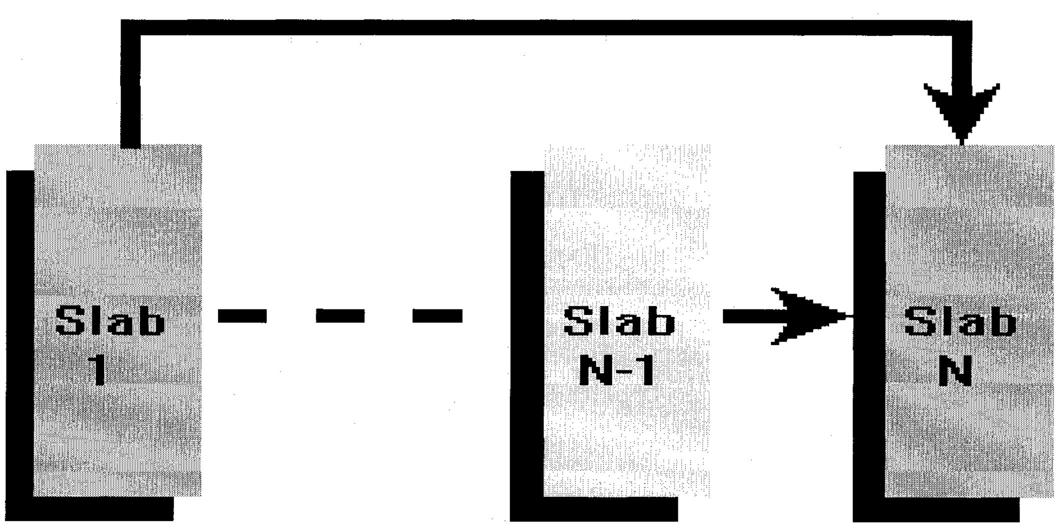

Figure 4.4 The structure of GMDH paradigm in NeuralShell2

Figure 4.5 is the structure of Model 11th GRNN in neural network.

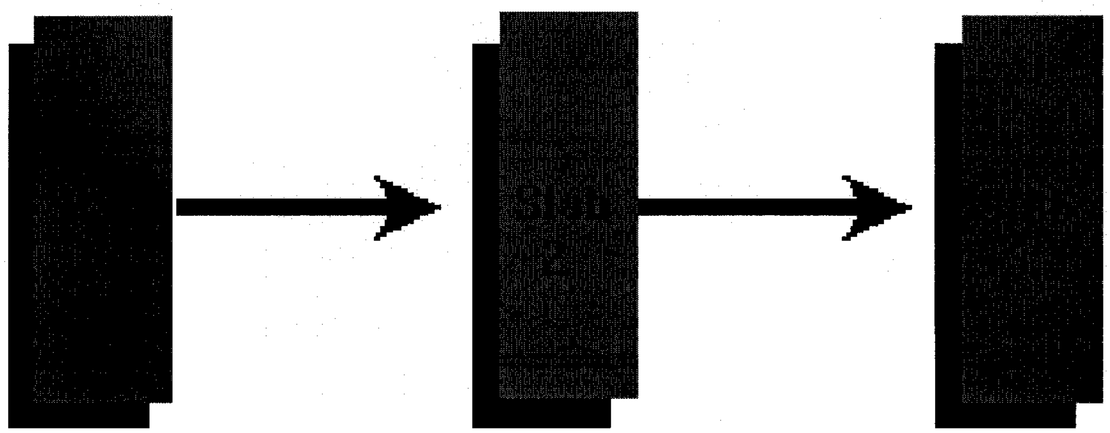

Figure 4.5 The structure of GRNN paradigm in NeuralShell2

Figure 4.6 shows the structure of 3-layer jump connection paradigm in neural network.

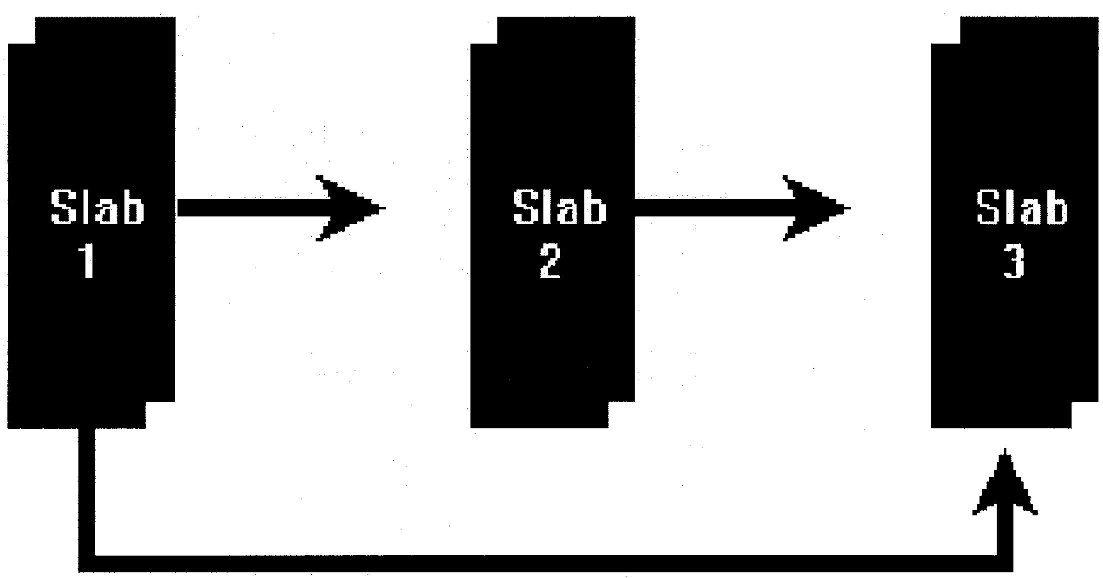

Figure 4.6 The structure of 3-layer jump connection paradigm in NeuralShell2

Figure 4.7 shows the structure of 5-layer jump connection paradigm in neural network.

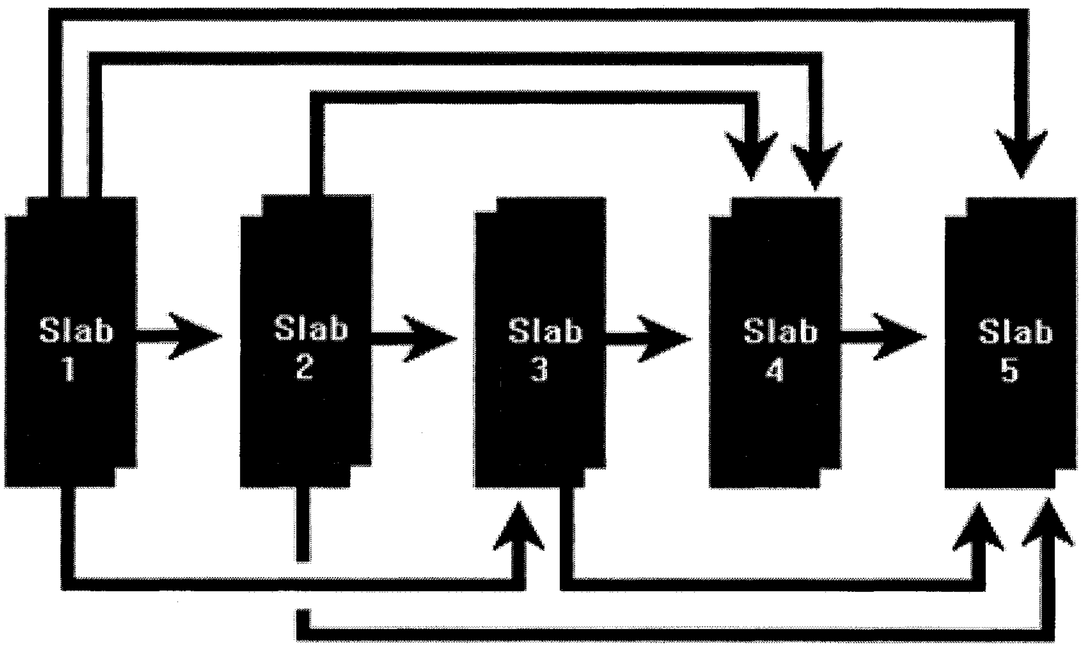

Figure 4.7 The structure of 5-layer jump connection paradigm in NeuralShell2

4.3.2 Detailed Information of the Developed Models

In this section, comparison information among selected BPNN models, the GMDH model, and the GRNN model is provided.

4.3.2.1 BPNN models

The general information about developed models 1^{st} to 8^{th}, 11^{th} and 12^{th} are given as follows. The detailed information of selected Model 5^{th}, GMDH model 9^{th} and GRNN model 10^{th} will be discussed later as a comparison. Table 4.1 is detailed statistic results of the developed models.

Table 4.1 Outlined statistic results of the developed models

Parameters	Model- 1	Model- 2	Model - 3	Model- 4	Model - 5	Model - 6	Model - 7	Model - 8	Model - 11	Model - 12
R squared:	0.9472	0.9477	0.9517	0.9477	0.9559	0.9551	0.9473	0.9476	0.9375	0.9397
r squared:	0.9487	0.9502	0.9528	0.9486	0.9561	0.9564	0.9485	0.9495	0.9381	0.9399
Mean squared error:	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.003	0.003
Mean absolute error:	0.039	0.039	0.038	0.039	0.037	0.036	0.04	0.039	0.044	0.043
Min. absolute error:	0	0	0	0	0	0	0	0	0	0
Max. absolute error:	0.139	0.139	0.133	0.143	0.15	0.178	0.165	0.15	0.164	0.145
Correlation coefficient r:	0.974	0.9748	0.9761	0.9739	0.9778	0.978	0.9739	0.9744	0.9686	0.9695
Percent within 5%:	39.367	37.557	33.484	36.652	33.937	36.652	34.389	33.937	30.317	30.769
Percent within 5% to 10%:	23.529	25.792	32.127	27.602	29.412	33.032	27.602	30.317	26.244	25.339
Percent within 10% to 20%:	27.149	26.244	22.624	25.792	25.792	19.005	27.602	23.982	31.222	30.769
Percent within 20% to 30%:	5.43	4.525	5.882	5.43	7.24	5.882	4.525	7.692	6.787	8.597
Percent over 30%:	3.62	4.977	4.977	3.62	2.715	4.525	4.977	3.167	4.525	3.62

1) Model 1^{st}:

Network settings: Model type – formwork

Network type – BPNN multiple-layer ward network, all default settings.

2) Model 2^{nd}

Network settings: Model type – formwork

Network type – BPNN multiple-layer ward network. Change learning rates (0.05) and momentum (0.5).

3) Model 3rd

Network settings: Model type – formwork

Network type – BPNN multiple-layer ward network. Change activation function (1st – Gaussion, 2nd –Tanh, output – Logistic).

4) Model 4th

Network settings: Model type – formwork

Network type – BPNN multiple-layer ward network. Change activation function (1st and 2nd – Gaussion, output – Logistic).

5) Model 5th

Network settings: Model type – formwork

Network type – BPNN multiple-layer ward network. Change activation function (1st and 2nd – Tanh15, output – Linear).

6) Model 6th

Network settings: Model type – formwork

Network type – BPNN multiple-layer ward network. Change the number of hidden neurons (6 each in the1st hidden layers, 7 in the 2nd hidden layer).

7) Model 7th

Network settings: Model type – formwork

Network type – BPNN multiple-layer ward network. Change the number of hidden neurons (4 each in the hidden layers).

8) Model 8th

Network settings: Model type – formwork

Network type – BPNN multiple-layer ward network. Change the number of hidden neurons (5 each in the 1st hidden layers, 9 in the 2nd hidden layer).

9) Model 11th

Network settings: Model type – formwork

Network type – 3-layer jump connection network. All default settings.

10) Model 12^{th}

Network settings: Model type – formwork

Network type – 5-layer jump connection network. All default settings.

4.3.2.2 Detail Information of Model 5^{th} (shown the best results)

1) Network Settings

Model type: formwork

Network type: BPNN 3-layer ward network, activation function changed

2 hidden layers: both Tanh15.

Output: Linear

Number of neurons: Input - 7, Hidden layer - 5 each, Output - 1

Scaling function: none (data normalized)

The outputs and the error percentage for 221 used data points are listed in Appendix 3.

2) Weights' Values

The values of the weights in the links of the network are as shown in Table 4.2.

Table 4.2 The values of the weights of the BPNN

Link 1							
-0.723357	-0.207236	-0.290415	-0.360953	-0.002547	-0.208412	-0.342658	-0.222191
0.4112264	0.1654138	0.4022115	-0.11449	0.1340289	0.6640693	0.2057558	-0.012829
-0.660802	-0.124578	0.1704701	-0.196059	-0.520137	0.1706002	-0.162821	-0.372421
0.5882308	0.5345358	0.118877	0.0413532	-0.274033	0.6208663	0.0942089	-0.103598
-0.371198	-0.103093	-0.209106	-0.295176	-0.521703	-0.295294	-0.424389	-0.200676
Link 2							
0.1801399	0.0631129	0.1791223	0.288391	0.3484478	0.053457		
Link 3							
0.3478898	0.4332756	-0.045339	-0.127712	0.0155521	0.4715784	0.1346214	-0.01872
-0.525934	0.2223374	-0.357858	0.1011264	-0.352542	-0.660565	0.2464696	0.314688
0.6157207	0.5162728	0.2665215	-0.156657	0.2399078	0.1244423	0.3086474	0.1681447
-0.628113	0.0937958	-0.539162	-0.596738	-0.043063	0.2885241	-0.323477	-0.555287
0.441011	0.1857477	0.0227396	0.3899595	0.0255873	0.7787446	-0.037384	-0.450558
Link 4							
-0.254511	0.0926768	-0.224202	-0.039699	0.4629777	0.3216838		
Link 5							
0.1344741	-0.29222	-0.244205	-0.495458	0.4179336	0.3618816	-0.127271	-0.384324
-0.579886	-0.165617	0.1531101	0.1506982	-0.195242	-0.550737	-0.154842	-0.376319
-0.626212	-0.189491	-0.086499	-0.089497	-0.299731	-0.506597	-0.016677	-0.06621
0.4403654	-0.045083	-0.158938	0.0103249	-0.317774	0.9976979	0.2341187	-0.233148
-0.685444	0.1149854	0.1670933	0.3244733	-0.098775	0.7333032	0.2220182	-1.666194
Link 6							
-0.035235	0.1968951	0.0761385	-0.101027	0.3863179	0.5847854		

3) Contribution Factors

The contribution factors are as listed in Table 4.3.

Table 4.3 Contribution factors of BPNN

Contribution factors	
DW	0.27598
D	0.20727
Type	0.11469
Method	0.1081
%	0.10424
GS	0.10081
S	0.08892

4) Statistical Parameters

Statistical parameters reveal the performance of the developed model (Table 4.4).

Table 4.4 Statistical parameters of BPNN model

File name: H:\BPNN fw changed AF-3\BPNN changed AF-3.pat			
Patterns processed	221	Max. absolute error	0.15
Output	C1	Correlation coefficient r	0.9778
R squared	0.9559	Percent within 5%	33.937
r squared	0.9561	Percent within 5% to 10%	29.412
Mean squared error	0.002	Percent within 10% to 20%	25.792
Mean absolute error	0.037	Percent within 20% to 30%	7.24
Min. absolute error	0	Percent over 30%	2.715

4.3.2.3 GRNN Model

1) Table 4.5 shows information of GRNN settings. Network outputs values and calculated error percentage are listed in Appendix 4.

Table 4.5 GRNN network settings

Network type	GRNN, genetic adaptive
Problem name	H:\GRNN\GRNN
Input file name	H:\GRNN\GRNN.pat
Number of inputs	7
Number of outputs	1
Number of training patterns	177
Number of test patterns	44
Patterns processed	221
Smoothing factor	0.2584706

2) Individual Smoothing Factors

Table 4.6 displays individual Smoothing factors (in ascending order).

Table 4.6 Individual smoothing factors of GRNN

Input Number	Input name	Individual smoothing factor
4	Method	0.09412
3	Type	0.30588
1	GS	0.49412
2	%	1.58824
6	S	2.67059
7	D	2.98824
5	DW	3

Note: GS - Gang Size, % - Labor Percentage, Type - Work Type, Method - Work Method, DW - Direct Work, S - Support Work, D – Delay

3) Statistical Parameters

Table 4.7 shows statistical parameters of GRNN model.

Table 4.7 Statistical parameters of GRNN model.

Factors	Values	Factors	Values
Current best smoothing factor	0.3827	Mean absolute error	0.039
Smoothing test generations	47	Min. absolute error	0
Last mean squared error	0.003887	Max. absolute error	0.202
Minimum mean squared error	0.003887	Correlation coefficient r	0.9765
Generations since min. ms. error	20	Percent within 5%	39.367
Output	C1	Percent within 5% to 10%	26.244
R squared	0.9433	Percent within 10% to 20%	23.529
r squared	0.9535	Percent within 20% to 30%	5.43
Mean squared error	0.003	Percent over 30%	5.43

4.3.2.4 GMDH Model

1). Network Settings

Table 4.8 shows information of GMDH network settings. Network outputs and calculated error percentage are listed in Appendix 5.

Table 4.8 GMDH network settings

Network type	Polynomial net (GMDH)
Problem name	H:\GMDH
Input file name	H:\GMDH.pat
Number of inputs	7
Number of outputs	1
Number of training patterns	177
Number of test patterns	0
Network type	GMDH
Patterns processed	221

2) Best Formula

Table 4.9 shows the best formula resulted from GMDH model. DW, S, and D are three most significant variables with great impact on output. Type and % are two less significant variables.

Table 4.9 Best formula resulted from GMDH model

Layers constructed	2
Best formula	Y= -0.89+1.6*X5+0.35*X5*X6-0.67*X5*X7 Legend: X1=G.S X2=% X3=Type X4=Method X5=DW X6=S X7=D Y=2.*Produc.-1.
Most significant variables	DW, S, D
Less significant variables	Type, %

3) Statistical Parameters

Table 4.10 shows statistical measures to indicate the performance of the developed model by GMDH paradigm.

Table 4.10 Statistical results of GMDH model

Output	C1
R squared	0.9525
r squared	0.9525
Mean squared error	0.0023
Mean absolute error	0.0372
Min. absolute error	0
Max. absolute error	0.1271
Correlation coefficient r	0.976
Percent within 5%	38.914
Percent within 5% to 10%	26.244
Percent within 10% to 20%	23.529
Percent within 20% to 30%	7.692
Percent over 30%	2.715

4.4 Regression Model

In order to validate the developed neural network model, a multiple regression model was developed through Microsoft Excel as follows:

$$LP = 0.04449 - 0.00658{*}V_1 - 0.04369V_2 - 0.03234V3 - 0.00479V4 + 0.79894V_5 + 0.13026V_6 - 0.07157V_7$$

Where: LP = labor productivity

V_1 = Value of variable 1 (Gang size)

V_2 = Value of variable 2 (Labor percentage)

V_3 = Value of variable 3 (Work type)

V_4 = value of variable 4 (Work method)

V_5 = Value of variable 5 (Direct work)

V_6 = Value of variable 6 (Support work)

V_7 = Value of variable 7 (Delay)

The performance of the developed regression model is shown in Table 4.11.

Table 4.11 Regression statistics

Regression Statistics	
Multiple R	0.971162374
R Square	0.943156357
Adjusted R Square	0.941288256
Standard Error	0.0531521
Observations	221

ANOVA

	df	SS	MS	F	Significance F
Regression	7	9.984406283	1.426343755	504.8744045	7.5018E-129
Residual	213	0.601756035	0.002825146		
Total	220	10.58616232			

4.5 Summary

In this chapter, neural network-based models were developed, and the best performance model has also been identified with released statistic parameters as well. At the end of this chapter, the regression model was developed associated with general information (for more statistical results, see appendix 6 to 8).

Chapter 5

Models Validation and Analysis

5.1 General

In this chapter, the selected neural network model will be validated through a verified regression model. Plotted analysis is then developed based on the validated neural network model.

5.2 Regression Model Validation

The developed regression model must be validated in order to compare it with the developed neural network model. If the model is proven to be valid, it can be used as comparison with the best performance neural network model. The validation can be performed through four steps: 1) overall model test, 2) independent variables test, 3) statistical parameters test, and 4) random error assumptions test (McClave et al. 1998).

1) Overall Model Test

The overall model test is performed to confirm whether the regression model is valid in predicting its dependent variable, i.e. the labor productivity. The analysis of variance (ANOVA) is used for the test (McClave et al. 1998). The hypothesis test involves the entire model's coefficients, also called β parameters:

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

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

Two conditions must be fulfilled in order to refuse the null hypothesis: 1) ANOVA F value must be greater than the critical value of F (i.e. $F > F_\alpha$), and 2) the level of significance 'α' must be greater than the corresponding P-value (i.e. α>P-value).

Accordingly, there would be sufficient evidence to reject 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 would occur when we reject a null hypothesis when it is true, while a type II error would occur when we accept a null hypothesis when it is false. The value of α is usually set to 0.05 (McClave et al. 1998).

The F value which is given by Excel is calculated using the following equation.

$$F = \frac{\text{Mean Square of Model}}{\text{Mean Square of Error}} = \frac{SS(Model)/k}{SSE/[n-(k+1)]} \qquad \text{(Eq. 5.1)}$$

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

SSE= Sum of the Squared Errors

n = Number of Observations

k = Number of parameters in the model (independent variables) excluding β_0

F_α value is derived from the corresponding statistical tables of the critical F values (see Appendix 9) as function of numerator degrees of freedom (k) and the denominator degrees of freedom [n- (k+1)]. The P- value is already given by Excel. The following Table 5.1 illustrates that the ANOVA F value is greater than F_α. We therefore have sufficient evidence to reject H_0 and to conclude that at least one of the independent variable coefficients (β_S) is non-zero (McClave et al. 1998).

Table 5.1 ANOVA F-Test for the developed regression model

n	k	α	F	F_α	P-value	Evaluation
221	7	0.05	504.8744	2.05	7.5018E-129	Passed

n: number of data points

k: number of parameters

α: level of significance

F: ANOVA value

$F\alpha$: critical value

2) Independent Variable Test.

The independent variables test checks whether or not the β coefficients are capable of representing the dependent variable. It is tested through one or more tests on the coefficients. The number of tests 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 H_a, it implies that the independent variable 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) (McClave et al. 1998).

The t value is given by Excel and can be calculated by equation as follows:

$$t = \frac{\beta_k \left(\sum y^2 - \frac{\left(\sum y^2\right)}{n} \right)}{s} \quad \text{(Eq. 5.2)}$$

Where: β_k = the value of the coefficient (β parameter)

S = the standard deviation error of the factor

y = the variable's data

n = the number of observations.

The critical value of t for the two tailed test ($t_{\alpha/2}$) is driven from the corresponding tables (see Appendix 10) as a function of: 1) $t_{0.025}$ (i.e. $t_{\alpha/2}$), and 2) the denominator degrees of freedom [n- (k+1)].

As shown in Table 5.2, most independent variables' t-statistics are greater than $t_{\alpha/2}$. Therefore, the test concludes that the independent variables contribute to the prediction of the dependent variable (i.e. labor productivity).

