University of Alberta

Estimating Concrete Formwork Productivity

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Estimating Concrete Formwork Productivity** submitted by **Jason B. Portas** in partial fulfillment for the degree of **Master of Science in Construction Engineering & Management**.

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Abstract

This research involves the development of a neural network system to aid in the estimation of labor productivity for concrete formwork. The goal of the research project is to improve the ability to estimate labor productivity by studying the factors that affect it, as well as to develop analytical tools that implement the findings. The research includes the construction of a historical project information collection, storage and retrieval system, the modeling and implementation of a historical information analysis model, a study into the factors which affect labor productivity, and the modeling and implementation of a neural network system to aid in the estimation of labor productivity.

The final neural network is a backpropagation, feedforward neural network. The network uses a sigmoid transfer function, with a normal cumulative learning rule. There are approximately 55 input nodes representing 30 factors, 30 hidden nodes in 1 hidden layer and 13 output nodes. The inputs to the network are factors that were determined to have an effect on productivity. The output formulation of the model is a binary output pattern matching technique that predicts labor productivity. The productivity is predicted as a set of scores that represent certainty of occurrence corresponding to subset ranges of productivity values.

The contributions of the investigation include providing new ways of analyzing historical data so that it can be used to predict performance for future projects, enhancement of the accuracy of current labor productivity estimates and an increased understanding of construction activities and the factors that affect labor productivity.

Acknowledgment

Many thanks to my graduate studies supervisor Dr. Simaan M. Abourizk for his support, encouragement and guidance throughout this research. Appreciation is extended to the members of my examining committee, including Professor S.P. Dozzi, Dr. D.M. Rogowsky, and Dr. R.W. Toogood.

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Table of Contents

List of Tables

List of Figures

Chapter 1

1. Introduction

1.1 OVERVIEW

A key factor for a successful construction project is the preparation of an accurate estimate. Issues ranging from project feasibility to profitability can be influenced by an estimate. A cornerstone of a successful estimate is determining the cost of labor, which is dependent on determining the expected labor productivity of the work crews.

Certain construction tasks are highly repetitive and standardized, such as prefabrication of structural steel components. Other construction tasks such as concrete formwork are specialized and nonrepetitive, employing a range of construction. Concrete formwork labor productivity is difficult to predict and improper judgments may lead to significant cost overruns. This study focuses on the estimation of concrete formwork labor productivity.

Presently, labor productivity estimates are performed by individuals using combinations of analytical techniques and judgment. Experience and knowledge of construction activities are combined with historical information and detailed work studies to estimate labor productivity. The major drawbacks of the method are inconsistencies and improper judgments. Estimators may not have a proper understanding of the work, may not be able to identify the factors influencing productivity and may not be able to quantify the influence of the factors. Analysis of a contractor's estimate versus actual labor productivity values demonstrated an accuracy of plus or minus 15% approximately 40% of the time for concrete wall formwork. The analysis also demonstrated that inaccuracies of 50% or 100% are possible. The goal of the study is to aid in increasing the accuracy of labor productivity estimates.

1.2 OBJECTIVES

The objective of the project is to develop and implement a model to aid in the estimation of labor productivity. The objective will be achieved with the completion of the following subobjectives:

- Exploring the implementation of artificial intelligence techniques, specifically neural networks for the process of predicting productivity.
- Identifying the factors that affect productivity of labor on concrete formwork.
- Establishing a framework for data collection to facilitate implementation of analysis models in the future.
- Implementing the model as a computer application for a general contractor in the building construction industry.

1.3 METHODOLOGY OF THE SOLUTION

The procedure followed for achieving the objectives was to study the factors affecting labor productivity, complete a detailed data collection investigation, experiment with neural networks and prepare an overall model to be implemented as a computer program. The procedure involves reevaluation of previous decisions and conclusions as data collection and experimentation progresses. Constant feedback and reevaluation is an important component in ensuring continuous improvement to the original systems and procedures as demonstrated in Figure 1-1 Methodology of the Solution.

The first stage of the study focuses the factors that affect labor productivity for concrete formwork construction activities. All possible factors are outlined and decisions either to investigate or neglect factors are made based on the parameters of the study. The parameters include predicting labor productivity on the activity level for concrete formwork, or in other words the average productivity for a specific task such as the construction of concrete foundation walls. Other parameters deal with limitations of the data collection techniques and procedures, and the sources of the data.

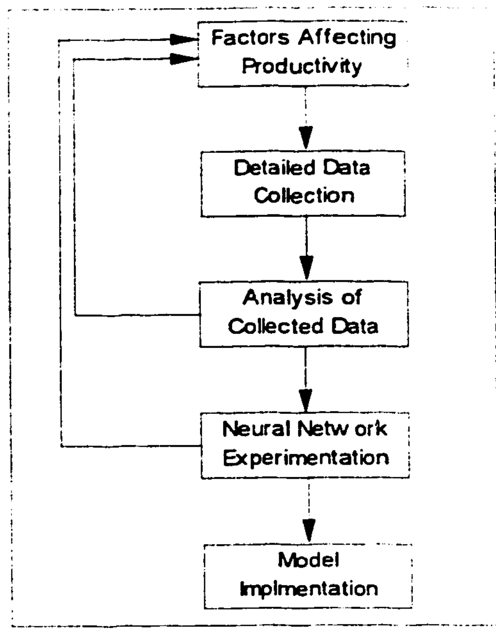

Figure 1-1 Methodology of the Solution

The second stage of the study involves collection of data to support the study. Information on the factors affecting productivity is required for use in later experimentation. Information is required from a wide range of sources, therefore data collection procedures and techniques are necessary to ensure accuracy and consistency. The study focuses on historical projects. The information is to be used in building an information base for the system, providing information for experimentation.

The third stage of the study involves the preparation of, and experimentation with, neural networks. Input models, output models and network structures are investigated.

The fourth stage of the study deals with the construction of a model that implements the findings of the study. Figure 1-2 Conceptual Computer System illustrates the components of the system. The model consists of a historical data collection and storage module, a neural network training and testing module and a neural network recall module.

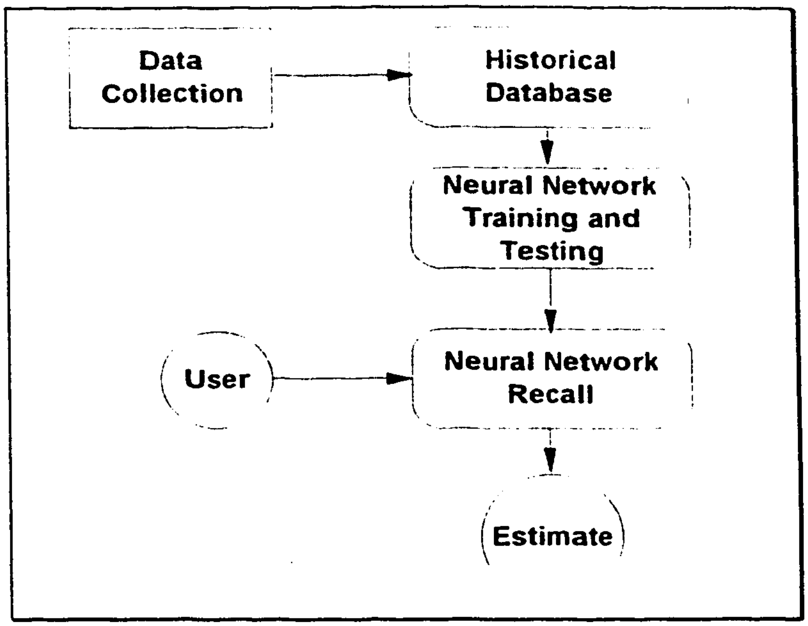

Figure 1-2 Conceptual Computer System

1.4 EXPECTED CONTRIBUTIONS

The contributions of the study can be classified in two areas, academic and industrial.

The academic contributions of the study are:

- Implementation of artificial intelligence tools in a practical setting (put theory into practice).
- Better understanding of construction activities and the factors that affect labor productivity.

The industrial contributions of the study are:

- Enhancement of the accuracy of current labor productivity estimates.
- Providing new ways of analyzing historical data so that it can be used to predict performance for future projects.

1.5 THESIS ORGANIZATION

Chapter 2 review s the literature and discusses the state of the art. Factors affecting productivity as well as neural networks and their applicability to construction engineering problems are discussed. Chapter 3 discusses the factors affecting productivity and the evolution of the data collection framework implemented in the study. Chapter 4 outlines neural networks; the experimentation procedure; and conclusions from the study. Chapter 5 outlines the prototype system, from the user interface to the storage of information that drives the entire system. Chapter 6 presents concluding remarks and future research.

Chapter 2

2. Literature Review and State of the Art

2.1 Introduction

The literature review focused on two topics: investigating and collecting information on factors that affect productivity; and investigating neural networks applications for estimating productivity. Both topics were investigated as they pertain to construction.

2.2 Construction Labor Productivity

Construction labor productivity for commercial and building construction is defined in this thesis as the ratio of input to output, or man hours per unit of work. Values for productivity are calculated by accumulating worker hours and dividing by the quantity of work performed measured in standard units.

Labor productivity is measured at several levels of detail. Measurements can be recorded on an hourly, daily, weekly, activity or project basis. For this investigation, the level of detail desired is the activity level. Labor productivity will be examined as the total man hours to complete a construction activity, divided by the unit of quantity measure for the construction activity (for example, total man hours per square foot of contact area of concrete formwork).

The starting point of estimating labor productivity is determining the factors that influence it.

2.3 Factors that Affect Productivity

Russell (1993) focused on data collection for factors that affect productivity on a daily basis. The investigation used data collection procedures based on a superintendent's daily site reporting diary. Information collected included:

1. Weather: temperature, humidity, precipitation and climate.

2. Site conditions: storage space, access, congestion, soil conditions.
3. Owner/Consultants: changes, interface/stop, extra work, inspection/tests .
4. Design/Drawings: insufficient/incomplete, errors, changes, coordination.
5. Work force: manning levels, skill, turnover, motivation, inadequate instructions.
6. Work: rework, estimating errors, construction error, workmanship.
7. Insufficient materials / equipment.
8. Schedule: delays, improper sequencing.
9. Utilities/City: permits, connections, Inspections/tests, problems with utilities.
10. Miscellaneous: theft, strikes, vandalism, shutdowns.

Sanders and Thomas (1991) focused on the factors affecting masonry-labor productivity. The investigators outlined the deficiencies of previous labor productivity investigations. To define the factors affecting labor productivity, the elements of a construction activity and the factors that might disrupt the activity were discussed.

Sanders and Thomas outlined problems with past studies on labor productivity as a starting point for building a new model. Their conclusions were:

1. Most studies deal with the investigation of a single factor as it affects productivity. This ignores the interaction of factors which combine to influence labor productivity.
2. Previous studies were conducted with a preconceived notion of which factor(s) should be investigated. Exploratory analysis into the factors that affect labor productivity must be conducted to determine which factors are significant and which may be discarded from the investigation.
3. Data collection procedures were not standardized, yielding inaccurate results. Data is typically collected and assessed by several individuals, therefore standardization is required for the data to be meaningful.

The project related factors were summarized into four categories for analysis purposes.

1. Work Type - identifies design differences that may affect productivity. Classification of work type was by design features and required resources.
2. Building Element - identifies different building components that require different amounts of labor. Classification of building elements was based on the types of structure components.

3. Construction Method - identifies construction techniques chosen by the contractor. Classification of construction methods was based on performance, support and supply methods.
4. Design Requirements - identifies unusual requirements necessitated by the design. Classification of design requirements was by nontypical conditions or methods.

Information was collected in a daily reporting system and the changes in productivity were identified by determining possible disruptions to productivity. Disruptions included:

1. Weather
2. Congestion/Interference
3. Sequencing/Reassignment
4. Material Storage
5. Material Availability/Shortage
6. Rework
7. Improper or Insufficient Tools
8. Accidents
9. Improper or Insufficient Equipment
10. Lack of Supervision
11. Over staffing
12. Remobilization

Kuntz and Sanvido (1995) presented the Construction Crew Evaluation Model, which is a tool that can be used to diagnose and improve craft productivity. The model provides a framework which guides a contractor through a thought and planning process to identify specific parameters than can be altered to improve a crew's productivity.

The Construction Crew Evaluation Model consists of 8 factors which site personal can control to influence performance of work crews. The factors are :

1. Design - represents information that describes what is to be built and is composed of:
   a) finish requirements of the final product
   b) dimensions
   c) details
   d) materials to be used
2. Team - represents the actual crew that will do the work and is composed of:
   a) crew skill (abilities, experience, knowledge, motivation)
   b) crew composition - balance of trades in the group
   c) crew size
   d) task to be completed
   e) task assignments (specific assignments of each individual)
   f) cohesiveness (how the team functions together)
3. Tools and Equipment - represents mechanical instruments to aid a crew in completing their work and is composed of:
   a) type of equipment (job, discipline, crew, individual tools)
   b) adequacy, availability, and acceptance
4. Method - represents the processes and procedures by which the crew completes their work and must:
   a) be safe
   b) yield quality work
   c) allow completion in a timely manner (production)
   d) be known, understood and accepted by the crew
   e) allow effective use of resources
5. Material Supply - represents the supply and flow of material which sustains a crew and is composed of:
   a) flow rate (timing of material deliveries, adequacy for requirements)
   b) level of effort (amount of time crew spends supplying themselves)
6. Area of Operations - represents the condition of the crews work area before and during the work period and is described by five factors :
   a) existing work (should be complete and correct)
   b) physical characteristics

c) energy supply (adequacy and availability of resources the crew requires)

d) environmental conditions (climatic conditions)

e) other activity in the work area (work or activities of other crews in the immediate area)

7. Goals and Feedback - establishes performance goals the crew has to achieve, provides feedback concerning the achievement of the goals and is a vehicle for crews to provide feedback to management. It is composed of two elements:

   a) downward communication (site management to the crews)

   b) upward feedback (crews to site management)

8. Planning Information - represents the predetermined method or scheme developed to complete a project, area of work, or specific work task and includes :

   a) work items to be completed

   b) assigns a crew or individual to complete the task

   c) tells the crew what, where, and how to build

Smith and Hanna (1991) identify the types of factors that influence formwork productivity and identify a methodology to consistently evaluate productivity data. Many non-behavioral factors were identified, but factors relating to organizational and motivational factors were not addressed.

Their study investigated several formwork systems (conventional forms, ganged forms, jump forms, slipforms and self-raising forms) and classified the formwork systems based on their characteristics. Classification was by the following categories:

1. Building Design (lateral support system, building shape)
2. Job Specification (speed of construction, concrete finish, construction sequence)
3. Supporting Organization (cost, hoisting equipment, safety, supporting yard, local conditions)

Smith and Hanna (1991) identified factors that may influence formwork productivity. The factors were:

1. System Factors

   a) Cost per square foot per use

b) Number of connections
c) Number of (and type) ties required
d) Weight for handling
e) Ease of stripping
f) Ease of ganging panels
g) Cost of replacement parts
h) Technical design support available
i) Flexibility of the system
j) Connection hardware
k) Interchangeable system hardware
l) Panel attachments
m) Ease of attaching accessories
n) Availability of accessories
o) Safety accessories

2. Design Factors
   a) Dimensions of walls
   b) Length of walls
   c) Joint pattern
   d) Irregular spacings
   e) Irregular floor heights
   f) Height of wall or column
   g) Number of vertical intersections
   h) Surface finish
   i) Inconsistent column sizes
   j) Shape irregularities

3. Project Summary Factors
   a) Project cost
   b) Underground structure
   c) Above ground structure
   d) Floor plan area
   e) Site area
   f) Formwork contact area
   g) Number of workdays required

h) Time frame

i) Average crew size

j) Labor force (union or nonunion)

4. Disruption Factors

a) Weather

b) Material

c) Sequencing

d) Accidents

Dozzi and AbouRizk (1990) presented an investigation into labor productivity. They split productivity into macro and micro levels. The macro level deals with contracting methods, labor legislation and labor organization. The micro level deals with management and operation of a project, primarily at the job site. The factors seriously impairing construction productivity were outlined as follows:

1. Project conditions (weather variability)
2. Market conditions (material shortages, lack of experienced personnel)
3. Design and procurement (large number of changes)
4. Construction management (ineffective communications, inadequate planning and scheduling, lack of sufficient supervisory training)
5. Labor (restrictive union rules)
6. Government policy (slow approvals and issue of permits)
7. Education and training (lack of training for site management)

Dozzi and AbouRizk outlined techniques for measuring and improving productivity at construction sites. The techniques included, studies measuring and interpreting work and crew effectiveness (field rating, work sampling, five-minute rating), field surveys (foreman delay survey, craftsman questionnaire), the method productivity delay model, charting techniques (crew-balance charts), and simulation modeling and analysis.

Dozzi and AbouRizk (1990) outlined human and management factors that can affect productivity. The factors are as follows:

1. Human Factors

a) Motivation

b) Physical limitations

c) Learning curve

d) Crews and teamwork

e) Environmental factors

f) Work space

g) Job site planning

h) Safety issues

2. Management Issues

a) Quality of supervision

b) Material management

c) Constructability

d) Change management

Alfeld (1988) presented the Methods Engineering Model which identifies factors that will lead to productivity improvement. The author splits factors into environmental, and behavioral elements.

1. Environmental Elements

a) Information

i) Provide clear and correct plans and well-written specifications.

ii) Avoid changes to the plans as the work progresses.

iii) Plan the work well ahead and keep people informed of plans.

iv) Provide frequent feedback on how well people perform.

v) Tell people exactly what is expected of them.

vi) Show people how to perform well.

vii) Keep the work force informed about progress versus schedule.

b) Resources

i) Use equipment that is well suited to the task.

ii) Have tools available when they are needed.

iii) Use adequate materials.

iv) Follow all safety rules.

v) Provide equipment when it is needed.

vi) Make sure materials are available as needed.

c) Incentives

i) Make wages contingent upon performance.

ii) Provide nonmonetary incentives.

iii) Reward people for good performance.

iv) Tell people when they have done a good job.

2. Behavioral Elements

a) Skills

i) Design the training to fit job site conditions.

ii) Use only exemplary performers to train new workers on the job.

iii) Remove obstacles to continued training.

iv) Ensure that competent people teach job site safety.

v) Draw on individual experience whenever possible.

b) Capability

i) Fit the crew staffing to the tasks.

ii) Protect workers from adverse weather.

iii) Provide acceptable toilets and wash up facilities.

iv) Select people for tasks they perform best.

v) Insist that all workers wear safety protection.

c) Motivation

i) Hire individuals who enjoy construction work.

ii) Make people feel good about working on the job.

iii) Keep good performers on the job.

iv) Offer career advancement opportunities.

Means Man-Hour Standards (1983) is a publication of labor productivity values for all types of activities for building construction. The manual states that accurate productivity information is an important starting point for any cost estimate. The manual outlines the factors affecting productivity as:

1. Job Conditions

a) Scope of project

b) Site conditions

c) Material storage and movement

d) Height of work performed

e) Accessibility to work area

f) Space allowed for work

2. Supervision (skill can be measured by)
   a) Experience
   b) Rate of pay
   c) Labor pool
3. Other Factors
   a) Weather
   b) Season
   c) Contractor management
   d) Local labor restrictions
   e) Building code requirements
   f) Natural disasters
   g) Availability of skilled labor
   h) Availability of material
   i) General building conditions
   j) Substitute methods
   k) Substitute materials

The general contractor involved in the investigation, had forms to calculate labor productivity for specific types of formwork and forms collecting information for concrete formwork construction activities. The forms include information deemed important in representing concrete formwork activities. The basic information in the form was as follows:

1. Project Information
   a) Project Name
   b) Location
   c) Site personnel
      i) superintendent name
      ii) foreman name
2. Activity Information
   a) Cost code (cost center)
   b) Estimated and actual values for:
      i) man hours

- ii) material quantities
- iii) crew rate
- iv) productivity

c) Time frame
- i) start date
- ii) finish date
- iii) duration

d) Labor crew (number of carpenter foreman, carpenters, apprentice, laborers)

e) Equipment (types and usage)

f) Repetitive production
- i) number of cycles
- ii) typical quantity per cycle
- iii) typical cycle time

g) Items charged to labor cost centre
- i) fabrication, modifications, repairs, dismantling
- ii) openings, bulkheads
- iii) concrete repair
- iv) equipment operators
- v) clean up
- vi) scaffolding
- vii) overtime

h) Contributing factors
- i) crew effectiveness
- ii) job site inspection
- iii) weather conditions
- iv) form difficulty
- v) access to work area

i) Forms systems used (loose, gang, or patented system)

j) Design specifics
- i) tie system used
- ii) tie spacing
- iii) typical form size

    iv) form weights

k) Acceptable final finish (point & patch, rubbed, architectural)

2.4 Neural Networks

Neural networks are a branch of artificial intelligence. A neural network is a computing environment loosely modeled after the structure and operation of the human brain. The functions of the human brain modeled by neural networks are problem solving and memory functions (NeuralWare, 1993).

The basic element in a neural network is a processing element. It is modeled after the basic unit of the human brain, the neuron. Processing elements and neurons receive input from other elements and produce output for other elements. Information is propagated through connections between elements. Neural network connections are modeled after the synapse junctions in the human brain.

The process of information propagation by a processing element is a combination of information collection, processing and output. The processing element receives input from connected processing elements and combines the information. Combination is performed by a summation of the input values. The combined input is modified for output by a transfer function. The transfer function can be a threshold function, which only passes on information if the combined input reaches a particular value or threshold (activation). The transfer function can also be a continuous function which allows emphasis to be placed on certain input values. The output from the transfer function is propagated to other processing elements through connections. The connections have associated weights, which modify the outputs from previous processing elements to be input for subsequent processing elements. Figure 2-1 Processing Element illustrates the components and functions of a processing element.

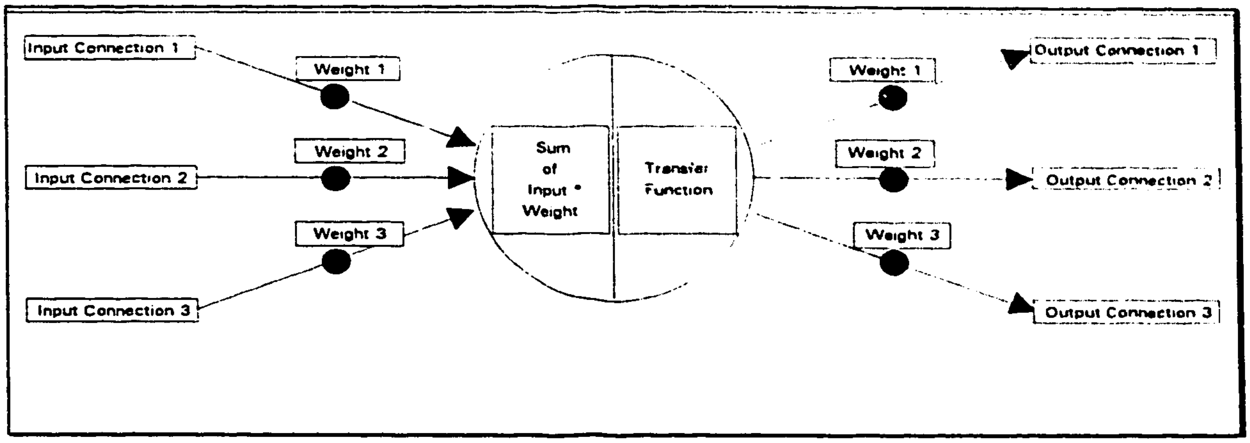

Figure 2-1 Processing Element

The human brain is composed of billions of neurons forming a complex network. Neural networks are a simplification, composed of far less processing elements, restricted by the scope of the problem being investigated and the computational requirements to determine a solution. Neural network processing elements are arranged in layers so that the connections are systematic and the network can be solved. Inputs are provided to processing elements in the input layer, and outputs are results from processing elements in the output layer. Any layers between the input and output layers are designated as hidden layers. Figure 2-2 Neural Network Structure illustrates the basic components of an entire network.

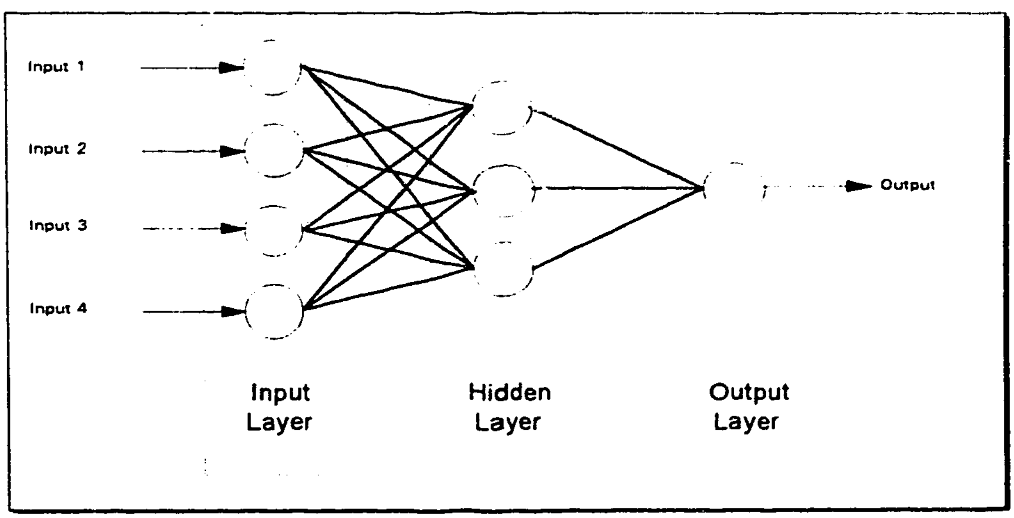

Figure 2-2 Neural Network Structure

The primary operations of a artificial neural networks are the same as the human brain, learning and recall.

Learning is the process of adapting connections weights within the network such that the correct output is predicted. The network learns the proper connection weights to produce the output given inputs and their corresponding outputs. Providing the correct output to the network for training is called supervised learning. Providing no output to the network for training is called unsupervised learning.

Recall is the process of creating a response in the output layer. Inputs are provided to the network, the internal processes of the network are executed and output is calculated. Recall is a integral part of training in neural networks. By comparing desired outputs to predicted outputs a prediction error can be calculated. The error is used in training to modify the connection weights to produce predictions with increased accuracy.

2.5 NEURAL NETWORK APPLICATIONS IN CONSTRUCTION

Moselhi, Hegazy and Fazio (1990) examined neural networks and their applicability to the construction industry. The competitive and risk-averse nature of the construction industry and its heuristic problem solving needs lend themselves to the use of artificial intelligence. First implementations of artificial intelligence were expert systems, which did not perform to desired level of accuracy and ability. Newer implementations of artificial intelligence have incorporated neural networks to supplement or replace expert systems.

Expert systems attempt to model intelligent reasoning and problem solving techniques of the human brain. Neural networks attempt to model the humans brain functions of learning, thinking, storage and retrieval of information.

Advantages of neural networks over other artificial intelligence techniques include:

1. They are suited for pattern recognition, with a large number of attributes that must be considered in parallel.
2. They learn by example. They can learn many example patterns and their associations.
3. They produce fast responses.
4. They can classify based on characteristics from a large number of input examples.
5. They have distributed memory, the individual connection weights are the memory of the network.
6. They have associative memory. That is, the network responds in an associative or interpolative way to noisy, incomplete, or previously unseen data. Full output may be realized with only partial input (generalization).
7. They are fault tolerant. The memory is distributed, therefore small failures of portions of the network will only have a slight effect on the overall network.
8. They can represent uncertainty. A measure of belief can be incorporated by:
   a) selecting input values to represent a measure of belief in the attribute.
   b) by adding another attribute representing the measure of belief in the input.
9. They require a lesser amount of storage memory. The network weights carry all the required knowledge.

An example of a network for estimating a productivity level of a certain trade was outlined. Input included job size, job type, time frame, overtime and management ability. Output includes predicting the achievable productivity level and required progress reporting.

Another example was provided for estimating optimum bid markup. The attributes associated with the bid situation were the number of typical competitors, the mean of the distribution of the ratio of the competitors bid prices to the contractors estimate of cost in previous encounters and the standard deviation of the previously described distribution. The output of the network was the optimum bid markup.