Table 5.2 Independent variable test of the regression model

Input Parameter	Standard Error	n	k	α	T	$t_{0.025}$	P-value	Evaluation
Intercept	0.13372				0.33275		0.73965	Fail
X Variable 1	0.01254				-0.52497		0.06001	Fail
X Variable 2	0.02795				-2.56318		0.01194	Pass
X Variable 3	0.01461	221	7	0.05	-2.41330	2.365	0.02794	Pass
X Variable 4	0.01049				-4.57720		0.00647	Pass
X Variable 5	0.12241				6.52649		4.83985E-10	Pass
X Variable 6	0.03757				3.46688		0.00064	Pass
X Variable 7	0.13139				-0.54476		0.58649	Fail

3) Statistical Parameters Test

The statistical parameters test is performed in this step in order to evaluate the strength of the developed model. There are several statistical parameters that have been shown in the developed model that could be chosen for the statistical parameters test. Here, the coefficient of multiple determination (R^2) was selected for the test. This value can be calculated by the following equation (McClave et al. 1998):

$$R^2 = \frac{SST - SSE}{SST} = \frac{SSR}{SST} \qquad \text{(Eq. 5.3)}$$

Where: SSR = [SST] - [SSE]

$SSR = [\Sigma(y - \bar{y})^2] - [\Sigma(y - \hat{y})^2]$

$\hat{y}$ = Predicted value of output

$\bar{y}$ =Average value of the output

The value of determination varies between 0 and +1. A regression model with a high R^2 (i.e. > 0.50) provides a better ability to predict the dependent variable (McClave et al. 1998). The R^2 value of the developed model is .0943156; that is much higher then the required value which is 0.50.

4) Random Error Assumption Test

The random error (Є) represents the difference between the actual values and the predicted values. The first assumption to be fulfilled in the test is that the mean of Є equals 0. This assumption is violated if the model is misspecified. The values of the independent values (x) are plotted against the corresponding residuals ($y - \hat{y}$) to detect the misspecification of the model. Plots of residuals against each variable indicate the distribution of the residuals as a function if the variables. There should be no discernible trend in the plot versus any variable, only a random scatter of points about the horizontal line of 0. Such a horizontal band of residuals would be an indicator that the specification is satisfactory (Gunst and Mason, 1980). Figures 5.1 to 5.7 depict the residual plots of the developed regression model. There are no systematic patterns in any of the graphs.

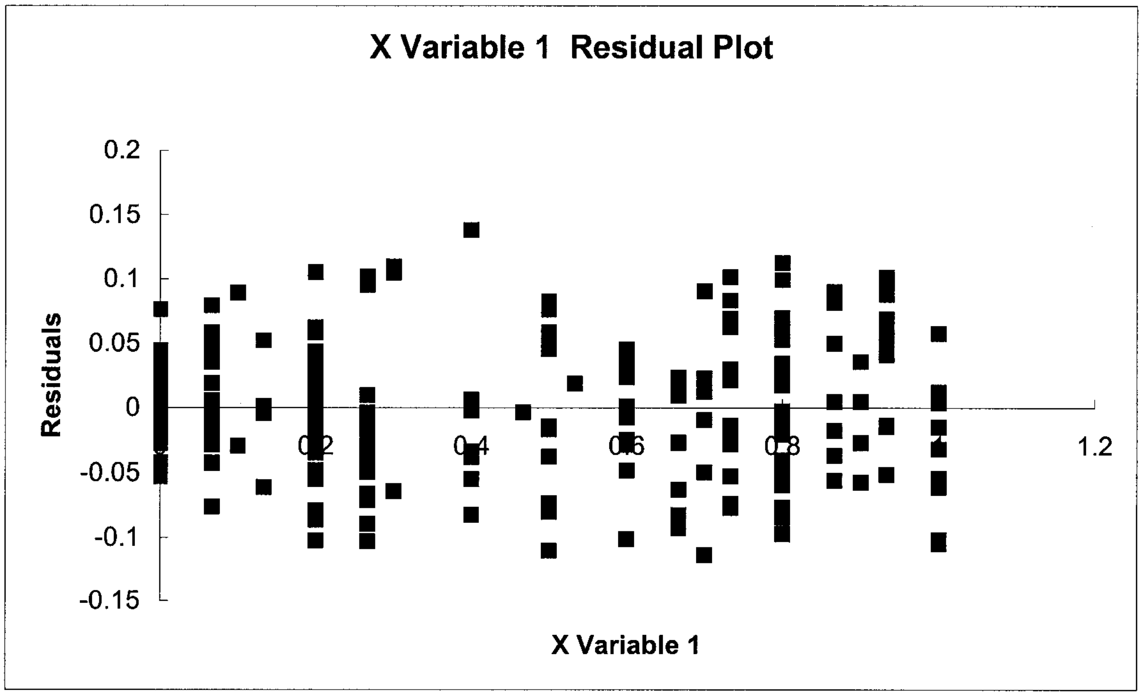

Figure 5.1 Variable 1 (Gang Size) residual plot

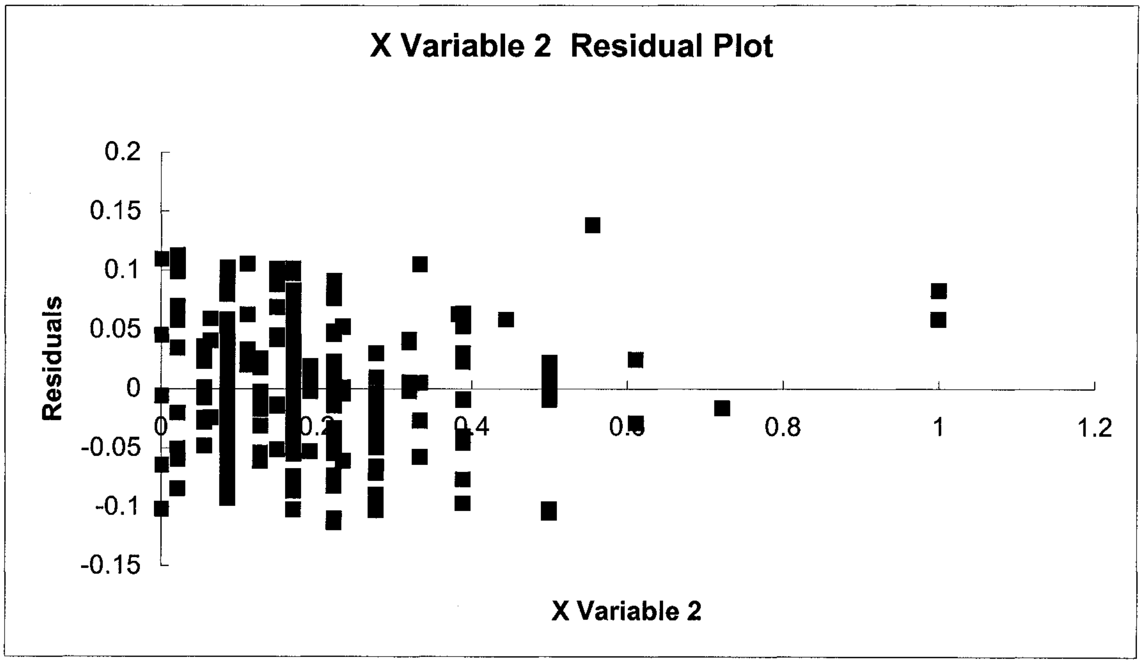

Figure 5.2 Variable 2 (Labor Percentage) residual plot

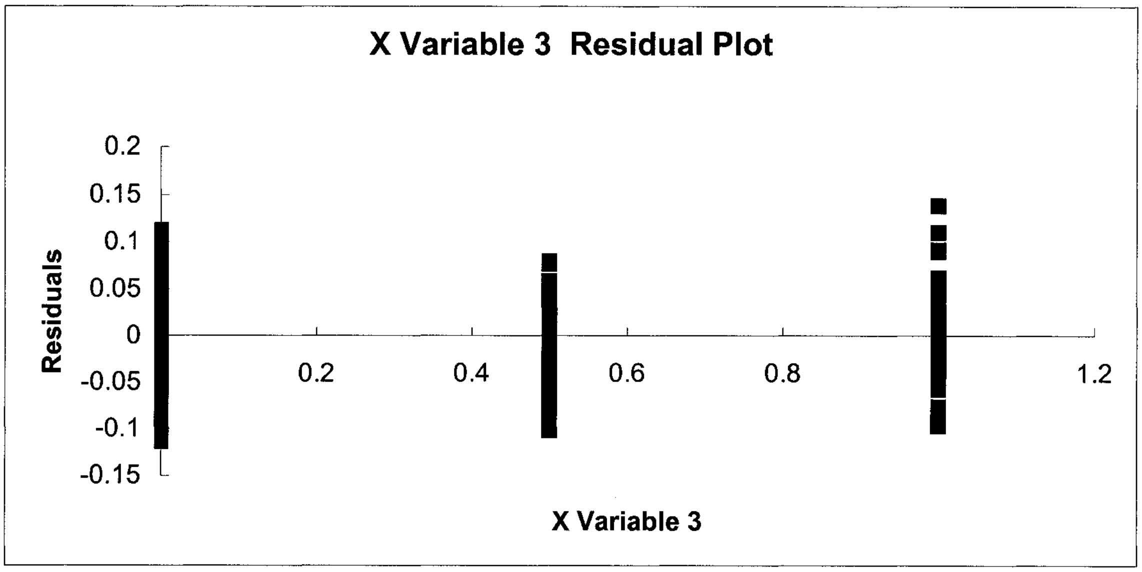

Figure 5.3 Variable 3 (Type) residual plot

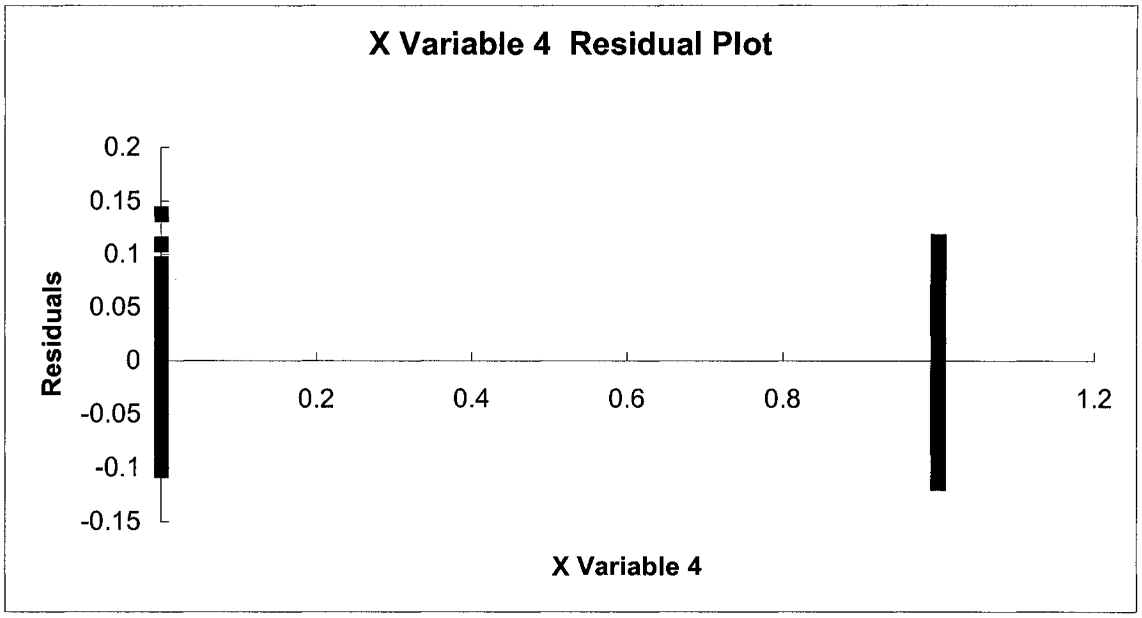

Figure 5.4 Variable 4 (Method) residual plot

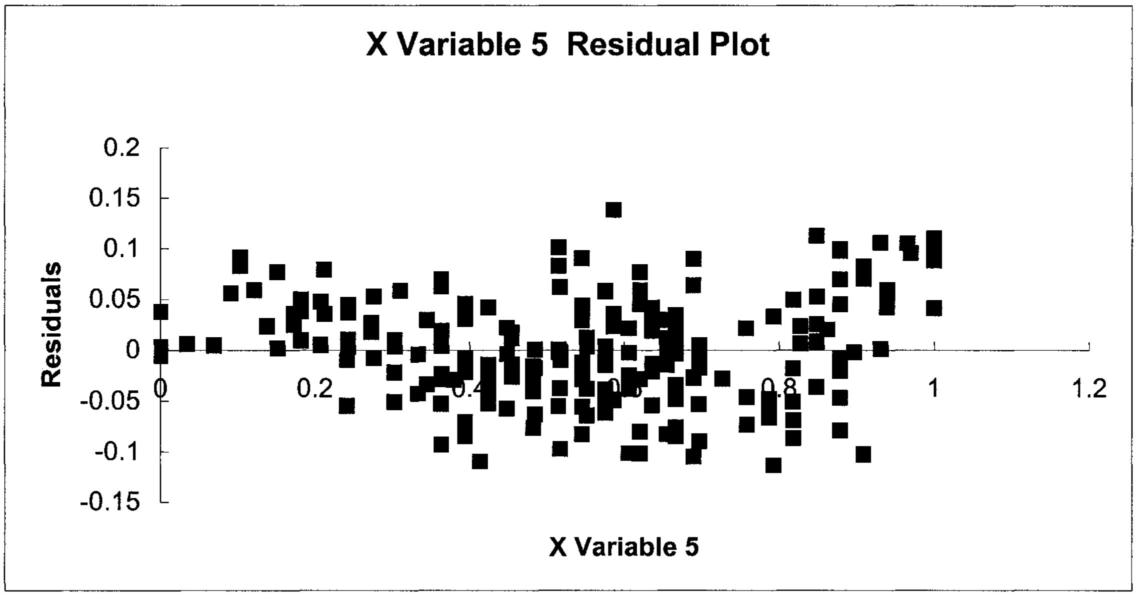

Figure 5.5 Variable 5 (Direct Work) residual plot

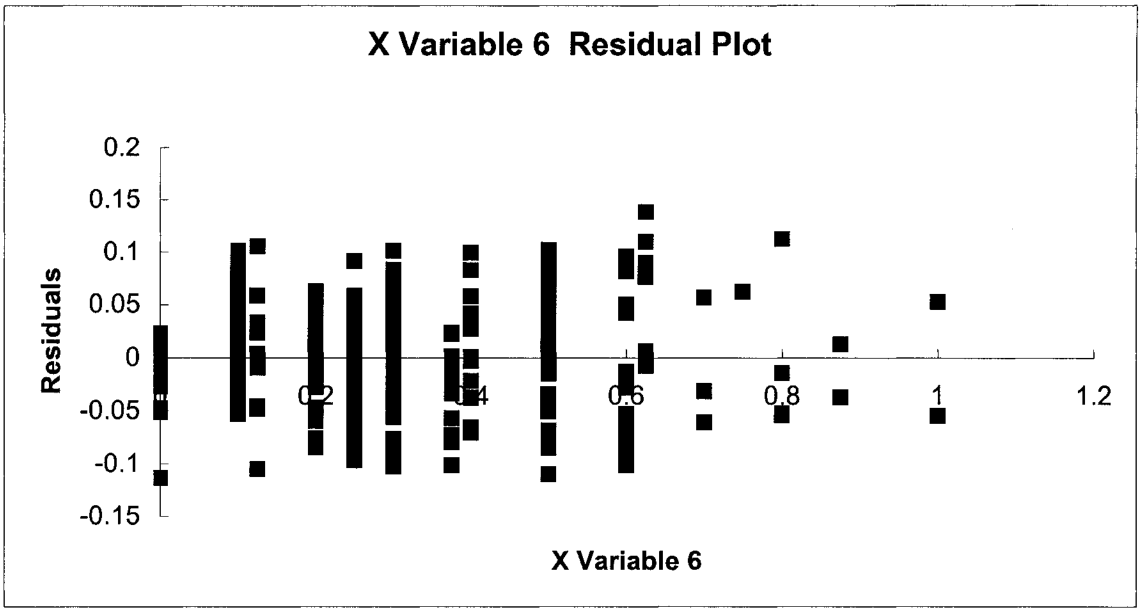

Figure 5.6 Variable 6 (Support Work) residual plot

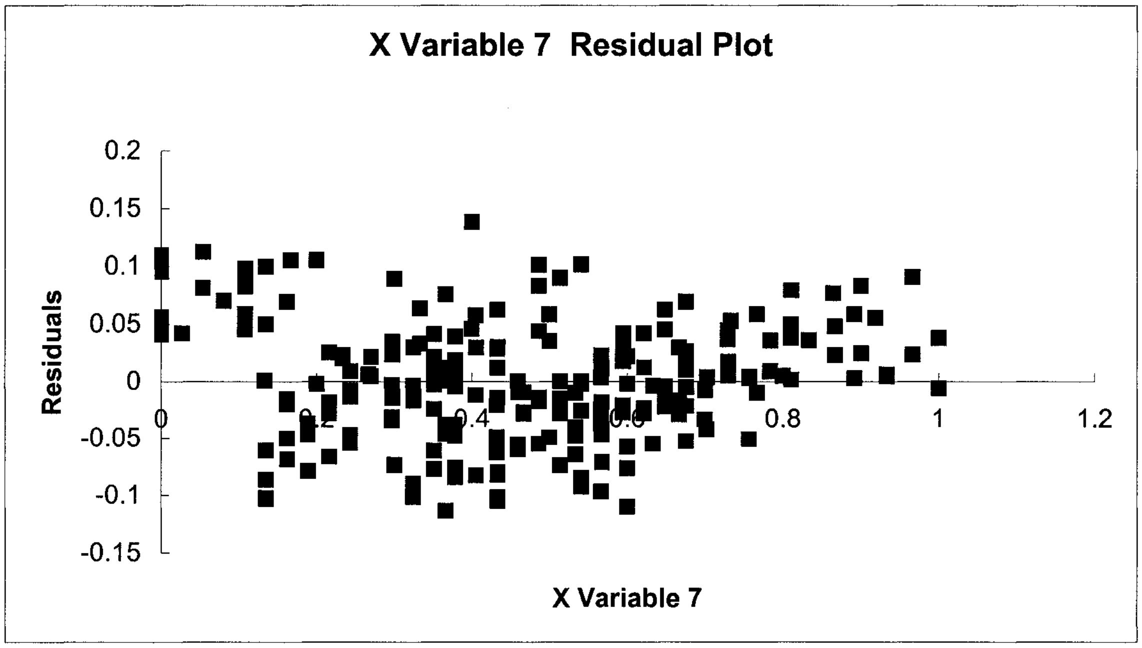

Figure 5.7 Variable 7 (Delay) residual plot

As shown in the above figures, no specific pattern was formed in the developed regression model, which implies that the model was not misspecified.

On the other hand, the assumption that the probability distribution of Є is normal is to be tested. Output data values are plotted against the frequency of their occurrence, the distribution should be a bell shape (McClave et al, 1998). As shown in Figure 5.8, although the probability plot is not a bell shape here, this doesn't affect the relevancy of the model (McClave et al, 1998). This implies that the developed model needs more data.

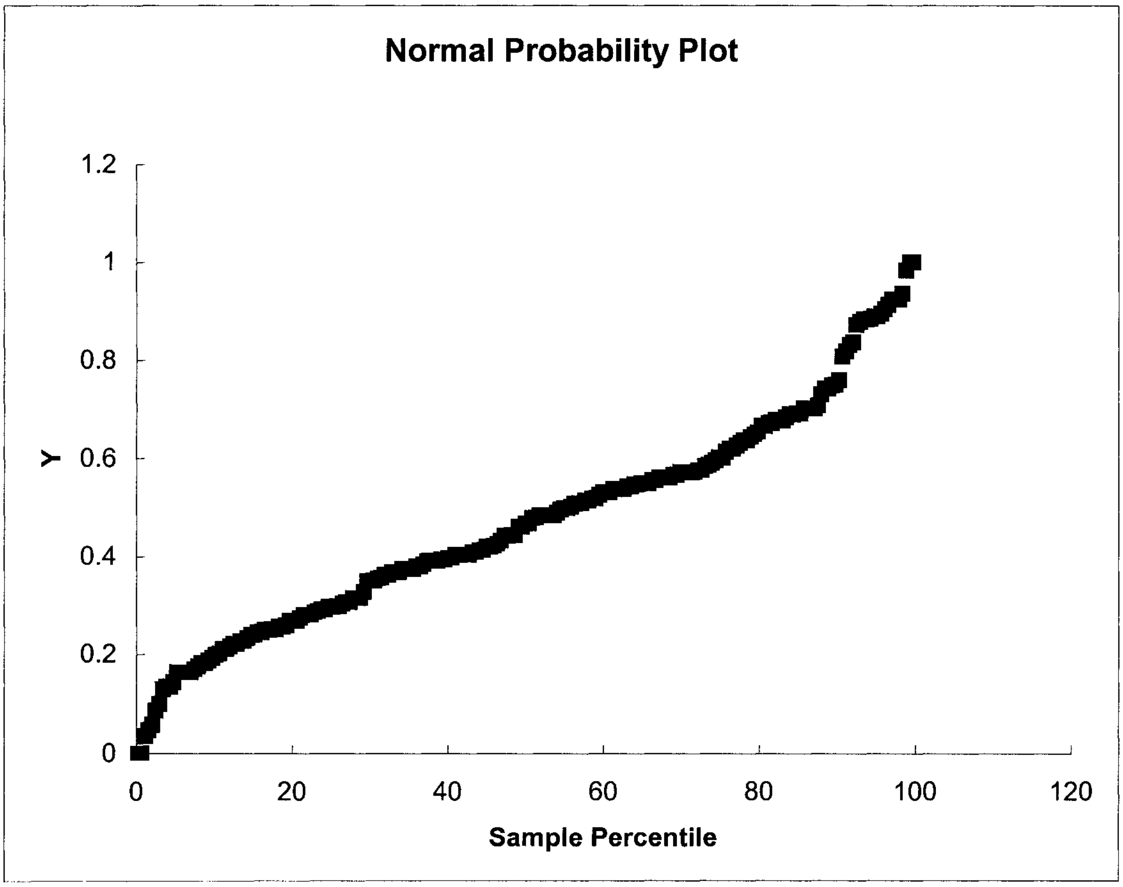

Figure 5.8 Normal probability plot

The performance of the developed regression model is validated since the model has successfully passed the above tests.

5.3 Neural Network Model Validation

In this step, the selected neural network-based model with the best performance will be compared to the validated regression model in order to validate the performance of the neural network model. The values of three parameters in the two models are compared.

Table 5.3 Performance comparison of the two developed models

Performance Measure	Neural Network Model	Regression Model
R-Squared	0.9559	0.9431
MSE	0.002	0.0027
MAE	0.037	0.0415

As shown in Table 5.3, the performance parameters of the neural network-based models are better than the validated regression model. The neural network model is therefore validated as well.