Moselhi, Hegazy and Fazio (1990) outlined other potential neural network applications for the construction industry which include:

1. Selection between alternatives (formwork and equipment selection).
2. Estimation and classification (provide with input and estimate a productivity).
3. Function synthesis (similar to optimum bid markup).
4. Diagnostic problems (such as encountered in building or facility defects).
5. Dynamic modeling (model dynamic fluctuations in inflation or escalation rates).
6. Optimization tasks (optimization of a construction activity and its resources).
7. Real time applications (associated with time dependent changes, such as material costs)

Choa and Skibniewski (1993) presented an approach for prediction of excavator and transporter productivity. Neural networks were employed because complex mapping of environment and management factors had to be performed.

The model Choa and Skibniewski proposed was a feedforward, backpropagation, multilayer neural network. The model incorporated factors affecting an excavator's cycle time. A simulation using a robot was utilized to produce data for the training of the neural network. Inputs to the network were swing angle, horizontal reach, vertical position and soil type. Output of the network was cycle time.

Karshenas and Feng (1992) presented an application of neural networks for the estimation of construction equipment productivity. A modular neural network architecture was utilized. The modular structure allowed the addition of different types of equipment without extensive retraining of the network. The information representing each piece of equipment resides in its own subnetwork, making retraining of all networks unnecessary when adding or changing a specific piece of equipment.

The prototype neural network captured the information contained in equipment speed charts for scrapers. The speed chart information determined equipment cycle times for various project conditions. The type of network employed was a backpropagation, feedforward network with three layers. The inputs were equipment gross weight and total haul road resistance. The hidden layer had four nodes. The output was the equipment speed.

Wales (1994) outlined a neural network application that assists in estimating construction labor productivity. Construction labor productivity may vary due to environmental site conditions such as temperature, relative humidity, wind speed, and precipitation.

The environmental processes, being random events can be modeled in a random simulation model. The author developed a model that incorporated Critical Path Method scheduling with a neural network to predict daily productivity that in turn is used in a simulation to generate schedules based on labor productivity.

Wales constructed a neural network for the prediction of earthwork operation productivity. The network had three layers. The inputs consisted of daily average temperature, precipitation and cumulative precipitation over the previous seven days. The output of the network was a productivity factor. The productivity factor was used in the model as an "environmental conditions" adjustment to predicted overall productivity.

Forecasting productivity with neural networks was found to be advantageous and several conclusions were stated. The neural network approach is simple in nature, not requiring a sophisticated multivariate regression analysis to create functions that relate the various inputs to one another. Neural network enhancements allow the modeler to achieve any desired level of sophistication. Customizing neural networks to user provided data to reflect the construction techniques employed within a specific organization offers a significant advantage over other forecasting models. As conditions change, the neural network can be retrained to reflect the changes in circumstances and continue to provide accurate results. Productivity data has many complex relationships to numerous factors making neural networks the ideal technology to map relationships between uncertainty factors and productivity.

Sawhney, AbouRizk, and Dozzi (1993) presented a model for accurate forecasting of construction cost escalation. Accurate forecasting of construction cost escalation can provide an improved confidence in the bid preparation process. If price escalation is known, then contingency can be reduced to correspond to the decrease in risk associated with the possibility of escalation.

Sawhney, AbouRizk, and Dozzi constructed a recursive Neural Network to forecast the prefabricated wooden buildings industry index (PWBII). The neural network was a three-layer network with a recursive slab that models time dependent processes. The network was trained with the indexes documented in Catalogue 62.0007 - Construction Price Statistics, by Statistics Canada. The inputs to the network were month and year. The output of the network was the price index values. The month and year were converted to equivalent binary values for proper presentation to the network without any bias. The input to the recurrent slab was equal to a weighted sum of the current value and output from previous iterations. This ensured that monthly trends of the indexes were fed as input into the neural network, thus influencing the outcome of the following month.

The neural network has the ability of continuously learning and improving its performance based on further training. The authors envision that neural networks can provide solution to numerous forecasting, optimization and classification problems in Civil Engineering.

Creese and Li (1995) outline Neural Networks as effective tools for complex estimation problems where the relationship between the input and the output cannot be represented by mathematical functions. A traditional estimate is accurate, and is commonly used for detailed estimates, but takes significant resources.

A neural network model was constructed to aid in the cost estimation of timber bridges. A backpropagation network was used with a single hidden layer. The inputs were the volume of the webs for the bridge, the volume of the decks for the bridge and the weight of the steel used in the bridge. The output was the cost of the bridge. Different combinations were experimented with in three separate models.

The neural network method was found to out perform common linear regression. The estimation accuracy improved when more independent variables were introduced to training. The accuracy of the network was dependent on the historical data available.

Murtaza and Fisher (1993) presented a neural network model as an approach for decision making in the modular construction industry. The decision to be made was to use conventional stick-built method or to use modularization while constructing an industrial process plant. Factors considered included plant location, labor considerations, environmental and organizational factors, plant characteristics and project risks.

Murtaza and Fisher developed a neural network using the Kohonen Model for classification to construct the decision making model. The model employed a self-organizing map feature with competitive learning functions (unsupervised competitive learning) to complete the training. Sub neural networks were built to produce output for each decision process (each major factor) and then the system fed those results into an overall neural network. The combined network had approximately 40 inputs. The output was a decision on the extent of modularization that should be used.

Kamarthi, Sanvido and Kumara (1988) presented a computer application to select a vertical formwork system. The authors compared the developed neural network to a rule base expert system. The neural network was named NEUROFORM and allows selection of a formwork system.

Kamarthi, Sanvido and Kumara outlined the differences between a neural network system and a rule based system as the representation and application of domain knowledge. In a neural network system, domain knowledge is abstracted from a set of training examples through self-learning and self-organization of the network and is captured in the network parameters. In contrast, in a rule based system, the domain knowledge is elicited from a domain expert and is captured in the form of well defined rules.

The knowledge represented in the form of rules can be easily analyzed, documented and explained. But the rules are only approximate descriptions of complex relationships. The imprecision and context dependence of individual rules can produce inconsistencies in rules and may cause errors in the final output of the system. Neural network systems allow precision representation of complex relationships between the input and the output. Knowledge can be learned directly from experience or examples. A neural network can make generalizations for the unknown situations from the known experience or examples. But neural networks are not capable of providing verbal descriptions and explanations.

The following are the key factors considered by Kamarthi, Sanvido and Kumara in the formwork selection model:

1. Building Height
   a) High rise
   b) Medium rise
   c) Low rise
2. Structural System
   a) Tube in tube
   b) Tube system
   c) Shear walls
   d) Framed shear walls
   e) Bearing wall
   f) Frames
3. Concrete Finish
   a) As cast
   b) Exposed
   c) Architectural concrete
4. Site Characteristics
   a) Open site
   b) Restricted site
5. Hoisting Equipment
   a) Adequate
   b) Inadequate

6. Building Shape
   a) Uniform
   b) Irregular

The neural network employed in the application was a two layer feedforward backpropagation neural network. The inputs listed above were presented as binary input and the output of the network was a recommendation for the type of vertical formwork to use.

2.6 Discussion on State of the Art

The current state of factors affecting productivity is inconclusive. All possible factors have been identified, from environmental to management factors. The actual solution of how factors specifically affect productivity in a given situation has still not been solved.

Many solutions have been proposed for estimating labor productivity, but none have the scope or accuracy to be widely accepted. The solution being investigated will not revolutionize the research into estimating productivity, but will give insight into it and will produce an application that will estimate labor productivity within desired accuracy for a specific set of circumstances.

Possible solutions for estimating labor productivity given a set of factors are as plentiful as the factors themselves. Solutions come in the form of mathematical models, multivariate statistical analysis, expert systems and neural networks. The decision to pursue a neural network solution was based on the desire to explore artificial intelligence applications and their applicability to the problem presented.

Current state of the art for neural networks for the construction industry is of limited scope and acceptance. The typical neural network is a feedforward backpropagation network with a small number of inputs and a single output for prediction of a value. The previous research has focused on the applicability and feasibility of neural networks for applications found in the construction industry. Very little work has been pursued in expanding the boundaries of neural networks, to develop a large and complex neural network systems that can be readily implemented to aid in the estimation of labor productivity.

Chapter 3

3. Model for Data Collection of Factors Affecting Productivity

3.1 Introduction

The model for data collection of factors affecting productivity consists of determining what information to collect and how to collect it.

The literature review previously presented outlined numerous factors that affect labor productivity. Determining what factors affecting productivity will be pursued is dependent on the context of the study being undertaken.

Detailed data collection is an integral part of the investigation. Preliminary research into the information required for the study revealed inadequacies in currently available data. Completion of a data collection model and investigation was required before the development of neural networks.

3.2 Factors Affecting Productivity

Factors affecting labor productivity vary from human to environmental, behavioral to non behavioral and building system to building design. The goals of the study were to determine all possible factors affecting productivity and then propose a limited number of factors affecting productivity within the specific context of the study.

The parameters of the study included predicting labor productivity on the activity level for concrete formwork activities. The concrete formwork activities consist of conventional, loose and panel formwork for slabs, walls, and columns. Information to be investigated was identified as overall project information and specific activity information.

3.2.1 Sources of Factors

The sources for the factors were the literature review, existing data collection forms and interviews with company personnel from a general contractor. Results for the literature review and examination of existing data sheets were presented in Chapter 2. To supplement the information, interviews were conducted with staff from a general contractor. Specific results from interviews with estimators and superintendents are presented.

3.2.1.1 Superintendent Viewpoint

Several superintendents were questioned for their views on what affects labor productivity for concrete formwork. The following factors were discussed:

1. Repetition of the formwork system is an integral component of a "good" design and is important for increasing productivity.
2. Inadequate supporting equipment for material handling and placement such as tower cranes and mobile cranes can cause significant problems and loss of productivity.
3. The accuracy and detail of the design prepared by the architect and engineer can have a significant effect on the project. Ambiguities and missing information slows down production while the problems are resolved.
4. Weather conditions are typically known for a region. The adverse affects of weather conditions on productivity can be compensated for at the time of the estimate.
5. The project crew is of paramount importance. Skilled and knowledgeable workers that can work together will lead to better productivity. Experience is key, supervisors do not have to explain details of how to perform the tasks to the workers
6. The quality of supervision for the work crews is very important for motivation and supervision of crews. Excellent supervision effects all aspects of a project. Workers are given proper guidance and motivation, increasing productivity. Experienced staff leads to proper coordination of resources of the project.

3.2.1.2 Estimator Viewpoint

Various interviews were held in order to determine the factors to be important by estimators. The major factors considered while preparing an estimate are:

1) Crew availability - if an experienced crew is known to be available, the estimator knows that the learning curve will not be significant and crew productivity and quality of work will be better than a new or inexperienced crew.
2) Superintendent - if an experienced and knowledgeable superintendent is available for a project, the estimator can reduce some of the contingency placed on the bid, knowing that the project has a good chance of being executed without significant problems.
3) Weather - the typical weather conditions of the different seasons can have a significant effect on labor productivity. Weather must be considered in labor productivity values by adding contingency on the affected construction tasks (winter heat and hoarding).
4) Location - the location of a project will have various impacts on the performance of the project. Material handling and supply, work force availability, weather and site conditions are all depend on location.
5) Repetitive Uses - while estimating the productivity of work crews, the repetition of the activity must be considered. Learning can increase or decrease labor productivity values. Use of repetitive elements increases productivity.
6) Quantity - linked to the number of repetitive uses, quantity affects labor productivity. If the quantity is significant, learning will be reduced or fulfilled, allowing crews to reach a better productivity rate.
7) Non-Union - if the project has union or non-union workers it can affect crew skill, crew availability and the cost of the crew.
8) Owner - the owner can affect how the estimate is prepared. Specifically, number of changes, inspection tolerances, availability of site and resources and previous relationships between the owner and the contractor can all affect how an estimator will bid a project.

3.2.2 Parameters and Context of the Study

The parameters of the study include predicting labor productivity on the activity level for a concrete formwork activity, or in other words, predicting the average productivity for a task such as the construction of concrete foundation walls. Collected data is not to be on a daily or weekly basis but rather a final summary for a construction activity. The information is be used for estimating purposes. Factors involved in the investigation had to be able to be estimated by the estimator. If an estimator could not determine a value or response for a factor, it is not necessary to include it in the model. Other parameters deal with limitations of the data collection techniques and procedures and the sources of the data.

The first step is to analyze construction projects and tasks, determine which factors aid in accurate representation of the tasks and determine guidelines for the selection of factors. It is very difficult to ascertain what factors are significant and which have no significance. For the first stage of the study, many factors were collected. It is desired that from the wide range of factors, that the investigation will be able to determine a small set of factors that will model the situation to a desired accuracy (+- 10%).

3.2.3 Selection and Elimination of Factors

Required information was identified as either project or activity related. Project information includes data on the size of the project, the project staff and physical data of the project. The activity information includes information on the design of the formwork, the construction methods and the crew performance.

In order to be thorough, all factors meeting the parameters of the study were considered. Data collection and experimentation would remove unnecessary factors. A wide range of factors were collected, and then reduced for neural network experimentation.

3.2.4 Reevaluation of Selection of Factors Affecting Productivity

After each step of the study including, data collection, data compiling and neural network experimentation, reevaluation of the selected factors affecting productivity was performed. Factors were added to improve modeling of productivity, while unnecessary factors were eliminated.

Factors were added because:

1. Existing factors were not representing the situation properly. For example, degree of difficulty was not consistently predicting changes in productivity. To supplement the factor it was broken into complexity of geometry, working conditions, level of required finishes and level of formwork irregularities.
2. Existing factors were not thorough, in other words some factors were missing from the data collection. For example, calculated superintendent skill was added to supplement collected data.
3. Calculated factors from information already available could provide common reference points. For example, district performance was added to illustrate the relative performance of each district in relation to all districts.

Factors were discarded if:

1. The information demonstrated typical responses. For example, overall weather where responses were that weather was rarely the cause of lost days or extreme conditions.
2. Activity level responses were available to replace project level responses. For example, accuracy of design was an overall project level and an activity level question posed to project staff, for which the activity level was deemed to supersede the project level factor.
3. Through experimentation it became evident that the factor was irrelevant or misleading. For example, amount of precipitation per region was deemed not to be representative of an overall summary level weather condition for comparison from district to district and was replaced with temperature.
4. Factors could be represented or contained the same information as other factors. For example percent prefabricated, which is the inverse of number of reuses.

3.2.5 Factors Examined in the Study

The list of factors examined in the study is in Appendix A. The focus of implementing a neural network drove the selection of the factors affecting productivity, therefore the list of factors is structured around neural network implementation. The list groups the factors by:

1. Current Activity Factors
2. Current Network Project Factors
3. Proposed New Activity Factors
4. Proposed New Project Factors
5. Discarded Activity Factors
6. Discarded Project Factors

Discarded factors may still be included in data collection at this time, but are not part of the neural network experimentation.

3.2.6 Example Factor Descriptions and Explanations

Factors for the neural network were summarized in document format. The document is meant to illustrate the meaning, development and use of each factor. To illustrate, documentation for three factors will be shown.

1. Quantity of Formwork where the source is a cost report.
2. Degree of Difficulty where the source is the data collection questionnaire.
3. District Performance where the source is a statistical analysis of database information.

3.2.6.1 Quantity

The formwork quantity factor represents the quantity of formwork to be constructed on the specific formwork activity. The information was collected from the historical productivity database, which is constructed from project cost reports and was confirmed by project staff during data collection.

Previous use of historical productivity information has made the assumption that the larger the quantity, the better the productivity. Studies have shown that there is poor correlation between quantity and productivity, that typical construction or repetition is more important.

Quantity also incorporates the working conditions, learning curve and the possibility of optimum use of repetitive panels. With small quantities the crews may be working in a restricted or closed in area, where material and equipment supply is restrictive. With large quantities, the crew will start to be more productive due to learning curve effects. Small quantities will have the opposite effect, where the workers will not become accustomed to the procedures and productivity will not increase. The larger the quantity, the possibility of the productive use of repetitive panels grows.

3.2.6.2 Degree of Difficulty

The degree of difficulty factor represents the opinion of the project staff in relation to the difficulty of the formwork constructed for a concrete formwork activity. Responses from the project staff during data collection were on a subjective scale from low to high.

The factor encompasses several factors including difficulty in terms of geometry, irregularities, and required finishes for the formwork. Degree of difficulty encompasses the general feeling on the difficulty of the activity in relation to past work of a similar nature.

Individuals were asked questions on the difficulty of the work, but the answers required clarification. For example, the work could have been simple, given the circumstances. It is very difficult to determine the circumstances through a subjective question. An assumption previously made is that all the superintendents would have approximately the same reference point or level of experience while answering the questions. This may be true for most of the responses from project staff, but the answers needed to be supported with other information. Enhancement of the degree of difficulty was done by including the complexity factors, a statistical ranking of a record compared to all other records.

3.2.6.3 Activity District Performance

The activity district performance factor represents the past performance of the various company districts based on historical productivity database information. The factor represents a generalization of district performance which includes such factors as crew skill, supervision skill, environmental factors, management factors and location factors.

Calculation is based on comparing district performance (geographic and organization area) to the corporate performance (company wide information). An average score is accumulated based on the district average divided by corporate average for the cost center. The analysis is for the specific activity or activities being analyzed.

3.3 Development of the Data Collection Model

The development of a data collection model requires the specification and investigation of procedures and methods. Periodic testing, usage and reevaluation of the model are necessary for the model to evolve. The goals of the model include the collection of meaningful, accurate, consistent and thorough information. Figure 3-1 Data Collection Model illustrates the data collection model.

3.3.1 Scope of Data Collection

Scope of data collection deals with the circumstances and boundaries of the data collection investigation. Scope covers the specific types of information to be collected, how the information will be collected, when the information will be collected, who will collect the information, who will provide the information and why the information is to be collected.

3.3.2 Types of Information and Data Structures

Collected data can be objective or subjective data (quantitative and qualitative). The objective data is comprised of actual numerical values, or written descriptions. The subjective information and a portion of the objective data can come in the form of ratings or descriptions.

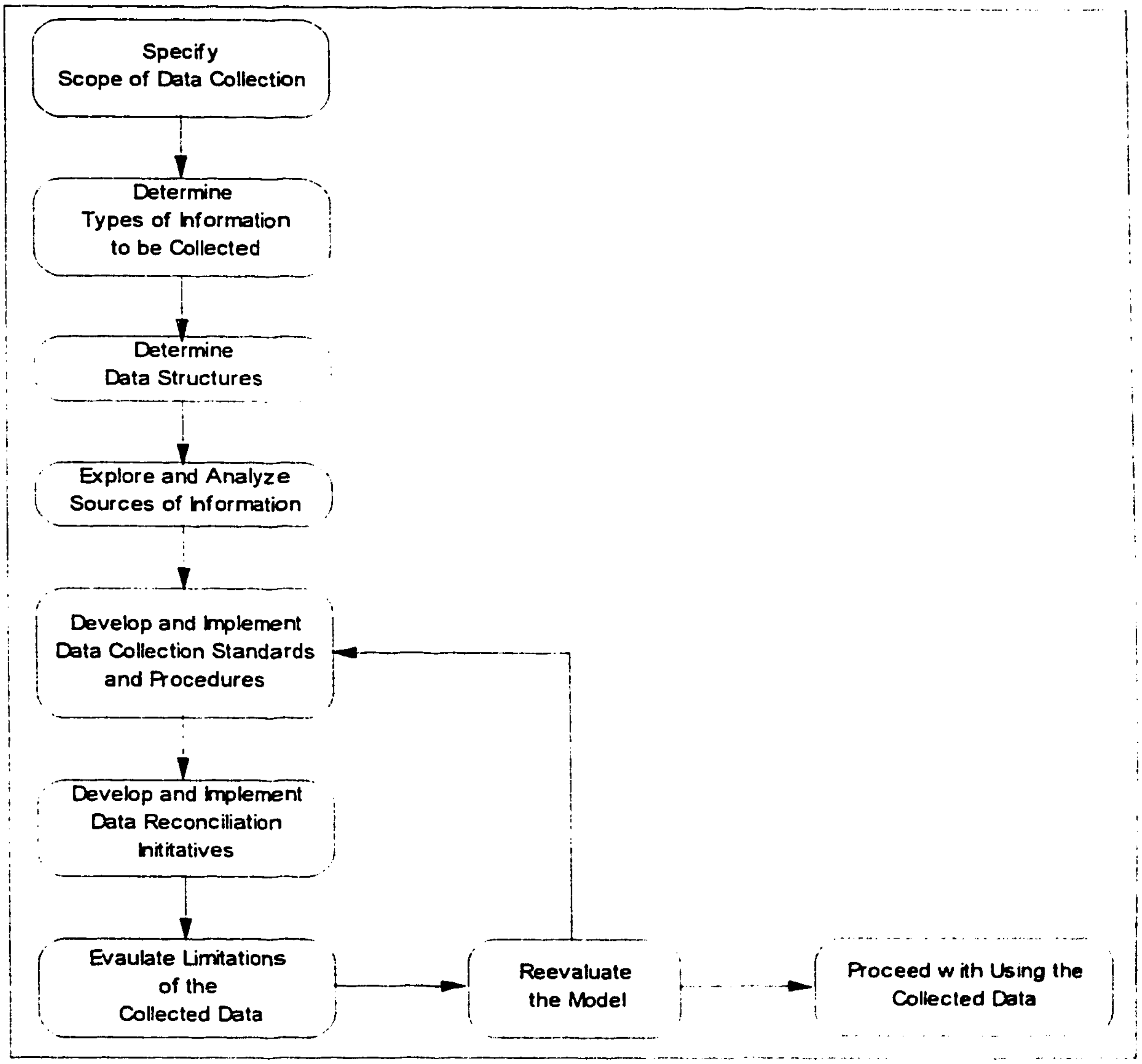

Figure 3-1 Data Collection Model

Objective or numerical data must be structured in common units of measures and significance. Standard units of measure will ensure consistent results that can be compared without conversion. Subjective responses that require a rating must be structured in a manner as to properly represent the responses. Ratings for all factors should be structured to mean approximately the same thing. For example, a high rating should be beneficial, while a low rating should be detrimental.

3.3.3 Sources of Information

The sources of the information must be examined to ensure accuracy and consistency. The source must be accurate in that it properly reflects the actual conditions. The source must be consistent in that the information is reproducible, the information is based from a common reference point and that the information is complete.

3.3.4 Data Collection Standards and Procedures

In order to ensure accurate and consistent data, data collection standards must be developed and implemented. Data collection standards provide references or base lines for responses, eliminating any confusion in what a response should be. Standards guide the user into providing meaningful responses and eliminate any confusion in relation to what factor is being investigated. Data collection procedures are compiled to aid in the execution of the actual data collection.

3.3.5 Data Reconciliation

Data reconciliation and checks are an integral part of the data collection process. Since information may be collected by several individuals, reconciliation of the data is a requirement. Statistical checks, rules of thumb, alternate sources of information and an overall review of the data by a single individual improves the accuracy of the collected information. Unnecessary, ambiguous, inaccurate and improper information can be corrected or eliminated from the model. A thorough review of the data will also lead to the possible addition or consolidation of information.

3.3.6 Limitations of Collected Data

The limitations of collected data are the basis for how subsequent work will be deemed accurate. Severe limitations can render any subsequent work meaningless.

Problems occur with monitoring progress and problems. Poor non-standard data collection, no links to other systems, lack of training and extra resource expenditure can lead to problems and limitations in a data collection procedure (Russell 1993).

Limitations in the collected data can be a result of:

1. Who is collecting the information.
2. What type of information is being collected.
3. When the information is being collected.
4. Where the information is coming from.
5. Why the information is being collected.
6. How the information is being collected and used.

3.3.7 Reevaluation of the Model

Revaluation of the entire process as a model is developed and implemented is key. New areas of interest, errors, additions, deletions will all be realized. A preliminary investigation will never be absolutely thorough and investigators will learn as the model is implemented. A perfect model will not be constructed immediately. Limitations in the preliminary model will not become apparent until the model is implemented.

3.4 DETAILED DATA COLLECTION - IMPLEMENTATION

3.4.1 Scope

The scope of the overall investigation is to use neural networks to aid in the estimation of labor productivity. The neural network model will receive a set of inputs and will estimate labor productivity. A broad range of factors that affect productivity were introduced in Chapter 2. For the purposes of this investigation, only information collected on an activity summary level is relevant. Minor daily or weekly fluctuations are not relevant to the scope of the investigation. Overall, summary, typical, or average information is relevant to the scope of the project.

3.4.2 Types of Information and Data Structures

The data collected for factors affecting concrete formwork labor productivity are a mixture of subjective and objective information, with several sources. Objective information is in the form of numerical data and descriptions. Subjective data is in the form of descriptions, positive or negative responses and ratings on subjective scales. Numerical information was collected in standard imperial units of measures. Values included inches, feet, square feet and cubic yards. Other values were dollar amounts, and numerical counts. Subjective ratings were typically on a scale from low to high with corresponding numerical scores as follows:

1. Low - represents 'below average' or 'poor' ratings
2. Medium - Low
3. Medium - represents 'average' or 'fair' ratings
4. Medium - High
5. High - represents 'excellent' or 'high' ratings

Typically, a low score would be representative of a detriment to labor productivity, while a high score would be representative of a benefit to labor productivity.

3.4.3 Sources of Information

Objective information sources are cost reports, existing information databases, statistical calculations and data collection questionnaires. Subjective information sources are data collection questionnaires, expert advice and expert opinion.

The collected data came from a limited number of sources. The primary source for the quantitative information was from existing databases. The information was derived from general project information databases and cost reporting. The systems currently collected the information from individuals in the form of direct or indirect data entry.

The primary source of qualitative information will be the project staff for each project of interest to the investigation.

3.4.4 Data Collection Standards and Procedures

The development stage of the data collection standards commenced with the development of data collection sheets and questionnaires. Previous company data sheets were examined. Previous data sheets had dealt with an overall project wrap-up questionnaire and detailed formwork reports. Both reports were used on a limited basis, thus the information from the sheets was not available.

The investigation into factors affecting labor productivity was evaluated against the scope of the project and the requirements of the model. All the information that is required was mapped out and it was determined new data sheets would be developed. The preliminary data collection sheets would deal with concrete formwork.

The premise for the new data sheets was to collect relevant data for concrete formwork. The data sheets are a mix of estimated values, actual values, empirical data and subjective questions. The data sheets were to be kept simple, short, but comprehensive. Preformulated responses would be an integral part of the questionnaires.

Table 3-1 General Project Data - Questionnaire contains objective project level information on the individual involved in the project, the type of project, project physical components and contract information. Table 3-2 Overall Project Factors - Questionnaire contains a list of subjective project level questions that focuses on overall site conditions and if they affected labor productivity. Table 3-3 - Part 1 of Formwork Information - Questionnaire and Table 3-4 Part 2 of Formwork Information - Questionnaire contains a combination of objective and subjective information on the activity level for a concrete formwork activity.