5.4 Plotted Analysis of Independent Variables' Impact on Labor Productivity

The analysis was developed based on the validated neural network model in the same order as the input data sheet. In order to get interrelationship among input parameters and output value, i.e. productivity, neural network is applied first to reveal the interrelationship. Every input parameter is normalized between 0 and 1 like model development step. Only one parameter's normalized actual value is selected while keeping other six parameters in average value. Therefore, interrelationship between every parameter and productivity is derived by applying neural network.

5.4.1 Gang Size (GS) vs. Productivity

Increase in the size of the labor force reduces productivity. The amount of the reduction depends on whether the increase is planned or unplanned. In general, the published data shows that productivity on big sites is lower than productivity on little ones. An unplanned 25 per cent increase in the size of the labor force would reduce productivity by 10 per cent (Horner and Duff, 2001). The curve in Figure 5.9 has shown the impact of parameter gang size on productivity. There should be a certain number of workers in a group to complete formwork installation. All workers must co-operate well in order to get good performance, i.e. optimized productivity. However, this number has an optimum value. It would be ineffective if the number in the group exceeded this optimum value since the over-sized group could result in congestion and unproductive activities. As shown in Figure 5.9, productivity value reaches the highest level 0.4475 at gang size value 0.4. Productivity performance goes down when the gang size is greater than the point 0.4. There is a reasonable explanation to disclose this change. Group could not perform well if group lacks work force. On the other hand, group can't work in high efficiency if it is oversized. In Figure 5.9, actual value range of normalized gang size is between 8 and 24; actual value range of normalized productivity is between 0.82 and 2.53.

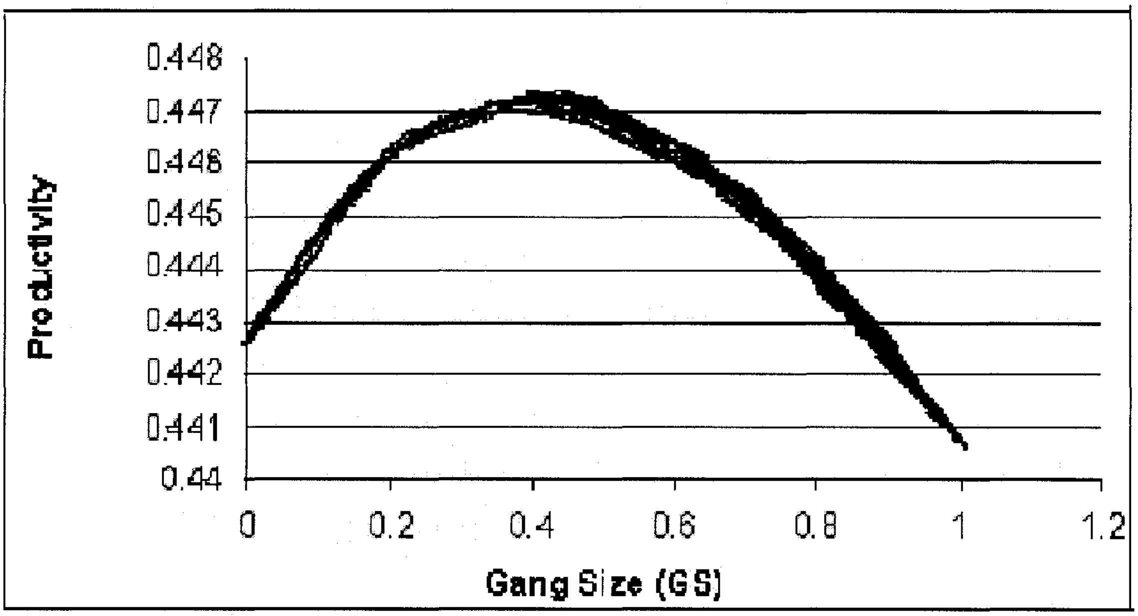

Figure 5.9 Gang Size (GS) vs. Productivity

5.4.2 Labor Percentage (%) vs. Productivity

Usually, both skilled and unskilled labors provide support each other. However, increased labor percentage doesn't imply productivity will be certainly increased. In this study, as shown in Figure 5.10, productivity goes down with the increase of labor percentage within the range between 29% and 47%. This implies labor percentage between 29% and 47% is negative to productivity. Figure 5.10, actual value range of normalized labor percentage is between 29 and 47; actual value range of normalized productivity is between 0.82 and 2.53.

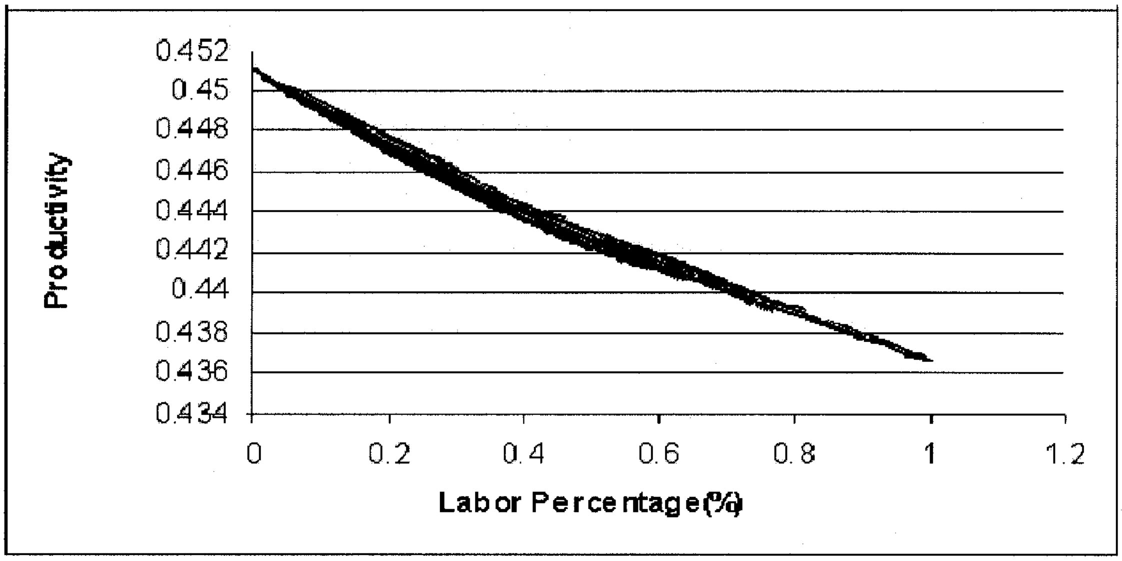

Figure 5.10 Labor Percentage (%) vs. Productivity

5.4.3 Work Type (T) vs. Productivity

In this study, work type is coded as: 1) column is 1, 2) wall is 2, and 3) slab is 3. In construction, workers have the highest productivity when working on slab formwork installation because installation performed on slab gives installers more space, easy access and a relatively fast and easy connection. Workers performing column formwork installation are less productive because of smaller pieces and connections in column formwork (as shown in Figure 5.11). In Figure 5.11, actual value of normalized work type is 1, 2, or 3; actual value range of normalized productivity is between 0.82 and 2.53.

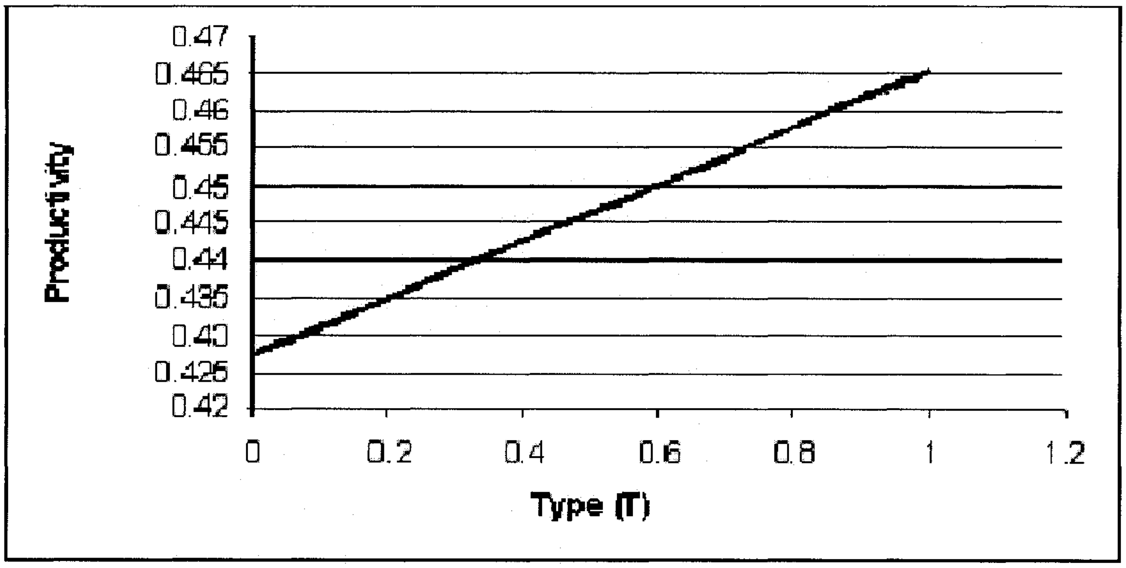

Figure 5.11 Type (T) vs. Productivity

5.4.4 Method (M) vs. Productivity

Traditional formwork and flying formwork, which coded as 1 and 2 respectively, are two work methods in this thesis. As shown in Figure 5.12, the straight line discloses that flying form method in construction could result in higher productivity than traditional formwork. In Figure 5.12, actual value of normalized work method is 1 or 2; actual value range of normalized productivity is between 0.82 and 2.53.

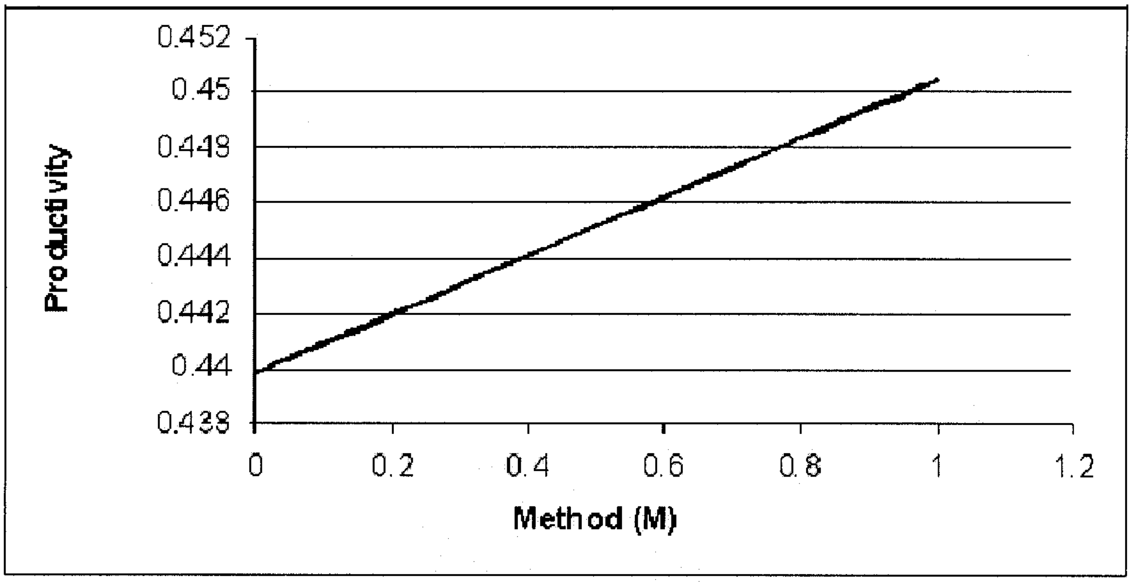

Figure 5.12 Method (M) vs. Productivity

5.4.5 Direct Work (DW) vs. Productivity

Direct work is productive work that has a great contribution to productivity. Productivity will be increased with the increase of direct work since it is positive to productivity (as shown in Figure 5.13). In Figure 5.13, actual value range of normalized direct work is between 53 and 86; actual value range of normalized productivity is between 0.82 and 2.53.

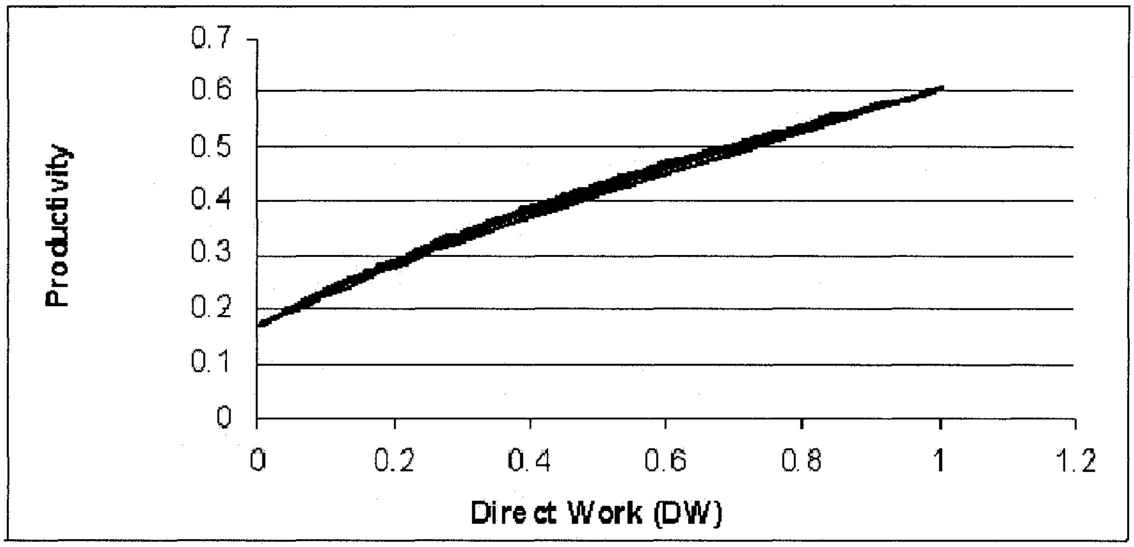

Figure 5.13 Direct Work (DW) vs. Productivity

5.4.6 Support work (S) vs. Productivity

There is the most complicated interrelationship to be discussed between these two factors. Theoretically, support work is necessary in a group to provide assistance to the direct work. Adequate support work is necessary to achieve a higher productivity. A certain group can't obtain unlimited support form outside, i.e. some group members will perform supporting work instead of performing direct work. Therefore, a potential conflict exists because more supporting work implies some workers may be withdrawn from direct work. In this case, supporting work increase is negative to productivity. However, if supporting work increases because of decrease of delay level, productivity performance will be improved accordingly.

In this study, as shown in Figure 5.14, the curve appears a U shape. The most intensive section is left part of the curve, which shown productivity goes down with the increase of supporting work. This implies a majority of increases of supporting work is because of decrease of direct work level in the selected cases. In Figure 5.14, actual value range of normalized support work is between 2 and 13; actual value range of normalized productivity is between 0.82 and 2.53.

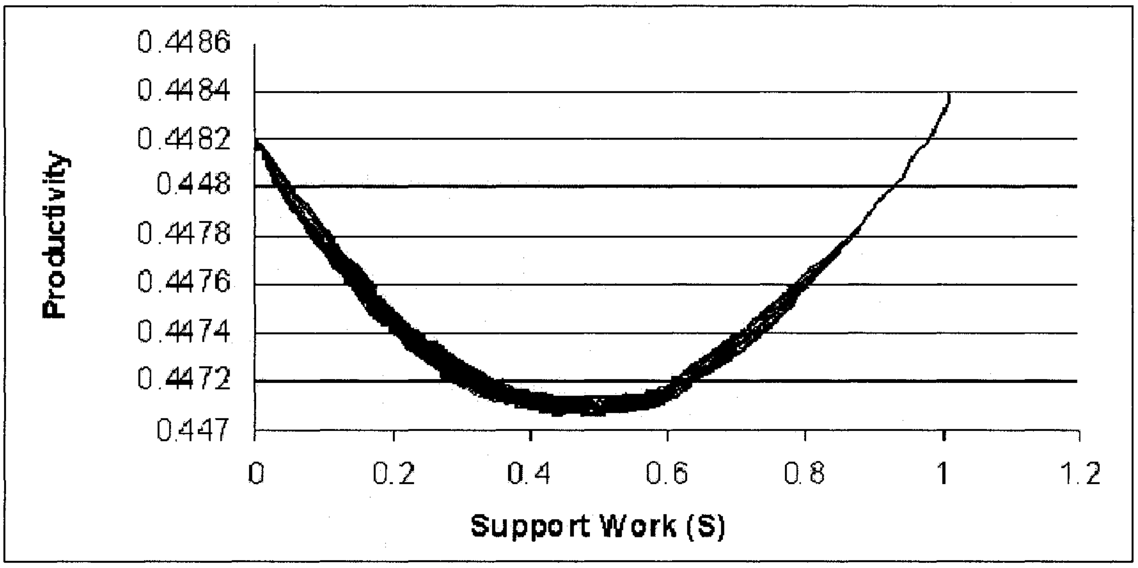

Figure 5.14 Support (S) vs. Productivity

5.4.7 Delay (D) vs. Productivity

Delay includes all non-productive activities that are negative to productivity. As shown in Figure 5.15, productivity will go down with the increase of delay. In Figure 5.15, actual value range of normalized delay is between 6 and 43; actual value range of normalized productivity is between 0.82 and 2.53.

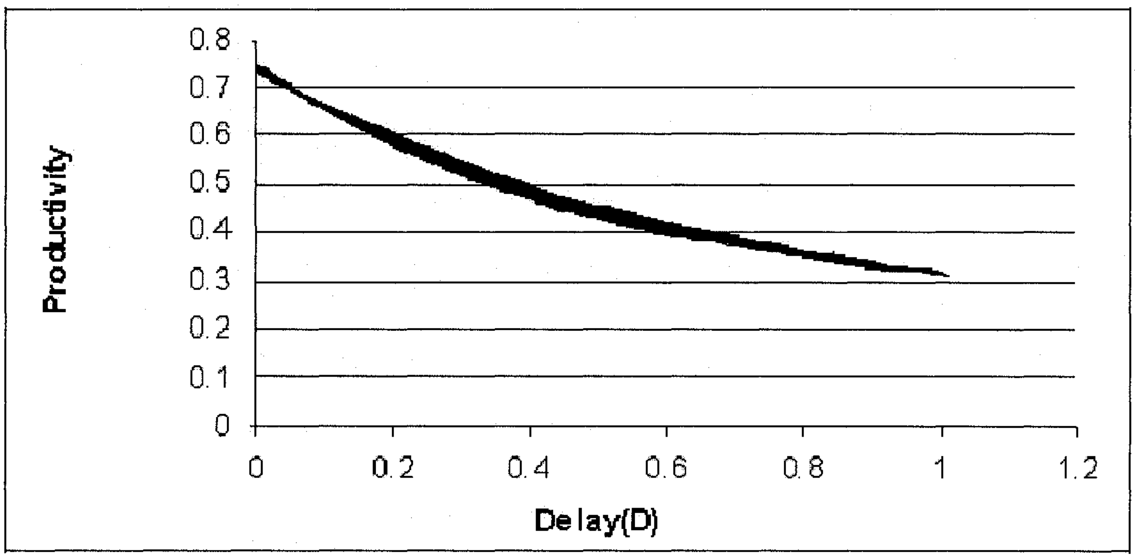

Figure 5.15 Delay (D) vs. Productivity

5.5 Summary

In this chapter, the regression model was first verified, and the model passed several tests to confirm its validity. Hence, the neural network-based model was validated through comparison with verified regression model. Finally, analysis of the impact of the involved independent variables on productivity performance was performed. The analysis has revealed interrelations among input parameters and output parameter, i.e. productivity.

Chapter 6

Conclusion

6.1 Summary and Concluding Remarks

The performance of on-site labor productivity is a major issue in construction activities. Field investigation was carried out in this study on three selected building construction projects. These projects are Richard J. Renaud Science Complex of Concordia University, Engineering, Computer Science and Visual Arts Complex of Concordia University, and a condominium style residential building on Rene-Levesque Street.

Data collection from three construction sites includes piling, excavation and earthmoving, blasting, shoring and lagging, reinforcing bars, formwork, and concrete pouring. In on-site observation, work sampling method was used to collect data from three construction sites. Formwork data was analyzed for models development purpose.

Neural network was used in this study to develop a productivity performance-evaluating model based on the work sampling method, in order to reveal impacts of involved factors on on-site labor productivity performance. Three groups of neural network-based models were developed in this study. In category, they are the back propagation paradigm of neural network (BPNN) models, the GRNN model, and the GMDH model. Twelve models were developed totally. BPNN Model 5th shows the best performance in twelve developed models; therefore, this model was selected for analysis of parameters impacts on labor productivity. Meanwhile, a regression model was developed as well in order to validate selected neural network-based model. After verification of regression model, the selected neural network-based was validated through comparing to the verified regression model. According to the validation, the developed model's performance is better than that of the regression model.

Analysis of independent variables' impacts on labor productivity was done by applying validated model. Seven independent variables are gang size (GS), labor percentage (%), work type (T), method (M), direct work (DW), support work (S), and delay (D), respectively. The purpose of this study is to gain an insight into impacts of seven input parameters on labor productivity of formwork installation through work sampling method. The impacts of labor percentage (%), work type (T), method (M), direct work (DW) and delay (D) on labor productivity are straightforward; gang size (GS) and support work (S) have relatively complicated impacts to labor productivity performance, and the complexities were discussed in the study.

6.2 Recommendations

The developed model and analysis in this study is for formwork installation. It provides a view to model labor productivity of formwork installation. Similarly, other models could be developed to provide analysis function for piling, shoring and lagging, blasting, reinforcing bars, concrete pouring, mechanical and electrical installation, etc. based on real projects data obtained from field investigation using work sampling method. Developed model can be used to analyze how involved factors influence labor productivity, and provides an assistant method to management to improve on-site productivity.

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APPENDICES

Appendix 1

Craftsmen's Questionnaire (Oglesby et al. 1989)

This voluntary, anonymous questionnaire is a follow-up form on this project. The purpose of the study is to find the problems that affect on-site productivity. We want to identify what you feel is good for your job and what you feel needs improvement.

Please don't leave any blank in the questions. For example, if you answer "Yes" to a question about a delay source, then place your best estimate of the hours spent waiting in the blank for the related number of hours lost. If you answer "No", place a zero (0) in the space for number of hours lost.

You are welcome to use the back of the questionnaires if you need more space to add your comments for some important concerns of yours has been left out of this questionnaire.

This questionnaire is only for our study, not for evaluation of your performance. We will be very careful not to disclose your individual identity, and we assure you that no one but we as productivity students will see the questionnaire. Thank you in advance for your help!

1. Under what craft designation or jurisdiction do you work?
   _____Carpenter _____Steel worker _____Form worker
   _____Other: specify___________________________

2. What kind of work does your crew do?

3. What do you like about your job?

4. What do you like least about your job?

MATERIALS

5. How many hours per week would you estimate you spend waiting for

materials, getting materials from somewhere else, or moving to a different area because materials are not available at all?
_________Hours per week

6. In your opinion, what materials are in short supplies at present?

TOOLS

7. Are the tools supplied to you the best ones for the job? Yes___ No___
   If the answer is No, what tools would you recommend?

8. Do you often have to stop work, wait, or move to another spot because you do not have the tools you need?
   _______Yes _______No

9. How many hours per week would you estimate you spend waiting for suitable tools, getting tools, or moving to a different area because no tools are available?
   _________Hours per week

10. What specific tools are in short supplies?

11. What consumable items are in short supplies?

EQUIPMENT

12. Do you often have to stop work and wait, or move to another spot because you do not have the equipment you need?
    _______Yes _______No

13. How many hours per week would you estimate waiting for equipment, getting equipment, or moving to a different area because equipment is lacking?
    _______ Hours per week

14. Which equipment that is not available would help you work more efficiently?

SCAFFOLDS

15. Do you often have to stop work and wait, or move to another spot because you do not have scaffolds?

    ______Yes ______ No

16. How many hours per week would you estimate waiting for scaffolds, getting scaffolds, or moving to another spot because you do not have scaffolds?

    _______ Hours per week

17. How could the material, tool, equipment, and scaffold situation be improved?

REWORK

18. Do you often spend time doing completed work over again?

    _______ Yes ________ No

19. How many hours per week would you estimate that you spend doing work over again?

    _______ Hours per week

20. Rank from 1 to 3 the items listed below that most frequently cause rework:

    _____ Changed drawings or specifications

    _____ It was not done right first time

    _____ It was caused by work to be done or damage caused by other crews

21. Please list other cause of rework:

CREW INTERFERENCE

22. Do you often have to stop work and wait or move to another spot because another crew has not finished or was moved in ahead of your crew?

    _____ Yes _____ No

23. How many hours per week would you estimate that you lose because you are waiting or moving from one spot to another because of another crew?

OVERCROWDED WORK AREAS

24. Do you often have to work in an area that is so overcrowded with people that it slows you down from doing work as efficiently as you could have done under

normal conditions?

_______ Yes _______ No

25. How many hours per week would you estimate that you lose because an area is overcrowded with people?

________ Hours per week

INFORMATION

26. Do you often spend time waiting for someone to give you the information that you need to do your job?

_______ Yes _______ No

27. How many hours per week would you estimate that you spend waiting to get information you need to do your job?

________ Hours per week

28. What can be done to reduce delays because of crew interference, overcrowded, and lack of information?

INSPECTION

29. Do you often have to stop work and wait or not begin work because of inspection?

_______ Yes _______ No

30. How many hours per week would you estimate that you lose because of waiting for or moving to another area because of inspection?

________ Hours per week

31. In your opinion, are delays because of the listed factors decreasing, staying the same, or increasing? (Check one for each factor)

	Decreasing	The Same	Increasing
A. Materials	_______	_______	_______
B. Tools	_______	_______	_______
C. Equipment	_______	_______	_______
D. Scaffolds	_______	_______	_______
E. Rework	_______	_______	_______
F. Interference	_______	_______	_______
G. Overcrowding	_______	_______	_______
H. Information	_______	_______	_______
I. Inspection	_______	_______	_______

WORKING CONDITIONS

32. How would you describe the morale and attitudes of the workers on this project?

Good _____ Fair_____ Poor_____

33. How do you rate the safety program and record on this job, as compared with other jobs you have been on?

Good _____ Fair_____ Poor_____

34. Can you suggest safety improvements that could be made on this project?

35. What do you see as the most common reason that planned activities are interrupted?

End of the Form

Appendix 2

Important Concepts in NeuralShell2

1. Hidden neurons

As processing element, neuron is the basic unit of the neural network. NeuralShell2 sets the number of neurons of the input and output layers to be equal to the number of input and output parameters. This default setting is not changeable by user. For the number of neurons in hidden layers, the optimum settings is the one with minimum error during the training phase and generate the best results when applied to the data pattern file (Moselhi et al. 1991b). In Back propagation networks, the number of hidden neurons determines how well a problem can be learned. If using too many neurons, the network will tend to try to memorize the problem, and thus not generalize well later. If using too few neurons, the network will generalize well but may not have enough ability to learn the patterns well. Getting the right number of hidden neurons is a matter or trial and error, since there is no science to it (NeuralShell2, 1996). As the suggestion in NeuralShell2 user's manual that the number of neurons in hidden layer could be calculated as the following equation:

$$N_H = (N_I + N_O) / 2 + T^{1/2}$$

Where: N_H is the number of hidden neurons

N_I is the number of inputs

N_O is the number of outputs

T is the total number of data points in the training set

2. Extraction Methods

The network offers five different methods for selecting data from the training set. Choose one by clicking on the appropriate button. All of these options will leave the .PAT file as it was (NeuralShell2, 1996).

1). N percent (Test Set), M percent (Production Set), randomly chosen: This option will extract N percent of the .PAT file to make a Test Set (.TST) and/or M percent of the .PAT file to make a Production Set (.PRO). The remainder of the pattern file will become the Training Set (.TRN). The default setting extracts 20 percent of the .PAT file to create a .TST set. You may change any of the percentages by typing a new percentage in the edit box.

2). Every Nth pattern (Test Set), Every Mth pattern (Production Set): This option will extract every Nth pattern from the .PAT file to create a Test Set (.TST) and/or every Mth pattern from the .PAT file to create a Production Set (.PRO). The remainder of the pattern file will become the training file (.TRN).

3). All patterns after N thru M (Test Set), all after M (Production Set): Use this option if the patterns you want to include in your Test Set appear at the end of the file. This option will extract from the .PAT file all patterns after the Nth pattern through pattern M to create a Test Set (.TST). All patterns after pattern M will create a Production Set (.PRO). The remainder of the pattern file will become the training file (.TRN).

4).Last M patterns (Production Set), N percent (Test Set), randomly chosen: Use this option to extract a Production Set from the end of the file and randomly extract a Test Set from the remainder. This option will extract from the .PAT file the final M patterns to create a Production Set (.PRO) and will randomly extract N percent from the remaining patterns for a Test Set (.TST). The remainder of the pattern file will become the training file (.TRN).

5).By row marker: Use this option if the data file has a column that contains strings or numbers which can be used as keys or search strings to extract patterns from a file.

3. Statistical Information of Neural Network

1) R Squared: This parameter is also called the multiple coefficient of determination, which compares the accuracy of the model to the accuracy of a trivial benchmark model wherein the prediction is just the mean of all of the samples (NeuralShell2, 1996). The perfect value of an R squared is 1. The value is more close to 1 indicates good fit. If your neural model predictions are worse than you could predict by just using the mean of your sample case outputs, the R squared value will be less than 0 (NeuralShell2, 1996).

The formula that NeuralShell2 uses for R Squared is the following:

$$\text{R suqared} = 1 - SSE/SS_{yy}$$

Where: $SSE = \sum(y-\tilde{y})^2$

$SS_{yy} = \sum(y-\bar{y})^2$

y is the actual value

y˜ is the predicted value of y

y¯ is the mean of the y values

2) Mean Squared Error

This a statistical measure of the differences between the outputs values in the training set and the output values the network is predicting. This is the mean over all patterns in the file of the square of the actual value minus the predicted value, i.e., the mean of (actual - predicted)^2. The errors are squared to penalize the larger errors and to cancel the effect of the positive and negative values of the differences (NeuralShell2, 1996)

3) Mean Absolute Error

This is the absolute value of the difference between the value the network is predicting for an output and the actual value of that output. i.e., the mean of |actual - predicted|.

4) Maximum Absolute Error

This is the absolute value of the difference between the value the network is predicting for an output and the actual value of that output. i.e., the maximum of |actual - predicted|.

5) Minimum Absolute Error

This is the absolute value of the difference between the value the network is predicting for an output and the actual value of that output, i.e. the minimum of

|actual - predicted| of all patterns.

6) Mean Absolute Error

This is the absolute value of the difference between the value the network is predicting for an output and the actual value of that output. i.e., the mean of |actual - predicted|.

4. Contribution Factor

This is the statistical measure of the importance of a certain variable in predicting the network's output, relative to the other input variables in the same network. Higher value implies more contribution to network's prediction. However, contribution factors in different networks are not comparable. Users could remove the variables with less contribution to the prediction from a network by comparing the values of the contribution factors in order to simplify data inputs and shorten training time. However, the number of inputs must be more enough if users are going to do so. According to the recommendation of the NeuralShell2's manual, the minimum data points should not less than 100.

5. Smoothing Factor

The smoothing factor is a parameter of PNN and GRNN networks. Higher smoothing factors cause more relaxed surface fits through the data. However, the genetic adaptive versions of the PNN and GRNN networks compute an individual smoothing factor for each input which may be thought of as a sensitivity factor for the input. The higher the value of the smoothing factor, the more impact that input has on predicting the output (NeuralShell2, 1996)

6. Calibration

NeuroShell2 uses Calibration to optimize the network by applying the current network to an independent test set during the training. Calibration finds the optimum network for the data in the test set (which means that the network is able to generalize well and give good results on new data).

Calibration does this by computing the mean squared error between actual and predicted for all outputs over all patterns. (The mean squared error is the standard statistical technique for determining closeness of fit.) Calibration computes the squared error for each output in a pattern totals them and then computes the mean of that number over all patterns in the test set.

For back propagation networks, the network is saved every time a new minimum average error (or mean squared error) is reached. In order to use Calibration, users need to set the Calibration test interval, which is how often the test set is evaluated.

For GRNN networks, Calibration optimizes the smoothing factor based upon the values in the test set. Calibration does this by trying different smoothing factors and choosing the one that generates the least mean squared error between the actual and predicted answers. For PNN, Calibration also optimizes the smoothing factor, but does so by minimizing the probabilistic error (NeuralShell2, 1996).

7. Calibration Test Interval

This number defines the number of training patterns the network processes before NeuroShell2 temporarily stops training and computes the error factor for the test set. The default setting for the test set error computation interval is 200. The usual range is between 50 and 500, although there are times when users may want to set it higher (NeuralShell2, 1996).

8. Scaling Function

The input variables must be scaled from their numeric range into the other numeric range that the neural network deals with efficiently. In this study the scaling function is selected as "none" since the inputs data are already normalized into the range of [0, 1].

9. Activation Function

The activation function also is called the squashing function that maps the sum of weighted values into the output value, which is then "fired" on to the next layer (NeuralShell2, 1996). The activation functions may be changed in back propagation networks only. Different activation could result in different features of the outputs. The default activation function is the logistic function in NeuralShell2. The activation functions in the network are as shown as the follows:

BPNN outputs and error percentage

Actual(1)	Network(1)	Act-Net(1)	% Error
0	-0.006864607	0.006864607	0
0.163461536	0.127836317	0.035625219	21.79425195
0.057692308	0.088250041	-0.030557733	-52.96673692
0.307692319	0.252879828	0.054812491	17.81405892
0.182692304	0.158728868	0.023963436	13.11682839
0.211538464	0.229322106	-0.017783642	-8.406812484
0.086538464	0.108224899	-0.021686435	-25.05987973
0.201923072	0.199801296	0.002121776	1.05078433
1	0.959094942	0.040905058	4.0905058
0.144230768	0.159919173	-0.015688404	-10.87729353
0.048076924	0.071088612	-0.023011688	-47.86431012
0.163461536	0.122596502	0.040865034	24.99978588
0.576923072	0.507336497	0.069586575	12.0616731
0.298076928	0.342548698	-0.044471771	-14.91956164
0.182692304	0.17313689	0.009555414	5.230331979
0.307692319	0.264419675	0.043272644	14.06360878
0.480769217	0.44807443	0.032694787	6.800515891
0.538461566	0.467413127	0.071048439	13.19470943
0.403846145	0.397874653	0.005971491	1.478654947
0.413461536	0.447436482	-0.033974946	-8.217196291
0.288461536	0.356559485	-0.068097949	-23.60728919
0.519230783	0.495946229	0.023284554	4.484432503
0.375	0.347468108	0.027531892	7.341837867
0.394230783	0.397165984	-0.002935201	-0.744538764
0.259615391	0.303417742	-0.043802351	-16.87201627
0.375	0.357571781	0.017428219	4.647525067
0.240384609	0.269894302	-0.029509693	-12.27603261
0.423076928	0.493229836	-0.070152909	-16.58159648
0.442307681	0.515846848	-0.073539168	-16.6262471
0.298076928	0.381136298	-0.083059371	-27.86507884
0.509615362	0.513342261	-0.0037269	-0.731316259
0.394230783	0.42136538	-0.027134597	-6.882921925
0.25	0.233608782	0.016391218	6.5564872
0.375	0.384674489	-0.009674489	-2.579863733
0.134615391	0.102158576	0.032456815	24.11077571
0.25	0.276216537	-0.026216537	-10.4866148

0.5	0.470973074	0.029026926	5.8053852
0.355769217	0.326664776	0.029104441	8.180708057
0.403846145	0.401738673	0.002107471	0.521849973
0.269230783	0.369014204	-0.099783421	-37.06241162
0.5	0.503114879	-0.003114879	-0.6229758
0.375	0.353095025	0.021904975	5.841326667
0.519230783	0.59712714	-0.077896357	-15.00226095
0.384615391	0.360104918	0.024510473	6.372722874
0.567307711	0.576759219	-0.009451509	-1.66602865
0.413461536	0.42663902	-0.013177484	-3.187112428
0.548076928	0.504496634	0.043580294	7.951492167
0.403846145	0.395754308	0.008091837	2.003693015
0.692307711	0.665002167	0.027305543	3.944133882
0.538461566	0.51715374	0.021307826	3.957167483
0.673076928	0.574047148	0.099029779	14.71299563
0.509615362	0.487946659	0.021668702	4.251971902
0.596153855	0.553165913	0.042987943	0.072108807
0.442307681	0.486763269	-0.044455588	-10.05082885
0.586538434	0.615533948	-0.028995514	-4.943497701
0.432692319	0.478343487	-0.045651168	-10.55049188
0.653846145	0.53294611	0.120900035	18.49059384
0.490384609	0.511799932	-0.021415323	-4.367046316
0.75	0.672892153	0.077107847	10.28104627
0.903846145	0.774198771	0.129647374	14.34396492
0.730769217	0.720621586	0.010147631	1.388623216
0.759615362	0.730263889	0.029351473	3.863991497
0.576923072	0.504350662	0.07257241	12.57921784
0.817307711	0.819636345	-0.002328634	-0.284915212
0.644230783	0.517603099	0.126627684	19.65564008
0.884615362	0.73443985	0.150175512	16.97636266
0.701923072	0.608220696	0.093702376	13.34937969
0.692307711	0.601483107	0.090824604	13.11910911
0.548076928	0.435003579	0.113073349	20.63092665
0.163742691	0.200178683	-0.036435992	-22.2519807
0.549707592	0.526863873	0.022843719	4.15561279
0.678362548	0.650861144	0.027501404	4.054086429
0.444444448	0.453419358	-0.00897491	-2.019354734
0.368421048	0.349591732	0.018829316	5.110814407
0.257309943	0.323651642	-0.066341698	-25.78279612

0.701754391	0.765128434	-0.063374043	-9.030801063
0.421052635	0.459149301	-0.038096666	-9.047958101
0.9239766	0.92212832	0.00184828	0.200035369
0.391812861	0.403871477	-0.012058616	-3.077646805
0.836257339	0.854689777	-0.018432438	-2.204158593
0.807017565	0.797689021	0.009328544	1.155928248
0.467836261	0.499547213	-0.031710953	-6.77821615
0.298245609	0.347890854	-0.049645245	-16.6457589
0.830409348	0.804164648	0.0262447	3.160453343
0.543859661	0.54398042	-0.000120759	-0.022204074
0.649122834	0.589744568	0.059378266	9.14746222
0.356725156	0.322796106	0.03392905	9.511258017
0.485380113	0.478161007	0.007219106	1.487309802
0.485380113	0.55320698	-0.067826867	-13.9739691
0.602339208	0.641110837	-0.038771629	-6.436842976
0.573099434	0.609592378	-0.036492944	-6.367646142
0.292397648	0.362690687	-0.070293039	-24.04022039
0.426900595	0.493375957	-0.066475362	-15.57162552
0.163742691	0.272844911	-0.109102219	-66.63028336
0.380116969	0.365495265	0.014621705	3.846633061
0.350877196	0.321254075	0.029623121	8.442589412
0.391812861	0.415679902	-0.023867041	-6.091438892
0.368421048	0.355277985	0.013143063	3.567402859
0.4619883	0.526437998	-0.064449698	-13.95050437
0.409356713	0.45415771	-0.044800997	-10.94424388
0.549707592	0.572423279	-0.022715688	-4.132322044
0.543859661	0.450891495	0.092968166	17.09414628
0.532163739	0.460468918	0.071694821	13.4723236
0.637426913	0.62413162	0.013295293	2.085775283
0.567251444	0.567156196	9.52E-05	0.016791178
0.555555582	0.508878469	0.046677113	8.40187994
0.573099434	0.558455765	0.014643669	2.555170732
0.350877196	0.312155664	0.038721532	11.03563653
0.391812861	0.404140562	-0.012327701	-3.146323724
0.61403507	0.56972146	0.04431361	7.216788123
0.69005847	0.756247282	-0.066188812	-9.591768651
0.561403513	0.461273491	0.100130022	17.83566003
0.315789461	0.337593973	-0.021804512	-6.904762411
0.935672522	0.991371691	-0.05569917	-5.952848747

0.871345043	0.861104369	0.010240674	1.175271964
0.742690086	0.717653036	0.02503705	3.371130229
0.573099434	0.56715703	0.005942404	1.036888827
0.602339208	0.588961065	0.013378143	2.221031409
0.61988306	0.639922917	-0.020039856	-3.232844595
0.561403513	0.514040232	0.047363281	8.436584365
0.883040965	0.844404399	0.038636565	4.375398937
0.526315808	0.449488848	0.07682696	14.59712189
0.514619887	0.433111519	0.081508368	15.83855775
0.742690086	0.780667782	-0.037977695	-5.113531972
0.877192974	0.805418253	0.071774721	8.182318273
0.888888896	0.870658875	0.018230021	2.050877346
0.61988306	0.575249434	0.044633627	7.200330172
0.631578922	0.677970409	-0.046391487	-7.34531907
0.485380113	0.537024498	-0.051644385	-10.63998784
0.883040965	0.832870901	0.050170064	5.68151037
0.894736826	0.937496424	-0.042759597	-4.779013868
0.9239766	0.963233054	-0.039256454	-4.248641578
0.912280679	0.899018586	0.013262093	1.453729461
0.9239766	0.874939144	0.049037457	5.307218494
1	0.952024817	0.047975183	4.7975183
0.982456148	0.941142321	0.041313827	4.205157358
0.573099434	0.532103181	0.040996253	7.153427585
0.514619887	0.448922545	0.065697342	12.76618795
0.888888896	0.895069838	-0.006180942	-0.695355969
0.678362548	0.733469784	-0.055107236	-8.123566987
0.53801167	0.498465866	0.039545804	7.35036175
0.561403513	0.575393438	-0.013989925	-2.491955372
0.573099434	0.536235392	0.036864042	6.432398954
0.502923965	0.519874692	-0.016950727	-3.37043533
0.397660822	0.394088387	0.003572434	0.898362072
0.53801167	0.480992377	0.057019293	10.59815171
0.584795296	0.508971334	0.075823963	12.96589824
0.532163739	0.499366224	0.032797515	6.163049565
0.748538017	0.748315632	0.000222385	0.029709246
0.701754391	0.725919127	-0.024164736	-3.443474855
0.637426913	0.653071523	-0.01564461	-2.454337851
0.672514617	0.726755619	-0.054241002	-8.065401202
0.69005847	0.676222026	0.013836443	2.005111683

0.701754391	0.691023111	0.01073128	1.529207389
0.549707592	0.52037096	0.029336631	5.336770208
0.555555582	0.531878233	0.023677349	4.261922617
0.590643287	0.527271807	0.06337148	10.72923055
0.350877196	0.345929503	0.004947692	1.410092208
0.222222224	0.29087323	-0.068651006	-30.89295245
0.561403513	0.537054181	0.024349332	4.33722473
0.666666687	0.74689424	-0.080227554	-12.03413273
0.421052635	0.402047575	0.01900506	4.513701713
0.707602322	0.678984165	0.028618157	4.044384269
0.684210539	0.776928663	-0.092718124	-13.55111018
0.625730991	0.667845905	-0.042114913	-6.730514168
0.508771956	0.566614091	-0.057842135	-11.36897078
0.666666687	0.718535602	-0.051868916	-7.780337163
0.678362548	0.779463112	-0.101100564	-14.90361818
0.479532152	0.518131256	-0.038599104	-8.049325543
0.298245609	0.291084379	0.00716123	2.401118335
0.245614037	0.254056811	-0.008442774	-3.437415102
0.23391813	0.247416317	-0.013498187	-5.770474909
0.467836261	0.444455862	0.023380399	4.997560247
0.216374263	0.241735637	-0.025361374	-11.72106777
0.222222224	0.251833558	-0.029611334	-13.32510019
0.286549717	0.324847281	-0.038297564	-13.36506781
0.532163739	0.477013767	0.055149972	10.36334646
0.274853796	0.297783703	-0.022929907	-8.342583342
0.257309943	0.290042579	-0.032732636	-12.72109255
0.30409357	0.330942273	-0.026848704	-8.829092966
0.327485383	0.360737085	-0.033251703	-10.15364493
0.239766076	0.242064208	-0.002298132	-0.958489223
0.280701756	0.303066015	-0.022364259	-7.967267223
0.269005835	0.244802058	0.024203777	8.997491448
0.22807017	0.215745866	0.012324303	5.403732983
0.198830411	0.184998274	0.013832137	6.956751198
0.163742691	0.172173411	-0.008430719	-5.148760503
0.134502918	0.142456591	-0.007953674	-5.913383976
0.03508772	0.013621539	0.021466181	61.17861463
0.251461983	0.246846229	0.004615754	1.835567327
0.251461983	0.287033528	-0.035571545	-14.14589378
0.280701756	0.301332593	-0.020630836	-7.349735283

0.368421048	0.393388569	-0.024967521	-6.776898642
0.22807017	0.178014755	0.050055414	21.94737435
0.187134504	0.160424948	0.026709557	14.27291944
0.169590637	0.126394302	0.043196335	25.4709433
0.175438598	0.160424948	0.01501365	8.557780426
0.128654972	0.100442946	0.028212026	21.92843818
0	-0.016681552	0.016681552	0
0.362573087	0.324407876	0.038165212	10.52621206
0.315789461	0.338435531	-0.02264607	-7.171255788
0.19298245	0.208753586	-0.015771136	-8.172316187
0.403508782	0.38226223	0.021246552	5.265449712
0.362573087	0.372481555	-0.009908468	-2.732819494
0.403508782	0.399483383	0.0040254	0.997599106
0.444444448	0.476243168	-0.03179872	-7.154711943
0.485380113	0.476326287	0.009053826	1.865306336
0.391812861	0.435921788	-0.044108927	-11.25765165
0.292397648	0.326097131	-0.033699483	-11.52522369
0.380116969	0.353801131	0.026315838	6.923089508
0.280701756	0.357043803	-0.076342046	-27.19685373
0.099415205	0.072777838	0.026637368	26.79405831
0.315789461	0.345350742	-0.029561281	-9.361072693
0.210526317	0.269799173	-0.059272856	-28.15460644
0.269005835	0.306139946	-0.037134111	-13.8042028
0.245614037	0.21537298	0.030241057	12.31243025
0.4619883	0.445202351	0.016785949	3.633414309
0.485380113	0.498926312	-0.013546199	-2.790843431
0.409356713	0.436545491	-0.027188778	-6.641830251
0.497076035	0.509375751	-0.012299716	-2.474413396
0.397660822	0.433834761	-0.03617394	-9.096681895