Table 3-1 General Project Data - Questionnaire

General Project Data

Report Date		Prepared by	
Contract #		Project Name	
District/City			
Project Manager		Superintendent	
Project Start Date			
Sched. Finish Date		Act. Finish Date	
Project Type Code/Desc		Horiz. Frame Code/Desc	
		Vert. Frame Code/Desc	
Owner Code/Desc		Designer Code/Desc.	
Type of Owner	(Inst.) (Private) (Gov.)		
Original Contract Amount	$	Final Contract Amount	$
Gross Building Area	(sf) (m2)	# Floors Below Grade	
Total # Floors		# Floors Above Grade	
Typical Floor Area	(sf) (m2)	# of Typ. Floors	
Typical Bay Size	x (ft) (m)	Typ. Height Between Floors	(ft) (m)
Number of Changes			
Number of Claims			

Additional Notes

Total Number of Men
Non-Typical Floor Heights
Structure Shape

Table 3-2 Overall Project Factors - Questionnaire

Overall Project Factors

Report Date ______________________ Prepared by ______________________

Contract # ______________________ Project Name ______________________

1)	How would you rate the Labor Crew Performance for the project ?	( )Low ( )Medium ( )High
2)	How would you rate the Availability of Skilled Labor for the project ?	( )Low ( )Medium ( )High
3)	How would you rate Employee Turnover for the project ?	( )Low ( )Medium ( )High
4)	How would you rate the Subcontractor Performance for the project ?	( )Low ( )Medium ( )High
5)	Did the Weather Conditions adversely affect the project ?	( )No ( )Yes
6)	Did Access to the Work Area adversely affect the project ?	( )No ( )Yes
7)	Did the Site Conditions adversely affect the project ?	( )No ( )Yes
8)	Did Site Congestion adversely affect the project ?	( )No ( )Yes
9)	Did Sequencing or Phasing adversely affect the project ?	( )No ( )Yes
10)	Did Reassignment of staff or crews adversely affect the project ?	( )No ( )Yes
11)	Did Owner Inspection, Safety or Quality Requirements adversely affect the project ?	( )No ( )Yes
12)	Did Material Supply adversely affect the project ?	( )No ( )Yes
13)	Did Improper or Insufficient Equipment adversely affect the project ?	( )No ( )Yes
14)	Was the project unionized ?	( )No ( )Yes
15)	Did Walkouts or Strikes adversely affect the project ?	( )No ( )Yes
16)	Did Changes adversely affect the project ?	( )No ( )Yes
17)	Were there any Claims on the project ?	( )No ( )Yes
18)	How would you rate the accuracy and detail of the Design ?	( )Low ( )Medium ( )High
19)	How would you rate the Constructability (Ease of Construction) of the project?	( )Low ( )Medium ( )High
20)	How would you rate the accuracy of the Estimate ?	( )Low ( )Medium ( )High
21)	What was the Degree of Difficulty for the project ?	( )Low ( )Medium ( )High
22)	What was the Degree of Repetition for the project ?	( )Low ( )Medium ( )High

Table 3-3 - Part 1 of Formwork Information - Questionnaire

Loose Formwork - Wall Information

030000 Loose Formwork		Report Date	________
( ) 030300 Fdn/Ret Walls/Pilasters			
( ) 030310 Walls/Pilasters		Prepared by	________
( ) 030320 One Sided Wall/Pilasters			
( ) 030330 Low Walls/Upstand Beams			
( ) 030340 Curved Walls/Pilasters			
Contract #	________	Project Name	________
Cost Code (new/old)	____ / ____	Cost Code Description	________
Split #	________		
Season	________ ____	Superintendent	________

Classification

Duty	( ) Light Duty - Handset	Tie Type	( ) Snap Tie & Wedge
	( ) Medium Duty - Semi Panelized		( ) Camlock
	( ) Heavy Duty - Panelized		( ) Taper Tie
	( ) Other		( ) Single Waler Bracket
			( ) Other

Additional Notes

Materials and Methods

Problems Encountered

Any other Contributing Factors

Design Information

Total Formed Area	________	(sf) (m2)	Tie Spacing (h,v)	____ x ____	(inch) (mm)
% Prefab (Panel/Total Area)	________	%	Typ. Panel Dimensions (l,w)	____ x ____	(ft) (m)
% Repetition (Similar Work)	________	%	Typ # of Panels	________	#
Number of Reuses/Cycles	________		Height of Wall	________	(ft) (m)
Typical Cycle Duration	________	(hrs) (days)	Wall Thickness	________	(inch) (mm)

Typical Crew		***Productivity Rates***	
Craft	**No.**		**Rate**
Carp. Foreman	________	Estimated Prod Rate	________
Carpenters	________	Actual Prod Rate	________
Apprentice	________	Corporate Mode	________
Laborers	________	Corporate P10%	________
	________	Corporate P90%	________
Total		District Mode	

Table 3-4 Part 2 of Formwork Information - Questionnaire

Specific Project Activity Factors	*(L-Low or Below Average, M-Medium or Average, H-High or Above Average)*	
1) How would you rate the Complexity of the Geometry for the activity?	(inconsistencies in size, shape, x-section)	( )L ( )M ( )H
2) How would you rate the Formwork Irregularities for the activity?	(blockouts, openings, inserts)	( )L ( )M ( )H
3) How would you rate the Level of Required Finishes for the activity ?	(exposed and architectural)	( )L ( )M ( )H
4) How would you rate the Working Conditions for the activity ?	(congestion, working height, weather)	( )L ( )M ( )H
5) What was the Degree of Prefabrication for the activity ?	(fabricated to be cycled or reused)	( )L ( )M ( )H
6) What was the Degree of Repetition for the activity ?	(similar or typical construction)	( )L ( )M ( )H
7) Was Cycle Continuity maintained for the activity ?	(continue construction in a linear manner)	( )No ( )Yes
8) How would you rate the need for Material Handling or Crane Time?	(resource requirement)	( )L ( )M ( )H
9) Was Material Handling or Crane Time a problem for this activity ?	(inadequate crane time)	( )No ( )Yes
10) Were there Extended Work Hours for the activity ?	(double shifts or significant overtime)	( )No ( )Yes
11) How would you rate the Accuracy and Detail of the Design ?	(proper dimensions, details, drwgs, specs)	( )L ( )M ( )H
12) How would you rate the Crew Performance for the activity ?	(taking into account the circumstances)	( )L ( )M ( )H
13) How would you rate the Degree of Difficulty for the activity ?	(overall difficulty of construction activity)	( )L ( )M ( )H

The next step was to examine the data sheets and document them for standardization. A questionnaire explanation document was prepared to illustrate responses and their meanings. For example, the question dealing with accuracy of design was dealing with the accuracy, completeness, and consistency of the drawings and specifications prepared for the project by the architect and engineer. A low rating would mean a poor design, while a high rating would mean an excellent design.

The explanation documents are contained in Table 3-5 General Project Data - Data Sheet Overview, Table 3-6 Overall Project Factors - Data Sheet Overview and Table 3-7 Formwork Data Sheets - Data Sheet Overview.

Table 3-5 General Project Data - Data Sheet Overview

General Project Information	
A large portion of the General Project Information already exists in Project List Database. The following fields are present in the Project Information Table. The information would be automatically completed for the questionnaire, and the information would be checked by respondents for accuracy and completeness	
Contract #	Project Name
District/City	Project Manager
	Superintendent
Project Start Date	Sched. Finish Date
	Act. Finish Date
Project Type Code/Desc.	Horiz. Frame Code/Desc.
	Vert. Frame Code/Desc.
Owner Code/Desc	Designer Code/Desc
Type of Owner	
Original Contract Amount	Final Contract Amount
Gross Building Area	# Floors Below Grade
	# Floors Above Grade
The following information must be completed by the respondents, or found elsewhere (estimators, managers):	
Total # Floors	-sum of floors above and below grade
Typical Floor Area	-per floor
# of Typ. Floors	-
Typical Bay Size	-or the typical column to column dimension
Typ. Height Between Floors	-
Number of Changes	-
Number of Claims	-
Additional Notes	-typically any additional comments on the structure -such as building shape, non typical floor heights -Total Number of Men under Company supervision

Table 3-6 Overall Project Factors - Data Sheet Overview

Overall Project Factors

The Overall Project Factors are asked in order to get a picture for the project as a whole. While asking the questions, it is expected that the respondent will elaborate on the questions, and the investigator will prompt for explanations of given answers. The questions are asked for the project as a whole, although the emphasis should be on the structure.

1) How would you rate the Labor Crew Performance for the project ?
   -compared to other projects
2) How would you rate the Availability of Skilled Labor for the project ?
   -compared to other projects
3) How would you rate Employee Turnover for the project ?
   -compared to other projects and possibly a % (low approximately 5-10%)
4) How would you rate the Subcontractor Performance for the project ?
   -in relation to the project schedule and milestones
   -for the project as a whole, medium being normal
   -note any exceptions
5) Did the Weather Conditions adversely affect the project ?
   -were any days lost than was more than normal for the location
6) Did Access to the Work Area adversely affect the project ?
   -was there roadways and infrastructure sufficient for needs
   -for equipment and material supply
7) Did the Site Conditions adversely affect the project ?
   -was there a problem with soil conditions or dewatering
8) Did Site Congestion adversely affect the project ?
   -was there enough lay down area for material and equipment
9) Did Sequencing or Phasing affect the project ?
   -for construction activities and continuity of cycle
10) Did Reassignment of staff or crews affect the project ?
   -to other activities or projects
11) Did Inspection, Safety or Quality Requirements adversely affect the project ?
   -anything other than usual
12) Did Material Supply adversely affect the project ?
   -
13) Did Improper or Insufficient Equipment adversely affect the project ?
   -
14) Was the project unionized ?
   -
15) Did Walkouts or Strikes adversely affect the project ?
   -
16) Did Changes adversely affect the project ?
   -made by owner or architect, specifically affecting for structure
17) Were there any Claims on the project ?
   -by owner or by the Company, specifically affecting the structure
18) How would you rate the accuracy and detail of the Design ?
   -how the drawing and specs were prepared for clarity and consistency
   -medium is normal
19) How would you rate the Constructability (Ease of Construction) of the project ?
   -was how the building was to be constructed considered
   -was there a lot of non typical work
   -medium is normal
20) How would you rate the accuracy of the Estimate ?
   -were the quantities accurately estimated
   -were the costs adequate for the as-built projects
   -Medium is normal
21) What was the Degree of Difficulty for the project ?
   -compared to other projects of similar nature
   -Medium is normal
22) What was the Degree of Repetition for the project ?
   -use of repetitive formwork, similar to constructability
   -compared to other projects of similar nature
   -Medium is normal
23) Additional Notes
   -not any exceptions or examples to backup the given answers

Table 3-7 Formwork Data Sheets - Data Sheet Overview

Formwork Data Sheets

For the manual data collection, individual sheets were prepared for each type of formwork (for example loose walls, loose slabs, repetitive walls, repetitive slabs). The majority of the sheets are very similar, information not relevant to the specific type of formwork is not present. Each data sheet has the type of formwork as a title, and the related cost codes underneath it.

Loose Formwork - Wall Information
- Fdn/Ret Walls/Pilasters, Walls/Pilasters, One Sided Wall/Pilasters
- Low Walls/Upstand Beams, Curved Walls/Pilasters

Loose Formwork - Columns Information
- Columns, Short Piers, Circular Columns

Loose Formwork - Beams Information
- Grade Beams, Beams

Loose Formwork - Slabs Information
- Flat Slabs, Slabs/Dropheads/Beams , Pan Slabs, Dome Slabs, Sloped Slabs

Repetitive Formwork - Walls Information
- FDN/RET Wall, Curved Wall, Onesided Wall, Walls/Pil

Repetitive Formwork - Column Information
- Columns

Repetitive Formwork - Beam Information
- Grade Beam/Pil, Beams

Repetitive Formwork - Slabs Information
- Flat Slab, Slab/DHD/Beam, Pan/Dome Slab, Arch Slab

Repetitive Formwork - Core Information
- Core

Cost Code (new/old) -chosen from the above list, or from the cost report
- -new code - from standard cost code list
- -old code - from cost report

Cost Code Description -description of construction activity from standard list

Split # -for internal use
- -identifies different instances of the same cost code

Season -either spring, summer, fall, or winter

Superintendent -typically is with project team in

Classification -the prevailing factors that describe a type of formwork

Duty -standard list for all types
- -typically includes Handset, Semi-Panelized, Gang, Hi-Flyer, Fly Formwork

Support System -typically just for slabs
- -typically includes Trusses, EFCO, Cantilever, Brackets, Panelized Scaffold, Loose Scaffold, Ellis Shores

Tie Type -standard list for all types (except slabs)
- -typically includes Snap Tie, Camlock, Taper Tie, Single Waler Bracket, Coil Rod, Column Clamps

Additional Notes (Construction Methods and Material)
- -Materials and Methods of Construction
- -Problems Encountered
- -Any other contributing factors

Design Information -specific technical information (estimate)

Total Formed Area	-from cost report or HP
Percent Prefabricated	-% fabricated (prefab/total area or 1/# of reuses if rep.)
Percent Repetition (Typical)	-typical or similar construction
Number of Reuses/Cycles	-
Typical Cycle Duration	-from setup to pour to cure, or turn around time
Tie Spacing	-
Typical Panel Dimensions	-if applicable (repetitive)
Typical # of Panels	-if applicable (repetitive)
Component Height	-important for slabs and walls
Beam (Depth, Width)	-if applicable
Slab Thickness	-if applicable
Wall Thickness	-if applicable
Column (Width, Depth)	-if applicable

Table 3-7 Formwork Data Sheets - Data Sheet Overview Continued

Typical Crew -# of men typically working on specific activity for
-Carp. Foreman, Carpenters, Apprentice, Laborers

Productivity Rates -productivity values to put activity in perspective

Specific Project Activity Factors

1) How would you rate the Complexity of the Geometry for the activity?
=>Low - simple geometry, all constant and prismatic cross sections
=>High - complex geometry, variable cross section, curves

2) How would you rate the Formwork Irregularities for the activity?
=>Low - no blockouts, openings or inserts
=>High - significant blockouts, openings or inserts

3) How would you rate the level of Required Finishes for the activity ?
=>Low - no special finishes
=>High - architectural, exposed concrete

4) How would you rate the Working Conditions for the activity ?
=>Low - large work area, working at grade, low-rise structure
=>High - congested work area, working on scaffold, high rise structure

5) What was the Degree of Prefabrication for the activity ?
=>Low - all handset, no panels
=>High - all panelized work

6) What was the Degree of Repetition for the activity ?
=>Low - uneven surfaces, blockouts, change in elevation and thickness
=>High - flat and even surfaces, constant elevation and thickness, can reuse formwork, few or no blockouts

7) Was Cycle Continuity maintained for the activity ?
=>Low - 1 time formwork or in different phases,
- no improvement in learning curve
=>High - constant cycle of similar work, realization of learning curve

8) How would you rate the need for Material Handling or Crane Time?
=>Low - activity requires little in terms of crane or material handling time
=>High - activity required significant resources for material handling

9) Was Material Handling or Crane Time a problem for this activity?
=>

10) Were there extended work hours for the activity ?
=>No - normal 7 to 8 hour work day
=>Yes - double shifts or significant overtime

11) How would you rate the accuracy and detail of the Design ?
=>Low - poor details, difficult drawings to understand, lack of dimensions
=>High - excellent details, easy to follow drawings and specifications

12) How would you rate the Crew Performance for the activity ?
=>Low - could have performed work better
=>Medium - performed up to expectations given the circumstances
=>High - performed work extremely well

13) How would you rate the Degree of Difficulty for the activity ?
=>Low - easy
=>High - difficult

The data collection procedure dealt with the implementation and use of the data collection sheets. The first step was to identify the projects that were to be included in the investigation. The second step was to identify who would collect the information, and where it would come from. The third stage was to determine how the information was to be collected.

Projects to be investigated were chosen from the historical database using the following criteria. The project would have a reinforced concrete frame, either horizontal or vertical, but the preference was for both. The projects were to be in Western Canada. The projects were to have been completed in the past four years in order to obtain accurate information from the data sheets being filled out by field personnel. The projects were to be a mixture of sizes from $1 million and upwards.

The first trial of the data sheets consisted of meeting with several superintendents and project managers and filling out the first revision of the data sheets. It was decided that the best source of information was the project superintendent. The superintendent is directly responsible for and supervises the work crews performing the work being studied, therefore they have the knowledge on how the work was being performed. Project managers could answer information on a project level, but deal more with coordination, control and communication rather than supervising work crews.

It was determined that a mailed questionnaire or a unaided data collection procedure would fail. Project staff are reluctant to perform extra paper work and the learning process of the investigators would be lost without personal interaction with the respondents. The preliminary data collection was carried out by mailing questionnaires to respondents and then performing phone interviews with the project staff respondents.

Throughout data collection, advice and comments from the respondents dealing with the questionnaires were addressed. Ambiguities, duplication and missing information were corrected and new revisions of the data sheets were produced.

3.4.5 Data Reconciliation

The consistency, accuracy and completeness of the collected data was continuously monitored. It was a difficult task due to the sources of the information. Most information was subjective judgments from the personal recollection of project staff. Checks and other sources for information were nonexistent.

Objective and numerical information from databases was checked against the project cost reports and verified by the project staff at the time of data collection. Subjective information was taken as being accurate.

Statistical analysis of the objective data consisted of examining the coverage of the information. For example, the productivity rates for each concrete formwork activity were analyzed. It was desired that the values would span all possible values and the sample of values would be distributed similariy to the overall population.

For the subjective data, histograms and limited statistical analyses were performed to determine the typical response and the distribution of responses. It was that the collected information would cover all possibilities as thoroughly and consistently as possible.

3.4.6 Limitations of Collected Data

Limitations of the collected data are a result of who is collecting the information, what type of information is being collected, when the information is being collected, where the information is coming from, why the information is being collected and how the information is being collected and used. Limitations encountered while conducting the investigation included:

1. Investigator inexperience or lack of knowledge on construction activities being investigated
2. Different individuals conducting the interviews, thus directing the responses and information differently.
3. Half the information collected was subjective information, which has several drawbacks.
    a) Little or no supporting quantitative information that can be used as a check or supplement.
    b) Answers had to be formatted in a usable format, which is typically a rating. Long answers or explanations cannot be used in the model.
    c) Some discussions and responses involved factors that were not included in the model, but may have affected productivity.

4. The data collection investigation focused on historical projects. All the information was for projects in the last five years. Information was hard to collect and difficult for respondents to remember.

5. The majority of the information was from project staff. Limitations were:
   a) The memory of the respondent was relied upon to provide accurate responses.
   b) Lack of common reference point. Different individuals will have different experiences, thus opinions for similar occurrences or situations.
   c) Respondents must rate a situation or factor over an entire activity. They must make a summary judgment, given their knowledge and what occurred during the construction activity.

6. The information was collected to build a neural network for estimating labor productivity. Requirements for later usage of the data included:
   a) Responses had to be in numerical format to be used in the neural network.
   b) Information had to be comprehensive in order for the neural network to have all necessary information to produce an accurate model.

3.4.7 Reevaluation of the Model

After first trial of the data sheets, it was determined that all the required information was not attainable. The projects are historical, therefore it was difficult getting the information. Electronically stored data was limited and was not easily accessible. Detailed information dealing with actual construction activities could only be collected from the superintendents or project managers. The first trial of data sheets included questions that required too much detail, including information that would not be known or remembered by the respondents. The data sheets were constructed more for an immediate post project data collection investigation, rather than a historical data collection investigation.

Several conclusions were drawn from the first trial of the data collection investigation. Since the data must be collected from individuals, the information must be broad based and easy to remember. Detail on specific items would be difficult to collect and probably inaccurate if it was collected. The data sheets must continue to be a mix of subjective and short answer questions to allow simple and quick responses.

Steps were outlined to correct the problems with the data sheets. In order to simplify the process, general subjective questions were only to be asked for the project on a whole. If any extreme cases or exceptions came to mind they could be noted. Individual activities would be examined by set of subjective questions, in particular factors that have a large impact on labor productivity for the activity. The results of the general questions were taken to cover all activities, unless an exception is known.

Upon further trials of the data collection procedure it was determined that data collection would continue to be difficult. It was decided that an unsupervised data collection procedure would not be possible, due to lack of interest of staff, misunderstandings, improper interpretation of sheets, time delay in obtaining the data sheets back, and less information or knowledge gained due to lack of communication.

3.5 Extension of Data Collection Model

One of the goals of this investigation is to develop a scheme for future data collection. The preliminary investigation has been focused on collecting a broad range of data and attempting to determine what factors have a significant impact on historical productivity. Once the significant factors are determined, then a future data collection scheme may be developed. The scheme will be a mix of electronic data transfer and direct data collection and entry into a central database or database system.

As data collection currently stands, significant systems will have to be implemented in order to collect all the data that is required for maintaining a historical productivity analysis program. A detailed report concerning all chosen high risk areas will have to be compiled for each project. The report should be completed as the project progresses, or could be compiled at the end. The difficulty will be in making the supervisors complete the additional paperwork. The main obstacle to overcome is to demonstrate the importance of such a system to the individuals that are required to collect the data.

Significant thought and work will have to be invested for the development of data sheets for future projects. The data sheets will have to be easily completed by the project staff. During the preliminary investigation, interviewers were asking and explaining the questions, and sometimes modifying the response. In the future, corrections will not be available when the investigators are not present for the completion of the forms.

Guidelines that will have to be followed when implementing the future data collection are as follows; questions for the data sheets will have to be explicit and contain additional information or explanation in order to receive an accurate response. Data collection within the company involved in the study is rapidly changing. Old systems are being updated and replaced. Additional information is becoming available. Thought must be put into where information will come from, and what will be done with it. A post project analysis of the important cost centers will still be required. Detailed analysis is the only way that meaningful data for the neural network may be collected.

Links between the estimate stage and the completion stage of a project will have to be developed. A possible solution is for the estimators to maintain the system. The estimators, as the primary users of the application, should be responsible for maintaining it, or at least involved in maintaining it. The estimators gain the largest benefit from the application. The estimators as users of the system should receive feedback from the results. Expectations and estimates should be compared to actual occurrences through the data collection procedure allowing the estimators to learn and gain knowledge into construction activities being estimated.

3.6 Conclusions

Limitations of a model dictate the success of an investigation and the further usage of the information. Limitations must be known and addressed. Limitations of collected data are a result of who is collecting the information, what type of information is being collected, when the information is being collected, where the information is coming from, why the information is being collected and how the information is being collected and used. Limitations encountered while conducting the investigation included:

1. Investigator inexperience or lack of knowledge on construction activities being investigated
2. Different individuals conducting the interviews, thus directing the responses and information differently.
3. Half the information collected was subjective information, which has several drawbacks.
    a) Little or no supporting quantitative information that can be used as a check or supplement.
    b) Answers had to be formatted in a usable format, which is typically a rating. Long answers or explanations cannot be used in the model.
    c) Some discussions and responses involved factors that were not included in the model, but may have affected productivity.
4. The data collection investigation focused on historical projects. All the information was for projects in the last five years. Information was hard to collect and difficult for respondents to remember.
5. The majority of the information was from project staff. Limitations were:
    a) The memory of the respondent was relied upon to provide accurate responses.
    b) Lack of common reference point. Different individuals will have different experiences, thus opinions for similar occurrences or situations.
    c) Respondents must rate a situation or factor over an entire activity. They must make a summary judgment, given their knowledge and what occurred during the construction activity.
6. The information was collected to build a neural network for estimating labor productivity. Requirements for later usage of the data included:
    a) Responses had to be in numerical format to be used in the neural network.
    b) Information had to be comprehensive in order for the neural network to have all necessary information to produce an accurate model.

After each step of the study including, data collection, data compiling and neural network experimentation, reevaluation of the selected factors affecting productivity was performed. Factors were added to improve modeling of productivity, while unnecessary factors were eliminated.

Chapter 4

4. A Neural Network Model to Predict Labor Productivity

4.1 Introduction

The goal of the project was to aid in the prediction or estimation of labor productivity values for future projects.

The overall objectives of the neural network model are to:

1. Construct a neural network to aid in the estimation of concrete formwork labor productivity.
2. Identify important and relevant factors affecting labor productivity in order to produce an accurate estimate.

The overall objectives will be realized by the completion of the subobjectives which are:

1. Construct an accurate neural network through experimentation and development of an experimentation procedure, a network structure, an input structure and an output structure.
2. Determine the significant factors that affect labor productivity. The methodology of the solution will be in the form of determining all available and acceptable inputs and identifying the important or significant inputs.
3. Determine a useful and meaningful output formulation.
4. Determine procedures for maintaining the system including training and testing procedures.

The procedure for experimentation with neural networks is a trial and error process. Determining the proper configuration and parameters for a successful neural network is an iterative process. Several acceptable solutions are possible, therefore for the best results, exhaustive experimentation must be performed.

Each experiment is based on implementing a new concept or procedure. Neural networks take extensive experimentation time because each new concept or change should be done incrementally so that the effect of a change can be determined.

The procedure followed for experimentation was developed based on typical experimentation formulation and is illustrated in Figure 4-1 Experimentation Procedure.

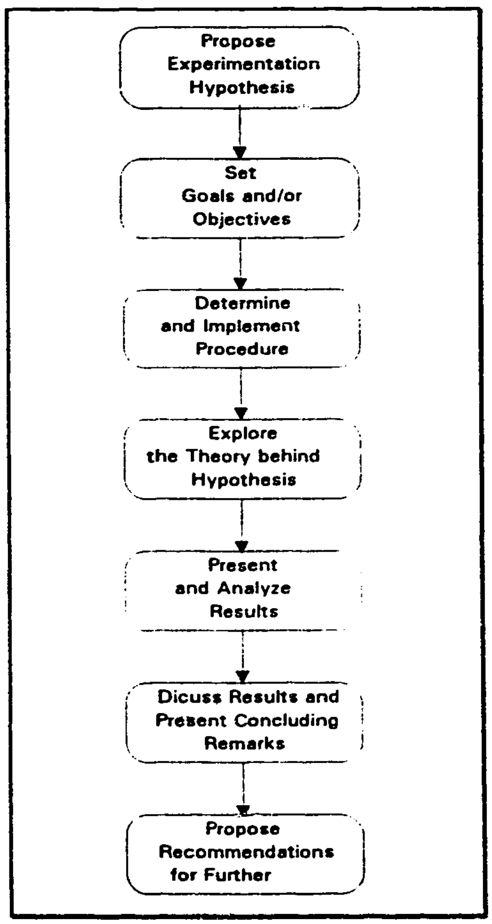

Figure 4-1 Experimentation Procedure

The experimentation hypothesis is the specific concept, idea, parameter, or modification to the network that is being tested.

The overall objective for all the experiments is the same, to increase the accuracy of the prediction of labor productivity by the neural network. A related objective is to prove or disprove the hypothesis being investigated.

The procedure for experimentation is as follows:

1. Collected data is combined and compiled.
2. Data is transformed to neural network input formats.
3. A training data file is constructed.
4. A testing data file is constructed.
5. A neural network is generated from specified parameters within a computer application.
6. The neural network is trained with 70-80% of available records.
7. The neural network is tested with 20-30% of available records.

The results from the experimentation are predicted labor productivity values. Analysis of the prediction was based on comparison to the actual values. Testing and validation is covered in a later section.

The results of the experiment are discussed and conclusions are made. The typical decision to discard concepts or ideas is based on the performance of the trial compared to a base line, or standard trial at that time.

Recommendations for further experimentation or other areas to investigate are an integral part of experimentation. The evolution of a neural network is slow and is dependent on detailed experimentation to investigate the problems thoroughly.

4.2 Experimentation Environment

Neural networks are computer based applications requiring extensive numerical calculations. Several computer applications were used for experimentation. Microsoft Access was used to collect, compile and combine information in a relational database format. NeuralWare Data Sculptor was used in preliminary experimentation for conversion of data to proper neural network input structures. Once input and output structures were relatively static, Microsoft Excel and later Microsoft Access was used to convert the data into neural network input format. Neural network experimentation was performed using Neural Works Professional II Plus. Analysis of the results of training was performed with Microsoft Excel.

4.3 Network Structure Experimentation

Neural network structure experimentation focused on the different types of neural networks available and the parameters that characterize the individual types of networks.

The primary neural network structure experimented with was a feedforward, backpropagation network. Experimentation was not limited to only one type of network. Other networks such as Modular, Probabilistic, General Regression and Learning Vector Quantization (LVQ) were investigated (Hesse, 1996 and Salem, 1996). The other types of networks did not produce accurate results. Requirements for more record sets, restrictive output methods and restrictive network structures all affected the accuracy of the other networks in contrast to the feedforward, backpropagation network.

The internal operations of a neural network are a function of several parameters. Through trial and error experimentation, the parameters defining the feedforward, backpropagation neural network were investigated. The parameters and the findings from experimentation are:

1. Number of Inputs. The inputs to the neural network are the factors affecting productivity that were collected in the data collection investigation. The number of inputs varied from 75 inputs to 12 during experimentation. The final prototype neural network has approximately 55 inputs representing approximately 30 individual factors.
2. Number of Hidden Layers. The number of hidden layers available in the experimentation application was one, two, or three. Most neural networks have one or two hidden layers. Through experimentation it was determined that one hidden layer was more accurate than two hidden layers (Hesse, 1996). The networks with

one hidden layer converge to a solution faster than networks with two hidden layers and have better accuracy.

3. Number of Hidden Processing Elements. The number of nodes in a hidden layer tended to be approximately one half to one third of the number of inputs. It is an empirical guess, which can affect accuracy of the network and convergence time. For the final prototype network with approximately 55 inputs, 30 hidden nodes were found to produce the best results (Hesse, 1996).
4. Number of Outputs. The number of outputs varied from one, a single point estimate of labor productivity, to fourteen nodes representing production zones.
5. Learning Rule. The experimentation software included options for several learning rules. The primary learning rules experimented with were the delta rule and the normal-cumulative rule. Experimentation demonstrated that the normal-cumulative rule produced superior results. The delta rule tended to overlearn the training sets, thus failing in testing due to poor generalization.
6. Transfer Function. The transfer functions experimented with were linear, hyperbolic tangent and sigmoid. The sigmoid transfer function was found to produce the best results. The linear transfer function did not function for the data and the hyperbolic tangent transfer function produced erratic results during training. Networks employing the linear and hyperbolic tangent transfer function did not learn.
7. Input Scaling. All information within a neural network must be numerical and scaled. Scaling can be performed in two ways, from 0 to +1 or from -1 to +1. The prototype network scales data from -1 to +1.
8. Number of Training Iterations. Neural networks learn in an iterative process of trial and error. A successful network will converge to an optimal solution given enough training iterations.