Appendix 4

GRNN outputs and error percentage

Actual(1)	Network(1)	Act-Net(1)	% Error
0	0.000471476	-0.000471476	0
0.163461536	0.163724378	-0.000262842	-0.160797461
0.057692308	0.057917994	-0.000225686	-0.391189065
0.307692319	0.26907742	0.038614899	12.54984171
0.182692304	0.210047945	-0.027355641	-14.97361432
0.211538464	0.236111462	-0.024572998	-11.61632619
0.086538464	0.151314139	-0.064775676	-74.85189014
0.201923072	0.223954439	-0.022031367	-10.91077249
1	0.982917845	0.017082155	1.7082155
0.144230768	0.144803092	-0.000572324	-0.39681131
0.048076924	0.057589822	-0.009512898	-19.78682746
0.163461536	0.163454637	6.90E-06	0.004220712
0.576923072	0.537269235	0.039653838	6.873331979
0.298076928	0.320595026	-0.022518098	-7.554458559
0.182692304	0.180813149	0.001879156	1.028590673
0.307692319	0.291814268	0.015878052	5.16036671
0.480769217	0.473553449	0.007215768	1.500879787
0.538461566	0.452647477	0.085814089	15.93690143
0.403846145	0.374956638	0.028889507	7.153592366
0.413461536	0.4216699	-0.008208364	-1.985278747
0.288461536	0.325401992	-0.036940455	-12.80602451
0.519230783	0.518417478	0.000813305	0.156636514
0.375	0.35135901	0.02364099	6.304264
0.394230783	0.358862877	0.035367906	8.971370965
0.259615391	0.281893522	-0.02227813	-8.581205419
0.375	0.374696642	0.000303358	0.080895467
0.240384609	0.277001619	-0.036617011	-15.23267698
0.423076928	0.456372023	-0.033295095	-7.869749636
0.442307681	0.476779014	-0.034471333	-7.793518964
0.298076928	0.346716642	-0.048639715	-16.3178396
0.509615362	0.506818056	0.002797306	0.548905353
0.394230783	0.398603886	-0.004373103	-1.109274869
0.25	0.281922936	-0.031922936	-12.7691744

0.375	0.383742154	-0.008742154	-2.331241067
0.134615391	0.135721564	-0.001106173	-0.821728475
0.25	0.250000089	-8.94E-08	-3.57628E-05
0.5	0.499997884	2.12E-06	0.000423194
0.355769217	0.340283334	0.015485883	4.352788904
0.403846145	0.414046288	-0.010200143	-2.525749751
0.269230783	0.284569204	-0.015338421	-5.697127509
0.5	0.48672545	0.01327455	2.65491
0.375	0.373880535	0.001119465	0.298524
0.519230783	0.524714172	-0.005483389	-1.056060076
0.384615391	0.404307961	-0.01969257	-5.120068115
0.567307711	0.558805406	0.008502305	1.49871134
0.413461536	0.430771589	-0.017310053	-4.186617495
0.548076928	0.503700495	0.044376433	8.096752615
0.403846145	0.403781384	6.48E-05	0.016035909
0.692307711	0.684794009	0.007513702	1.085312482
0.538461566	0.529074728	0.009386837	1.743269639
0.673076928	0.611917973	0.061158955	9.086473248
0.509615362	0.505694807	0.003920555	0.769316487
0.596153855	0.572284222	0.023869634	4.003938547
0.442307681	0.506645262	-0.064337581	-14.54588825
0.586538434	0.587402225	-0.000863791	-0.147269292
0.432692319	0.499922931	-0.067230612	-15.53774103
0.653846145	0.642853558	0.010992587	1.681219211
0.490384609	0.490989119	-0.00060451	-0.123272629
0.75	0.707643986	0.042356014	5.647468533
0.903846145	0.840019464	0.06382668	7.061675303
0.730769217	0.683511376	0.047257841	6.466862574
0.759615362	0.731803119	0.027812243	3.661358681
0.576923072	0.540032446	0.036890626	6.394375228
0.817307711	0.817862093	-0.000554383	-0.067830389
0.644230783	0.641356945	0.002873838	0.446088277
0.884615362	0.778470576	0.106144786	11.99897612
0.701923072	0.68328917	0.018633902	2.654692906
0.692307711	0.694157183	-0.001849473	-0.267146093
0.548076928	0.535743594	0.012333333	2.250292317
0.163742691	0.178716451	-0.01497376	-9.14468909
0.549707592	0.544911027	0.004796565	0.872566628
0.678362548	0.623050034	0.055312514	8.153827797

0.444444448	0.443211615	0.001232833	0.277387423
0.368421048	0.374911875	-0.006490827	-1.761795922
0.257309943	0.288531661	-0.031221718	-12.13389488
0.701754391	0.749503911	-0.047749519	-6.804306409
0.421052635	0.446202874	-0.025150239	-5.973181714
0.9239766	0.919321299	0.004655302	0.503833322
0.391812861	0.396236807	-0.004423946	-1.129096679
0.836257339	0.839969158	-0.00371182	-0.443860978
0.807017565	0.782223821	0.024793744	3.072268198
0.467836261	0.505961061	-0.0381248	-8.149175936
0.298245609	0.30222705	-0.003981441	-1.33495377
0.830409348	0.784459591	0.045949757	5.533386288
0.543859661	0.542006671	0.001852989	0.340710873
0.649122834	0.608649373	0.040473461	6.235100489
0.356725156	0.34995231	0.006772846	1.898617433
0.485380113	0.48367089	0.001709223	0.352141127
0.485380113	0.500302553	-0.01492244	-3.074382242
0.602339208	0.617734373	-0.015395164	-2.555896046
0.573099434	0.544281065	0.028818369	5.028511161
0.292397648	0.299986392	-0.007588744	-2.595350562
0.426900595	0.45244363	-0.025543034	-5.983368095
0.163742691	0.164806858	-0.001064166	-0.649901375
0.380116969	0.385650277	-0.005533308	-1.455685605
0.350877196	0.356889963	-0.006012768	-1.713638865
0.391812861	0.393630326	-0.001817465	-0.463860475
0.368421048	0.374997377	-0.006576329	-1.785003608
0.4619883	0.500903904	-0.038915604	-8.423504232
0.409356713	0.464370847	-0.055014133	-13.43916717
0.549707592	0.547477245	0.002230346	0.405733163
0.543859661	0.45454514	0.08931452	16.42234687
0.532163739	0.461995363	0.070168376	13.18548613
0.637426913	0.641075134	-0.003648221	-0.572335577
0.567251444	0.551258028	0.015993416	2.819457962
0.555555582	0.522305608	0.033249974	5.984995035
0.573099434	0.547572434	0.025527	4.454200874
0.350877196	0.344662964	0.006214231	1.77105582
0.391812861	0.40946126	-0.017648399	-4.504292931
0.61403507	0.604840457	0.009194613	1.497408446
0.69005847	0.783549011	-0.093490541	-13.5482057

0.561403513	0.53836441	0.023039103	4.103840191
0.315789461	0.345888466	-0.030099005	-9.531351966
0.935672522	0.915079176	0.020593345	2.20091373
0.871345043	0.835415661	0.035929382	4.123439077
0.742690086	0.740965843	0.001724243	0.232161844
0.573099434	0.557842553	0.015256882	2.662170139
0.602339208	0.590408206	0.011931002	1.980777914
0.61988306	0.610461235	0.009421825	1.519935873
0.561403513	0.547040343	0.01436317	2.558439637
0.883040965	0.855775535	0.027265429	3.087674307
0.526315808	0.48438257	0.041933239	7.96731513
0.514619887	0.472077429	0.042542458	8.266773025
0.742690086	0.789335191	-0.046645105	-6.280561149
0.877192974	0.830228806	0.046964169	5.353915318
0.888888896	0.86202091	0.026867986	3.022648401
0.61988306	0.575908244	0.043974817	7.094050449
0.631578922	0.625176072	0.00640285	1.013784624
0.485380113	0.536647916	-0.051267803	-10.56240287
0.883040965	0.875728548	0.007312417	0.828094878
0.894736826	0.901278496	-0.006541669	-0.731127725
0.9239766	0.902492642	0.021483958	2.325162564
0.912280679	0.892245591	0.020035088	2.196153932
0.9239766	0.921914399	0.002062202	0.223187687
1	0.983457386	0.016542614	1.6542614
0.982456148	0.975481033	0.006975114	0.709966955
0.573099434	0.518314004	0.05478543	9.559498186
0.514619887	0.456081808	0.058538079	11.37501299
0.888888896	0.888887346	1.55E-06	0.000174343
0.678362548	0.670926511	0.007436037	1.09617446
0.53801167	0.544357717	-0.006346047	-1.179537054
0.561403513	0.576146066	-0.014742553	-2.626017233
0.573099434	0.549597502	0.023501933	4.100847358
0.502923965	0.536086261	-0.033162296	-6.593898543
0.397660822	0.367437959	0.030222863	7.600161074
0.53801167	0.530175269	0.007836401	1.456548517
0.584795296	0.559979916	0.024815381	4.243430337
0.532163739	0.506237507	0.025926232	4.871852421
0.748538017	0.712740302	0.035797715	4.782350954
0.701754391	0.730733216	-0.028978825	-4.129482533

0.637426913	0.704856277	-0.067429364	-10.57836791
0.672514617	0.682913959	-0.010399342	-1.546336947
0.69005847	0.704784989	-0.01472652	-2.134097419
0.701754391	0.703613281	-0.00185889	-0.264891823
0.549707592	0.539805174	0.009902418	1.801397351
0.555555582	0.541895211	0.013660371	2.458866663
0.590643287	0.559149206	0.031494081	5.332166079
0.350877196	0.311912447	0.038964748	11.10495308
0.222222224	0.254139513	-0.031917289	-14.36277994
0.561403513	0.551683187	0.009720325	1.731432878
0.666666687	0.67996496	-0.013298273	-1.994740889
0.421052635	0.41177544	0.009277195	2.203333795
0.707602322	0.74437052	-0.036768198	-5.196166951
0.684210539	0.705811262	-0.021600723	-3.157028688
0.625730991	0.667840779	-0.042109787	-6.729694966
0.508771956	0.546413362	-0.037641406	-7.398482868
0.666666687	0.729179502	-0.062512815	-9.376921964
0.678362548	0.703376591	-0.025014043	-3.687415096
0.479532152	0.530712783	-0.051180631	-10.67303429
0.298245609	0.252795726	0.045449883	15.23907867
0.245614037	0.236252561	0.009361476	3.811458056
0.23391813	0.232535571	0.00138256	0.591044397
0.467836261	0.477927268	-0.010091007	-2.156952729
0.216374263	0.232358605	-0.015984342	-7.387358265
0.222222224	0.231634036	-0.009411812	-4.235315366
0.286549717	0.292383134	-0.005833417	-2.035743417
0.532163739	0.501341045	0.030822694	5.791956825
0.274853796	0.280930132	-0.006076336	-2.210752076
0.257309943	0.282081395	-0.024771452	-9.627086972
0.30409357	0.302268267	0.001825303	0.600243866
0.327485383	0.330660939	-0.003175557	-0.969679004
0.239766076	0.239255562	0.000510514	0.212921698
0.280701756	0.294713676	-0.014011919	-4.991746115
0.269005835	0.268660009	0.000345826	0.128557063
0.22807017	0.220518932	0.007551238	3.31092751
0.198830411	0.208059713	-0.009229302	-4.641795968
0.163742691	0.172067508	-0.008324817	-5.084084639
0.134502918	0.156247109	-0.021744192	-16.16633477
0.03508772	0.036892395	-0.001804676	-5.143326497

0.251461983	0.250911832	0.000550151	0.218780984
0.251461983	0.266512156	-0.015050173	-5.985068924
0.280701756	0.281048596	-0.000346839	-0.123561393
0.368421048	0.385390252	-0.016969204	-4.605926858
0.22807017	0.20100598	0.027064189	11.86660623
0.187134504	0.198251188	-0.011116683	-5.940477444
0.169590637	0.165465578	0.004125059	2.432362466
0.175438598	0.198251188	-0.02281259	-13.00317619
0.128654972	0.145173103	-0.016518131	-12.83909261
0	0.035721708	-0.035721708	0
0.362573087	0.316623211	0.045949876	12.67327269
0.315789461	0.311420918	0.004368544	1.383372322
0.19298245	0.216600299	-0.023617849	-12.23834033
0.403508782	0.401815534	0.001693249	0.419631263
0.362573087	0.335789293	0.026783794	7.387143437
0.403508782	0.39602077	0.007488012	1.855724667
0.444444448	0.468805909	-0.024361461	-5.481328681
0.485380113	0.495105445	-0.009725332	-2.003652754
0.391812861	0.443638623	-0.051825762	-13.22717224
0.292397648	0.301357895	-0.008960247	-3.064404608
0.380116969	0.319456011	0.060660958	15.95849776
0.280701756	0.303120255	-0.022418499	-7.986590223
0.099415205	0.125126794	-0.025711589	-25.86283356
0.315789461	0.324869841	-0.00908038	-2.875453782
0.210526317	0.241682708	-0.031156391	-14.79928564
0.269005835	0.265474856	0.003530979	1.312603126
0.245614037	0.236988187	0.00862585	3.511953187
0.4619883	0.467803538	-0.005815238	-1.258741401
0.485380113	0.499014616	-0.013634503	-2.809036183
0.409356713	0.404198617	0.005158097	1.260049447
0.497076035	0.491906434	0.0051696	1.040001858
0.397660822	0.399222404	-0.001561582	-0.392691941

Appendix 5

GMDH outputs and error percentage

Actual(1)	Network(1)	Act-Net(1)	% Error
0	0.057152867	-0.057152867	0
0.163461538	0.141579777	0.021881761	13.38648912
0.057692308	0.097821444	-0.040129137	-69.55717043
0.307692308	0.23836571	0.069326598	22.53114433
0.182692308	0.164617598	0.01807471	9.893525457
0.211538462	0.213010579	-0.001472118	-0.695910326
0.086538462	0.127944112	-0.04140565	-47.84652863
0.201923077	0.188427866	0.013495211	6.683342588
1	0.9822101	0.0177899	1.77899
0.144230769	0.153254569	-0.009023799	-6.25650065
0.048076923	0.078237236	-0.030160312	-62.73344906
0.163461538	0.119314402	0.044147136	27.00765975
0.576923077	0.525073748	0.051849329	8.987217025
0.298076923	0.361956075	-0.063879152	-21.43042519
0.182692308	0.17479223	0.007900078	4.324253214
0.307692308	0.244039834	0.063652474	20.68705403
0.480769231	0.424053118	0.056716113	11.7969515
0.538461538	0.462687466	0.075774072	14.07232767
0.403846154	0.420435458	-0.016589305	-4.107827903
0.413461538	0.432652958	-0.019191419	-4.641645531
0.288461538	0.374901295	-0.086439756	-29.96578213
0.519230769	0.503483969	0.015746801	3.032717231
0.375	0.361956075	0.013043925	3.47838
0.394230769	0.406717807	-0.012487038	-3.167443787
0.259615385	0.306566432	-0.046951048	-18.08484809
0.375	0.374588326	0.000411674	0.109779733
0.240384615	0.280030295	-0.03964568	-16.49260291
0.423076923	0.513947842	-0.090870919	-21.47858086
0.442307692	0.534699485	-0.092391792	-20.88857908
0.298076923	0.403390899	-0.105313976	-35.33114034
0.509615385	0.511973401	-0.002358016	-0.462705026
0.394230769	0.403390899	-0.00916013	-2.323545172
0.25	0.247456163	0.002543837	1.0175348
0.375	0.347184122	0.027815878	7.417567467

0.134615385	0.112496555	0.02211883	16.43113081
0.25	0.244827092	0.005172908	2.0691632
0.5	0.473040892	0.026959108	5.3918216
0.355769231	0.291393325	0.064375906	18.09484924
0.403846154	0.443370286	-0.039524133	-9.786928168
0.269230769	0.347510695	-0.078279926	-29.07540111
0.5	0.493494366	0.006505634	1.3011268
0.375	0.390809551	-0.015809551	-4.215880267
0.519230769	0.606845632	-0.087614863	-16.87397362
0.384615385	0.386346333	-0.001730948	-0.45004648
0.567307692	0.599447794	-0.032140102	-5.665373915
0.413461538	0.462687466	-0.049225928	-11.90580586
0.548076923	0.525073748	0.023003175	4.197070527
0.403846154	0.414472096	-0.010625942	-2.631185637
0.692307692	0.694557205	-0.002249513	-0.324929656
0.538461538	0.5235573	0.014904239	2.767930102
0.673076923	0.602877744	0.07019918	10.42959246
0.509615385	0.525073748	-0.015458363	-3.033339152
0.596153846	0.568253309	0.027900538	4.680090246
0.442307692	0.525073748	-0.082766056	-18.71232572
0.586538462	0.649445176	-0.062906715	-10.72507927
0.432692308	0.513947842	-0.081255534	-18.77905673
0.653846154	0.554854792	0.098991362	15.13985536
0.490384615	0.5235573	-0.033172684	-6.764625762
0.75	0.72182852	0.02817148	3.756197333
0.903846154	0.812231332	0.091614822	10.13610796
0.730769231	0.730771184	-1.9532E-06	-0.00026728
0.759615385	0.767757654	-0.00814227	-1.071893772
0.576923077	0.534401316	0.042521761	7.370438572
0.817307692	0.83619675	-0.018889058	-2.311131803
0.644230769	0.520638982	0.123591787	19.18439679
0.884615385	0.774836332	0.109779053	12.40980599
0.701923077	0.625603825	0.076319252	10.87287974
0.692307692	0.63298063	0.059327063	8.569464659
0.548076923	0.471569149	0.076507774	13.95931315
0.16374269	0.195416331	-0.031673641	-19.34354505
0.549707602	0.54360668	0.006100922	1.109848577
0.678362573	0.646309704	0.03205287	4.725035147
0.444444444	0.432225972	0.012218472	2.749156203

0.368421053	0.345292196	0.023128857	6.277832608
0.257309942	0.325908914	-0.068598973	-26.66005537
0.701754386	0.740124792	-0.038370406	-5.467782855
0.421052632	0.446671434	-0.025618802	-6.084465469
0.923976608	0.854524255	0.069452353	7.516678712
0.391812865	0.400877707	-0.009064841	-2.3135639
0.83625731	0.819043696	0.017213614	2.058411184
0.807017544	0.773307264	0.03371028	4.177143391
0.467836257	0.519283963	-0.051447706	-10.99694716
0.298245614	0.351882756	-0.053637142	-17.9842182
0.830409357	0.772497237	0.05791212	6.973924308
0.543859649	0.549779933	-0.005920284	-1.088568349
0.649122807	0.592759259	0.056363548	8.683033071
0.356725146	0.277757362	0.078967785	22.13687089
0.485380117	0.49522228	-0.009842163	-2.027722738
0.485380117	0.539792567	-0.054412451	-11.21027605
0.602339181	0.641892523	-0.039553341	-6.566622635
0.573099415	0.613193542	-0.040094127	-6.99601604
0.292397661	0.341449931	-0.04905227	-16.77587633
0.426900585	0.458292022	-0.031391438	-7.353336843
0.16374269	0.227460831	-0.063718141	-38.91357898
0.380116959	0.320584252	0.059532707	15.66168138
0.350877193	0.287387684	0.063489509	18.09451006
0.391812865	0.433106631	-0.041293766	-10.53915522
0.368421053	0.36717163	0.001249422	0.339128828
0.461988304	0.54911055	-0.087122246	-18.85810642
0.409356725	0.475562353	-0.066205628	-16.17308913
0.549707602	0.565161057	-0.015453454	-2.811213442
0.543859649	0.420353204	0.123506445	22.70924957
0.532163743	0.417780511	0.114383232	21.49399193
0.637426901	0.623434432	0.013992469	2.195148805
0.567251462	0.579487465	-0.012236003	-2.15706857
0.555555556	0.528928354	0.026627201	4.792896176
0.573099415	0.5751037	-0.002004285	-0.349727281
0.350877193	0.299718603	0.051158589	14.58019786
0.391812865	0.357330084	0.034482782	8.800829447
0.614035088	0.5751037	0.038931388	6.340254614
0.69005848	0.751639068	-0.061580589	-8.923966705
0.561403509	0.488787992	0.072615517	12.93463896

0.315789474	0.333465561	-0.017676088	-5.597427861
0.935672515	0.960457623	-0.024785108	-2.648908416
0.871345029	0.838893324	0.032451705	3.724323192
0.742690058	0.717654064	0.025035994	3.370988171
0.573099415	0.586518258	-0.013418843	-2.341451177
0.602339181	0.604976341	-0.00263716	-0.437819767
0.619883041	0.641892523	-0.022009482	-3.550586247
0.561403509	0.533060033	0.028343476	5.04868166
0.883040936	0.829495877	0.053545059	6.063711977
0.526315789	0.420353204	0.105962585	20.13289117
0.514619883	0.393067338	0.121552545	23.61986954
0.742690058	0.772497237	-0.029807178	-4.013407434
0.877192982	0.795770466	0.081422516	9.282166829
0.888888889	0.853571624	0.035317265	3.973192312
0.619883041	0.592759259	0.027123782	4.375628983
0.631578947	0.673920646	-0.042341699	-6.704102346
0.485380117	0.557448134	-0.072068017	-14.84774808
0.883040936	0.819043696	0.06399724	7.24736956
0.894736842	0.913528204	-0.018791362	-2.100211047
0.923976608	0.938406467	-0.014429859	-1.561712588
0.912280702	0.8776474	0.034633302	3.796342718
0.923976608	0.852478385	0.071498223	7.73809882
1	0.960457623	0.039542377	3.9542377
0.98245614	0.949959427	0.032496713	3.307701146
0.573099415	0.539792567	0.033306848	5.811705112
0.514619883	0.441717949	0.072901934	14.16617127
0.888888889	0.89741981	-0.008530921	-0.959728612
0.678362573	0.760493696	-0.082131123	-12.10726038
0.538011696	0.517009519	0.021002177	3.903665507
0.561403509	0.592759259	-0.03135575	-5.585242966
0.573099415	0.557448134	0.015651281	2.730988829
0.502923977	0.539792567	-0.036868591	-7.33084774
0.397660819	0.393067338	0.004593481	1.155125368
0.538011696	0.49522228	0.042789416	7.953250146
0.584795322	0.528928354	0.055866967	9.553251351
0.532163743	0.504035973	0.028127769	5.285547798
0.748538012	0.772497237	-0.023959225	-3.200802714
0.701754386	0.749223992	-0.047469606	-6.764418855
0.637426901	0.677031025	-0.039604125	-6.213124193

0.67251462	0.751639068	-0.079124448	-11.7654614
0.69005848	0.708302692	-0.018244212	-2.643864619
0.701754386	0.695183352	0.006571034	0.936372345
0.549707602	0.539792567	0.009915035	1.803692538
0.555555556	0.549602076	0.005953479	1.071626219
0.590643275	0.545781393	0.044861882	7.595427545
0.350877193	0.333254322	0.017622871	5.022518235
0.222222222	0.277757362	-0.055535139	-24.99081257
0.561403509	0.557448134	0.003955375	0.704551172
0.666666667	0.773307264	-0.106640597	-15.99608954
0.421052632	0.394585401	0.026467231	6.285967356
0.707602339	0.702677503	0.004924836	0.69598922
0.684210526	0.805420101	-0.121209574	-17.71524544
0.625730994	0.697896689	-0.072165695	-11.53302229
0.50877193	0.586518258	-0.077746328	-15.28117481
0.666666667	0.749223992	-0.082557326	-12.38359889
0.678362573	0.805420101	-0.127057528	-18.73003215
0.479532164	0.539792567	-0.060260404	-12.56649888
0.298245614	0.277757362	0.020488253	6.869590713
0.245614035	0.243511349	0.002102686	0.856093586
0.233918129	0.23548609	-0.001567962	-0.670303754
0.467836257	0.458292022	0.009544235	2.040080233
0.216374269	0.227460831	-0.011086562	-5.123789465
0.222222222	0.23548609	-0.013263868	-5.968740606
0.286549708	0.297017992	-0.010468284	-3.653217472
0.532163743	0.475562353	0.05660139	10.63608537
0.274853801	0.268127069	0.006726732	2.447385474
0.257309942	0.259373665	-0.002063723	-0.802037801
0.304093567	0.299718603	0.004374964	1.438690086
0.32748538	0.333465561	-0.005980181	-1.826090985
0.239766082	0.222398758	0.017367324	7.243444884
0.280701754	0.297017992	-0.016316237	-5.812659439
0.269005848	0.236844212	0.032161636	11.9557386
0.228070175	0.204038084	0.024032092	10.53714805
0.198830409	0.181824744	0.017005666	8.55284968
0.16374269	0.167178452	-0.003435762	-2.098268936
0.134502924	0.147464901	-0.012961977	-9.636948116
0.035087719	0.057152867	-0.022065148	-62.88567233
0.251461988	0.221097171	0.030364817	12.07531096

0.251461988	0.259561852	-0.008099863	-3.221108313
0.280701754	0.274002105	0.006699649	2.38674996
0.368421053	0.369367972	-0.000946919	-0.257020871
0.228070175	0.176207066	0.05186311	22.73997904
0.187134503	0.162363291	0.024771212	13.23711641
0.169590643	0.139439642	0.030151001	17.77869372
0.175438596	0.162363291	0.013075306	7.452924441
0.128654971	0.121881515	0.006773456	5.264822608
0	0.057152867	-0.057152867	0
0.362573099	0.320584252	0.041988847	11.58079491
0.315789474	0.333465561	-0.017676088	-5.597427861
0.192982456	0.201836556	-0.0088541	-4.58803364
0.403508772	0.393443733	0.010065038	2.494378982
0.362573099	0.368904576	-0.006331476	-1.746261931
0.403508772	0.381744996	0.021763776	5.393631443
0.444444444	0.473540004	-0.02909556	-6.546501007
0.485380117	0.475562353	0.009817764	2.022695956
0.391812865	0.420353204	-0.028540339	-7.284176082
0.292397661	0.297017992	-0.004620331	-1.580153201
0.380116959	0.322230205	0.057886754	15.22866913
0.280701754	0.331017092	-0.050315337	-17.92483883
0.099415205	0.104873776	-0.005458572	-5.490681229
0.315789474	0.344700918	-0.028911444	-9.155290591
0.210526316	0.256346539	-0.045820223	-21.7646059
0.269005848	0.289285764	-0.020279916	-7.538838338
0.245614035	0.208256751	0.037357284	15.20975135
0.461988304	0.433996141	0.027992163	6.059063132
0.485380117	0.504035973	-0.018655856	-3.843555874
0.409356725	0.417780511	-0.008423786	-2.057810581
0.497076023	0.517009519	-0.019933496	-4.010150375
0.397660819	0.417338699	-0.01967788	-4.948408055

Appendix 6

Regression model statistics

Variables	Coefficients	Standard Error	t Stat	P-value
Intercept	0.044495706	0.133722093	0.332747606	0.739652075
X Variable 1	-0.006585178	0.012543925	-0.524969439	0.060015042
X Variable 2	-0.043698507	0.027954844	-2.563181905	0.011949431
X Variable 3	-0.032342768	0.01461289	-2.413303994	0.027937864
X Variable 4	-0.004799597	0.010485872	-4.577204089	0.006476199
X Variable 5	0.798946039	0.122415745	6.526497373	4.83985E-10
X Variable 6	0.130266782	0.037574594	3.466884608	0.000636827
X Variable 7	-0.071577424	0.131393022	-0.544758182	0.586489736

Variables	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-0.21909	0.30808	-0.21909	0.3080839
X Variable 1	-0.03131	0.01814	-0.03131	0.018141
X Variable 2	-0.0988	0.01141	-0.0988	0.0114051
X Variable 3	-0.06115	-0.0035	-0.06115	-0.003538
X Variable 4	-0.02547	0.01587	-0.02547	0.0158698
X Variable 5	0.55764	1.04025	0.557645	1.0402475
X Variable 6	0.0562	0.20433	0.056201	0.2043325
X Variable 7	-0.33057	0.18742	-0.33057	0.1874197

Appendix 7

Regression model residual output

Observation	*Predicted Y*	*Residuals*	*Standard Residuals*
1	0.005708906	-0.005708906	-0.1091576
2	0.14080092	0.022660619	0.43328422
3	0.05323561	0.004456697	0.085214648
4	0.255275888	0.05241642	1.002232464
5	0.147033439	0.035658869	0.681818339
6	0.221143239	-0.009604777	-0.18364893
7	0.063065429	0.023473033	0.448818052
8	0.19717351	0.004749567	0.090814484
9	0.890540162	0.109459838	2.092935833
10	0.119736288	0.024494481	0.468348743
11	0.041969095	0.006107828	0.116785235
12	0.080867911	0.082593628	1.579238255
13	0.547230917	0.02969216	0.567731386
14	0.355711923	-0.057635	-1.102014753
15	0.134981679	0.047710629	0.912255
16	0.249396554	0.058295754	1.114648763
17	0.457962441	0.02280679	0.436079109
18	0.503242566	0.035218972	0.673407252
19	0.413814301	-0.009968147	-0.190596773
20	0.477710037	-0.064248499	-1.228468701
21	0.365209261	-0.076747723	-1.46746115
22	0.528561655	-0.009330886	-0.178411972
23	0.353038463	0.021961537	0.419917382
24	0.434890553	-0.040659784	-0.777438742
25	0.288970036	-0.029354651	-0.56127802
26	0.391673336	-0.016673336	-0.318803888
27	0.274052569	-0.033667953	-0.64375087
28	0.524992379	-0.101915456	-1.948682853
29	0.54752541	-0.105217718	-2.011824028
30	0.395145039	-0.097068116	-1.855998894
31	0.53679775	-0.027182366	-0.519742663
32	0.431946847	-0.037716078	-0.721153372
33	0.257485586	-0.007485586	-0.143128768
34	0.378699859	-0.003699859	-0.070743456
35	0.043857311	0.090758074	1.735347213

36	0.305134716	-0.055134716	-1.054207869
37	0.44155402	0.05844598	1.117521171
38	0.32623105	0.029538181	0.564787215
39	0.452230537	-0.048384383	-0.92513757
40	0.379478038	-0.110247269	-2.107991978
41	0.528378746	-0.028378746	-0.542618157
42	0.399761728	-0.024761728	-0.473458651
43	0.632777508	-0.113546739	-2.171079762
44	0.386392933	-0.001777548	-0.033987752
45	0.61356939	-0.046261698	-0.884550601
46	0.462958196	-0.049496658	-0.946404916
47	0.536258894	0.011818029	0.225967589
48	0.400239129	0.003607024	0.068968406
49	0.685937782	0.00636991	0.121796394
50	0.526368728	0.012092811	0.23122158
51	0.609705621	0.063371302	1.211696199
52	0.524146787	-0.014531402	-0.27784887
53	0.595653048	0.000500798	0.009575559
54	0.524805304	-0.082497612	-1.57740238
55	0.660166552	-0.07362809	-1.407811954
56	0.512880271	-0.080187963	-1.533240549
57	0.577761965	0.076084189	1.454773986
58	0.528344281	-0.037959666	-0.725810911
59	0.72686905	0.02313095	0.44227724
60	0.798904339	0.104941815	2.006548604
61	0.710592395	0.020176836	0.385792853
62	0.761898918	-0.002283533	-0.043662481
63	0.531549533	0.045373544	0.867568581
64	0.816470006	0.000837686	0.016017051
65	0.506375366	0.137855403	2.635875577
66	0.779337858	0.105277526	2.012967598
67	0.612724421	0.089198656	1.705530243
68	0.659594748	0.032712944	0.625490535
69	0.485911667	0.062165256	1.188635894
70	0.154653141	0.009089549	0.173797479
71	0.574098275	-0.024390672	-0.466363856
72	0.657225468	0.021137105	0.404153761
73	0.462090186	-0.017645742	-0.337396853
74	0.351102067	0.017318986	0.331149093
75	0.350210584	-0.092900643	-1.776314379

76	0.738501499	-0.036747113	-0.702626195
77	0.477051389	-0.055998758	-1.07072885
78	0.836075869	0.087900739	1.680713309
79	0.444436363	-0.052623497	-1.006191906
80	0.791340638	0.044916672	0.858832922
81	0.757240097	0.049777447	0.951773761
82	0.529171091	-0.061334834	-1.172757731
83	0.372197561	-0.073951947	-1.414004293
84	0.761418232	0.068991125	1.319150482
85	0.558602754	-0.014743104	-0.28189674
86	0.614782118	0.03434069	0.656613978
87	0.287417919	0.069307227	1.325194543
88	0.506551634	-0.021171517	-0.404811725
89	0.569898508	-0.084518391	-1.61604085
90	0.655888332	-0.05354915	-1.023890934
91	0.627554903	-0.054455488	-1.041220636
92	0.377565776	-0.085168115	-1.628463952
93	0.486663878	-0.059763293	-1.142708958
94	0.214979816	-0.051237126	-0.979683685
95	0.338298459	0.041818501	0.799594079
96	0.28828197	0.062595223	1.196857113
97	0.454790628	-0.062977763	-1.204171489
98	0.383484833	-0.01506378	-0.288028249
99	0.563528706	-0.101540402	-1.9415116
100	0.492119447	-0.082762722	-1.582471429
101	0.581649092	-0.031941489	-0.610739872
102	0.442878502	0.100981147	1.930818321
103	0.442329385	0.089834357	1.717685218
104	0.632899253	0.004527648	0.086571262
105	0.580970369	-0.013718907	-0.262313494
106	0.53686132	0.018694236	0.357444671
107	0.576547035	-0.00344762	-0.065920496
108	0.305707613	0.04516958	0.863668667
109	0.380172591	0.011640274	0.222568824
110	0.584303263	0.029731825	0.568489797
111	0.740707575	-0.050649095	-0.968440195
112	0.503897462	0.057506047	1.099549099
113	0.342655794	-0.02686632	-0.513699679
114	0.894840106	0.040832408	0.780739424
115	0.812627678	0.058717351	1.122709944

116	0.717320199	0.025369859	0.485086481
117	0.590184561	-0.017085146	-0.326677934
118	0.605145764	-0.002806583	-0.053663496
119	0.633647671	-0.01376463	-0.263187745
120	0.540251435	0.021152074	0.404439964
121	0.800953127	0.082087809	1.569566707
122	0.443265782	0.083050007	1.58796449
123	0.413343376	0.101276507	1.936465779
124	0.763075191	-0.020385132	-0.389775596
125	0.778036394	0.099156589	1.89593171
126	0.819142608	0.069746281	1.333589503
127	0.596699491	0.02318355	0.443282978
128	0.659792682	-0.028213735	-0.539463037
129	0.562619051	-0.077238934	-1.476853389
130	0.785611285	0.097429651	1.86291165
131	0.85286251	0.041874332	0.80066161
132	0.867823713	0.056152895	1.073676048
133	0.830875533	0.081405169	1.55651423
134	0.811736195	0.112240413	2.146102047
135	0.898300469	0.101699531	1.944554246
136	0.887116661	0.095339479	1.822946353
137	0.562541729	0.010557686	0.201869109
138	0.470988363	0.04363152	0.834260065
139	0.836751165	0.052137724	0.996903633
140	0.739577534	-0.061214961	-1.170465694
141	0.540561393	-0.002549697	-0.048751698
142	0.596053552	-0.034650043	-0.662528997
143	0.566131146	0.00696827	0.133237374
144	0.551169942	-0.048245966	-0.922490957
145	0.39985342	-0.002192601	-0.041923809
146	0.510063728	0.027947968	0.534381414
147	0.545727656	0.039067665	0.746996505
148	0.528990305	0.003173437	0.060677969
149	0.763798019	-0.015260007	-0.291780223
150	0.748836816	-0.04708243	-0.900243472
151	0.685362986	-0.047936085	-0.916565864
152	0.741430403	-0.068915783	-1.317709904
153	0.708227987	-0.018169507	-0.347411561
154	0.693078805	0.008675581	0.165882157
155	0.548819688	0.000887915	0.016977443

156	0.560003496	-0.00444794	-0.085047205
157	0.549317073	0.041326202	0.79018104
158	0.338619739	0.012257454	0.234369651
159	0.27514591	-0.052923687	-1.011931716
160	0.563780891	-0.002377382	-0.045456931
161	0.753111596	-0.08644493	-1.652877388
162	0.421020146	3.24854E-05	0.000621139
163	0.715634399	-0.00803206	-0.15357767
164	0.78666302	-0.102452494	-1.958951331
165	0.69195639	-0.066225396	-1.266268128
166	0.598560154	-0.089788224	-1.716803124
167	0.745556806	-0.078890139	-1.508425394
168	0.781575231	-0.103212658	-1.97348611
169	0.555766988	-0.076234824	-1.457654226
170	0.279355675	0.018889939	0.361186633
171	0.242026856	0.003587179	0.06858895
172	0.223785643	0.010132486	0.193739025
173	0.477331955	-0.009495698	-0.181563268
174	0.21210445	0.004269819	0.081641427
175	0.216838343	0.005383879	0.102942907
176	0.310965033	-0.024415326	-0.46683524
177	0.502845294	0.029318448	0.560585802
178	0.271169213	0.003684588	0.070451474
179	0.26191993	-0.004609988	-0.088145664
180	0.312275427	-0.00818186	-0.156441922
181	0.348293852	-0.020808472	-0.397870097
182	0.222656586	0.017109496	0.327143519
183	0.309278081	-0.028576327	-0.546396008
184	0.242524241	0.026481607	0.506343736
185	0.191671359	0.036398816	0.695966561
186	0.163591823	0.035238586	0.673782285
187	0.154094967	0.009647723	0.184470077
188	0.133037745	0.001465179	0.028015067
189	0.032235097	0.002852622	0.054543803
190	0.241395185	0.010066804	0.192483148
191	0.273636214	-0.022174226	-0.423984112
192	0.284820022	-0.004118268	-0.078743677
193	0.394487855	-0.026066803	-0.498412443
194	0.14863062	0.079439555	1.518930552
195	0.137446812	0.049687691	0.950057577

196	0.093060588	0.076530055	1.463299215
197	0.137446812	0.037991784	0.726425036
198	0.070195587	0.058459384	1.117777453
199	-0.037664467	0.037664467	0.720166535
200	0.332143082	0.030430017	0.581839647
201	0.34332689	-0.027537416	-0.526531435
202	0.189736834	0.003245622	0.062058181
203	0.41763552	-0.014126749	-0.270111657
204	0.380655709	-0.018082609	-0.345750022
205	0.403321408	0.000187363	0.003582498
206	0.49398011	-0.049535666	-0.947150767
207	0.497757505	-0.012377388	-0.236662871
208	0.446777877	-0.054965012	-1.050963027
209	0.316052822	-0.023655161	-0.45230046
210	0.338420438	0.041696521	0.797261762
211	0.352071247	-0.071369493	-1.364626259
212	0.044050576	0.055364628	1.058603933
213	0.358288093	-0.04249862	-0.81259835
214	0.253210664	-0.042684348	-0.816149591
215	0.290539483	-0.021533635	-0.411735637
216	0.201418027	0.044196008	0.845053402
217	0.46173908	0.000249224	0.004765304
218	0.523902516	-0.038522399	-0.736570704
219	0.437912693	-0.028555968	-0.546006727
220	0.535086324	-0.038010301	-0.726779081
221	0.445227451	-0.047566632	-0.909501699

Appendix 8

Regression model probability output

Percentile	*Y*
0.226244344	0
0.678733032	0
1.131221719	0.035087719
1.583710407	0.048076923
2.036199095	0.057692308
2.488687783	0.086538462
2.941176471	0.099415205
3.393665158	0.128654971
3.846153846	0.134502924
4.298642534	0.134615385
4.751131222	0.144230769
5.20361991	0.163461538
5.656108597	0.163461538
6.108597285	0.16374269
6.561085973	0.16374269
7.013574661	0.16374269
7.466063348	0.169590643
7.918552036	0.175438596
8.371040724	0.182692308
8.823529412	0.182692308
9.2760181	0.187134503
9.728506787	0.192982456
10.18099548	0.198830409
10.63348416	0.201923077
11.08597285	0.210526316
11.53846154	0.211538462
11.99095023	0.216374269
12.44343891	0.222222222
12.8959276	0.222222222
13.34841629	0.228070175
13.80090498	0.228070175
14.25339367	0.233918129
14.70588235	0.239766082
15.15837104	0.240384615
15.61085973	0.245614035

16.06334842	0.245614035
16.5158371	0.25
16.96832579	0.25
17.42081448	0.251461988
17.87330317	0.251461988
18.32579186	0.257309942
18.77828054	0.257309942
19.23076923	0.259615385
19.68325792	0.269005848
20.13574661	0.269005848
20.58823529	0.269230769
21.04072398	0.274853801
21.49321267	0.280701754
21.94570136	0.280701754
22.39819005	0.280701754
22.85067873	0.286549708
23.30316742	0.288461538
23.75565611	0.292397661
24.2081448	0.292397661
24.66063348	0.298076923
25.11312217	0.298076923
25.56561086	0.298245614
26.01809955	0.298245614
26.47058824	0.304093567
26.92307692	0.307692308
27.37556561	0.307692308
27.8280543	0.315789474
28.28054299	0.315789474
28.73303167	0.315789474
29.18552036	0.32748538
29.63800905	0.350877193
30.09049774	0.350877193
30.54298643	0.350877193
30.99547511	0.355769231
31.4479638	0.356725146
31.90045249	0.362573099
32.35294118	0.362573099
32.80542986	0.368421053
33.25791855	0.368421053
33.71040724	0.368421053

34.16289593	0.375
34.61538462	0.375
35.0678733	0.375
35.52036199	0.375
35.97285068	0.380116959
36.42533937	0.380116959
36.87782805	0.384615385
37.33031674	0.391812865
37.78280543	0.391812865
38.23529412	0.391812865
38.68778281	0.391812865
39.14027149	0.394230769
39.59276018	0.394230769
40.04524887	0.397660819
40.49773756	0.397660819
40.95022624	0.403508772
41.40271493	0.403508772
41.85520362	0.403846154
42.30769231	0.403846154
42.760181	0.403846154
43.21266968	0.409356725
43.66515837	0.409356725
44.11764706	0.413461538
44.57013575	0.413461538
45.02262443	0.421052632
45.47511312	0.421052632
45.92760181	0.423076923
46.3800905	0.426900585
46.83257919	0.432692308
47.28506787	0.442307692
47.73755656	0.442307692
48.19004525	0.444444444
48.64253394	0.444444444
49.09502262	0.461988304
49.54751131	0.461988304
50	0.467836257
50.45248869	0.467836257
50.90497738	0.479532164
51.35746606	0.480769231
51.80995475	0.485380117

52.26244344	0.485380117
52.71493213	0.485380117
53.16742081	0.485380117
53.6199095	0.485380117
54.07239819	0.490384615
54.52488688	0.497076023
54.97737557	0.5
55.42986425	0.5
55.88235294	0.502923977
56.33484163	0.50877193
56.78733032	0.509615385
57.239819	0.509615385
57.69230769	0.514619883
58.14479638	0.514619883
58.59728507	0.519230769
59.04977376	0.519230769
59.50226244	0.526315789
59.95475113	0.532163743
60.40723982	0.532163743
60.85972851	0.532163743
61.31221719	0.538011696
61.76470588	0.538011696
62.21719457	0.538461538
62.66968326	0.538461538
63.12217195	0.543859649
63.57466063	0.543859649
64.02714932	0.548076923
64.47963801	0.548076923
64.9321267	0.549707602
65.38461538	0.549707602
65.83710407	0.549707602
66.28959276	0.555555556
66.74208145	0.555555556
67.19457014	0.561403509
67.64705882	0.561403509
68.09954751	0.561403509
68.5520362	0.561403509
69.00452489	0.567251462
69.45701357	0.567307692
69.90950226	0.573099415

70.36199095	0.573099415
70.81447964	0.573099415
71.26696833	0.573099415
71.71945701	0.573099415
72.1719457	0.576923077
72.62443439	0.576923077
73.07692308	0.584795322
73.52941176	0.586538462
73.98190045	0.590643275
74.43438914	0.596153846
74.88687783	0.602339181
75.33936652	0.602339181
75.7918552	0.614035088
76.24434389	0.619883041
76.69683258	0.619883041
77.14932127	0.625730994
77.60180995	0.631578947
78.05429864	0.637426901
78.50678733	0.637426901
78.95927602	0.644230769
79.41176471	0.649122807
79.86425339	0.653846154
80.31674208	0.666666667
80.76923077	0.666666667
81.22171946	0.67251462
81.67420814	0.673076923
82.12669683	0.678362573
82.57918552	0.678362573
83.03167421	0.678362573
83.4841629	0.684210526
83.93665158	0.69005848
84.38914027	0.69005848
84.84162896	0.692307692
85.29411765	0.692307692
85.74660633	0.701754386
86.19909502	0.701754386
86.65158371	0.701754386
87.1040724	0.701923077
87.55656109	0.707602339
88.00904977	0.730769231

88.46153846	0.742690058
88.91402715	0.742690058
89.36651584	0.748538012
89.81900452	0.75
90.27149321	0.759615385
90.7239819	0.807017544
91.17647059	0.817307692
91.62895928	0.830409357
92.08144796	0.83625731
92.53393665	0.871345029
92.98642534	0.877192982
93.43891403	0.883040936
93.89140271	0.883040936
94.3438914	0.884615385
94.79638009	0.888888889
95.24886878	0.888888889
95.70135747	0.894736842
96.15384615	0.903846154
96.60633484	0.912280702
97.05882353	0.923976608
97.51131222	0.923976608
97.9638009	0.923976608
98.41628959	0.935672515
98.86877828	0.98245614
99.32126697	1
99.77375566	1

Appendix 9

Critical values of F-statistic (Sincich et al. 1999)

ν_2 \ ν_1	NUMERATOR DEGREES OF FREEDOM 1	2	3	4	5	6	7	8	9
DENOMINATOR DEGREES OF FREEDOM 1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88

Source: From M. Merrington and C. M. Thompson, "Tables of Percentage Points of the Inverted Beta (F)-Distribution," *Biometrika*, 1943, 33, 73–88. Reproduced by permission of the *Biometrika* Trustees and Oxford University Press.