Experimentation with input and output structures for the neural network was the focus of experimentation. Once a type of network was selected, the optimum parameters for the network were determined and remained constant throughout the remainder of experimentation. The difficulty in the investigation was the input and output structure modeling. Experimentation is required to represent the information to the network in an accurate, concise, and thorough manner.

4.4 Input Structure Experimentation

Investigating the input structure for the neural network was a primary component of experimentation. The investigation into factors affecting productivity proposed numerous factors to be included in the network, data collection provided the information and experimentation determined the factors to be included in the model.

The objectives for the input experimentation include:

1. Determine which factors significantly affect labor productivity.
2. Eliminate unnecessary factors from experimentation and data collection.
3. Explore new factors to increase prediction accuracy.
4. Reduce the number of inputs to a limited number in the recall stage.
5. Manipulate input formatting so that in recall, responses are preformulated and simple to answer.

The process of selecting a factor to be a neural network input evolved to general guidelines for inputs. The guidelines were the inputs had to:

1. have a significant effect on labor productivity.
2. be available from data collection or a calculation from collected data.
3. be known or determinable at the time of estimate.
4. be meaningful to the user.
5. be easy to answer with preformulated choices.
6. be meaningful to the network.

Experimentation with input structures included:

1. providing all possible factors as raw numerical inputs.
2. removing insignificant inputs from the model.
3. adding new inputs to increase the accuracy of the model.
4. scaling and setting boundaries for the inputs.
5. converting inputs to groups, where a single value represents a group which is composed of a range or set of values.
6. performing input consolidation.
7. using a mixture of all of the above to represent the data to the network.

For preliminary experimentation, experiments were conducted with all the collected data as raw input. The purpose of this was to become familiar with the factors, to become familiar with the computer software, to develop procedures for later experimentation and to determine the feasibility of the proposed solution.

For detailed experimentation, experiments first dealt with the number of inputs. The number of inputs to the network evolved by eliminating inputs that would not be known at the time of estimate and constructing calculated inputs to provide objective information to the network. Eliminating the inputs was necessary because they could not be used in the final implementation. Inputs such as number of changes and claims would not be known at the time of estimate, therefore are of no use to the network model. Calculated inputs were added to aid the network by providing objective empirical data. Inputs such as district performance were calculated from a historical labor productivity database to compare a district to all other districts.

Further experiments focused the input structures and formatting. The hypothesis was that providing the inputs in a representative manner would produce results within the desired accuracy.

Qualitative data was in the form of description and labels, for example concrete formwork tie type. Neural network inputs must be numbers and attaching an arbitrary number to a tie system could give the network the impression it is more or less important than other tie systems. The solution is to present the input as a binary number. All possible tie systems are given their own input node (called a 1 of N input). For example if possible tie systems are Snap Tie, Taper Tie and Camlock, each would have its own input node. If a record involves a specific tie type, that record is given a number of 1 in the input, while all other inputs representing tie types are given a 0 value.

Qualitative data was also in the form of ratings or either a positive or negative response. The ratings were typically from 1 to 5, 1 representing a low rating, 5 representing a high rating. If the rating were scaled from 0 to 1, a problem occurs. To the neural network, the value or score of 5 is 5 times as important as a score of 1. This could lead to significant problems in that the network would not receive the input in a meaningful manner. If the rating is scaled from -1 to 1, that problem is overcome. A low value would be at one side of the scale (-1), an average or middle score would be at 0, and a high score would be at the other side of the scale (1). Therefore, the network is given extreme cases as significant input, while normal or typical cases are given negligible significance. Positive and negative responses were implemented in the same manner, a negative response being a -1, while a positive responses is a +1. Another alternative to rating factors is to present the information to the network in the form of binary input. Each possible response is given its own input node, thus avoiding any bias that may be interpreted by the network.

Quantitative (numerical values) data is typically presented to the network as it was collected. Neural networks require the inputs to be scaled from 0 to 1 or -1 to 1, but most programs perform this task automatically. Scaling must be kept in mind because of the implications of problems occurring with data. Numbers with a large spread in values such as quantity of concrete formwork had to be adjusted to be presented to the network in a meaningful manner. Values ranged from 1000 to 100,000, rendering the lower values of the scale all but negligible to the network. The solution was to calculate the logarithm of the values, which became a range of 3 to 5, thereby reducing the range of values and allowing significance for smaller numbers.

Neural network scaling is an important topic. When the inputs are scaled, the high and low values that are used for scaling may have a significant impact. Data records may contain a tightly distributed set of values, with an extreme outlier. The outlier is not necessarily wrong, but can disrupt the ability of the network to receive all the scaled inputs properly. The typical solution is to manually set the high and low boundaries of the scale and truncate the outlier to the specified scaled. An example could be slab height. Values for slab height typically range from 8 to 30 feet, but one slab was at 60 feet. Instead of allowing the outlier to affect the scaling of the other values, the value would be truncated to 30 feet. The related assumption is that the extreme height is the same as the next highest value for height. Both values have approximately the same detrimental effect on productivity due to the working height, requirement for support structures and difficulty in material handling.

A goal of the project was to make the networks easy to use in the recall stage. A solution to this was to reexamine the inputs and take the viewpoint of how the questions would or could be answered by the users in the recall phase. It became evident that care was required to make the inputs simpler, with preformulated or typical responses that would aid the user in the recall phase. One of the solutions was to reexamine the quantitative data. Expert advice and statistical analysis lead to the setting of ranges for quantitative data. The ranges were used to construct groups, which became binary inputs. For example wall heights, can vary from 8 feet to 25 feet. By examining the data, and interviewing experts, it was decided that the walls could be modeled by two inputs, wall heights equal to or less than 12 feet and wall heights greater than twelve feet. The two groups have their own distinctive construction techniques and requirements and any detail beyond the two binary inputs was not required.

In an attempt to further reduce the number of inputs being provided to the network, input consolidation was investigated. Preliminary experimentation revealed that utilizing factors as raw input did not meet accuracy expectations. Problems encountered were the experimentation records did not contain all possible combinations of all the factors, some of the factors had little importance and factors were demonstrating improper importance to the network. Through preliminary data analysis and expert opinion it was demonstrated that several values or ranges of factors had approximately the same meaning, thus consolidation was feasible. An example of this is project site conditions. To capture the project site conditions, three questions were posed about site access, site congestion and site soil conditions. Instead of each question having to be asked in the recall phase, all three can be combined to a single input about project site conditions in general.

When determining the factors to be consolidated, the factors were split into two groups, quantitative and qualitative. Quantitative data is difficult to consolidate due to variance in its unit of measure. Quantity of formwork cannot be combined with the wall height and wall thickness in a reasonable manner. Qualitative data is typically easier to consolidate, once the responses are transformed to a similar scale or meaning.

Preceding any consolidation, the subjective or qualitative value scales had to be standardized. In order to combine the qualitative data the values had to have similar meanings. In other words a high score for one factor had to mean the same to labor productivity compared to a high score from another factor. A simple scale was devised which was simply from 1 to 5, 1 meaning adverse to productivity, 5 meaning beneficial to productivity. Conversion of quantitative to qualitative values could also be considered consolidation. A wide range of individual numerical values could be confusing to the neural network, mainly due to the gaps in the possible combinations. Quantitative values were set to qualitative based on analysis of the data (distribution) and by expert advice.

The mechanism to consolidate the inputs had several possibilities. The simplest way is to add or average several factors to yield an input. An alternative was to give specific combinations of inputs a specific consolidated value. A structured and theoretical solution was required. The solution was in the form adapting the Analytical Hierarchy Process technique, which incorporates Fuzzy Set theory and Pairwise Comparison into a decision making framework (Saaty, 1980). The technique provides a structured model to investigate and evaluate a problem, which incorporates both favorable and unfavorable evaluation factors in one framework. The Analytical Hierarchy Process technique is utilized to combine and evaluate various levels of information and to calculate a score to aid in making a decision based on the assigned framework.

The technique consists of three components, a hierarchy, pairwise comparisons, and aggregation of comparison results. The hierarchy reflects the interactions within the elements and the goals and concerns of the decision making situation. The investigation is not using the Analytical Hierarchy Process technique to render a final decision. The technique is being used to structure the inputs and to consolidate some of the inputs on a detail level. Pairwise comparison allows the investigator to compare the relative importance of multiple factors within a fuzzy set by assigning numerical values for importance. Using pairwise comparison matrices, scores are calculated that can represent the relative importance of each factor in relation to all factors. The technique continues the analysis for each level of the hierarchy and then aggregates the scores from each level to yield a solution. For the investigation, a neural network is substituted in place of the aggregation and will complete the investigation by learning the importance of various factors and inputs based on the data records (Portas, 1995).

The accuracy of the network utilizing consolidation did not increase or decrease significantly. The implementation could be considered a success because accuracy did not decrease. The network predictions were within 15% of the actual productivity achieved 80% of the time both with and without data consolidation (Hesse, 1996).
The experiment consolidated 29 factors into 7 inputs (75 % reduction). Previous versions of the neural network were cluttered by all the inputs and determining which inputs were important was difficult.

The limitations of the consolidation process must always be kept in mind. The major limitation is that the results are entirely dependent on the user. The qualitative results of the method are strictly based on qualitative judgment and reasoning. The hierarchy, and the construction of the matrices must be completed in a consistent manner, considering all relevant factors and interactions.

Final experimentation and development of a prototype dealt with the use of all of the above experimentation methods to construct the network. The final network was a combination of raw inputs for objective data, groups representing ranges of values and subjective ratings and consolidated inputs.

Consolidation experimentation lead to the construction of a hierarchy for the input structure. The final input structure is illustrated in Figure 4-2, 4-3 and 4-4.

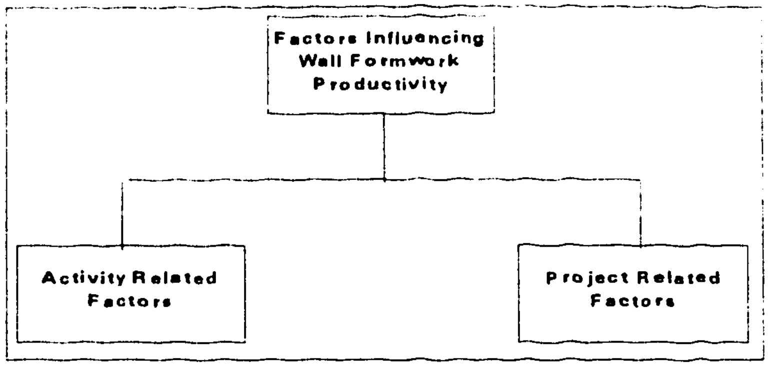

Figure 4-2 Wall Formwork Hierarchy

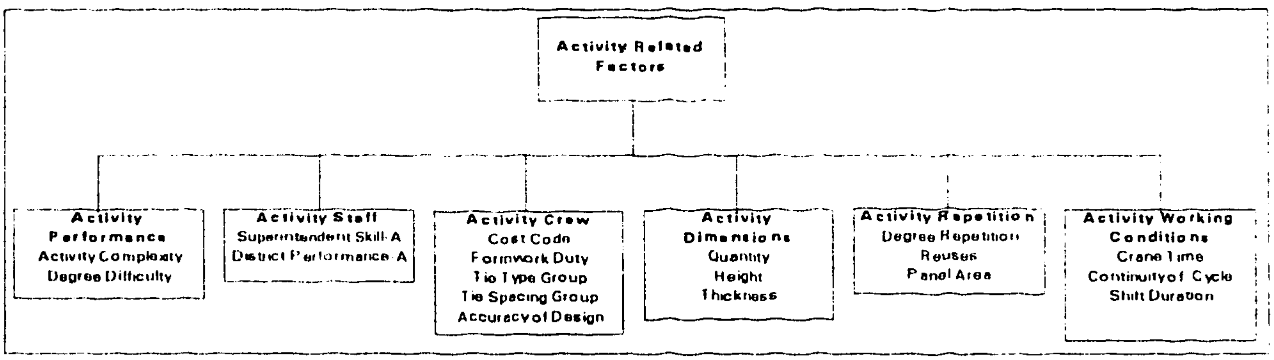

Figure 4-3 Activity Factor Hierarchy

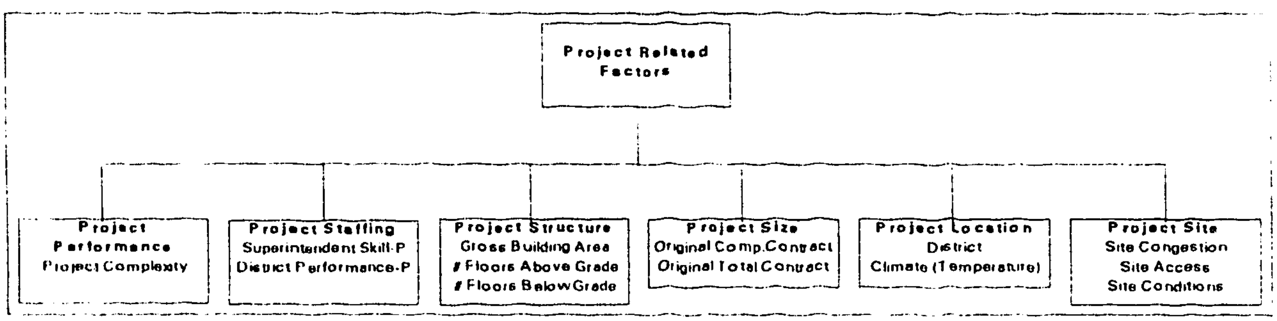

Figure 4-4 Project Factor Hierarchy

4.5 Output Structure Experimentation

Investigating the output structure for the neural network was a primary component of experimentation. The investigation into factors affecting productivity proposed numerous output structures, all focusing on predicting labor productivity.

The objectives for the output structure are:

1. Provide the user with estimates of parameters representing labor productivity that match the specified criteria (inputs).
2. Provide the user with smaller distributions or a subset range of the entire set of labor productivity values to select from.

Experimentation with possible output structures included the following schemes :

1. Point estimate of labor productivity.
2. Splitting the labor productivity values into predetermined zones or ranges of values based on productivity and predicting :
    a) a zone number.
    b) zone parameters (minimum, average, maximum).
    c) a zone mode (most likely value).
    d) a zone number by binary outputs.
    - zones calculated by:
        i) subjective judgment (investigator).
        ii) histogram calculation.
        iii) numerically - by number of records.
        iv) a classification neural network (LVQ or Kohonen).
3. Point estimate prediction and mapping to a zone.
4. Binary zone pattern recognition.

For preliminary experimentation, point estimates of labor productivity were used as the output structure. Point estimates are the typical output for the majority of all neural networks. In this case, the point estimate was labor productivity in man hours per square foot of contact area for concrete formwork. Figure 4-5 Productivity Point Estimate Output Scheme illustrates the output structure. Point estimates can perform well with neural networks, but can have significant limitations including:

1. no uncertainty measures.
2. do not show why or how error is manifested.
3. do not demonstrate partial or alternate matches or predictions.
4. does not allow the concept of fuzziness or overlap in determining zones.

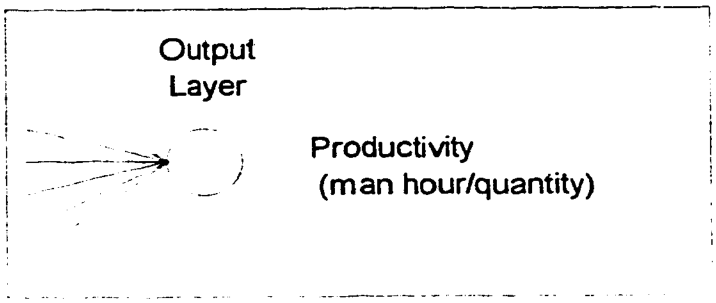

Figure 4-5 Productivity Point Estimate Output Scheme

The first proposed solution to the problem of determining an output structure was to split the labor productivity values into zones and then allow the network to predict a zone of values rather than a point estimate. Figure 4-6 Productivity Zone Formulation illustrates the sectioning of productivity values into zones. The zone would contain a sample of productivity values and could be represented by calculated statistics or a fitted distribution. The assumption was that similar productivity values (within a zone) would be from similar circumstances. The zone would be predicted and the statistics for the empirical data for the zone would represent the range of possible values. The concept of fuzziness could also be included in the zones, allowing the boundaries of adjacent zones to overlap due to uncertainty. Once the concept of zones was introduced, the investigation turned to how zones were to be used, how the zones would be calculated, and how the output zones would be represented in the network.

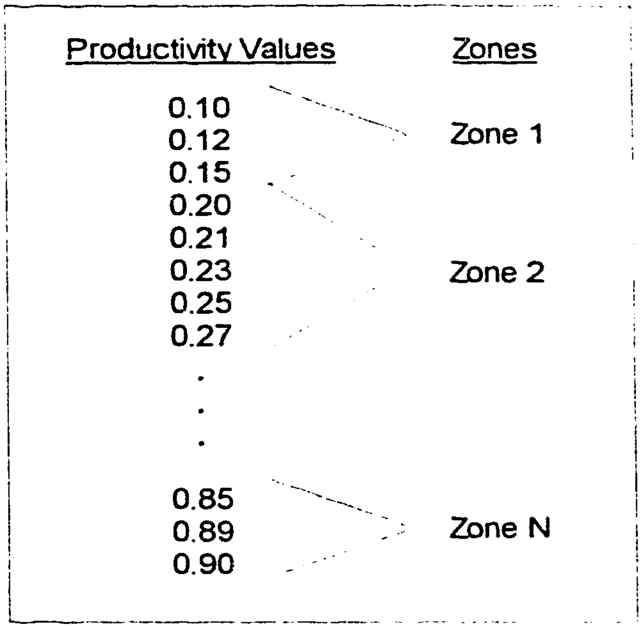

Figure 4-6 Productivity Zone Formulation

The first decision to be made while determining the zones was how many zones were to be used. The number of zones is linked to the performance of the network, therefore accuracy goals had to be considered. Desired accuracy was +-10 % at least 80% of the time. This translates into the network predicting a zone which spans 20% of the range of the possible values (accuracy +-10%), 80% of the time. Therefore, the number of zones was set to a minimum of five, with later trials to have more zones once more data is available and accuracy of the network increases.

The next decision to be made while determining the zones was where the zone boundaries would be located. The first solution was sorting the productivity values for the data records in ascending order and zone boundaries were placed subjectively at significant breaks in the data. Another method split the data into zones using a statistical histogram algorithm. The histogram had 5 cells, with each cell spanning 20% of the possible range of labor productivity values. Another method split the data into zones by the number of data points. The data points were ordered, counted and split into 5 zones based on a numerical count of the values (in other words if there were 25 data points, each zone would have 5 data points and the zone boundaries would be set accordingly). Another method employed the use of a Kohonen Model. The network uses unsupervised training algorithms to group or classify the labor productivity data, thereby determining the zones.

Once the number of zones and the boundaries of the zones were complete, the next step was to determine the method to predict the proper zone. The first solution was to predict a single value representing the zone. Figure 4-7 Productivity Zone Point Estimate Output Scheme illustrates the network structure. Each zone was given a number and the network was to predict the number that ranged from 1 to 5. Once the network had predicted a zone, the statistics or distribution for the zone could be presented to the user as output.

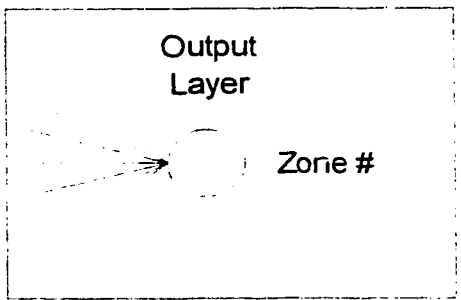

Figure 4-7 Productivity Zone Point Estimate Output Scheme

The next solution was for the network to predict three values, the low, average and high values of a zone (calculated for each individual zone). Figure 4-8 Productivity Zone Parameter Estimate Output Scheme illustrates the network structure. The network was directly predicting the output that the user would view.

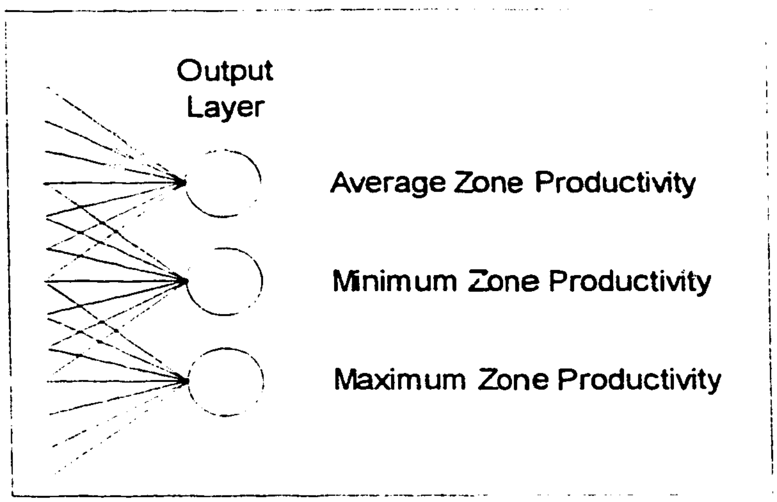

Figure 4-8 Productivity Zone Parameter Estimate Output Scheme

The next solution was for the network to only predict the most likely value of a zone. The output was the most likely value found for a specific zone. Figure 4-9 Productivity Zone Most Likely Point Estimate Output Scheme illustrates the network structure

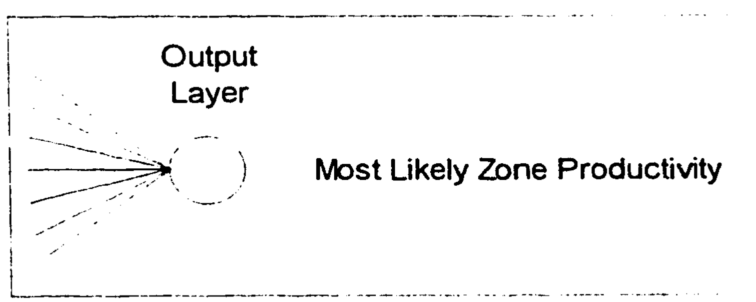

Figure 4-9 Productivity Zone Most Likely Point Estimate Output Scheme

Another solution was based on predicting a zone by a number label again. Instead of a single output to predict a zone, each zone was given an output node (binary, 1 of N output). Figure 4-10 Productivity Zone Binary Estimate Output Scheme illustrates the network structure.

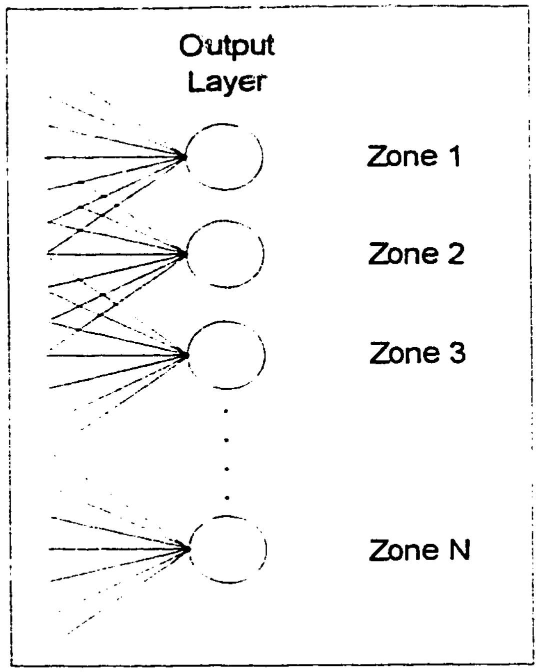

Figure 4-10 Productivity Zone Binary Estimate Output Scheme

Another variation of the zone concept was to use the network to predict a point estimate of the productivity, which in turn would be mapped to a zone using a classification network. Once the value was mapped to a zone, calculated statistics and fitted distributions for the zone would be presented to the user as output. Figure 4-11 Productivity Zone Point Estimate Mapping Output Scheme illustrates the network structure and extension of the model for output mapping. The calculation of the zones would be expanded to include the entire population of historical productivity records for a type of concrete formwork and was not to be restricted to the data collection sample as in the other methods.

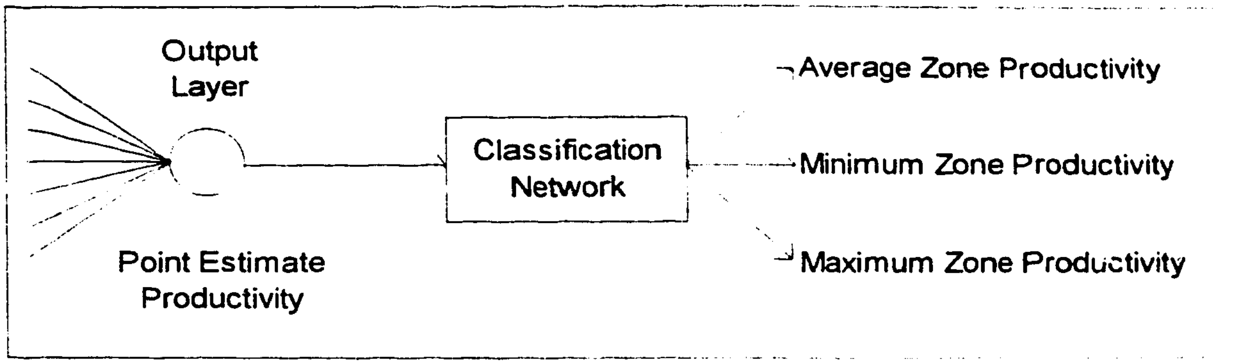

Figure 4-11 Productivity Zone Point Estimate Mapping Output Scheme

Experimentation showed that the concept of zones did not perform up to desired accuracy (Hesse, 1996). Possible problems with the concept of productivity zones as used in the above circumstance include:

1. No uncertainty measure. Predictions by the network are an all or nothing concept. The neural networks are structured to yield a single and do not provide a certainty or accuracy measure.
2. No measure for near matches. Neural networks are structured to provide one answer, not answers that were close or came from similar circumstances (inputs).
3. Arbitrary selection of zones, not based on any thing other than actual labor productivity value. All the methods for determining and utilizing zones were based on the value of the labor productivity for the activity. The combination of the inputs producing a productivity value could not be included in the zone formulation.
4. Poor assumption of similar productivity values from similar circumstances. Data collection and analysis showed that similar productivity values can be the result of a wide range of circumstances.

A reevaluation of the output structure was undertaken and new goals were set based on the investigation findings to date. The model requires:

1. the prediction of a range of values for the output.
2. a measure of uncertainty.
3. production zones or groups that are not static.
4. a method to include overlap in zones or groups or ranges.
5. a method to track near misses or close predictions.

Specifically, the overall goal is to predict a range of values. Referring to Figure 4-12 Goals of Output Structure (a), the range of all productivity values is assumed to range from 0 to 1 and the goal is to predict a likely subset of the overall range. The subset would match the information provided by the recall stage.

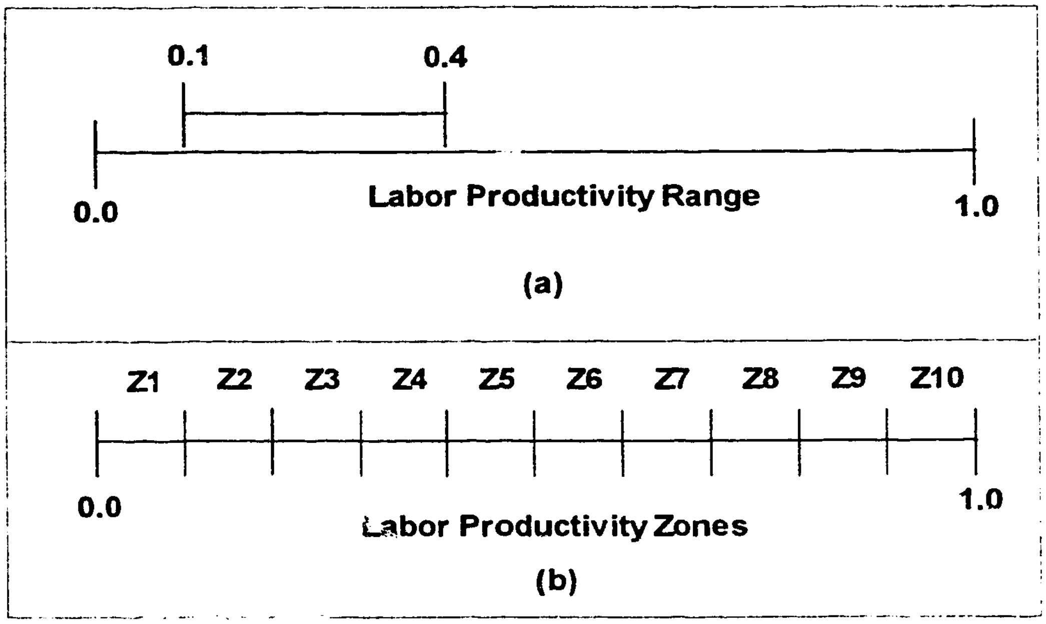

Figure 4-12 Goals of Output Structure

The final proposed solution to the problem was a Binary Zone Pattern Recognition method. The method employs the concepts of zones, or groups of similar labor productivity values. Records are mapped into binary output zones. The output zones represent a small range of productivity values.

The first step in the model is to determine the likely range of values. Referring to Figure 4-12 Goals of Output Structure (a) the likely range of values is scaled from 0 to 1. The goal of the model is to predict a subset of the overall range. For example, the subset range could be ranging from a value of 0.10 to 0.40 as shown in the figure.

The second step is to determine the number of zones for the analysis. Referring to Figure 4-12 Goals of Output Structure (b), the range of all possible values is divided into zones. Each zone represents a range of productivity values. The prototype network used 10 zones. The value of 10 was used to make each zone represent 10% of the entire range of possible values, therefore a score within the specific zone, or the two adjacent zones would be counted as a proper prediction (compared to the desired accuracy of +-15% or a 30% range).

The third step is to determine the boundaries of the zones and to add an extra zone on the top and bottom of the range of values to ensure that the entire range of possible values is modeled. Table 4-1 Example of Zone Boundary Definitions illustrates actual values from experimentation for zone boundaries.

Table 4-1 Example of Zone Boundary Definitions

Zone	Low	High	Mean
0	0.02	0.10	0.06
1	0.10	0.18	0.14
2	0.18	0.26	0.22
3	0.26	0.34	0.30
4	0.34	0.42	0.38
5	0.42	0.50	0.46
6	0.50	0.58	0.54
7	0.58	0.66	0.62
8	0.66	0.74	0.70
9	0.74	0.82	0.78
10	0.82	0.90	0.86
11	0.90	0.98	0.94

The fourth step is to map the records into the productivity zones. This is done by placing a 1 in the proper zone and values of 0 in all other zones. The output structure is a typical binary output scheme Each zone has its own processing element as shown in Figure 4-13 Binary Pattern Matching Output Scheme.

Utilizing a binary output scheme, the network will predict values of 0 to 1 for all output zones in the recall phase. From the predictions, near misses and measures of uncertainty can be derived. A value of 0 represents no match and a value of 1 represents an absolute match. Table 4-2 Binary Output Prediction illustrates the prediction results of a network. The predictions vary from -0.2 to +0.8. During training, the outputs converge to the absolute values of 0 or 1, but for test cases this does not occur. Scores are accumulated based on information from training, therefore the parameters and conditions manifest various scores for each zone. The value of 0.8 demonstrates that Zone 3 is the most likely range (certainty of 0.8), while Zones 2 and 4 also have significant scores (certainty of 0.3 and 0.5 respectively).

Table 4-2 Binary Output Prediction

Zone	Prediction
0	-0.1
1	+0.1
2	+0.3
3	+0.8
4	+0.5
5	+0.1
6	-0.2
7	-0.1
8	-0.1
9	0.1
10	-0.2
11	0.1

The extension of model from simple binary output prediction was done to include the concept of overlap or fuzziness in the predictions to allow prediction of ranges or subsets. The concept of fuzzy neural networks have been previously explored and implemented (Neural Computing Handbook, 1993). Fuzzy networks have been implemented with binary input, where the binary input is not only a 0 or 1 value, but a range of values from 0 to 1. If a node is active or contains a value, a corresponding feature is present, while if a node is not active or does not contain a value, a corresponding feature is not present. The values within a node are an assigned a degree of membership, or belongingness to a group. The extension of the model includes this concept for the output structure. Instead of prediction a binary 0 or 1 output, the network will predict a degree of membership value for each zone.

Kohonen used the idea of a neighborhood in developing the classification neural network. In the Kohonen model, during training the proper class is rewarded for a prediction, as well as the adjacent classes to a lesser degree (Neural Computing Handbook, 1993). This allows the network to achieve a solution faster, as well as to allow overlap in some of the predictions. Overlap is required because all classifications are not absolute.

Combining the concepts of fuzziness, overlap and neighborhood the output structure model was extended. Since the desired accuracy (and obtainable accuracy based on available information and requirements) of the network was approximately 20 to 30%, then for training a record would have multiple individual output zones instead of a single output zone. In other words, a productivity value for a record would be mapped to a zone and the value would also be mapped to the adjacent zones, combining to represent a larger range of possible values or a larger zone. All the collected records have a corresponding productivity value that seems absolute, but under similar circumstances, the productivity value could be different.

For the binary output scores, several alternatives were explored. During training, in all alternatives, the zone containing the actual productivity value was given a score of 1, while experimentation focused on what scores to give to the adjacent zones. The prototype was restricted to only the two adjacent zones, therefore the combined zones span 30% of the entire range of possible values. Restriction was based on desired accuracy and available information.

The two values representing fuzziness measures and neighborhood measures for the data were 0.4 and 0.8. A value of 0.4 represents the opinion that the likelihood of the specific productivity occurring in the adjacent zones is about half of occurring in the actual zone. A value of 0.8 represents the opinion that the likelihood of the specific productivity occurring in the adjacent zones is almost equivalent of occurring in the actual zone. The value of 0.4 represents the opinion that there is little or no fuzziness or overlap in the data. In other words that for the circumstances provided (inputs), there is little variation in possible productivity rates. The value of 0.8 represents the opinion that there is significant fuzziness and overlap in the data.

Figure 4-13 Binary Pattern Matching Output Scheme illustrates the mapping of a productivity value to the output zones. For the prototype model, a value of 0.8 was used for the majority of experimentation.

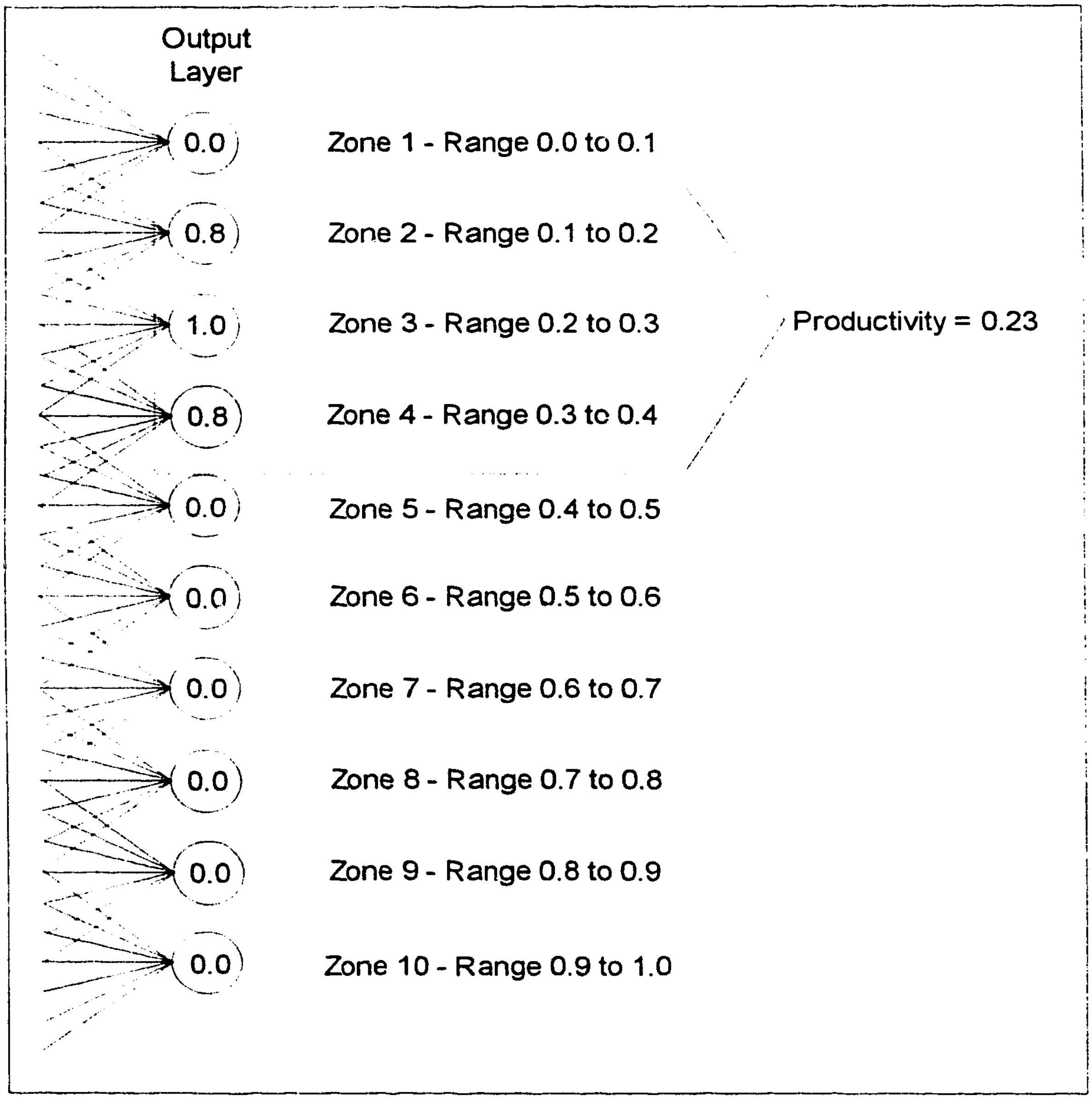

Figure 4-13 Binary Pattern Matching Output Scheme

Once the records have been trained and tested in the neural network, a typical output case is as illustrated in Table 4-2 Binary Output Prediction.

Several characteristics of the outputs should be noted:

- Output varies in both the positive and negative direction.
- Realistically, the output is only between 0 and 1
- For the purpose of this investigation
    - 0 is no match
    - 1 is absolute match

The goal of the project was to predict a range of values, requiring a post network output representation scheme. The first step can be to calculate a most likely value. A point estimate can be generated from the results using weighted averages. Each zone can be represented by its middle value and the weights for the weighted average are the output scores from 0 to 1. Refer to Table 4-3 Weighted Average Calculation Values for an example of the zone middle points and the output.

Table 4-3 Weighted Average Calculation Values

Zone	0	1	2	3	4	5	6	7	8	9	10	11
Low	0.02	0.10	0.18	0.26	0.34	0.42	0.50	0.58	0.66	0.74	0.82	0.90
High	[illegible]	[illegible]	0.26	0.34	0.42	0.50	0.58	0.66	0.74	0.82	0.90	0.98
Middle Value	0.06	[illegible]	0.22	0.30	0.38	0.46	0.54	0.62	0.70	0.78	0.86	0.94
Predicted Score	0	0.1	0.3	0.80	0.50	0.10	0	0	0	0.1	0	0.1
Score*Middle Value	0	0.014	0.066	0.240	0.190	0.046	0	0	0	0.078	0	0.094

$$\text{Weighted Average} = \frac{\text{Sum of Output Score * Middle Productivity Value}}{\text{Sum of Output Score}}$$

Sum of Output Score*Middle Value

= 0.014 + 0.066 + 0.240 + 0.190 + 0.046 + 0.078 + 0.094

= 0.728

Sum of Output Score

= 0.1 + 0.3 + 0.8 + 0.5 + 0.1 + 0.1 + 0.1

= 2.0

Weighted Average

= 0.728 / 2.0

= 0.36 mh/sf

The next step of the output representation scheme is to construct a distribution of predicted values based on historical records. For the example, zones 2, 3, and 4 were predicted by the network (refer to Table 4-3 Weighted Average Calculation Values). Table 4-4 Historical Records for Predicted Zones contains actual historical productivity values found in the predicted zones.

Table 4-4 Historical Records for Predicted Zones

Zone 2	Zone 3	Zone 3	Zone 4
0.18	0.26	0.30	0.36
0.18	0.26	0.30	0.36
0.18	0.26	0.30	0.36
0.18	0.26	0.30	0.36
0.20	0.26	0.32	0.36
0.20	0.28	0.32	0.38
0.20	0.28	0.34	0.40
0.24	0.28	0.34	
0.24	0.28	0.34	
0.24	0.28	0.34	
0.24	0.28		
0.24			

Table 4-5 Statistics for Historical Records Sample contains calculated statistics based on historical records that are to be presented to the user to represent the prediction of the network.

Table 4-5 Statistics for Historical Records Sample

Count of Records	40
Minimum	0.18
Average	0.28
Mode	0.28
Maximum	0.40
Standard Deviation	0.06

A problem that can occur with the prototype output model, is where two productivity zones may have close to the same positive score and the productivity zones are not adjacent. In other words, the network predicts two distinct and separate zones. The course of action is to present the wide range of values to the user, illustrating that the network cannot predict a small range based on available information.

Topics to resolve with the process through final implementation include:

1. Number of zones.
2. Neighborhood function values.
3. Threshold scores for acceptance of prediction of a zone.

Figure 4-14 Prototype Network Structure illustrates the overall neural network structure as developed.

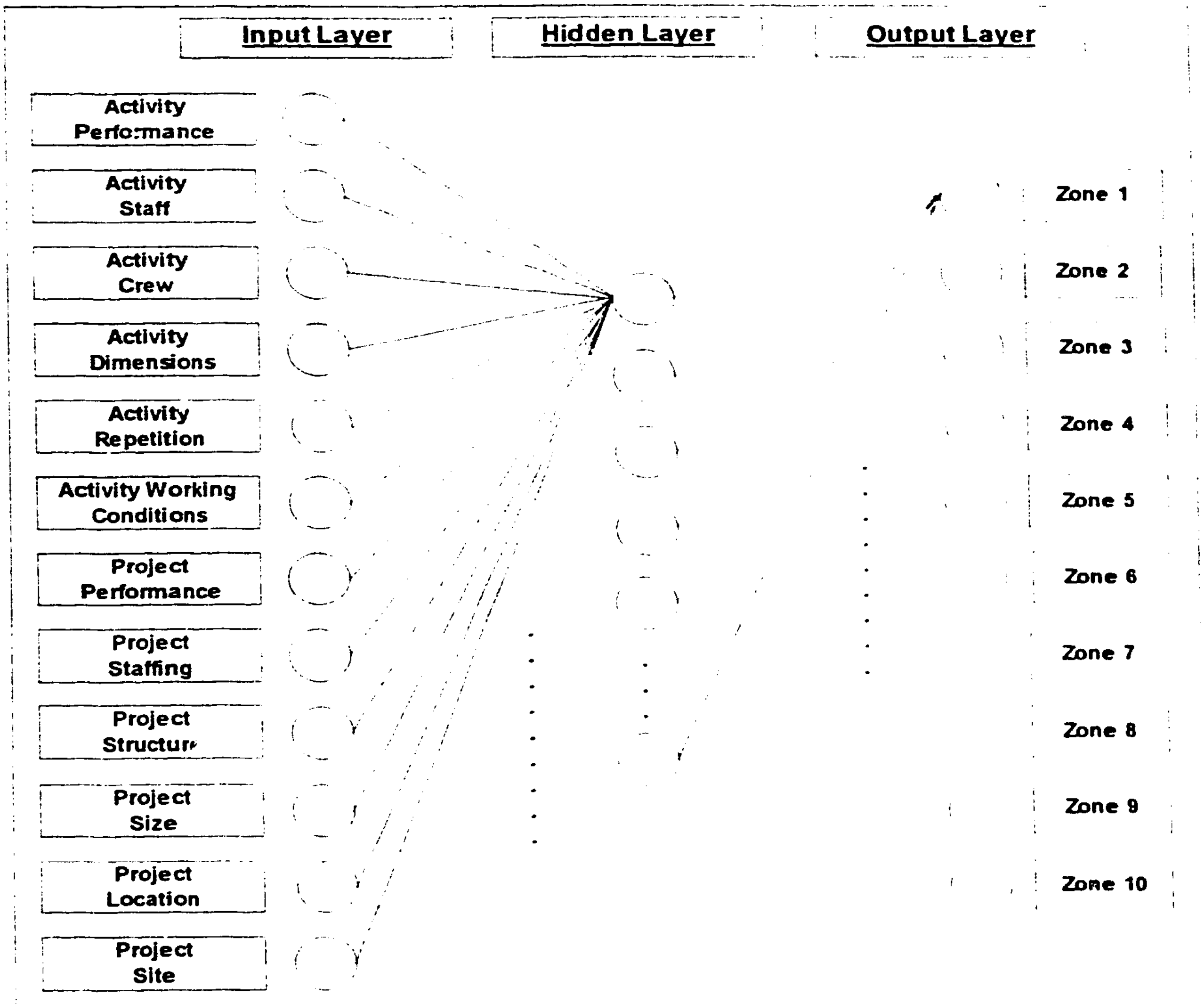

Figure 4-14 Prototype Network Structure

4.6 Testing and Validation

The process of training neural networks consists of constantly testing records, calculating errors and correcting errors. The typical method of experimentation is to split the available data records into two sets, a training set for learning and a testing set for recall. The testing set contains records not seen by the network during the training.

Therefore, the accuracy of the recall phase on the testing records yields instant results in relation to the accuracy of the network.

The difference or error between the predicted and actual values were the foundation for comparison of experiments. The error was determined by calculating a difference, calculating a percent error or matching values. The resultant errors were then compared to the base line network at the time and a conclusion was drawn based on the comparison of the two distinct network trials.

For example, take a point estimate prediction problem.

The Prediction of the Neural Network is 0.22 mh/sf.

The actual value known from data collection is 0.30 mh/sf.

Alternative A - Difference Calculation

The possible range of values is from 0.10 mh/sf to 0.90 mh/sf

Range = 0.90 mh/sf - 0.10 mh/sf = 0.80 mh/sf

Acceptable error is 15%

Acceptable difference = 0.80 mh/sf * 15% = 0.12 mh/sf

Difference between Actual and Predicted is

Difference = 0.30 mh/sf - 0.22 mh/sf = 0.08 mh/sf

0.08 mh/sf <= 0.12 mh/sf therefore the prediction is acceptable

Alternative B - Percent Error Ratio Calculation

Ratio error is equal to the predicted productivity divided by the actual.

Ratio = 0.30 mh/sf / 0.22 mh/sf = 1.36 or 36% over

36% > 15% therefore the prediction is unacceptable

Alternative C - Percent Error Normalized Ratio Calculation

Normalized ratio error is equal to the difference between the predicted and actual productivity divided by the possible range of values.

Ratio = (0.30 mh/sf - 0.22 mh/sf) / (0.90 mh/sf - 0.10 mh/sf) = 10%

10% < 15% therefore the prediction is acceptable

Alternative D - Pattern Matching

Pattern matching is used for the binary output formulation. A graphical analysis can be used, as well as the setting of a threshold of zone prediction. For example, if the allowable error is +-15%, and each zone represents 10% of the possible range of values, a prediction within the proper zone or the two adjacent zones would be acceptable.

Figure 4-15 Graphical Output Analysis illustrates the prediction of an actual network. For example, say the actual productivity value was known to be in zone 2. Referring to the figure, the prediction is within one zone of the actual. Accuracy benchmarks dictate the prediction must be in the proper zone or the two immediately adjacent zones, therefore the results are acceptable.

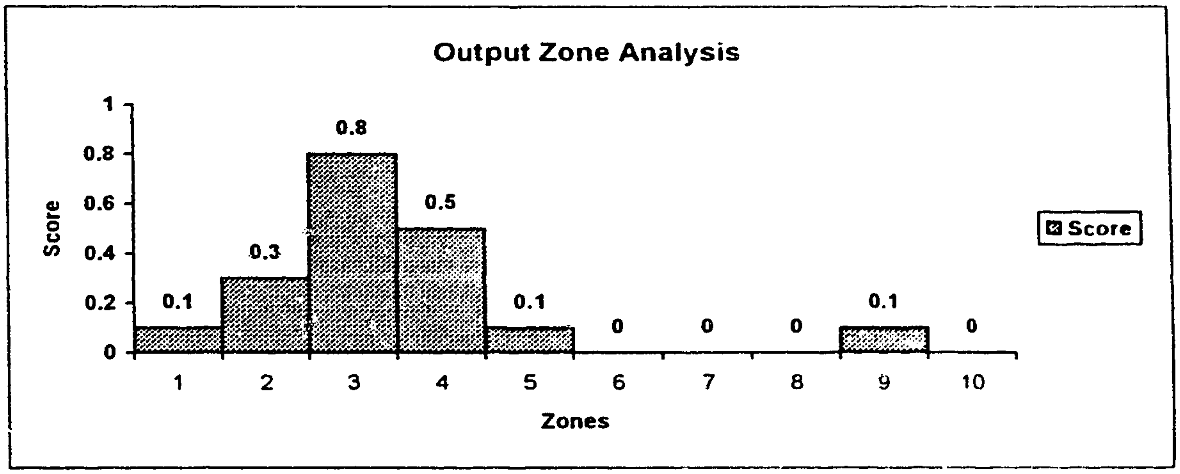

Figure 4-15 Graphical Output Analysis

Benchmarks for accuracy can be developed based on goals and past system accuracy. For a goal to be meaningful, it must be attainable, therefore benchmarks must be set at realistic levels.

To determine past system accuracy, the method decided upon was an analysis of all projects in the database by their specific cost centers. For each individual coded activity, an index was calculated as the actual value divided by the estimated value.

Therefore, an index greater than one means that the actual value was higher than the estimated or budget quantity, or that the project was under estimated.

A database is used to accumulate standings based on the error of the estimate, calculated by the index. The database examines a cost center and can determine the number of entries falling within a certain error.

Benchmarks were set based on current estimate accuracy. The current estimate accuracy is plus or minus 15% accurate, approximately 40% of the time. The final accuracy desired was plus or minus 10% accurate, approximately 80% of the time. Within the scope of the study and experimentation, a benchmark of plus or minus 15% accurate, approximately 75% of the time was set. Experimentation met the benchmark, which demonstrates almost twice the accuracy of current estimates.

4.7 Network Weight Analysis

The memory or knowledge of a neural network is contained in the connection weights. Analyzing the network weights demonstrates the relative importance of each input. All nodes in a layer are connected to all nodes in the next layer. By analyzing the combined weights of a single node to the next layer, its importance can be deduced.

For the neural network prepared for Wall Formwork, there were 53 input nodes and 30 hidden nodes in one layer. Therefore there are 1590 (53x30) connection weights between the input layer and the hidden layers. Actual connections weights from an experiment varied from -1.59 to 1.31, with an average of 0.00 and a standard deviation of 0.30.

The connection weights vary in the positive and negative direction, both types are significant to the prediction of a network. For the investigation, the absolute value of each weight can be taken, so that positive and negative values can be analyzed on a common standing.

The analysis for determining the importance of the inputs can be performed by two methods, both yielding the same results. The first method is to take the average of all the absolute weights connecting a single node to all the nodes in the hidden layer. The second method is to take the sum of all the absolute weights connecting a single node to all the nodes in the hidden layer. Through the analysis the relative importance of each node can be calculated based on its importance to the overall network.

The results from the final prototype as shown in Table 4-6 Ranking of Inputs from Network Analysis.

Table 4-6 Ranking of Inputs from Network Analysis

Rank	Field Name	Average	Sum	Rank	Field Name	Average	Sum
1	ACTIVITY PERFORMANCE	0.58	17.48	28	LOG_QUANTITY	0.21	6.25
2	CREWSIZE INPUT 1	0.43	13.02	29	Project Superintendent Score	0.20	6.14
3	Activity - Superintendent Score	0.40	12.01	30	# FLOORS_ABOVE_LOW	0.20	5.90
4	NUMBER OF REUSE INPUT 4	0.33	9.91	31	WALL_THICK	0.20	5.85
5	TIE TYPE_WALL_SNAP TIE	0.33	9.90	32	FORMWORK DUTY_LOOSE	0.19	5.83
6	# FLOORS_ABOVE_HIGH	0.31	9.42	33	PROJECT_SITE_FACTOR	0.19	5.79
7	TIE SPACING_VERTICAL	0.31	9.33	34	Material Handling and Crane Time Problems	0.19	5.71
8	NUMBER OF REUSE INPUT 3	0.31	9.25	35	DISTRICT_11_INPUT	0.19	5.70
9	NUMBER OF REUSE INPUT 1	0.30	9.04	36	Shift Duration	0.19	5.70
10	DISTRICT_6_INPUT	0.30	8.93	37	FORMWORK DUTY_REPETITIVE	0.19	5.67
11	PANEL AREA INPUT 2	0.29	8.67	38	TIE SPACING_HORIZONTAL	0.18	5.55
12	# FLOORS_BELOW_HIGH	0.28	8.51	39	Project Complexity	0.18	5.49
13	Crew Skill Rating	0.27	8.17	40	Union	0.18	5.39
14	PANEL AREA INPUT 1	0.27	8.04	41	CostCode1	0.18	5.37
15	# FLOORS_BELOW_LOW	0.26	7.76	42	# FLOORS_ABOVE_MEDIUM	0.17	5.11
16	PANEL AREA INPUT 3	0.25	7.50	43	Continuity of Cycle	0.17	4.96
17	CREWSIZE INPUT 2	0.25	7.46	44	TIE TYPE_WALL_WALER	0.16	4.85
18	CREWSIZE INPUT 4	0.23	7.04	45	LOG_COMPANY_CONTRACT	0.15	4.53
19	Season Mean Temperature	0.23	6.94	46	CostCode2	0.15	4.37
20	TIE TYPE_WALL_TAPER TYPE&BURKE	0.22	6.71	47	DISTRICT_4_INPUT	0.14	4.18
21	LOG_TOTAL_CONTRACT	0.22	6.71	48	DISTRICT_5_INPUT	0.14	4.17
22	HEIGHT_WALL_1	0.22	6.64	49	Activity - District Performance Score	0.14	4.12
23	CREWSIZE INPUT 3	0.22	6.51	50	Project District Performance Score	0.14	4.06
24	TIE TYPE_WALL_ANCHOR&CAMLOCK	0.21	6.42	51	LOG_GROSS BUILDING AREA	0.13	3.98
25	Design Rating	0.21	6.39	52	CostCode3	0.08	2.37
26	Degree of Repetition Rating	0.21	6.36	53	CREWSIZE INPUT 5	0.07	2.16
27	NUMBER OF REUSE INPUT 2	0.21	6.30				

4.8 Prototype Experimentation Procedure

As experimentation was finalized, a neural network experimentation procedure was constructed. The procedure allowed standardization of the tests and a base line for testing.

1. Examine all inputs from data collection, electronic sources and calculated sources.
   a) Fill in any missing data, making necessary assumptions or eliminate the record.
   b) Perform input collection, compiling and consolidation.
   c) Analyze the results from the consolidation and qualitative inputs for clarity.
2. Combine and compile all inputs for the network and convert for Neural Works.
3. Train and Test all records and analyze the results.
   a) Examine the testing results of the records. Prediction accuracy should be within 10-15%. Eliminate or edit up to 10% of the records to increase training accuracy.
   b) Examine the weights connecting each input to the hidden layer. Determine the relative importance of each input and consider elimination of unimportant inputs.
4. Train and Test records
   a) Either Train with 70-80% of records, Test with 20-30% of records
   b) Train with N-1 Records and, Test with 1 Record of 20-30% of Records
5. Evaluate Accuracy
   a) Predicts the proper output zone
   b) Within 15 % of Actual Productivity

4.9 Conclusions

The learning process of experimentation with neural network is a time consuming and difficult process. Setting a procedure for experimentation and reporting on the outcomes of experimentation is a necessity.

The major draw back of the investigation was the requirement for extensive data collection. The majority of the information required for the model was not immediately available. The data collection progressed slowly, thus hampering the neural network experimentation. Many problems and ambiguities could have been overcome with a larger training set. Most data sets were restricted to 40 records, which is typically almost inadequate for proper training. The problem is that the network is not seeing enough combinations to make proper inferences as to the relationships.

Experimentation with neural networks requires a significant amount of time. Each hypothesis or idea must be investigated one step at a time. Network parameters must be kept constant so experiments can be compared and the comparison be accurate.