Appendix 10

Values of t_α (Sincich et al. 1999)

Degrees of Freedom	$t_{.100}$	$t_{.050}$	$t_{.025}$	$t_{.010}$	$t_{.005}$	$t_{.001}$	$t_{.0005}$
1	3.078	6.314	12.706	31.821	63.657	318.31	636.62
2	1.886	2.920	4.303	6.965	9.925	22.326	31.598
3	1.638	2.353	3.182	4.541	5.841	10.213	12.924
4	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	1.319	1.714	2.069	2.500	2.807	3.485	3.767
24	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	1.296	1.671	2.000	2.390	2.660	3.232	3.460
120	1.289	1.658	1.980	2.358	2.617	3.160	3.373
∞	1.282	1.645	1.960	2.326	2.576	3.090	3.291

Source: This table is reproduced with the kind permission of the Trustees of Biometrika and Oxford University Press from E. S. Pearson and H. O. Hartley (eds.), *The Biometrika Tables for Statisticians*, Vol. 1, 3rd ed., *Biometrika*, 1966.

Appendix 11

Normalized formwork data points

GS	%	T	M	DW	S	D	Produc.
0.000	0.000	1.000	0.000	0.000	0.500	1.000	0.000
0.000	0.389	0.000	0.000	0.138	0.500	0.867	0.163
0.400	0.222	1.000	0.000	0.069	0.500	0.933	0.058
0.800	0.389	0.000	0.000	0.276	0.500	0.733	0.308
0.900	0.056	1.000	0.000	0.172	0.500	0.833	0.183
0.700	0.500	0.000	0.000	0.241	0.500	0.767	0.212
0.600	0.056	1.000	0.000	0.138	0.125	0.967	0.087
0.900	0.333	0.000	0.000	0.207	0.500	0.800	0.202
0.300	0.000	1.000	0.000	1.000	0.625	0.000	1.000
0.600	0.611	0.000	0.000	0.172	0.250	0.900	0.144
0.400	0.222	1.000	0.000	0.034	0.625	0.933	0.048
0.500	1.000	0.000	0.000	0.103	0.500	0.900	0.163
0.800	0.389	0.000	0.000	0.655	0.250	0.433	0.577
0.900	0.333	1.000	0.000	0.448	0.375	0.600	0.298
0.500	0.222	1.000	0.000	0.207	0.250	0.867	0.183
0.200	0.444	0.000	0.000	0.310	0.250	0.767	0.308
0.700	0.222	0.000	0.000	0.586	0.000	0.567	0.481
0.600	0.056	0.000	0.000	0.586	0.250	0.500	0.538
0.800	0.389	1.000	0.000	0.517	0.375	0.533	0.404
0.300	0.000	0.000	0.000	0.552	0.250	0.533	0.413
0.800	0.389	1.000	0.000	0.483	0.250	0.600	0.288
0.800	0.389	0.000	0.000	0.655	0.125	0.467	0.519
0.200	0.500	1.000	0.000	0.448	0.375	0.600	0.375
0.800	0.389	0.000	0.000	0.483	0.500	0.533	0.394
0.100	0.611	1.000	0.000	0.379	0.375	0.667	0.260
0.500	0.722	0.000	1.000	0.483	0.375	0.667	0.375
0.400	0.222	1.000	0.000	0.345	0.375	0.700	0.240
1.000	0.500	0.000	1.000	0.621	0.375	0.433	0.423
1.000	0.500	0.000	1.000	0.690	0.125	0.433	0.442
0.800	0.389	1.000	0.000	0.517	0.250	0.567	0.298
0.900	0.333	0.000	1.000	0.690	0.000	0.467	0.510
0.500	0.222	0.000	1.000	0.517	0.250	0.567	0.394
0.600	0.056	1.000	0.000	0.276	0.625	0.700	0.250
0.600	0.056	0.000	1.000	0.448	0.250	0.633	0.375

0.700	0.222	1.000	0.000	0.103	0.250	0.967	0.135
0.400	0.222	0.000	1.000	0.241	1.000	0.633	0.250
0.500	1.000	1.000	0.000	0.621	0.125	0.500	0.500
0.600	0.056	0.000	1.000	0.345	0.500	0.667	0.356
0.600	0.056	1.000	0.000	0.586	0.125	0.533	0.404
0.500	0.222	0.000	1.000	0.414	0.500	0.600	0.269
0.600	0.056	0.000	1.000	0.621	0.250	0.467	0.500
0.600	0.056	1.000	0.000	0.483	0.375	0.567	0.375
0.700	0.222	0.000	1.000	0.793	0.000	0.367	0.519
0.400	0.222	1.000	0.000	0.517	0.125	0.600	0.385
0.800	0.389	0.000	1.000	0.759	0.125	0.367	0.567
0.700	0.222	1.000	0.000	0.586	0.250	0.500	0.413
1.000	0.500	0.000	1.000	0.655	0.250	0.433	0.548
1.000	0.500	1.000	0.000	0.552	0.125	0.567	0.404
1.000	0.500	0.000	1.000	0.828	0.250	0.267	0.692
0.700	0.222	1.000	0.000	0.552	0.875	0.367	0.538
0.800	0.389	0.000	1.000	0.690	0.500	0.333	0.673
0.500	0.222	1.000	0.000	0.655	0.250	0.433	0.510
0.600	0.056	0.000	1.000	0.655	0.500	0.367	0.596
0.400	0.222	1.000	0.000	0.655	0.250	0.433	0.442
0.500	0.222	0.000	1.000	0.759	0.375	0.300	0.587
0.500	0.222	1.000	0.000	0.621	0.375	0.433	0.433
0.500	0.222	0.000	1.000	0.621	0.625	0.367	0.654
0.400	0.222	1.000	0.000	0.552	0.875	0.367	0.490
0.200	0.111	0.000	1.000	0.828	0.375	0.233	0.750
0.300	0.333	0.000	1.000	0.966	0.125	0.167	0.904
0.200	0.111	1.000	0.000	0.862	0.250	0.233	0.731
0.400	0.222	0.000	1.000	0.897	0.250	0.200	0.760
0.500	0.222	1.000	0.000	0.621	0.500	0.400	0.577
0.600	0.056	0.000	1.000	0.931	0.375	0.133	0.817
0.400	0.556	1.000	0.000	0.586	0.625	0.400	0.644
0.200	0.111	0.000	1.000	0.931	0.125	0.200	0.885
0.100	0.222	1.000	0.000	0.690	0.625	0.300	0.702
0.200	0.111	0.000	1.000	0.793	0.125	0.333	0.692
0.200	0.111	1.000	0.000	0.517	0.750	0.433	0.548
0.667	0.085	1.000	0.000	0.242	0.100	0.784	0.164
0.733	0.064	0.000	0.000	0.606	0.600	0.351	0.550
0.733	0.170	0.000	0.000	0.758	0.300	0.270	0.678
0.867	0.085	0.000	0.000	0.545	0.200	0.486	0.444

0.800	0.128	0.500	0.000	0.455	0.100	0.595	0.368
0.667	0.085	0.500	0.000	0.364	0.600	0.541	0.257
0.867	0.085	0.000	0.000	0.848	0.300	0.189	0.702
0.867	0.085	0.000	0.000	0.545	0.300	0.459	0.421
0.933	0.149	0.000	0.000	1.000	0.100	0.108	0.924
0.733	0.170	0.000	0.000	0.424	0.800	0.432	0.392
0.933	0.149	0.000	0.000	0.879	0.500	0.108	0.836
0.867	0.085	0.000	0.000	0.818	0.600	0.135	0.807
1.000	0.128	0.500	0.000	0.576	0.600	0.351	0.468
0.733	0.170	0.500	0.000	0.394	0.600	0.514	0.298
0.933	0.149	0.000	0.000	0.879	0.300	0.162	0.830
0.933	0.149	0.500	0.000	0.576	0.800	0.297	0.544
0.800	0.021	0.000	0.000	0.667	0.500	0.297	0.649
0.733	0.170	0.000	0.000	0.364	0.100	0.676	0.357
0.733	0.170	0.500	0.000	0.636	0.100	0.432	0.485
0.800	0.021	0.000	0.000	0.667	0.200	0.378	0.485
0.800	0.021	0.000	0.000	0.697	0.600	0.243	0.602
1.000	0.128	0.000	0.000	0.636	0.800	0.243	0.573
0.667	0.085	0.000	0.000	0.394	0.500	0.541	0.292
0.800	0.021	0.000	1.000	0.576	0.200	0.459	0.427
0.933	0.149	0.000	1.000	0.303	0.000	0.757	0.164
0.933	0.149	0.000	1.000	0.394	0.300	0.595	0.380
0.733	0.383	0.000	1.000	0.364	0.200	0.649	0.351
0.667	0.085	0.500	0.000	0.485	0.600	0.432	0.392
1.000	0.128	0.500	0.000	0.424	0.500	0.514	0.368
0.600	0.000	0.500	0.000	0.606	0.600	0.324	0.462
0.667	0.085	0.500	0.000	0.545	0.500	0.405	0.409
1.000	0.128	0.000	1.000	0.606	0.700	0.297	0.550
0.933	0.149	0.000	1.000	0.515	0.300	0.486	0.544
0.867	0.085	0.000	1.000	0.545	0.100	0.514	0.532
0.867	0.085	0.000	1.000	0.697	0.500	0.270	0.637
0.933	0.149	0.500	0.000	0.636	0.600	0.297	0.567
0.533	0.191	0.500	0.000	0.636	0.300	0.378	0.556
0.467	0.234	0.500	0.000	0.667	0.400	0.324	0.573
0.600	0.000	0.500	0.000	0.394	0.100	0.649	0.351
0.667	0.085	0.000	1.000	0.455	0.200	0.568	0.392
0.733	0.277	0.000	1.000	0.667	0.400	0.324	0.614
0.800	0.021	0.000	1.000	0.818	0.500	0.162	0.690
1.000	0.021	0.500	0.000	0.576	0.400	0.405	0.561

0.667	0.085	0.500	0.000	0.424	0.200	0.595	0.316
0.933	0.064	0.000	1.000	1.000	0.500	0.000	0.936
0.933	0.064	0.000	1.000	0.939	0.300	0.108	0.871
0.800	0.128	0.000	1.000	0.848	0.200	0.216	0.743
0.800	0.128	0.500	0.000	0.697	0.300	0.324	0.573
0.800	0.128	0.500	0.000	0.697	0.400	0.297	0.602
0.733	0.170	0.500	0.000	0.697	0.600	0.243	0.620
0.733	0.170	0.500	0.000	0.606	0.500	0.351	0.561
0.867	0.085	0.000	1.000	0.909	0.400	0.108	0.883
0.733	0.170	0.000	1.000	0.515	0.300	0.486	0.526
0.733	0.170	0.000	1.000	0.515	0.100	0.541	0.515
0.800	0.021	0.000	1.000	0.879	0.300	0.162	0.743
0.800	0.021	0.000	1.000	0.879	0.400	0.135	0.877
0.800	0.021	0.000	1.000	0.909	0.500	0.081	0.889
0.667	0.085	0.500	0.000	0.667	0.500	0.297	0.620
0.733	0.170	0.500	0.000	0.727	0.600	0.216	0.632
0.733	0.170	0.500	0.000	0.667	0.300	0.351	0.485
0.933	0.170	0.000	1.000	0.879	0.500	0.108	0.883
0.933	0.170	0.000	1.000	0.939	0.600	0.027	0.895
0.933	0.170	0.000	1.000	0.939	0.700	0.000	0.924
0.867	0.085	0.000	1.000	0.909	0.600	0.054	0.912
0.800	0.021	0.000	1.000	0.848	0.800	0.054	0.924
0.267	0.085	0.000	1.000	1.000	0.500	0.000	1.000
0.267	0.085	0.000	1.000	0.970	0.600	0.000	0.982
0.200	0.170	0.000	1.000	0.667	0.200	0.378	0.573
0.200	0.170	0.000	1.000	0.545	0.300	0.486	0.515
0.133	0.234	0.000	1.000	0.848	1.000	0.000	0.889
0.133	0.234	0.000	1.000	0.788	0.700	0.135	0.678
0.000	0.191	0.000	1.000	0.606	0.400	0.378	0.538
0.200	0.170	0.500	0.000	0.667	0.500	0.297	0.561
0.200	0.170	0.500	0.000	0.667	0.300	0.351	0.573
0.200	0.170	0.500	0.000	0.667	0.200	0.378	0.503
0.067	0.319	0.500	0.000	0.515	0.100	0.541	0.398
0.200	0.170	0.500	0.000	0.636	0.100	0.432	0.538
0.067	0.319	0.000	1.000	0.636	0.300	0.378	0.585
0.200	0.170	0.000	1.000	0.576	0.500	0.378	0.532
0.267	0.085	0.000	1.000	0.879	0.300	0.162	0.749
0.267	0.085	0.000	1.000	0.879	0.200	0.189	0.702
0.267	0.085	0.000	1.000	0.788	0.300	0.243	0.637

0.267	0.277	0.000	1.000	0.303	0.400	0.649	0.251
0.267	0.277	0.000	1.000	0.333	0.300	0.649	0.281
0.200	0.170	0.000	1.000	0.455	0.300	0.541	0.368
0.067	0.085	0.500	0.000	0.212	0.100	0.811	0.228
0.067	0.085	0.500	0.000	0.182	0.200	0.811	0.187
0.000	0.170	0.500	0.000	0.152	0.100	0.865	0.170
0.067	0.085	0.500	0.000	0.182	0.200	0.811	0.175
0.067	0.085	0.500	0.000	0.121	0.100	0.892	0.129
0.000	0.170	0.500	0.000	0.000	0.100	1.000	0.000
0.000	0.170	0.500	0.000	0.394	0.300	0.595	0.363
0.000	0.170	0.500	0.000	0.424	0.200	0.595	0.316
0.067	0.085	0.500	0.000	0.242	0.200	0.757	0.193
0.067	0.085	0.500	0.000	0.455	0.500	0.486	0.404
0.000	0.170	0.500	0.000	0.485	0.100	0.568	0.363
0.133	0.234	0.000	1.000	0.485	0.200	0.541	0.404
0.267	0.277	0.000	1.000	0.576	0.300	0.432	0.444
0.267	0.277	0.000	1.000	0.545	0.500	0.405	0.485
0.200	0.170	0.000	1.000	0.515	0.300	0.486	0.392
0.200	0.170	0.000	1.000	0.364	0.300	0.622	0.292
0.200	0.170	0.000	1.000	0.424	0.100	0.622	0.380
0.267	0.277	0.000	1.000	0.394	0.400	0.568	0.281
0.067	0.085	0.500	0.000	0.091	0.100	0.919	0.099
0.000	0.170	0.500	0.000	0.424	0.300	0.568	0.316
0.067	0.085	0.500	0.000	0.333	0.100	0.703	0.211
0.067	0.085	0.500	0.000	0.394	0.000	0.676	0.269
0.000	0.170	0.500	0.000	0.242	0.300	0.730	0.246
0.200	0.170	0.000	1.000	0.515	0.400	0.459	0.462
0.267	0.277	0.000	1.000	0.576	0.500	0.378	0.485
0.267	0.277	0.000	1.000	0.545	0.100	0.514	0.409
0.267	0.277	0.000	1.000	0.606	0.400	0.378	0.497
0.267	0.277	0.000	1.000	0.576	0.000	0.568	0.398

Note: GS = Gang size, % = Labor percentage, T = Work type, M = Method,
DW = Direct work, S = Support work, D = Delay, Porduc. = Productivity

Appendix 12

Original work sampling data for formwork

G.S	%	T	M	DW	S	D	Produc.
14	29	2	1	55	6	39	0.95
14	36	1	1	59	6	35	1.12
18	33	2	1	57	6	37	1.01
22	36	1	1	63	6	31	1.27
23	30	2	1	60	6	34	1.14
21	38	1	1	62	6	32	1.17
20	30	2	1	59	3	38	1.04
23	35	1	1	61	6	33	1.16
17	29	2	1	84	7	9	1.99
20	40	1	1	60	4	36	1.1
18	33	2	1	56	7	37	1
19	47	1	1	58	6	36	1.12
22	36	1	1	74	4	22	1.55
23	35	2	1	68	5	27	1.26
19	33	2	1	61	4	35	1.14
16	37	1	1	64	4	32	1.27
21	33	1	1	72	2	26	1.45
20	30	1	1	72	4	24	1.51
22	36	2	1	70	5	25	1.37
17	29	1	1	71	4	25	1.38
22	36	2	1	69	4	27	1.25
22	36	1	1	74	3	23	1.49
16	38	2	1	68	5	27	1.34
22	36	1	1	69	6	25	1.36
15	40	2	1	66	5	29	1.22
19	42	1	2	69	5	29	1.34
18	33	2	1	65	5	30	1.2
24	38	1	2	73	5	22	1.39
24	38	1	2	75	3	22	1.41
22	36	2	1	70	4	26	1.26
23	35	1	2	75	2	23	1.48
19	33	1	2	70	4	26	1.36
20	30	2	1	63	7	30	1.21
20	30	1	2	68	4	28	1.34
21	33	2	1	58	4	38	1.09

18	33	1	2	62	10	28	1.21
19	47	2	1	73	3	24	1.47
20	30	1	2	65	6	29	1.32
20	30	2	1	72	3	25	1.37
19	33	1	2	67	6	27	1.23
20	30	1	2	73	4	23	1.47
20	30	2	1	69	5	26	1.34
21	33	1	2	78	2	20	1.49
18	33	2	1	70	3	27	1.35
22	36	1	2	77	3	20	1.54
21	33	2	1	72	4	24	1.38
24	38	1	2	74	4	22	1.52
24	38	2	1	71	3	26	1.37
24	38	1	2	79	4	17	1.67
21	33	2	1	71	9	20	1.51
22	36	1	2	75	6	19	1.65
19	33	2	1	74	4	22	1.48
20	30	1	2	74	6	20	1.57
18	33	2	1	74	4	22	1.41
19	33	1	2	77	5	18	1.56
19	33	2	1	73	5	22	1.4
19	33	1	2	73	7	20	1.63
18	33	2	1	71	9	20	1.46
16	31	1	2	79	5	16	1.73
17	35	1	2	83	3	14	1.89
16	31	2	1	80	4	16	1.71
18	33	1	2	81	4	15	1.74
19	33	2	1	73	6	21	1.55
20	30	1	2	82	5	13	1.8
18	39	2	1	72	7	21	1.62
16	31	1	2	82	3	15	1.87
15	33	2	1	75	7	18	1.68
16	31	1	2	78	3	19	1.67
16	31	2	1	70	8	22	1.52
18	33	3	1	61	4	35	1.1
19	32	1	1	73	9	19	1.76
19	37	1	1	78	6	16	1.98
21	33	1	1	71	5	24	1.58
20	35	2	1	68	4	28	1.45

18	33	2	1	65	9	26	1.26
21	33	1	1	81	6	13	2.02
21	33	1	1	71	6	23	1.54
22	36	1	1	86	4	10	2.4
19	37	1	1	67	11	22	1.49
22	36	1	1	82	8	10	2.25
21	33	1	1	80	9	11	2.2
23	35	2	1	72	9	19	1.62
19	37	2	1	66	9	25	1.33
22	36	1	1	82	6	12	2.24
22	36	2	1	72	11	17	1.75
20	30	1	1	75	8	17	1.93
19	37	1	1	65	4	31	1.43
19	37	2	1	74	4	22	1.65
20	30	1	1	75	5	20	1.65
20	30	1	1	76	9	15	1.85
23	35	1	1	74	11	15	1.8
18	33	1	1	66	8	26	1.32
20	30	1	2	72	5	23	1.55
22	36	1	2	63	3	34	1.1
22	36	1	2	66	6	28	1.47
19	47	1	2	65	5	30	1.42
18	33	2	1	69	9	22	1.49
23	35	2	1	67	8	25	1.45
17	29	2	1	73	9	18	1.61
18	33	2	1	71	8	21	1.52
23	35	1	2	73	10	17	1.76
22	36	1	2	70	6	24	1.75
21	33	1	2	71	4	25	1.73
21	33	1	2	76	8	16	1.91
22	36	2	1	74	9	17	1.79
16	38	2	1	74	6	20	1.77
15	40	2	1	75	7	18	1.8
17	29	2	1	66	4	30	1.42
18	33	1	2	68	5	27	1.49
19	42	1	2	75	7	18	1.87
20	30	1	2	80	8	12	2
23	30	2	1	72	7	21	1.78

18	33	2	1	67	5	28	1.36
22	32	1	2	86	8	6	2.42
22	32	1	2	84	6	10	2.31
20	35	1	2	81	5	14	2.09
20	35	2	1	76	6	18	1.8
20	35	2	1	76	7	17	1.85
19	37	2	1	76	9	15	1.88
19	37	2	1	73	8	19	1.78
21	33	1	2	83	7	10	2.33
19	37	1	2	70	6	24	1.72
19	37	1	2	70	4	26	1.7
20	30	1	2	82	6	12	2.09
20	30	1	2	82	7	11	2.32
20	30	1	2	83	8	9	2.34
18	33	2	1	75	8	17	1.88
19	37	2	1	77	9	14	1.9
19	37	2	1	75	6	19	1.65
22	37	1	2	82	8	10	2.33
22	37	1	2	84	9	7	2.35
22	37	1	2	84	10	6	2.4
21	33	1	2	83	9	8	2.38
20	30	1	2	81	11	8	2.4
12	33	1	2	86	8	6	2.53
12	33	1	2	85	9	6	2.5
11	37	1	2	75	5	20	1.8
11	37	1	2	71	6	24	1.7
10	40	1	2	81	13	6	2.34
10	40	1	2	79	10	11	1.98
8	38	1	2	73	7	20	1.74
11	37	2	1	75	8	17	1.78
11	37	2	1	75	6	19	1.8
11	37	2	1	75	5	20	1.68
9	44	2	1	70	4	26	1.5
11	37	2	1	74	4	22	1.74
9	44	1	2	74	6	20	1.82
11	37	1	2	72	8	20	1.73
12	33	1	2	82	6	12	2.1
12	33	1	2	82	5	13	2.02