Problems encountered were that the experimentation records did not contain all possible combinations of all the factors, that some of the factors had little variance (typically the same value) and that factors were demonstrating improper importance to the network.

Chapter 5

5. Prototype System

5.1 Introduction

The prototype system for aiding in estimating labor productivity will be implemented as a computer application. Developing a computer application requires a detailed preliminary investigation to detail the application. Proper decisions at the onset of development will save resources over the entire length of the development. A detailed investigation will also be thorough in determining and implementing all the desired functionality of an application.

Items to consider in the development of a computer application deal with technical objectives, as well as human or organizational issues. The objectives of the application should be stated and can be a benchmark for the development. Existing systems should be investigated and emulated by the new application. The new applications must be integrated with existing systems as to eliminate duplication and to share information efficiently. The development environment must provide the programming needs for the application. The user interface for the application must be user friendly and provide maximum information in the simplest way. The implementation of the application must be planned to allow proper error trapping and correction, as well as to gain the support of the individuals that will be the end users of the product.

5.2 Objectives

The objectives for a new computer application or system include:

1) Increase productivity of users of the system.
2) Increase quality of work by users of the system.
3) Increase the competitiveness of the company.
4) Provide a product whose benefits outweigh its costs.

The overall objective of the computer application is to provide an aid for estimating labor productivity. Subobjectives of the prototype system to reach the overall objective include:

1) Refinement and additions to the current computer applications.
2) Provide user interface for recall and calculation of information.
3) Implement the system.
4) Test and validate the system.

5.3 Existing System

5.3.1 Overview

The existing system must be studied in detail. Examination of existing processes and functions are an excellent starting point for the development of a new system. The existing systems have evolved from use and are typically constructed of sound methods. Individual users have become accustomed to specific procedures, therefore altering them drastically will not be well received.

5.3.2 Existing Estimating System

The existing system for estimating labor productivity includes expert opinion and analysis, as well as statistical recall of historical projects.

Currently estimators predict labor productivity using several methods. New systems have been recently implemented in the company involved in the investigation. Databases and programs were developed and implemented to collect, compile, analyze and recall information on a project and activity level.

Current estimating practices at the company involved in the investigation are based in part on determining labor productivity from historical records of similar projects to the one being estimated. The process of selecting the projects that best resemble the project being estimated is time consuming, driving productivity of estimators down and using up resources during bid preparation.

Construction projects are unique and productivity values for work items are rarely the same for any two projects. This represents a challenge to estimators who must use subjective judgments in selecting productivity values for use in preparing a new bid. This increases the levels of risk associated with a bid item leading to greater than acceptable uncertainties in the overall bid. The process may lead to loosing a bid or losing money when the projects are completed. Although such risks cannot be totally eliminated, they can be mitigated using appropriate analytical and artificial intelligence tools.

The current practice can be enhanced by completing and delivering a sound model for productivity analysis. The model is based on neural network technologies that are trained with information from the company information system. The model will quantify and properly model factors that affect productivity for a given cost center, combine these factors using appropriate analytical and artificial intelligence techniques and deliver estimates of productivity that are far more accurate than the ones currently produced.

5.3.3 Existing Computer Applications

Current development environment of the company involved in the investigation is MS Access and MS Visual Basic. The current operating systems is Windows 3.1.

The existing computer applications in Windows consists of three databases with three programs interacting with the databases. Figure 5-1 Existing Computer Applications illustrates the components.

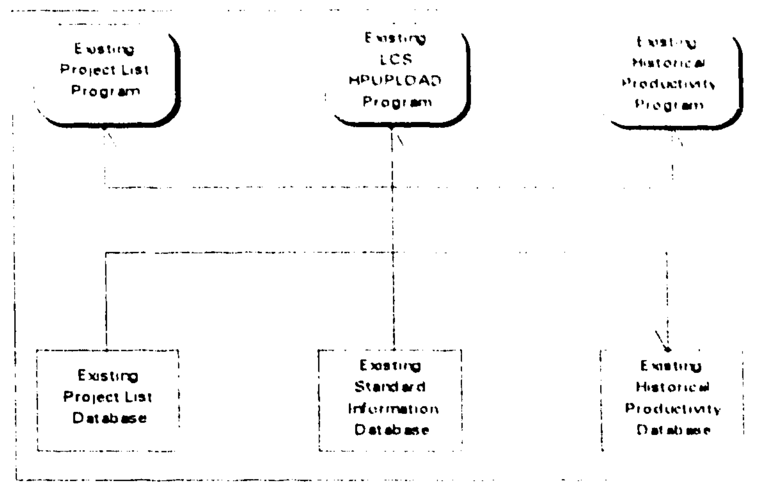

Figure 5-1 Existing Computer Applications

The existing databases are:

1) Project List Database - The project list database includes general project information
2) Historical Productivity Database - The historical productivity database stores labor productivity information on an activity level, as well as calculated statistics based on the labor productivity information.
3) Tables Database - The standard tables database contains standard company information that is sourced from the other two databases. The standard tables database is the central storage for company wide information such as company lists and cost code lists.

The existing programs are:

1) Project List Program - The Project List program allows the user to recall information on projects stored in the Project List database. The program allows specification of a list of criteria and the recall of projects matching the criteria specified.
2) Historical Productivity Program - The Historical Productivity Program allows the user to recall labor productivity information found from the projects contained in the Project List database. The program uses a module similar to the project list program to find projects matching a specified criteria. The program then performs a

statistical analysis by cost code on selected projects. The output of the program is both numerical and graphical.

3) Historical Productivity Upload Program - The Historical Productivity Upload Program allows the user to edit Labor Cost Reports from the company's accounting and cost control program. Cost reports are edited for content and to match report cost coding to the standard cost code list. Edited information is uploaded directly into the historical productivity database.

5.4 CONCEPTUAL DESIGN

5.4.1 Overview

The study of existing systems will lead to the development of a conceptual design. The conceptual design defines the major components and functions of an application. The development of a conceptual design is based on the data requirements, data collection, data storage, data compiling, and data usage.

1. Data requirements includes the data and information required to reach the objectives of the application.
2. Data collection includes the development of methods to collect the information that is required.
3. Data storage includes the database structures that will contain the data and allow usage of the information.
4. Data compiling includes the modification, alteration, calculation, summary and transformation of the required data.
5. Data usage covers the functions or calculations based on the data. Analysis of the data is also included.

A primary component of a conceptual design is the development of an integration and connectivity plan. The plan is instrumental in eliminating duplication and errors with the incorporation of new systems into existing systems. Mapping of specific data sharing and program integration will aid in development of requirements of the systems.

5.4.2 Prototype System Conceptual Design

The two major functions of the prototype system will be recall and analysis. Recall is based on information collected from past projects and historical information. The system will include methods to find information matching selected criteria. The system will aid the user in analyzing the results of the system. The analysis will be in the form of numerical, statistical and graphical analysis.

Specifically, the system will predict a probable labor productivity based on user supplied information. The system will use neural networks to provide results. Information from the system will be able to be viewed graphically. Histograms and cumulative density plots will allow user to view the distributions of data and make informed choices.

The primary component of the prototype system consists of a program module that will aid users in predicting labor productivity. The application will be composed of several modules and databases as illustrated in Figure 5-2 Conceptual Design of Prototype System. One module will be for the collection, analysis, storage and recall of data. The second module will be for the training and testing of neural networks. The third module will be for recall of the trained neural networks.

The data requirements were outlined in earlier chapters. The various factors affecting productivity and factors of interest are not all required, but will be collected and stored. The data will be derived from the detailed data collection.

Data collection was a mixture of sharing of existing information, collecting information, and determining information. The sources of the information include:

1. Existing databases
2. Cost reports
3. Historical information questionnaires
4. Expert opinion
5. Calculations
6. Subjective judgment

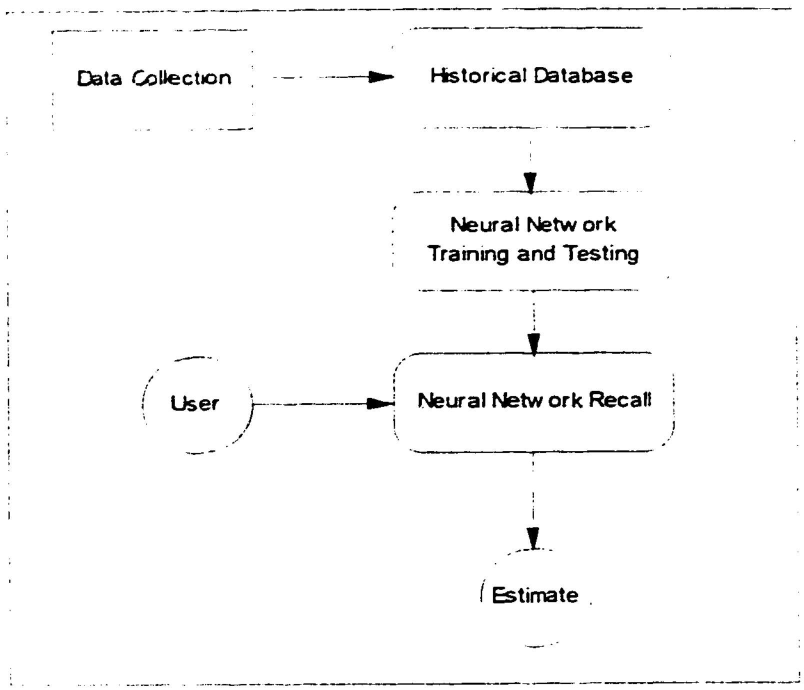

Figure 5-2 Conceptual Design of Prototype System

The investigation developed data collection methods and procedures. Existing systems did not contain the information. Databases were constructed to collect , store and recall the information. Databases were modeled after existing databases.

The functions of relational databases were used in the construction of the collection and storage systems. Information was not duplicated in the system. The system draws upon existing databases and incorporates the information from the new databases.

Data compiling involves the error checking on the collected data, as well as the translation of collected data into formats that can be used by other modules such as the neural network.

Systems for the continual updating and enhancement of the neural networks are required. The system must:

1. Perform data checks.
2. Select information to be included in the neural network.

3. Prepare selected information for the neural network.
4. Train and test neural networks with provided information.
5. Discard poor records or information.
6. Provide an analysis of the results of the training.

The portion of the system that will be used by the majority of the time is the neural network recall module. The results analysis will provide the user with methods to analyze the information retrieved or calculated by the system.

5.5 Detailed Design of Prototype System and Its Components

The prototype system will be composed of 4 new program modules and 4 new databases.

5.5.1 Module and Database Overview

The new modules are:

1) Data Collection Module - will collect detailed information from the data questionnaires and combine it with currently stored information. The data collection program will allow editing of information from the historical productivity, project information and standard information databases. The main functions of the module are allowing the addition of new data, editing of new data, checking of data, recall of information and performance of consolidation and statistical calculations required for the neural network program.

2) Neural Network Setup Module - will collect information from the data collection database and from the historical productivity, project information and standard information databases. The module combines the information into a common table or tables. The module allows the user to set up input and output types and translate the data from the raw input into summary or neural network information tables. The module stores the translated information in the Neural Network Training Information Database.

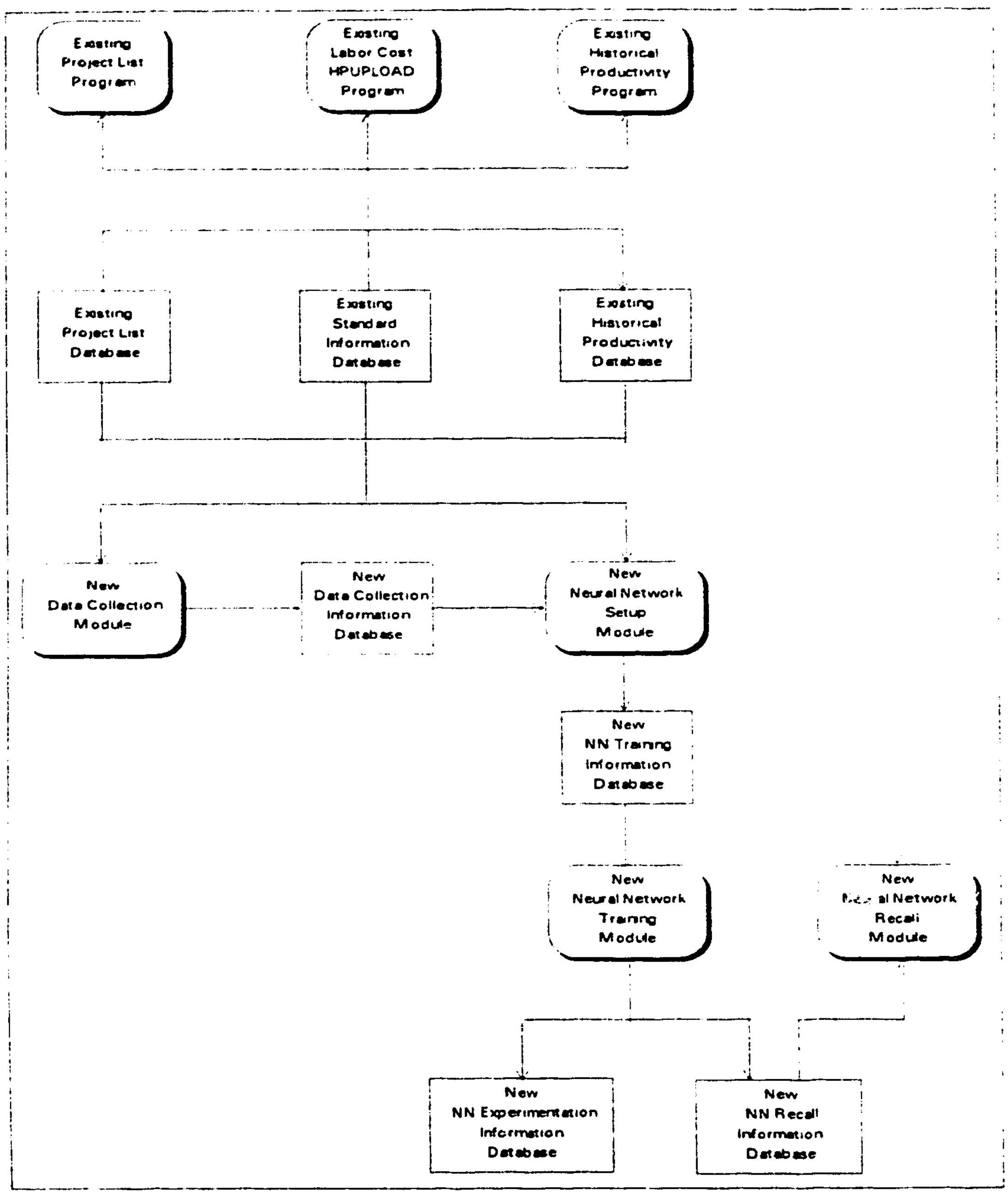

Figure 5-3 Prototype System

3) Neural Network Training Module - allows the user to setup the parameters of a neural network, specify network parameters, generate a network, train a network and test a trained network. The module will be restricted to developers use. The module will use information from the Neural Network Training Information Database, stores

training results in the Neural Network Experimentation Information Database, and stores final results of network training in the Neural Network Recall Information Database.

4) Neural Network Recall Module - allows the user provide inputs for factors affecting labor productivity for a type of formwork and predicts a labor productivity value using neural networks. The module will be incorporated into the existing Historical Productivity Program. The module will use information from the Neural Network Recall Information Database.

The new Databases are:

1) The Data Collection Database - will store new information from detailed data collection, as well as calculated statistical, summary and consolidated information from the other databases. The information will be used as a knowledge base supporting some of the information contained in the Project List and Historical Productivity databases and as the basis for neural network training.

2) The Neural Network Training Information Database - will contain all translated, summarized and consolidated information as setup and formatted by the developer. The data will be in the proper format for the Neural Network Training Module to use.

3) The Neural Network Experimentation Information Database - will contain the results of network training and testing.

4) The Neural Network Recall Information Database - will store the results of successfully trained neural networks, as well as save work in progress for users.

5.5.2 Module Functions

Data Collection Module Functions

- Edit data in existing databases.
- Specify new projects to investigate.
- Specify new activities to investigate.

- Generate data collection questionnaires.
- Add or edit detailed data collection information.
- Produce reports on collected information.

Neural Network Setup Module Functions

- Specify inputs and outputs to add and/or edit.
- Specify or edit parameters (properties, source, transformations, labels, explanations, groups or ranges).
- Specify records from database (specify parameters or selections).
- Generate the records into a table.
- Produce input/output reports (explanations, transforms, histogram analysis).

Neural Network Training Module Functions

- Specify source table.
- Edit inputs and outputs.
- Select records for training and testing.
- Specify network parameters.
- Train the neural network.
- Test the neural network.
- Analyze the results (error calculations and connection weight analysis).

Neural Network Recall Module Functions

- Select cost code or type of formwork.
- Specify activity and project related factors.
- Neural network predicts a productivity rate.
- Productivity zone is displayed.
- Example projects are displayed that match specified criteria.

5.5.3 Database Table Structures

The following tables are the contents of each of the major databases except the Neural Network Training Database. The Neural Network Training database's structure will change depending on the networks being constructed.

Table 5-1 Existing Databases

Project Information Table
Project #
Project Name
Owner Id
Owner Contact
Designer Id
Designer Contact
Project Description
City
State/Province
Airport Code
Original Contract Amount
Final Contract Amount
Original Fee
Final Fee
Company #
District #
Company %
SUB %
Start Date
Scheduled Finish Date
Actual Finish Date
Floors Above
Floors Below
Gross Area
Contract Type
Framing Material Code - Vertical
Framing Material Code - Horizontal

Historical Information Table
Contract Number
Cost Code
Split #
Imperial Quantity
Metric Quantity
Total Man hours
Imperial Prod Rate
Metric Prod Rate
Comments
Date Of Last Update

Cost Code Table
Cost Code
Description
UoM - Imperial
UoM - Metric
Conversion Factor
Flag
Memo

Table 5-2 Data Collection Information Database

Additional Project Information Table
Project #
Report Date
Prepared By
Superintendent
Foreman
Typical Floor Area
Typical Floor Area UoM
Typical Bay Length
Typical Bay Width
Typical Bay UoM
Number of Typical Floors
Typical Height of Floors
Typical Height of Floors UoM
Peak Company Crew Size
Peak Project Crew Size
Comments

Project Factors Table
Project #
Report Date
Prepared By
Crew Performance Rating
Available Skilled Labor Rating
Employee Turnover Rating
Subcontractor Performance Rating
Weather Condition Problems
Site Access Problems
Site Conditions Problems
Site Congestion Problems
Sequencing Problems
Reassignment Problems
Inspection or Quality Problems
Material Supply Problems
Equipment Supply Problems
Unionized
Walkouts or Strikes Problems
Change Problems
Claim Problems
Design Accuracy Rating
Constructability Rating
Estimate Accuracy Rating
Degree of Difficulty Rating
Degree of Repetition Rating
Degree of Rework Rating
Comments

Formwork Systems Table
Project #
Cost Code
Split #
Cost Report Cost Code A
Cost Report Cost Code B
Cost Report Cost Code C
Report Date
Report Prepared By
Activity Start Date
Activity Finish Date
Season
Superintendent
Foreman
Formwork Classification Code
Formwork Duty Code
Formwork Tie Type Code
Formwork Support System Code
Reshore Included in Code
Total Formed Area
Total Formed Area UoM
Prefabricated Form Area
Prefabricated Form Area - UoM
Percent Prefabrication
Percent Repetition
Percent Typical
Number of Reuses
Cycle Duration
Cycle Duration UoM
Formwork Tie Horizontal Spacing
Formwork Tie Vertical Spacing
Formwork Tie Spacing UoM
Panel Length
Panel Width
Panel UoM
Number of Panels
Component Height
Component Height UoM
Slab Thickness
Slab Thickness UoM
Beam Depth
Beam Width
Beam UoM
Wall Thickness
Wall Thickness UoM
Column Width
Column Depth
Column UoM
Crew Foreman
Crew Carpenters
Crew Apprentice
Crew Labor
Crew Other Skilled Labor
Crew Total Size
Complexity of Geometry Rating
Formwork Irregularities Rating
Required Finishes Rating
Working Conditions Rating
Degree of Prefabrication Rating
Degree of Repetition Rating
Maintained Cycle Continuity
Material Handling Requirement Rating
Material Handling Problems
Extended Work Hours
Design Accuracy Rating
Crew Performance Rating
Degree of Difficulty Rating
Construction Materials and Methods
Degree of Rework Rating
Constructability Rating
Estimate Accuracy Rating
Include in Neural Network
Why not Include in Neural Network

Table 5-3 Neural Network Experimentation Information Database Tables

NN Source Table
Inputs & Outputs
Status
Record Index
Comments

NN Field Parameters
Trial #
Input Index #
Minimum
Maximum
Type (Input or Output)

Network Weights File
Weights

NN Configuration
Network Description
Trial #
Experimentation File
Network Type
Learn Rule
Transfer Function
Scaling
Learning Rate
Momentum
Error Threshold
Iterations
Average Error
Maximum Error
Input Nodes
Hidden 1 Nodes
Hidden 2 Nodes
Hidden 3 Nodes
Output Nodes
Training Records
Testing Records
Time
Date
Comments

Table 5-4 Neural Network Recall Information Database

NN Question Table
Network
Trial
Question #
Question
Comments

NN Response Table
Network
Trial
Question #
Response #
Response
Response Type
Comments

NN Response Action Table
Network
Trial
Question #
Response #
Action Field
Action Value
Comments

NN Recall Save Table
Network
Trial
Save #
User
Date
Time
Comments

NN Response Save Table
Network
Trial
Save #
Question #
Response #
Comments

NN Results Save Table
Network
Trial
Save #
Output 1
Output 2
Output 3
Output 4
Output 5
Output 6
Output 7
Output 8
Output 9
Output 10
Output 11
Output 12
Output 13
Output 14
Output 15

5.6 Development Platform

The proper choice of a development platform will aid in the avoidance of limitations of the computer application. Development platforms have their own advantages and disadvantages and must be investigated on a project to project basis.

The most common development platforms include Spreadsheets, Relational Databases, and Programming Languages.

The development platforms for the computer application are Microsoft Access and Microsoft Visual Basic. The platforms were selected based on familiarity, functionality and compatibility.

5.7 User Interfaces

5.7.1 Overview

A successful user interface incorporates many principles. Simplicity, standardization, and flexibility are important components of a successful user interface.

5.7.2 Existing System User Interfaces

Refer to Appendix D.

5.7.3 New Program User Interfaces

Refer to Appendix D.

5.8 Implementation Procedures

Implementation of a new computer application can be a difficult task. Development of an application can be simply relative to the problems involved with implementation. To aid implementation, detailed plans should be developed. The plans should outline the responsibilities, time frames, and methods. The plans for implementation can be based on six questions, who, what, when, where, why and how.

1. Who covers the personnel in charge of the implementation, as well as the users that will test the application. The personnel directing the implementation should be the individuals that developed the application. They know the characteristics, the limitations, the functions, as well the program specifics that will aid in an efficient implementation. The users that will test the application must be thorough and knowledgeable enough to test the extents of the application, as well as to question omissions or components of the application.
2. What covers what components will be launched in a particular order or method, as well as what the individuals involved in the project will be responsible for.
3. When covers the time frames of implementation, such as initial launching, testing, validation, reissue, and wide spread distribution.
4. Where ties into the individual that will be using the application. The application should be sent to individuals that will use the application to its full functionality.
5. Why covers the topic of explaining the reason for the new application to the users.
6. How covers the specific methods that will be followed in launching the application. From initial installation to error reporting to suggestion for improvements.

The system will be implemented and tested as each module is constructed.

5.9 Conclusions

Development of a prototype system requires detailed planning and fore thought. Development time and resource requirements can be reduced by avoiding problems during development. Integration with current systems and functionality will ensure use once the application is completed.

The prototype system will be composed of 4 new program modules and 4 new databases.

The new program modules are:

1. Data Collection Module

2. Neural Network Setup Module
3. Neural Network Training Module
4. Neural Network Recall Module

The new databases include:

1. Data Collection Database
2. Neural Network Training Information Database
3. Neural Network Experimentation Information Database
4. Neural Network Recall Information Database

Chapter 6

6. Final Discussion

The objective of the project was to develop and implement a model to aid in the estimation of labor productivity. The objective was achieved by exploring the implementation of neural networks, identifying the factors that affect labor productivity for concrete formwork, establishing a framework for data collection and implementing the findings in a model in a computer application for a general contractor in the building construction industry.

The first stage of the study dealt with the factors that affect labor productivity, focusing on concrete formwork construction activities. Through reevaluation and an iterative process of investigation, data collection and neural network experimentation, the factors affecting labor productivity within the scope of the investigation were identified. The factors were grouped by activity and project factors. Table 6-1 Activity Factors contains the final set of activity factors. Table 6-2 Project Factors contains the final set of project factors.

Table 6-1 Activity Factors

Activity Performance	Activity Complexity Degree Difficulty	
Activity Staff	Activity Superintendent Skill Activity District Performance	
Activity Crew	Crew Skill Crew Size	Union
Activity Design	Cost Code Formwork Duty Tie Type Group	Tie Spacing Group Accuracy of Design
Activity Dimensions	Quantity of Formwork Height of Formwork	Thickness of Wall
Activity Repetition	Degree of Repetition Number of Reuses	Panel Area
Activity Working Conditions	Crane Time Continuity of Cycle	Shift Duration

Table 6-2 Project Factors

Project Performance	Project Complexity
Project Staffing	Project Superintendent Skill Project District Performance
Project Structure	Gross Building Area # Floors Above # Floors Below
Project Size	Original Company Contract Original Total Contract
Project Location	District (Region) Climate (Temperature)
Project Site	Site Congestion Site Access Site Conditions

The factors are a mixture of quantitative numbers (quantity of formwork, height of formwork), qualitative ratings (degree of difficulty, site congestion) and calculated statistics (district performance). Factors were eliminated from the analysis based on several parameters. Factors were discarded if the information demonstrated typical responses. For example overall weather, responses were that weather was typically never the cause of lost days or extreme conditions. Factors were discarded if activity level responses were available to replace project level responses. For example, accuracy of design was an overall project level and an activity level question posed to project staff, for which the activity level was deemed to supersede the project level factor. Factors were discarded if through experimentation it became evident that the factor was irrelevant or misleading. For example, amount of precipitation per region was deemed to not be representative of an overall summary level weather condition for comparison from district to district and was replaced with temperature. Factors were discarded if they could be represented or contained the same information as other factors. For example percent prefabricated, which is typically the inverse of number of reuses.

The second stage of the study dealt with a detailed data collection investigation. Due to a lack of available information, project superintendents were interviewed to obtain detailed information. The source of the data is its major limitation. Project superintendents were relying upon their memory in answering questions about projects, some of which were completed four years in the past. Another limitation is the lack of a common reference point. Project superintendents were basing their responses on their personal experiences and knowledge. Data collection procedures and techniques went through several iterations, rendering preliminary investigations inaccurate or incomplete.

The third stage of the study dealt with the preparation and experimentation with the collected data in neural networks. The model consists of the inputs presented in Table 6-1 Activity Factors and Table 6-2 Project Factors. The inputs were presented to the network in numerical format, as single or multiple inputs per factor depending on ensuring proper representation of the information. The output formulation of the model is a binary output pattern matching technique that predicts the overall labor productivity. The productivity is predicted as a set of scores corresponding to subset ranges of productivity values. A single subset range or zone represents approximately 10% of the total range of values of productivity known for the specific formwork activity.

The final neural network was a back propagation, feed forward neural network. The network uses a sigmoid transfer function, with a normal cumulative learning rule. The network uses bipolar inputs (all inputs scaled from -1 to 1) and trains for approximately 50,000 iterations. There are approximately 55 input nodes, 30 hidden nodes in 1 layer and 13 output nodes (12 zones and 1 point estimate). Experimentation was performed with approximately 45 records.

A major limitation of the neural network experimentation was the number of data records available. The lack of available detailed information required extensive data collection which was time consuming and was slow to produce results.

Results of experimentation were compared to calculated current estimate accuracy, and bench marks set based on current estimate accuracy. The current estimate accuracy is plus or minus 15% accurate, approximately 40% of the time. The final accuracy desired was plus or minus 10% accurate, approximately 80% of the time. Within the scope of the study and experimentation, a benchmark of plus or minus 15% accurate, approximately 75% of the time was set. Experimentation met the benchmark, which demonstrates almost twice the accuracy of current estimates. Accuracy is expected to increase with the addition of new data records.

The limitations of the results are that the experiments are based on occurrences where the final outcome, or actual circumstances are known. An estimator does not know all the prevailing circumstances at the time of the estimate and must rely upon their knowledge and experience to make a decision.

The fourth stage of the study was the development of a model for implementation of all the findings within the study. The model incorporates existing computer applications, a data collection module, a neural network experimentation module and a neural network recall and analysis module. Figure 6-4 Prototype System illustrates all the components of the model.

The investigation had several benefits, both academic and industrial. The academic benefits of the investigation include development and implementation of a practical artificial intelligence tool, understanding of construction activities, understanding of the significant problems with collecting required information and understanding in the intricacies of developing a new computer application. Industry benefits include training of inexperienced personnel by developing a structured approach to estimating labor productivity, reducing the guess work involved in an estimate, improved accuracy of estimates, and development of a feedback system between the estimate stage and the completion stage of a project pertaining to labor productivity estimates and performance.

Recommendations for future research include expanding the data collection investigation and expanding the areas for neural network implementation. Data collection was an integral part of the investigation and is the source of the majority of the limitations of the new system. Collection of detailed, accurate and abundant information is difficult. Work must be done in order to improve existing data collection systems and to add new data collection systems. Other neural networks for crane utilization, project staffing and conceptual estimating should be investigated.

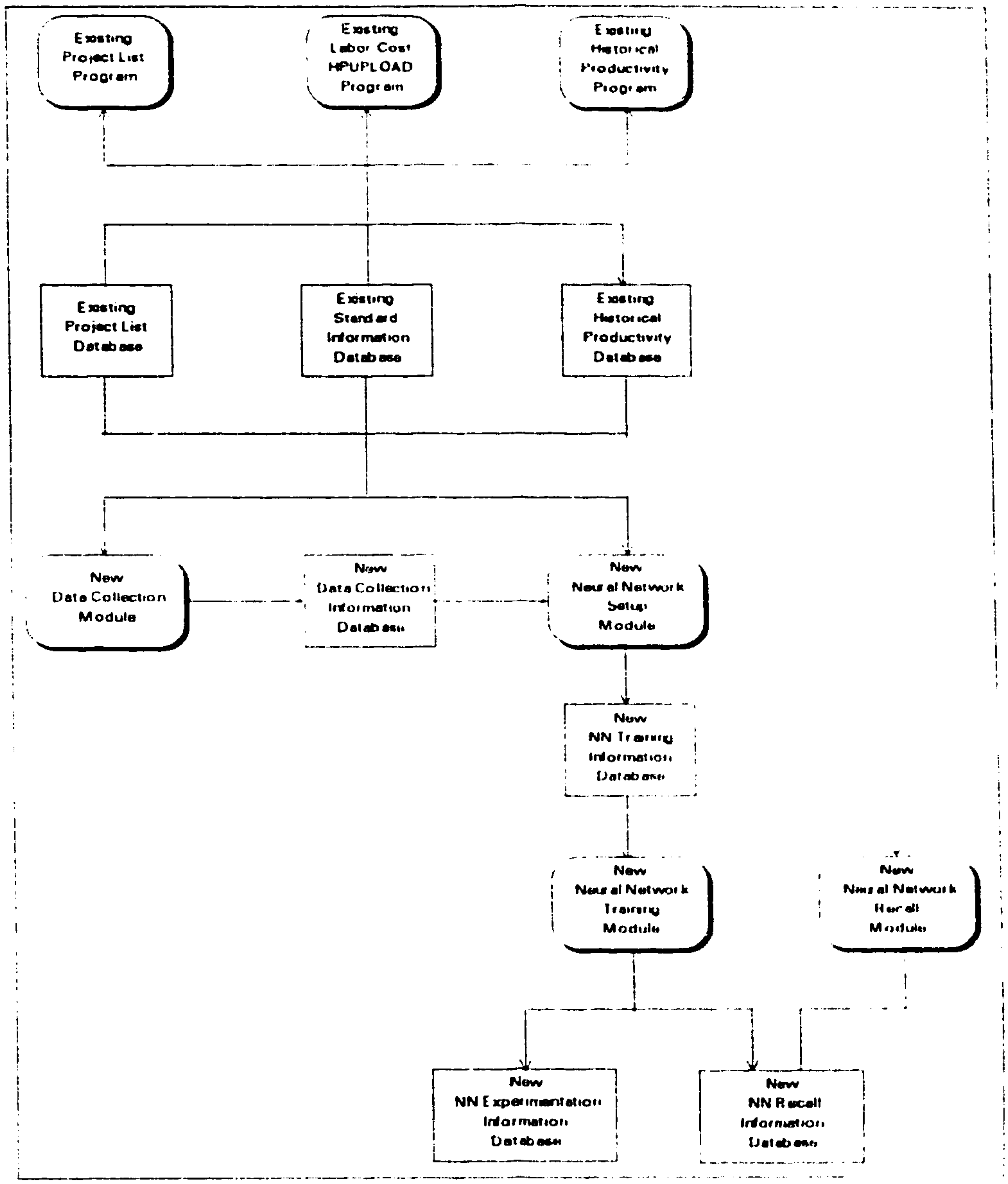

Figure 6-4 Prototype System

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Appendix A Factors Influencing Productivity

Contents

ACTIVITY FACTORS

Activity Performance

The activity performance group represents the attained performance for a concrete formwork activity. The activity performance group is composed of a complexity factor and a degree of difficulty factor. The factors are based on a comparison of actual labor productivity values to other records in the database and on subjective scoring by project staff.

A question posed to the user will be to select a probable zone of productivity (Performance) based on the complexity and difficulty of the concrete formwork activity. The user input for the question will be easy (probable excellent performance), normal (probable typical performance), and hard (probable poor performance).

Activity Complexity

The activity complexity factor represents a base line for ranges of actual productivity values from the historical productivity database. Complexity is to be used as a starting point or first guess of the user in determining the productivity and to normalize the degree of difficulty rating from project staff.

Current implementation of complexity is based on splitting the possible productivity values into three zones. The zones represent productivity values below the mode, around the mode, and above the mode (excellent, average, poor).

Specifically, the records are split as 25% - excellent, 50% - average and 25% - poor. The records are split by using the calculated company wide statistics for the type of formwork in question. The range between the 10th percentile and mode and 90th percentile are split in half to represent boundaries.

Calculation based on corporate statistics from the Historical Productivity Database. The goal is to split the range or distribution into three sections that can be used as a first guess by the estimator. The estimator will see the overall distribution, therefore they can decide either visually or by matching another project what the initial guess will be. The initial guess will set the excellent and the poor activities apart from the normal.

The calculation will split the data as follows:

```
|-------------------------|---------------------------------------------|
10th                  Mode                                           90th

<------------|-------------------------------------|---------------------->
    25%                    50%                       25%
```

The calculations will be :

Boundary 1 = lowest possible productivity rate
Boundary 2 = (Mode - 10th%)*0.5 + 10th%
Boundary 3 = (90th% - Mode)*0.5 + Mode
Boundary 4 = highest possible productivity rate

Complexity was deemed necessary due to limitations in the responses of project staff in relation to degree of difficulty. By ranking records based on productivity values, there in no noticeable correlation in degree of difficulty. It is not expected of project staff to know the relation of the performance of their crews on an activity in relation to all other projects, only projects they have been personally involved in. Therefore a common reference point was required.

Degree of Difficulty

The degree of difficulty factor represents the opinion of the project staff in relation to the difficulty of the formwork constructed for a concrete formwork activity. Responses from the project staff during data collection were on a subjective scale from low to high.

The factor covers several factors. Difficulty in terms of geometry, irregularities, and required finishes for the formwork. Degree of difficulty encompasses the general feeling on the difficulty of the activity in relation to past work of a similar nature.

Individuals were asked questions on the difficulty of the work, but the answers need some clarification. For example, the work could have been simple, given the circumstances. It is very difficult to determine the circumstances through a subjective question. An assumption previously made is that all the superintendents were experienced, and would have approximately the same reference point or level of experience while answering the questions. This may be true for most of the responses from project staff, but the answers need to be enhanced with other information.

Activity Staff

The activity staff group represents the project staff skill. The activity staff group is composed of a superintendent skill factor, and a district performance factor. The factors are based on calculated factors from information in the database on a project staff skill levels, and on a district skill level.

A question posed to the user will be to select a probable skill of the supervision for the project supervisor (superintendent) on the concrete formwork activity. The user input for the question will be above average (probable excellent performance), average (probable typical performance), and below average(probable poor performance).

A question posed to the user will be to select the district where the project is located. The user input for the question will be a company district number.

Refer to project related factors for a thorough discussion on the location factors.

Activity Superintendent Skill

The superintendent factor represents information on the skill of the supervision or project staff. A wide spread opinion is that good superintendents will always perform better than average, because they are able to deal with the problems that may occur on a project, and have the skills to have productive work crews. The calculation method for this factor is similar to the district performance factor. The factor grades superintendents based on data on past project available from the database.

Current implementation of superintendent skill calculation is based on comparing activity performance to the corporate performance. A score is calculated based on the index of actual productivity rate divided by corporate average for the cost center. Activities selected for the analysis are the cost centres of activities involved in the network.

Inputted to the neural network as the index based on historical records.

A statistical analysis from the historical table could be supplemented by opinions of management.

Activity District Performance

The district performance factor for the activity level represents the past performance of the different company districts based on historical productivity database information. The factor represents a generalization of district performance which includes such factors as crew skill, supervision skill, environmental factors, management factors, and location factors.

Calculation is based on comparing district performance (geographic and organization area) to the corporate performance (company wide information). An average score is accumulated based on the district average productivity value for a cost centre divided by corporate average for the cost center. The analysis is for the cost centres or activities being analyzed.

Inputted to the neural network as the average index based on historical records.

Activity Crew

The activity crew group represents the crew skill and crew make up. The activity crew group is composed of a crew skill rating, a crew size, and crew unionization. The factors are based on responses from the project staff from detailed data collection.

A question posed to the user will be to select a probable skill of the crew. The user input for the question will be above average (probable excellent performance), average (probable typical performance), or below average (probable poor performance).

A question posed to the user will be to select the size of crew being proposed. The user input for the question will be a group representing a range of values.

A question posed to the user will be to select the union status of the work crew. The user input for the question will be a yes or no response.

Crew Skill

The crew skill factor represents performance of a work crew on a formwork activity. Responses from the project staff during data collection were on a subjective scale from low to high.

The crew skill factor represents the skill, experience, and knowledge of the crew.

Deficiencies with the information are dependent on the lack of a common reference point.

Crew performance on an activity can be directly related to the superintendent performance factor. It is hypothesized that a good superintendent will have good crews. Crews will have the knowledge, skill, and experience to perform the work properly, and the superintendent will ensure smooth operation of the activity.

Crew Size

The crew size factor represents the number of men in a crew for a concrete formwork activity. Responses from the project staff during data collection were on a crew makeup, or at least a total for the number of men working on the formwork activity.

The crew size factor represents problems with overstaffing, proper staffing or understaffing of an activity.

Union

The union factor represents the unionization status of the work crews. Responses from the project staff from data collection were if the crew was unionized or not.

The union factor represents the possibility of different skill or performance of work crews based on their union status. It is hypothesized that union workers will be more skilled, with more knowledge due to experience and proper certification. But opposing views are of the opinion that unions are not beneficial to the performance of a construction project.

Activity Design

The activity design group represents the various design or physical characteristics of the concrete formwork activity. The activity design group is composed of the formwork cost code, the formwork duty, tie type, tie spacing, and accuracy of design. The factors are based on responses from project staff from detailed data collection.

A question posed to the user will be to select a formwork cost code (type of formwork). The user input will be a selection from the list of possible cost centres that neural networks have been compiled for.

A question posed to the user will be to select the duty of the formwork. The user input will be a selection of loose (handset), semi-repetitive (some panels prefabricated) or repetitive (ganged panels constructed for the majority of the work).

A question posed to the user will be to specify a formwork tie type to be used. The user input will be a selection form a list of possible tie types currently covered by the database and neural network.

A question posed to the user will be to specify the formwork tie spacing to be used. The user input will be a selection of a group representing a range of values.

Cost Code

The cost code classification represents the type of formwork constructed for a concrete formwork activity. Responses from the project staff during data collection were a standard cost code classification. The cost code is a way to group the types of formwork into similar types structural components.

Formwork Duty

The formwork duty factor represents the use of repetition for a concrete formwork activity. Responses from the project staff during data collection were whether the formwork was loose (handset), semi-repetitive (some panels prefabricated) or repetitive (ganged panels constructed for the majority of the work).

Tie Type Group

The formwork tie type factor represents the concrete formwork tie types on a formwork activity. Responses from the project staff during data collection were the type of tie used in the construction of the formwork.

The formwork tie type factor classifies different tie types used, and allows an investigation into the performance of tie types in relation to one another. The tie type represents information on the duty or difficulty of the formwork. Different tie types are used for varying sizes of structural components, therefore difficulty of structural components. Tie type in relation to tie spacing is measurement for the size and difficulty of the formwork being constructed.

Tie Spacing Group

The tie spacing factor represents the horizontal and vertical tie spacings of the formwork ties used on a concrete formwork activity. Responses from the project staff during data collection were the typical spacing formwork ties.

The tie spacing factor classifies different tie spacings. The combination of the tie type and tie spacing is a measurement for the size and difficulty of the formwork being constructed.

Accuracy of Design

The accuracy of the design factor represents the accuracy of the design on a concrete formwork activity. Responses from the project staff during data collection were the accuracy of the design from a scale of low to high.

The accuracy of the design factor represents the accuracy and consistency of the drawings and specifications prepared for the concrete formwork activity. The factor is a measure of the consistency and availability of accurate information for the work crews. It can also represent the possibility of work crew performing poorly due to problems related to inadequate information.

The accuracy of the design was merged with constructability on the activity level for the purposes of the data collection. Design also incorporates the concept of constructability. Proper designs incorporate the concepts of standardization, consistency, and considers construction techniques, which are the components of constructability.

Activity Dimensions

The activity dimensions group represents various physical characteristics of the structural components for a concrete formwork activity. The activity dimensions group is composed of formwork quantity, height, and thickness of the structural component. The factors are based on responses from the project staff from detailed data collection.

A question posed to the user will be to select a quantity of formwork. The user input will be a numerical value representing square feet of contact area for concrete formwork.

A question posed to the user will be to specify the height of the structural component being constructed. The user input will be to select a group representing a range of values.

A question posed to the user will be to specify the thickness of the structural component being constructed. The user input will be to select a group representing a range of values.

Quantity

The formwork quantity factor represents the quantity of formwork to be constructed on a formwork activity. The information was collected from the historical productivity database, which is constructed from project cost reports, and was confirmed by project staff during data collection.

Previous use of historical productivity information has made the assumption that the larger the quantity, the better the productivity. Studies have shown that there is poor correlation between quantity and productivity, that typical construction or repetition is more important.

Quantity also incorporates the working conditions, learning curve, and the possibility of optimum use of repetitive panels. With small quantities the crews may be working in a restricted or closed in area, where material and equipment supply is restrictive. With large quantities, the crew will possible start to be more productive due to learning curve effects. Small quantities will have the opposite effect, where the workers will not become accustomed to the procedures, and productivity will not increase. The larger the quantity, the possibility of the proper use of repetitive panels grows.

Height

The formwork height factor represents the height of formwork to be constructed on the a concrete formwork activity. The responses from the project staff during data collection give the height of the structural component being constructed.

Formwork height represents the difficulty of the construction of the formwork. Lower heights have the characteristics of being handset, easy to assemble, light duty formwork. Taller Heights have the characteristics of being repetitive work, heavy duty formwork, requiring a support system for the formwork and the work crews.

Thickness

The component thickness factor represents the thickness of the structural component to be constructed on a formwork activity. The responses from project staff during data collection give the thickness of the structural component being constructed.

Component thickness represents the difficulty of the construction of the formwork. Smaller thicknesses have the characteristics of larger tie spacing, smaller formwork ties, light duty formwork, and a smaller support system for the formwork. Greater thicknesses have the characteristics of smaller tie spacings, the use of heavy duty formwork ties, heavy duty formwork with the possibility of large gang panels, and the need for a support systems that can handle the large loads imposed by a large structural component.

Activity Repetition

The activity repetition group represents the amount of repetitive formwork involved in the construction formwork activity. The activity repetition group is composed of the degree of repetition, number of reuses, and panel area. The factors are based on responses from project staff from detailed data collection.

A question posed to the user will be to specify a degree of repetition. The user input will be a numerical value representing a percentage. If the percentage is zero, the remaining question are not applicable.

A question posed to the user will be to specify the number of reuses for the formwork. The user input will be to select a group representing a range of values.

A question posed to the user will be to select a panel area. The user input will be a selection of a group that represents a range of values for the size of the panels to be constructed

Degree of Repetition

The degree of repetition factor represents the degree of repetition for the formwork to be constructed on a formwork activity. Responses from the project staff during data collection give degree of use of repetition for the formwork of the structural component being constructed in a low to high range.

Degree of repetition is a measure of the consistency of the formwork, or in other words the amount of the formwork which may be prefabricated into panels to be reused in an attempt to increase productivity.

Repetition and typical construction was clouded in the past. Repetition may be taken two ways. The first way is the way it is being used in the investigation. Repetition is the amount of formwork that was placed using prefabricated panels. The second way of interpreting repetition is the consistency of the formwork, or how typical the structure component to be formed is.

Number of Reuses

The number of reuses factor represents the number of reuses for the repetitive formwork to be constructed on a concrete formwork activity. The responses from the project staff during data collection give number of reuses the repetitive formwork panels of the structural component being constructed in an actual number value.

Number of reuses is to be a measure of the repetition of the formwork.

Panel Area

The panel area factor represents the size of the repetitive panels on a concrete formwork activity. Responses from the project staff during data collection were the typical panel length and panel width if repetitive formwork panels were used on the project.

The panel area factor classifies the different sizes of panels used, and addresses the topic of the influence of the size of repetitive panels and their effect on productivity.

Activity Working Conditions

The activity working conditions group represents various influential conditions affecting the work crew's productivity. The activity working conditions group is composed of the crane time, continuity of cycle, and shift duration. The factors are based on responses from project staff from detailed data collection.

A question posed to the user will be to specify a if there were problems with crane time. The user input will be the selection of a positive or negative response.

A question posed to the user will be to specify if there were problems with continuity of cycle. The user input will be the selection of a positive or negative response.

A question posed to the user will be to specify if there were extended work hours. The user input will be the selection of a positive or negative response.

Crane Time

The crane time factor represents problems with crane time and material handling on a concrete formwork activity. The responses from project staff during data collection are if there were problems with crane time or material handling.

Problems with crane time and material handling can have several impacts on productivity. If the crew are waiting for the crane, time is lost. If the activity requires extensive lifting and repositioning of formwork using mechanical means, time is lost. If cranes provided are not of sufficient capacity, problems will occur with placement of material and formwork in a timely manner.

Continuity of Cycle

The continuity of cycle factor represents problems with maintaining continuity of cycle for a concrete formwork activity. The responses from project staff during data collection are if there was problems cycle continuity during construction of formwork for an activity, or whether once an activity was started, did it continue until completed.

Problems continuity of cycle can have several impacts on productivity. If a structural component is partially completed and is interrupted, learning curve factors will be influenced. If work is in sections spread over a large site, significant resources will be expended to transfer crews, equipment and material to the location.

Shift Duration

The shift duration factor represents if extended work hours were involved with a concrete formwork activity. The responses from project staff during data collection are if there was extended work hours on the construction of formwork for an activity, or whether it was standard work shift.

Problems due to extended work hours can have several impacts on productivity. Past productivity studies have shown that significant amount of overtime start to have a cumulative effect on work crews. Extended work hours will also lead to construction at different times of day, where environmental conditions can be detrimental to productivity.

PROJECT FACTORS

Project Performance

The project performance group represents the overall performance for the project. The project performance group is composed of project complexity. The project performance group is to modeled after the activity performance group. The performance is based on a comparison to other productivity records in the database.

A question posed to the user will be to select a probable zone for project difficulty based on the complexity and difficulty of the overall project, directly in relation to formwork and concrete placement activities (the concrete structural frame). The user input will be a rating of easy (probable excellent performance), normal (probable typical performance), or hard (probable poor performance).

Possible to supplement with subjective management evaluation of the factors.

Project Complexity

The complexity factor represents the difficulty of the project based on comparison to other projects. The complexity factor is a statistically determined factor calculating the difficulty of a project based on the labor productivity values attained.

Specifically, calculated by comparing the productivity achieved on formwork and concrete placing, and then relating the rates to the corporate statistics for each activity. Indexes are calculated, and average scores calculated, and then project can be compared on a common basis.

Project Staffing

The project staffing group represents various influential conditions based on staffing of the project. The project staffing group is based on superintendent skill and district performance. The factors are based on statistical calculations based on information in the current databases.

Project Superintendent Skill

The superintendent factor represents information on the skill of the supervision or project staff. A wide spread opinion is that good superintendents will always perform above average, because they are able to deal with the problems that may occur on a project, and have the skills to have productive work crews. The calculation method for this factor is similar to the district performance factor. The factor grades superintendents based on data on past project available from the database.

Current implementation of superintendent skill calculation is based on comparing activity performance to the corporate performance. An average score is accumulated based on the index of actual productivity rate divided by corporate average for the cost center. Activities selected for the analysis are all formwork activities, both loose and repetitive that the particular superintendents were supervising.

Inputted to the neural network as the average index based on historical records.

A statistical analysis from the historical table could be supplemented by opinions of management.

Project District Performance

The district performance factor for the project level was added to the investigation to identify the past performance of the different districts based on database information. The factor represents a generalization of district performance which includes such factors as crew skill, supervision skill, environmental factors, management factors, and location factors.

Calculation is based on comparing district performance to the corporate performance, and accumulating an average score based on the index of district average productivity values divided by corporate average of labor productivity for a cost center. Activities selected are all formwork activities, both loose and repetitive.

Originally, this factor was to be based on subjective opinions on what districts perform the work better, and later to be based on actual historical productivity information. Questionnaires were prepared for management, in which they ranked the performance of districts for completion of concrete structures. A numerical analysis was also performed on the individual districts based on the their historical productivity information stored in databases.

The current Historical Productivity Program, calculates statistics in order to aid in report generation. The statistics are in two levels of detail. Corporate statistics are calculated for each cost code. The corporate statistics take all records from all projects performed by the company and stored in the data base, and calculate a standard set of statistics (mean, mode, median, standard deviation, 10th percentile, and 90th percentile). District statistics are calculated based on grouping productivity information for all possible cost centers by each of the districts, and calculating the corresponding typical statistics (same as corporate). Thus two sets of statistics are already in the database, and ready for analysis purposes.

The preliminary comparison was performed by comparing each district statistics for cost centers to the corporate statistics, thus comparing each district to all the other districts. Cost codes for all loose and repetitive formwork, as well as for all concrete placing activities were selected. The statistics to be compared were to be focused on the mode and the mean (the most likely value, and the average value). The comparison was to come in the form of an index, which was to be constructed as the district mode for a cost code, divided by the corporate mode for the same cost code (and performed for the average). Therefore, and index less than one was a district that performed better than all the districts combined, while a index greater than one meant the district performs lower than all the districts combined. The analysis to this point yielded a list of indexes, each corresponding to a specific cost code, for a specific district. In order to consolidate the records, all the indexes were average to yield a single overall index value for each district. Based on the overall indexes, the districts could be ranked according to performance. In order to help the accuracy of the analysis, several conditions had to be met. The number of observations for a cost code had to be larger than 20 observations, which was done in order to get proper accuracy.

Project Structure

The project structure group represents information pertaining to the overall physical structure of the project being constructed. The project structure group is composed of gross building area, number of floors above grade, and number of floors below grade. The factors are derived from current data collection databases.

A question posed to the user will be to input the factors within the project structure group which include gross building area, and number of floors above and below grade. The user input will be numerical values or groups representing ranges of numerical values.

Gross Building Area

The gross building area factor represents the overall physical size of a project. The factor was collected from the current information databases and confirmed by project staff during data collection. The responses are the gross building area in square feet.

The gross building area can be a generalization of many factors. In relation to material handling, the larger the structure, the more time spent handling material. Or, the larger the building the less material handling required due to the availability of large equipment. In other words larger projects may have more resources available to work with. Larger projects may also be indicative of more repetition, therefore better productivity.

# of Floors Above Grade

The number of floors above grade represents the overall height of the structure for a project. The factor was collected from the current information databases and confirmed by project staff during data collection. The responses are the actual number of floors.

The number of floors above grade can be a generalization of several factors affecting productivity. The higher number of floors, the worse the working conditions for the workers. Extensive supporting and safety requirements will have to be met, and significant material handling problems may arise. But, the more floors, the more repetition of structural components, and therefore the probability of better productivity.

# of Floors Below Grade

The number of floors below grade represents the overall depth of the structure for a project. The factor was collected from the current information databases and confirmed by project staff during data collection. The responses are the actual number of floors.

The number of floors below grade can be a generalization of several factors affecting productivity. The deeper the excavation, the more support systems will be required to contain the excavation. But, the more floors, the more repetition of structural components, and therefore the probability of better productivity.

Project Size

The project size group represents information pertaining to the overall dollar amounts involved with the project. The project size group is composed of Original Company Contract Amount, and the Original Total Contract Amount. The factors are derived from current data collection databases.

A question posed to the user will be to input the overall contract value for the entire projects, and the portion of the contract that Company is performing, not subcontracting to other parties. The user input will be a numerical value or a group representing a range of values.

Original Company Contract

The Original Company Contract amount represents the amount of work in dollar value that company is performing. The factor was collected from the current information databases and confirmed by project staff during data collection. The response is the actual dollar amount of the company contract.

The contract amounts can be measures of several factors affecting productivity. The larger the contract, the more likely the availability of resources, in the form of management support and skilled workers. Or, the larger the project, the more workers are required, the more new (unskilled) workers must be hired.

Original Total Contract

The original Total Project Contract amount represents the overall dollar amount of the entire project. The factor was collected from the current information databases and confirmed by project staff. The response is the actual dollar amount of the Total Project contract.

The contract amounts can be measures of several factors affecting productivity. The larger the contract, the more likely the availability of resources, in the form of management support and skilled workers. Or, the larger the project, the more workers are required, the more new (unskilled) workers must be hired.

Project Location

The project location group represents various influential conditions affecting the productivity of the concrete formwork activity based on the location of the project. The project location group is composed of the district, and the weather conditions for a specific time frame for the specific activity. The factors are based on statistical calculations of data in the database.

A question posed to the user will be the location of the project. The user input will be the selection of a company district.

District

The district factor represents a general location parameter that models several unknowns. The factor was collected from the current information databases and confirmed by project staff. The responses are which company district the work was performed in or through (operated through).

Based on the district, the neural network will infer some conditions from the training records pertaining to the various districts. The unknowns that the district parameter may encompass are location factors pertaining to crew skill, weather, available resources, experience, and management skill and support.

Climate - Temperature

The climate - temperature factor for the project level was added to the investigation to identify the differences in climates and seasons for the various locations work is being performed in. The factor represents a generalization of district weather conditions which can affect the productivity due in part to adverse environmental conditions.

Calculation is based on climactic data (mean temperature per season or overall year) for nearest airport or city of the project.

Seasons assumed to encompass:

Season	Month
Winter	January
Winter	February
Winter	March
Spring	April
Spring	May
Summer	June
Summer	July
Summer	August
Summer	September
Fall	October
Fall	November
Winter	December
All	All

The season the work was performed in is already collected from the project staff during data collection (see discarded factors). The respondents can choose from spring, summer, fall, winter, and all (a mixture of the seasons, typically summer to winter). The factor to be determined is the relative effects of weather on productivity values. Working in the winter in Edmonton is significant different from working in the summer in Vancouver. One opinion is that by giving the network the district and the season, that the neural network should be able to learn of any correlation between good and bad seasons for each district. This may be true, but with a small data set, and many districts, and many other inputs, the network is probably not learning the effects of seasons. At this point in experimentation, we have not determined if the season has a significant effect on the productivity in the context of the investigation, thus we can not rule out the factor. Therefore, solutions to the problem must be explored. The first attempt was to collect climate data for the individual districts by seasons, in the form of average temperature and precipitation (see discarded factors- Precipitation).