12	33	1	2	79	6	15	1.91
12	33	1	2	80	8	12	1.97
11	37	1	2	80	6	14	2
11	37	2	1	81	4	15	2.02
10	40	2	1	75	5	20	1.76
10	40	2	1	76	4	20	1.77
9	44	2	1	74	7	19	1.83
8	38	2	1	68	3	29	1.42
8	38	2	1	65	4	31	1.2
10	40	2	1	75	6	19	1.78
11	37	1	2	80	9	11	1.96
8	38	1	2	69	6	25	1.54
11	37	1	2	82	3	15	2.03
11	37	1	2	83	6	11	1.99
12	42	1	2	79	7	14	1.89
12	42	1	2	76	6	18	1.69
11	37	1	2	82	5	13	1.96
12	42	1	2	83	6	11	1.98
9	33	2	1	75	5	20	1.64
9	33	2	1	65	4	31	1.33
9	33	2	1	63	5	32	1.24
8	37	2	1	63	4	33	1.22
9	33	2	1	72	5	23	1.62
9	33	2	1	63	3	34	1.19
9	44	2	1	63	4	33	1.2
12	42	1	2	65	6	29	1.31
11	37	1	2	71	8	21	1.73
11	37	1	2	65	3	32	1.29
11	37	1	2	64	4	31	1.26
11	37	1	2	66	4	30	1.34
12	42	1	2	67	5	28	1.38
11	37	1	2	62	5	33	1.23
9	33	2	1	65	6	29	1.3
8	37	2	1	62	7	31	1.28
9	33	2	1	61	5	33	1.21
9	33	2	1	60	5	35	1.16
12	42	1	2	59	6	35	1.1
11	37	1	2	58	6	36	1.05

11	37	1	2	53	8	39	0.88
11	37	1	2	61	8	31	1.25
12	42	1	2	63	7	30	1.25
12	42	1	2	64	6	30	1.3
11	37	1	2	68	6	26	1.45
9	33	2	1	60	4	36	1.21
9	33	2	1	59	5	36	1.14
8	37	2	1	58	4	38	1.11
9	33	2	1	59	5	36	1.12
9	33	2	1	57	4	39	1.04
8	37	2	1	53	4	43	0.82
8	37	2	1	66	6	28	1.44
8	37	2	1	67	5	28	1.36
9	33	2	1	61	5	34	1.15
9	33	2	1	68	8	24	1.51
8	37	2	1	69	4	27	1.44
10	40	1	2	69	5	26	1.51
12	42	1	2	72	6	22	1.58
12	42	1	2	71	8	21	1.65
11	37	1	2	70	6	24	1.49
11	37	1	2	65	6	29	1.32
11	37	1	2	67	4	29	1.47
12	42	1	2	66	7	27	1.3
9	33	2	1	56	4	40	0.99
8	37	2	1	67	6	27	1.36
9	33	2	1	64	4	32	1.18
9	33	2	1	66	3	31	1.28
8	37	2	1	61	6	33	1.24
11	37	1	2	70	7	23	1.61
12	42	1	2	72	8	20	1.65
12	42	1	2	71	4	25	1.52
12	42	1	2	73	7	20	1.67
12	42	1	2	72	3	27	1.5

Note: GS = Gang size, % = Labor percentage, T = Work type, M = Method,
DW = Direct work, S = Support work, D = Delay, Porduc. = Productivity

Appendix 13

Work sampling data for earthmoving

DW	S	D	Pro.
52	13	35	13.56
48	19	38	12.52
50	16	34	13.04
41	17	42	10.69
38	29	33	9.91
40	18	42	10.43
50	14	36	12.13
51	16	33	13.3
44	19	37	11.47
46	20	34	12.01
48	17	35	12.64
41	21	38	10.99
48	15	37	12.57
55	16	29	14.35
54	21	25	14.09
50	11	39	12.5
51	25	24	13.68
42	31	27	10.86
40	25	35	10.61
33	30	37	8.61
42	25	33	10.34
38	21	41	9.07
56	22	22	14.61
55	25	20	13.29
50	26	24	12.96
48	26	26	13.07
44	29	27	11.89
40	27	33	10.82
42	23	35	10.19
41	29	30	11.35
42	29	29	10.51
45	29	26	11.73
48	32	20	13.39

DW	S	D	Pro.
53	20	27	13.82
50	14	36	11.12
51	15	34	12.27
40	23	37	10.23
42	23	35	10.06
41	19	40	10.98
44	22	34	12.16
48	17	35	12.94
38	23	39	10.02
50	19	31	11.64
36	22	42	9.39
44	18	38	11.56
37	22	41	9.65
51	18	31	12.46
56	12	32	13.71
50	25	25	11.81
40	38	22	11.42
44	27	29	12.88
43	26	31	11.18
42	22	36	10.01
50	23	27	12.01
57	13	30	14.87
53	19	28	13.79
54	21	25	14.01
52	18	30	13.86
45	24	31	14.33
43	24	33	11.31
51	19	30	12.51
40	28	32	10.46
41	22	37	11.17
40	27	33	10.23
53	26	21	14.14

Note: DW = Direct work, S = Support work, D = Delay, Pro. = Productivity (m^3/man/man-hour)

Appendix 14

Work sampling data for lagging

GS	%	DW	S	D	Pro.
4	25	35	43	22	1.2
4	25	37	38	25	1.21
8	38	30	34	36	1.12
8	38	32	34	34	1.15
6	50	34	37	29	1.15
4	50	44	25	31	1.19
8	50	34	31	35	1.06
8	38	31	30	39	0.86
8	38	30	35	35	0.82
8	50	33	37	30	0.96
6	50	34	38	28	1.02
6	33	30	46	24	0.83
6	33	31	38	31	0.84
6	33	30	43	27	0.87
6	33	29	46	25	0.8
4	50	46	32	22	1.44
4	50	43	37	20	1.4
4	50	44	32	24	1.42
4	25	41	31	28	1.24
8	38	31	36	33	0.9
8	50	36	34	30	1.03
4	50	47	34	19	1.45
4	50	49	30	21	1.49
6	50	35	40	25	1.06
6	33	32	46	22	0.86
6	33	30	43	27	0.79
4	25	42	36	22	1.19
8	38	27	34	39	1.81
8	50	33	33	34	1.01
6	50	38	29	33	0.94
5	40	44	26	30	1.31
5	40	45	19	36	1.36
8	50	33	26	41	0.97
8	50	35	25	40	1.03

8	38	32	24	44	0.87
8	38	29	20	51	0.8
5	40	40	27	33	0.99
4	50	43	27	30	1.23
4	25	36	26	38	0.87
8	50	37	24	39	0.91
8	50	35	33	32	0.86
8	38	37	30	33	0.84
5	40	41	30	29	1.05
5	60	44	28	28	1.25
8	38	30	24	46	0.83
8	38	27	25	48	0.75
4	25	35	26	39	0.85
4	25	37	23	40	0.93
4	50	44	25	31	1.17
5	40	48	23	29	1.16
8	50	38	29	33	1.18
8	50	38	25	37	1.15
8	50	37	34	29	1.09
8	50	35	23	42	0.91
8	38	31	21	48	0.77
8	38	30	19	51	0.71
8	38	33	22	45	0.75
8	50	37	30	33	0.96
8	50	35	29	36	0.92
8	25	26	28	46	0.74
4	50	48	21	31	1.29
4	50	44	27	29	1.21
4	50	46	21	33	1.25
5	60	46	18	36	1.28
5	60	47	22	31	1.32
8	50	39	15	46	0.88
8	38	33	20	47	0.79
5	40	42	27	31	1.11
5	40	41	26	33	1.06
8	38	31	21	48	0.83
8	38	27	21	52	0.73
8	50	37	26	37	0.92
8	50	35	35	30	1.04

8	50	36	39	25	1.09
8	38	29	35	36	0.8
4	50	45	21	34	1.24
4	25	42	20	38	0.95
8	38	28	30	42	0.77
8	38	33	28	39	0.84
8	38	30	24	46	0.82
8	50	36	31	33	0.94
8	50	34	27	39	0.82
8	50	38	21	41	0.9
8	50	34	36	30	0.86
8	50	36	36	28	0.99
8	50	34	44	22	1.05
4	50	43	36	21	1.31
4	75	57	20	23	1.38
4	75	61	17	22	1.44
8	63	43	33	24	1.28
4	50	55	24	21	1.41
8	63	44	29	27	1.26
4	50	46	34	20	1.35
4	50	49	33	18	1.42
4	25	33	36	31	0.94
5	60	48	38	24	1.35
5	60	44	34	22	1.24
5	60	43	35	22	1.26
5	40	40	33	27	1.02
5	40	39	29	32	1
8	50	40	31	29	1.03
4	75	49	27	24	1.39
4	50	52	28	20	1.43
8	63	41	34	25	1.25
4	25	37	27	36	0.98
4	25	40	38	22	1.06
8	50	38	23	39	1.06
8	38	29	29	42	0.83
8	38	25	31	44	0.78
8	38	28	32	40	0.8
8	50	34	36	33	0.85
4	50	44	35	21	1.18

5	60	44	39	17	1.25
5	60	46	34	20	1.3
4	50	48	29	23	1.32
4	50	51	29	20	1.39
5	60	47	37	16	1.38
5	40	40	43	17	1.18
4	50	42	39	19	1.21
4	50	45	35	20	1.23
8	50	37	39	24	1.11
8	50	35	40	25	1.07
8	50	38	40	22	1.14
5	40	41	39	20	1.22
5	40	43	39	18	1.34
4	50	45	37	18	1.35
4	50	42	37	21	1.17
8	50	36	33	31	1.05
8	50	37	31	32	1.12
8	50	35	35	30	1.08
8	50	33	33	34	1.01
8	50	39	39	29	1.14
4	25	38	40	22	1.18

Note: GS = Gang size, % = Labor percentage, DW = Direct work, S = Support work, D = Delay, Pro. = Productivity (m^2/man/man-hour).

Appendix 15

Work sampling data for reinforcing bars

GS	%	T	DW	S	D	Pro.
8	40	2	52	17	31	1.51
10	40	2	39	35	26	1.23
10	50	1	31	36	33	0.86
9	44	2	58	20	22	1.59
5	47	3	69	14	17	2.82
8	56	3	63	17	20	2.69
11	40	2	55	21	24	1.63
15	40	1	33	32	35	0.93
11	53	2	50	15	35	1.62
5	45	3	68	12	20	3.06
6	58	3	61	13	26	2.36
15	40	1	40	20	40	0.95
6	50	1	43	17	40	0.93
9	33	3	59	19	22	2.48
12	38	1	34	33	33	0.86
7	57	3	57	25	18	2.67
9	33	2	46	34	20	1.52
8	50	2	45	21	34	1.38
11	40	2	38	27	35	1.23
6	53	1	36	43	21	1.06
9	45	1	41	33	26	1.22
8	33	2	41	33	26	1.25
14	50	2	43	14	35	0.97
9	40	2	46	33	24	1.43
8	53	2	38	39	28	1.13
14	40	2	34	26	40	0.96
9	53	1	31	40	29	1.04
10	45	3	46	23	31	1.84
5	33	1	44	37	19	1.81
6	50	3	38	42	20	2.16
9	33	2	40	35	25	1.2
8	50	2	40	36	24	1.19
10	40	2	45	18	38	1.07
6	53	2	41	39	20	1.29

9	40	2	35	35	30	1.19
8	53	3	39	31	30	1.96
9	45	3	51	21	28	2.09
9	45	3	45	22	33	1.92
7	33	3	58	19	23	2.43
14	50	2	30	24	46	0.87
9	33	2	44	33	23	1.23
9	50	1	41	34	15	1.26
8	40	1	44	40	16	1.28
15	53	1	32	29	39	0.91
6	40	2	42	39	19	1.33
10	53	2	38	26	36	1.03
10	40	2	36	26	38	1.02
5	53	1	45	40	15	1
13	45	2	32	29	39	1.24
9	45	3	46	32	22	2.12
8	33	3	56	21	23	2.23
6	50	3	62	19	19	2.48
6	33	3	57	20	23	2.26
8	33	3	61	14	25	2.32
9	50	2	40	37	23	1.39
8	40	2	49	20	31	1.46
5	53	1	60	24	16	1.84
6	40	1	51	28	21	1.6
9	53	2	46	19	25	1.49
13	40	2	36	34	30	0.91
14	53	2	32	27	41	0.86
9	45	2	39	36	25	1.31
8	45	2	46	35	19	1.46
6	33	1	50	35	15	1.06
8	50	1	42	35	23	0.97
11	33	2	34	27	39	1.18
14	33	2	34	22	44	1.14
9	50	2	47	17	36	1.28
7	40	1	56	22	22	1.5
8	53	1	50	27	23	1.37
9	40	1	40	35	25	1.24
8	53	1	41	39	20	1.3
11	40	3	36	33	31	1.71

14	53	3	32	27	41	1.44
15	45	3	30	26	44	1.35
9	45	1	36	39	25	0.93
15	33	2	33	26	41	0.94
15	50	2	30	25	45	0.88
11	33	1	37	23	30	0.85
10	33	2	37	28	25	1.2
8	50	2	38	47	15	1.3
8	40	2	31	41	28	1.24
14	53	2	26	30	44	0.96
12	40	1	38	32	33	0.88
14	53	1	30	28	42	0.79
10	40	2	42	27	31	1.31
8	53	1	40	45	15	1.26
15	45	3	33	29	38	1.41
11	45	2	39	33	28	1.24
11	33	2	36	34	30	1.19
8	50	2	45	36	19	1.32
9	33	3	38	40	22	1.88
12	33	2	33	32	35	1.43
8	50	3	49	28	23	1.98
11	40	2	35	39	26	1.16
8	53	1	50	28	22	1.33
14	40	3	42	35	33	1.78
9	45	3	46	33	21	2.01
9	33	2	49	26	25	1.53
8	50	2	41	32	27	1.38
7	33	3	49	21	20	2.21
8	33	3	44	33	23	2.11
6	50	3	47	38	15	2.26
5	40	3	50	36	14	2.39
9	53	3	41	36	23	2.04
5	40	1	31	44	15	0.88
6	50	1	36	42	22	0.91
10	40	3	39	37	24	1.77
8	53	3	51	28	21	2.02
15	40	1	33	31	36	0.91
8	45	1	33	45	22	1.02
14	33	3	39	22	39	1.68

14	50	3	41	23	36	1.81
9	33	2	40	36	24	1.44
9	33	2	44	35	21	1.51
8	50	3	41	46	23	1.98
6	40	3	44	41	15	2.18
5	53	1	46	40	14	1.84
11	40	3	33	31	36	1.76
15	50	3	26	28	46	1.29
9	40	1	38	36	26	1.2
12	53	1	32	40	28	0.89
8	40	1	41	41	18	1.24
10	45	2	38	38	24	1.27
8	33	3	39	36	25	2.11
12	50	2	33	39	28	1.01
10	33	3	35	39	26	1.88
7	33	3	48	35	17	2.24
14	50	2	32	47	31	0.99
6	40	1	46	40	14	1.02
10	53	1	35	40	25	0.96
6	40	3	55	30	15	2.21
8	50	3	48	29	23	2.12
11	40	3	41	26	33	1.78
9	53	1	44	23	23	1.31
8	40	1	37	43	20	1.19
15	45	3	31	35	34	1.38
8	33	2	43	34	23	1.41
14	50	2	33	31	36	1.06
6	33	2	46	30	24	1.4
9	50	2	42	31	27	1.33
9	40	1	41	26	33	1.19
8	53	1	44	32	24	1.22
7	40	3	47	31	22	2.11
6	50	3	56	28	16	2.45
14	50	3	39	30	31	1.81
11	40	3	37	34	29	1.73
14	53	3	30	36	34	1.7
8	40	2	38	41	21	1.18
6	50	2	42	40	18	1.34
8	41	1	40	35	25	1.23

Note: GS = Gang size, % = Labor percentage, T = Work type (1-Column, 2- Wall, 3-Salb), DW = Direct work, S = Support work, D = Delay, Pro. = Productivity (m^2/man/man-hour).

Appendix 16

Work sampling data for concrete pouring

GS	%	T	M	DW	S	D	Pro.
6	50	1	1	44	19	37	1.92
9	33	1	1	33	11	56	1.86
7	57	1	1	43	23	34	1.73
11	36	2	2	63	7	30	2.63
11	36	2	2	68	9	23	2.76
5	60	1	2	51	21	28	2.01
9	33	2	2	60	17	33	3.92
6	33	2	2	51	19	30	3.61
6	33	3	1	75	14	8	4.12
8	38	3	1	72	8	20	3.82
7	43	3	1	65	22	23	3.65
10	40	2	2	62	14	20	3.61
8	38	2	2	63	13	18	3.66
9	44	1	1	50	8	42	1.61
8	50	2	1	64	10	26	3.6
9	44	3	2	61	9	24	3.81
7	29	2	1	53	19	28	3.31
9	33	1	1	39	2	31	1.75
6	50	1	1	43	24	33	1.88
6	50	1	1	41	33	26	1.84
8	38	2	1	54	18	28	3.09
8	38	2	2	56	17	27	3.41
7	43	1	1	42	24	34	1.86
10	30	3	1	64	11	25	3.89
9	33	3	1	66	12	22	4.01
8	38	2	1	58	12	30	3.32
6	50	1	1	57	19	24	2.23
10	40	3	2	65	12	23	3.68
7	43	1	1	52	14	34	1.96
8	38	2	2	64	6	30	3.11
9	33	2	1	62	7	31	3.25
8	50	2	1	61	14	25	3.36
10	40	3	2	62	14	24	3.41
9	33	3	2	60	16	24	3.25

6	33	1	2	48	20	32	1.36
6	33	1	1	44	20	36	1.96
9	33	3	2	71	9	20	3.91
8	50	3	1	67	10	23	3.33
9	33	1	1	51	9	40	1.64
8	50	2	1	57	21	22	3.27
10	33	2	2	53	13	34	2.75
8	38	2	1	48	24	28	2.19
6	50	1	1	52	23	35	2.07
10	33	2	2	53	23	34	2.76
8	50	2	1	57	18	25	3.04
9	33	3	2	61	12	27	3.51
6	50	1	1	53	11	36	2.1
10	40	3	2	62	12	26	3.53
9	33	3	2	60	16	24	3.58
6	33	1	2	48	16	36	1.94
6	33	1	1	44	20	36	1.9
9	33	3	2	71	9	20	3.96
8	38	2	2	64	6	30	2.71
9	33	2	1	62	7	31	3.22
10	33	2	2	53	16	31	2.86
10	40	2	1	51	20	29	2.36
6	50	1	1	52	23	35	2.13
10	33	2	2	53	23	34	2.87
8	38	2	1	58	12	30	3.22
6	50	1	1	57	19	24	2.14
10	40	3	2	65	12	23	3.42
8	50	2	1	64	11	25	3.58
10	40	3	2	62	12	26	3.46
6	33	1	1	44	20	36	1.89
9	33	3	2	71	9	20	3.87
8	38	2	2	64	12	24	3.24
8	38	2	2	64	10	26	3.22
9	33	2	1	62	7	31	3.24
10	33	2	2	55	11	34	2.59
10	33	2	2	53	13	34	2.57
8	38	2	1	48	24	28	3.08
6	50	1	1	52	23	35	1.96
8	50	2	1	57	18	25	3.38

9	33	3	2	61	12	27	3.44
6	50	1	1	53	11	36	1.95
10	40	3	2	62	12	26	3.62
9	33	3	2	64	12	24	3.74
6	33	1	2	48	16	36	2
10	40	3	1	62	16	22	3.21
9	33	3	2	60	16	24	3.5
6	33	1	2	51	13	36	1.97
6	33	1	1	44	20	36	1.94
9	44	2	2	72	10	18	4.08
9	33	2	1	62	7	31	3.49
10	33	2	2	56	10	34	3.23
8	38	2	1	51	21	28	2.98
7	43	1	1	52	17	31	1.96
6	33	1	1	50	22	28	2.06
6	50	1	1	52	13	35	2.02
10	33	2	2	53	13	34	3.13
8	38	2	1	58	12	30	3.11
8	38	2	2	65	13	22	3.72
6	33	1	2	48	16	36	1.89
6	33	1	1	44	20	36	1.9
9	33	3	2	71	9	20	4.03
7	43	1	1	44	23	33	1.82
9	33	3	2	71	9	20	3.86
9	33	2	1	62	7	31	3.33
10	33	2	2	53	11	36	3.14
9	33	2	1	62	7	31	3.4
10	40	2	2	53	17	30	2.97
8	38	2	1	48	24	28	2.76
6	50	1	1	52	17	31	2.13
8	38	1	1	48	23	29	1.65
6	50	1	1	52	23	35	2.18
8	38	2	1	49	23	28	2.77
6	33	1	1	52	23	35	2.06
7	43	2	1	55	21	24	3.37
6	50	1	1	52	23	35	2.2
10	33	2	2	53	23	34	2.76
8	38	2	1	58	12	30	3.19
9	33	3	2	60	16	24	3.42

8	50	2	1	64	9	27	3.55
9	33	3	2	60	16	24	3.51
6	33	1	2	48	16	36	1.87
6	33	1	1	44	20	36	1.94
6	33	1	2	48	16	36	1.85
8	38	1	1	48	21	31	1.81
9	33	3	2	72	7	21	4.03
6	33	1	1	48	17	35	2
7	43	1	1	44	20	36	1.88
9	33	3	2	71	9	20	3.94
6	33	1	1	48	16	36	1.95
8	33	3	2	72	10	18	4.07
9	33	2	1	62	7	31	3.21
9	33	3	2	71	8	21	3.99
8	38	2	1	62	13	25	3.56
9	33	2	2	56	13	31	3.69
9	33	2	1	62	12	26	3.46
10	33	2	2	53	13	34	2.45
9	33	2	1	62	7	31	3.34
10	30	2	2	53	13	34	3.14
7	38	2	1	55	21	24	3.37
8	38	1	1	52	17	31	1.86
8	38	2	1	48	24	28	3.09
6	50	1	1	52	23	35	2.11
8	38	2	1	48	24	28	3.03
6	33	1	1	56	13	31	2.1
8	38	2	1	51	21	28	3.24
8	38	1	1	54	9	37	2.15
8	38	2	1	50	25	25	3..9
7	43	1	1	53	12	35	1.83
8	38	2	1	53	21	26	3.04
6	50	1	1	52	16	32	2.14
6	50	1	1	52	23	35	2.1
8	38	2	1	49	24	27	2.94
6	50	1	1	52	23	35	2.03
10	33	2	2	53	23	34	3.27
8	38	2	1	58	12	30	3.29
8	38	2	1	52	20	28	3.21
7	57	1	1	54	10	36	1.94

6	50	2	1	55	17	28	3.28
8	38	2	1	58	12	30	3.4
9	33	3	2	60	16	24	3.61
8	38	2	1	58	12	30	3.2
6	33	1	2	48	16	36	1.85
6	33	1	1	44	25	31	1.88
6	33	1	2	48	16	36	1.94
6	33	1	1	45	22	33	1.95
6	50	1	1	48	21	31	2.04
9	33	3	2	70	8	22	4.1
8	38	1	1	55	16	29	1.76
8	38	2	1	57	15	28	3.24
6	50	1	1	52	18	30	2.04
8	38	2	1	55	24	17	3.31

Note: GS = Gang size, % = Labor percentage, T = Work type (1- Column, 2- Wall, 3- Slab), M = Work method (1-Bucket, 2- Pump), DW = Direct work, S = Support work, D = Delay, Pro. = Productivity (m^3/man/man-hour).