There were several possible solutions to the season/weather dilemma that were investigated. The first one was to eliminate the factor from the inputs. The second was to rely on the inputs of the district and the season. The third is to stay with inputting the precipitation and the weather. The fourth is to generate new factors, which would be based on subjective judgment of the relative effect of weather for each district, for each season based on the climactic data. The fifth may be to feed in the temperature or precipitation as an input based on season, thus the network could compare and contrast the inputs properly.

Project Site

The project site group represents various influential conditions determining overall conditions on the project site. The project site group is composed of site congestion, site access and site conditions.

A question posed to the user will be to specify a factor for general site conditions. The user input will be a yes or no response to the presence of possible adverse site conditions on the project. Factors to consider include site congestion, site access, and site (soil) conditions.

Site Congestion

The site congestion factor represents problems with site congestion on a project. The responses from project staff during data collection are if there was problems with site congestion, specifically no lay down area, and tight working spaces.

Problems with site congestion can have several impacts on productivity. Significant site congestion has been demonstrated in past studies to have a detrimental affect on productivity. If there is no area for storage of assembly of material, time is lost to waiting for material delivery and due to shortages. Productivity is affected when the work is being performed in confined spaces. Equipment, men, and materials become congested and time is wasted due to problems with coordination and proximity.

Site Access

The site access factor represents problems with site access on a project. The responses from project staff during data collection were if there was problems with site access, specifically poor access roads, and poor crane or equipment access.

Problems with site access can have several impacts on productivity. Poor roads to the site can lead to problems with material and equipment delivery. If access to the site for equipment is restricted, resources can be lost to being forces to use non optimum substitutions to perform required work (mobile crane instead of tower crane). If access to the site is restricted, then resources are wasted being idle.

Site Conditions

The site conditions factor represents problems with site access for a project. The responses from project staff during data collection were if there was problems with the site conditions, specifically for soil conditions, for dewatering, and any other general conditions that may have an impact on labor productivity.

Problems with site conditions can have several impacts on productivity. Poor soil conditions can lead to a poor working area, and the requirement of additional time due to the need to compensate for weak soils conditions or a muddy work area.

PROPOSED NEW ACTIVITY FACTORS

Activity Performance

Geometry Complexity

The geometry complexity factor represents the consistency in cross section for a structural component that concrete formwork is being constructed for. Responses from project staff during data collection were a rating from low to high, low meaning prismatic, consistent cross section, while high meant irregular cross section.

The factor was added to supplement the degree of difficulty factor.

Formwork Irregularities

The formwork irregularities factor represents the presence of blockouts, opening or inserts for a structural component that concrete formwork is being constructed for. Responses from project staff during data collection were a rating from low to high, low meanings no irregularities, high meaning a significant number of irregularities.

The factor was added to supplement the degree of difficulty factor.

Level of Required Finishes

The level of required finishes factor represents the difficulty of the concrete finish required for a structural component that concrete formwork is being constructed for. Responses from project staff during data collection were a rating from low to high, low meaning no finishes required, medium meaning exposed finish required, and high meaning an architectural finish is required.

The factor was added to supplement the degree of difficulty factor.

Level of Typical Construction

The level of typical factor represents the amount of typical formwork is constructed. Responses from project staff during data collection were a rating from low to high, low not typical construction, high meaning all typical construction.

The factor was added to supplement the degree of repetition factor.

For the current implementation will be a combination of Geometry Complexity, and Formwork Irregularities

Activity Staff

None to Date

Activity Crew

None to Date

Activity Design

Typical # of Panels

The number of typical panels represents the number of repetitive panels constructed for a concrete formwork activity. Responses from project staff during data collection are the number of panels.

The factor was added to supplement information on the degree of repetition and the percent prefabrication.

Activity Dimensions

None to Date

Activity Repetition

None to Date

Activity Working Conditions

Activity Working Conditions

The activity working conditions factor represents the on site working conditions for the work crew for a concrete formwork activity. Responses from the project staff during data collection are on a scale from low to high, relating to the size of the work area, the location or height of the work, and access to the work area.

The factor was added to supplement project information on the working conditions.

Crane Time Requirement

The crane time requirement factor represents the requirement of a formwork activity for excessive material handling or crane time. Responses from the project staff during data collection are a positive or negative response.

The factor was added to supplement material handling and crane time problem factor.

Proposed New Project Factors

Project Performance
None to Date

Project Staffing

Availability of Skilled Labor
The availability of skilled labor factor represents the skill level of the available pool of workers for crews for a project. Responses from project staff during data collection are a rating of low to high.

The factor was added to supplement information of the overall skill of the crews.

Project Structure
None to Date

Project Size
None to Date

Project Location

Project Location - Airport/City
The project location factor based on city or airport will represent the location of the project rather than the district as previously done. The factor will be collected from the current project information database.

The project location factor will be the basis for weather information instead of the district. It may represent projects outside of the normal district area.

Remote locations can have a significant affect on productivity. Unskilled labor, poor equipment and material supply, adverse weather conditions can all be a negative influence on productivity.

Project Site
None to Date

DISCARDED ACTIVITY FACTORS

Activity Performance

Degree of Rework

The degree of rework factor represents the amount of work that was performed in relation to correcting previous work for a concrete formwork activity. Responses from project staff during data collection was a rating from low to high.

The factor was discarded from data collection and neural network analysis due to it always received a low response (no significant rework on the activity).

Activity Staff

None to Date

Activity Crew

None to Date

Activity Design

Activity Estimate

The activity estimate factor represents the accuracy of the original estimate or budget prepared for a concrete formwork activity. Responses from project staff during data collection was a rating from low to high.

The factor was discarded from data collection and neural network analysis on an activity level due to the fact that it is an unknown at the time of the estimate.

It was to be used to be a first guess for the neural network, but was discard in favor of the complexity factor.

Panel Duty

The panel duty factor represents duty of repetitive formwork panels utilized on a concrete formwork activity. The factor was constructed based on other collected factors including the degree of repetition, number of reuses, percent prefabrication, tie type factors, and overall quantity of formwork.

The factor was discarded from the neural network analysis because of the decision was made to rely on the neural network to determine the proper relationships of relevant factors.

Tie Duty

The tie duty factor represents duty of tie system utilized on a concrete formwork activity. The factor was constructed based on other collected factors including the tie type, tie spacing, component height, and component thickness.

The factor was discarded from the neural network analysis because of the decision was made to rely on the neural network to determine the proper relationships of relevant factors.

Activity Dimensions

None to Date

Activity Repetition

Typical Cycle Duration

The typical cycle duration factor represents length in days of a typical repetitive cycle for a concrete formwork activity. Responses from project staff during data collection were the actual number of days in a typical cycle.

The factor was discarded from the neural network analysis because of inconsistent responses. The factor was replaced with continuity of cycle.

The factor is still included in the data collection.

Percent Prefabrication

The percent prefabrication factor represents the percent of panels prefabricated for the repetitive formwork to be constructed on a formwork activity. The responses from project staff during data collection give the percent prefabricated for repetitive formwork of the structural component being constructed in percentage value.

Percent prefabrication is to be a measure of the repetition of the formwork.

The factor was discarded from the neural network because it is the same as the number of reuses (one is the inverse of the other, typically).

Activity Working Conditions

None to Date

DISCARDED PROJECT FACTORS

Project Performance

Degree of Difficulty

The degree of difficulty factor represents the opinion of the project staff in relation to the difficulty of the overall project, specifically for the concrete frame portion of the project. Responses from project staff during data collection were on a subjective scale from low to high.

The factor covers several factors. Difficulty in terms of geometry, irregularities, and required finishes for the formwork. Degree of difficulty encompasses the general feeling on the difficulty of the activity in relation to past work of a similar nature.

The factor was discarded from the neural network due to information already provided on the activity level.

Degree of Repetition

The degree of repetition factor represents the degree of repetition of structural components on a project. Responses from the project staff during data collection give a degree of repetition of the structural components being constructed in a low to high range.

The question was to cover several factors. Repetition in terms of terms of significant portions of the structure were design and constructed using the same methods and techniques.

The factor was discarded from the neural network due to information already provided on the activity level.

Subcontractor Performance

The subcontractor performance factor represents the performance of the subcontractors on a project. Responses from project staff during data collection was rating from low to high.

The factor was discarded from the neural network analysis due to the fact that it is an unknown at the time of the estimate.

The factor is still included in data collection.

Sequencing or Phasing

The sequencing or phasing factor represents problems with scheduling or planing due to constraints on a project. Responses from project staff during data collection was positive or negative occurrence of problems.

The factor was discarded from the neural network analysis because it was replaced with the continuity of cycle factor.

The factor is still included in data collection.

Strict Quality Requirements

The quality requirements factor represents the occurrence of strict owner inspection or quality requirement on a project. Responses from project staff during data collection was positive or negative occurrence of problems.

The factor was discarded from the neural network analysis due to the fact that it is an unknown at the time of the estimate.

The factor is still included in data collection.

Equipment Supply

The equipment supply factor represents the occurrence of problems with supply of equipment on a project. Responses from project staff during data collection was positive or negative occurrence of problems.

The factor was discarded from the neural network analysis due to the fact that it is an unknown at the time of the estimate.

The factor is still included in data collection.

Material Supply

The material supply factor represents the occurrence of problems with supply of material on a project. Responses from project staff during data collection was positive or negative occurrence of problems.

The factor was discarded from the neural network analysis due to the fact that it is an unknown at the time of the estimate.

The factor is still included in data collection.

Degree of Rework

The degree of rework factor represents the amount of work that was performed in relation to correcting previous work for the overall project. Responses from project staff during data collection was a rating from low to high.

The factor was discarded from data collection and neural network analysis due to it always received a low response (no significant rework on the activity).

Project Staffing

None to Date

Project Structure

None to Date

Project Size

Contract Margin

The contract margin factor represents percent profit for the original estimate for a project. Information was collected from the current general project information databases.

The factor was discarded from the neural network analysis because of inconsistent and unavailable responses.

Project Location

Project Climate - Precipitation

The project climate - precipitation factor represents the level of precipitation for each district. The factor was to supplement season information.

The factor was discarded because the values were misleading to the network, rainfall amounts were too large for Vancouver, overshadowed the rest in importance.

Project Season

The project season factor represents the season the work was performed in. The factor was from the detailed data collection investigation.

The factor was replaced by a mixture of season information and the mean temperature for the season.

Project Site

None to Date

Project Crew

Crew Skill

The crew skill factor represents performance of a work crew on a project. The responses from project staff during data collection were what is the overall skill level of the work force on the project. The range of values is from low to high.

The overall crew skill can have several impacts on productivity. It is a generalization for the entire project, not limited to actual performance of the crews based on isolated individual activities.

Turnover

The crew turnover factor represents the hiring and firing levels of workers on a project. The responses from project staff during data collection were what is the employee turnover rate of the work force on the project. The range of values is from low to high.

The employee turnover rate can have several impacts on productivity. If workers are replaced during the completion of a construction activity, the affects of the learning curve are reset.

Worker motivation and morale may be affected by or may be a reason for excessive turnover, and the behavioral factors can influence labor productivity.

Reassignment

The crew reassignment factor represents the movement of work to and from the site due to reassignment to other projects. The responses from project staff during detailed data collection were if the reassignment of staff or crews affected the project. This factor is in conjunction with the rate of employee turnover factor.

The employee reassignment factor can have a significant impact on productivity. If workers are replaced during the completion of a construction activity, the affects of the learning curve are reset. Worker motivation and morale may be affected by or may be a reason for excessive turnover, and the behavioral factors can influence labor productivity.

Union

The union factor represents the unionization status of the work crew on a project. Responses from project staff during data collection were if the crew was unionized or not.

The union factors represents different skill or performance of work crew based on their union status. It is hypothesized that union workers will be more skilled, with more knowledge due to experience and proper certification. But opposing views are of the opinion that unions are not beneficial to the performance of a construction project.

Walkouts or Strikes

The walkouts or strikes factor represents the occurrence of a labor dispute on a project. Responses from project staff during data collection was positive or negative occurrence.

The factor was discarded from data collection and neural network analysis due to the fact that it is an unknown at the time of the estimate.

Project Design

Design

The accuracy of the design factor represents the accuracy of the design on an overall project. Responses from the project staff during data collection were the accuracy of the design from a scale of low to high.

The accuracy of the design factor represents the accuracy and consistency of the drawing and specifications prepared for an entire project. The factor is a measure of the consistency and availability of accurate information for the work crews. It can also represent the possibility of work crew performing poorly due to problems related to inadequate information.

The accuracy of the design was merged with constructability on the activity level, but kept separate for the project level. An overall assessment of design and constructability on a project level was deemed to be necessary.

Constructability

The Constructability factor represents a rating of the constructability of a construction project. Responses from project staff during data collection were a rating on a scale of low to high.

Constructability incorporates the concepts of standardization, consistency, and productive and efficient construction techniques.

The accuracy of the design was merged with constructability on the activity level, but kept separate for the project level. An overall assessment of design and constructability on a project level was deemed to be necessary.

Changes

The changes factor represents the affect of changes for a project. Responses from the project staff during data collection were if the project had significant changes, and they affected the formwork activities for the project, then a response was given.

Changes are detrimental to productivity in several ways. Changes alter the original design, estimate, schedule and plan. Resource selection and allocation can immediately become incorrect, affecting the ability of the crew to perform their work in an efficient manner.

The factor was discarded from the neural network analysis due to the fact that it is an unknown at the time of the estimate.

Project Estimate

The project estimate factor represents the accuracy of the overall estimate prepared for a project. Responses from project staff during data collection was rating from low to high.

The factor was discarded from the neural network analysis due to the fact that it is an unknown at the time of the estimate.

The factor is still included in data collection.

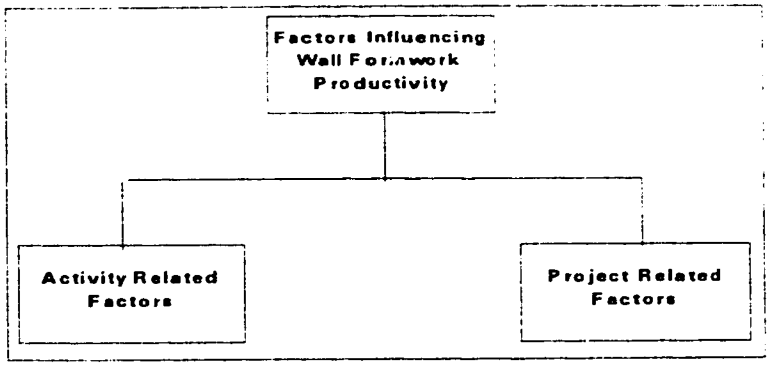
Project Claims

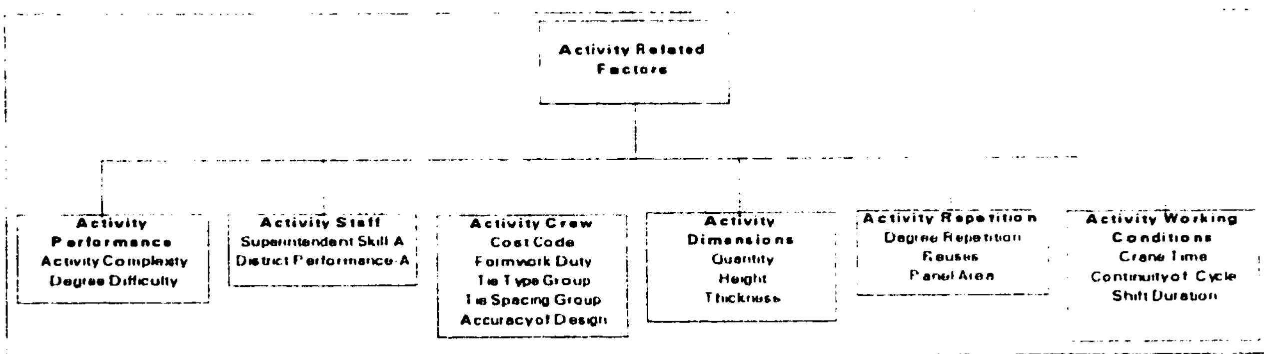
The project claims factor represents the occurrence of major disputes or claims on a project. Responses from project staff during data collection was positive or negative occurrence.

The factor was discarded from the neural network analysis due to the fact that it is an unknown at the time of the estimate.

The factor is still included in data collection.

Appendix B Neural Network Input Sheets





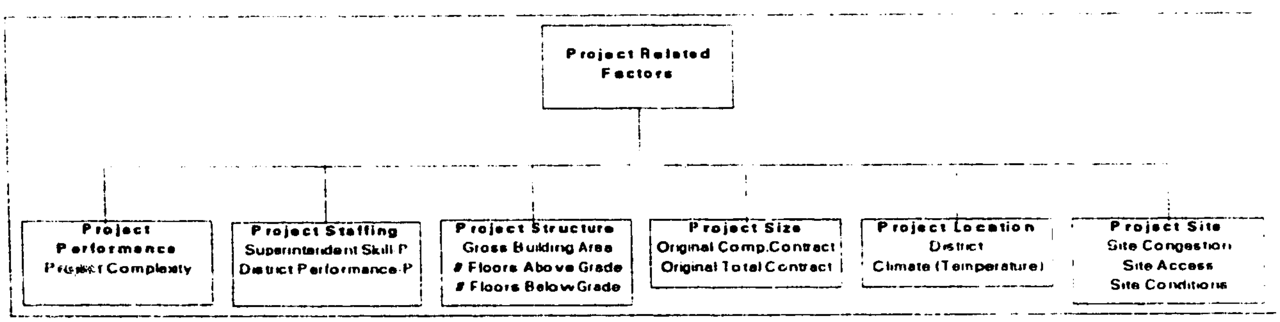


Table B-1 Activity Performance

Name of Parameter:	Activity Performance
Description:	Combines Activity Complexity and Degree of Difficulty
Classification:	Activity Factor - Activity Performance Group
Source:	Calculated from other factors
Qualitative/Quantitative:	Quantitative
Calculation Method:	(Activity Complexity Scorex0.75) +(Difficulty Scorex0.25)
Scale of Parameter:	1 (Difficult) - > 5 (Easy)
Name of Neural Network Input:	ACTIVITY_PERFORMANCE
Type of Input to Network:	Standard

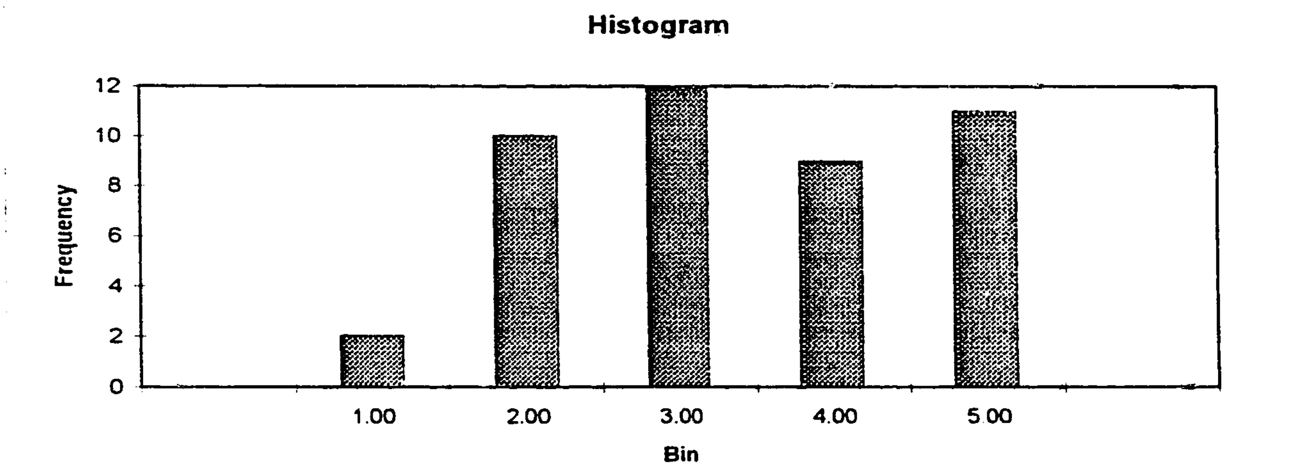


Figure B-1 Activity Performance Histogram

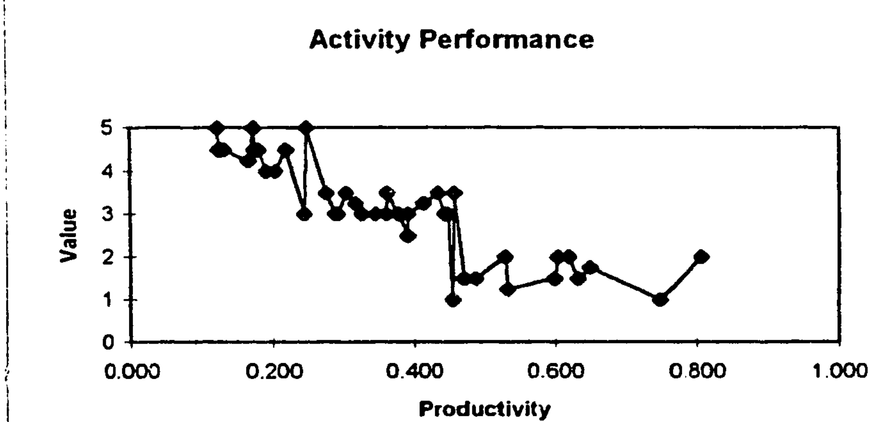


Figure B-2 Activity Performance versus Productivity Plot

Table B-2 Activity Complexity

Name of Parameter:	Activity Complexity
Description:	Supplement to Degree of Difficulty
Classification:	Activity Factor - Activity Performance Group
Source:	Calculated from HP Database
Qualitative/Quantitative:	Quantitative
Calculation Method:	Comparison of Region around the Mode (Corporate Statistics) Bound 1 - Lowest Productivity Rate Bound 2 - (Mode -10th%)*0.5 + 10th% Bound 3 - (90th% - Mode)*0.5 + Mode Bound 4 - Highest Productivity Rate
Scale of Parameter:	5 (Easy) - from Bound 1 to Bound 2 3 - from Bound 2 to Bound 3 1 (Hard) Bound 3 to Bound 4
Name of Neural Network Input:	ACTIVITY_COMPLEXITY
Type of Input to Network:	Standard

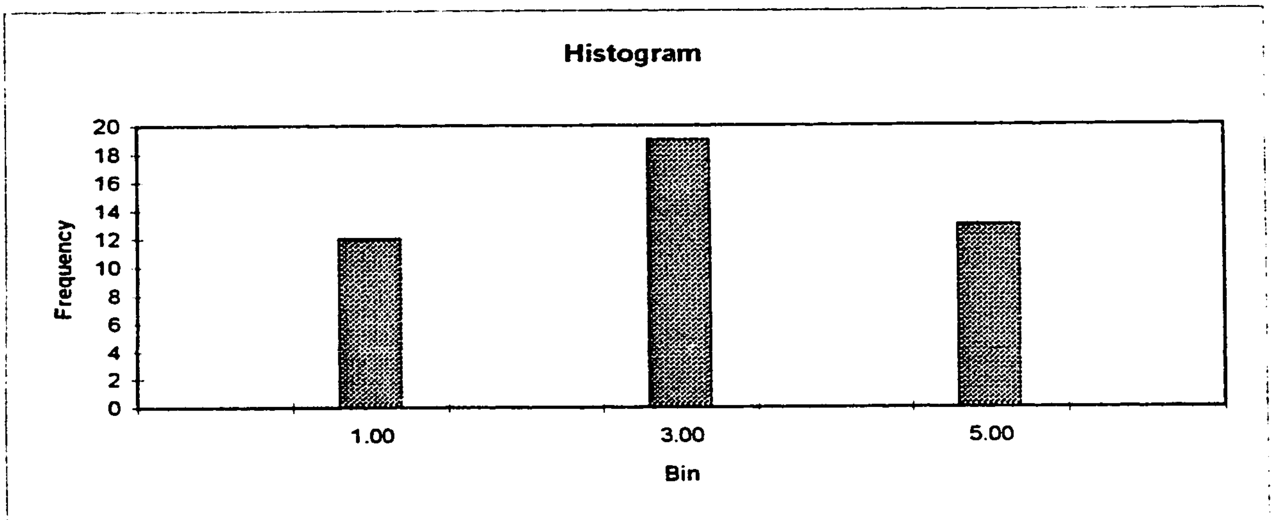


Figure B-3 Activity Complexity Histogram

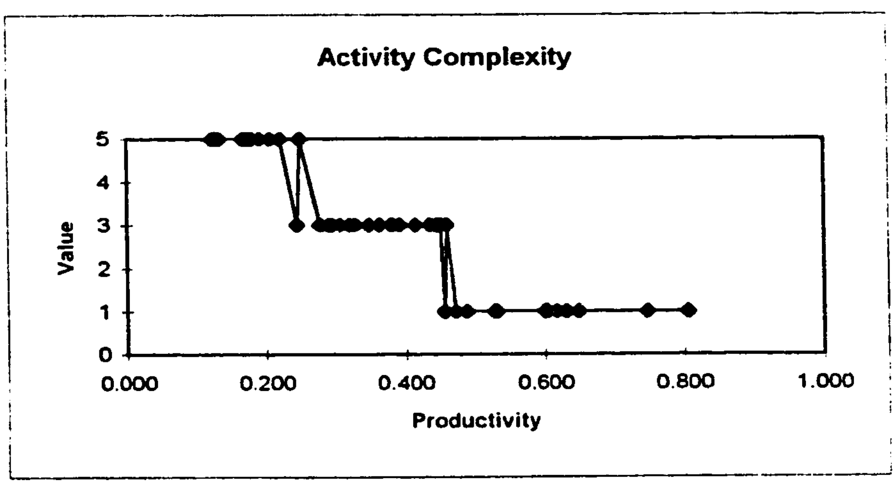


Figure B-4 Activity Complexity versus Productivity Plot

Table B-3 Degree of Difficulty

Name of Parameter:	Degree of Difficulty
Description:	Degree of Difficulty for Activity
Classification:	Activity Factor - Activity Performance Group
Source:	Data Sheet question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	1 (Easy) - 5 (Difficult)
Name of Neural Network Input:	DEG_DIFFICULTY
Type of Input to Network:	Standard

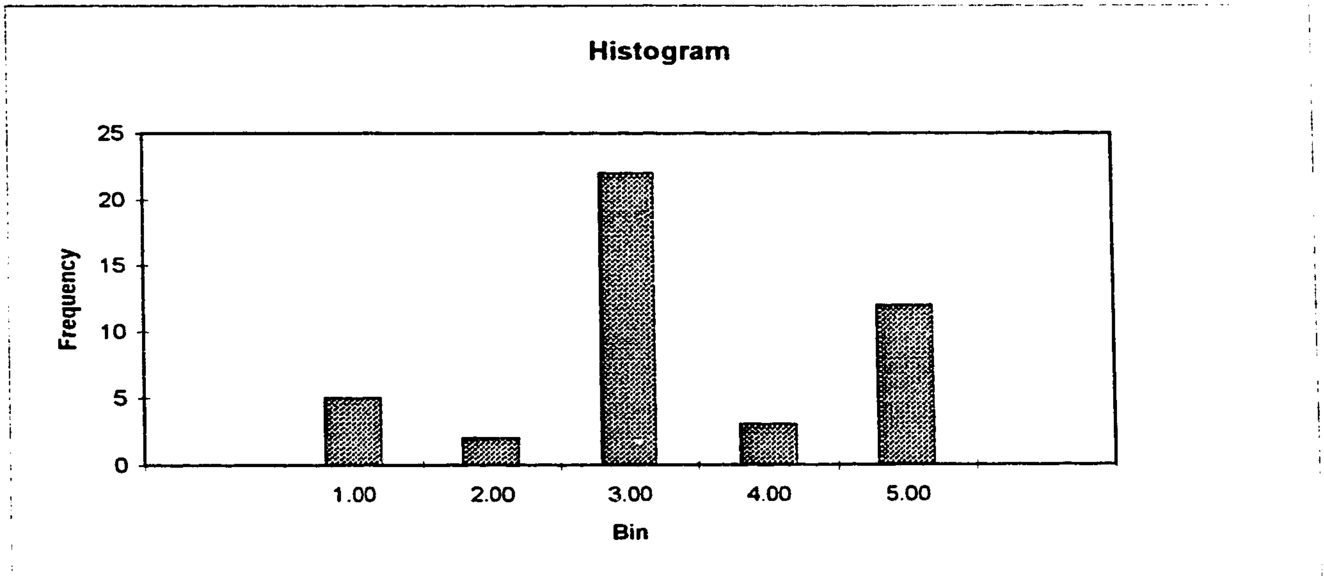


Figure B-5 Degree of Difficulty Histogram

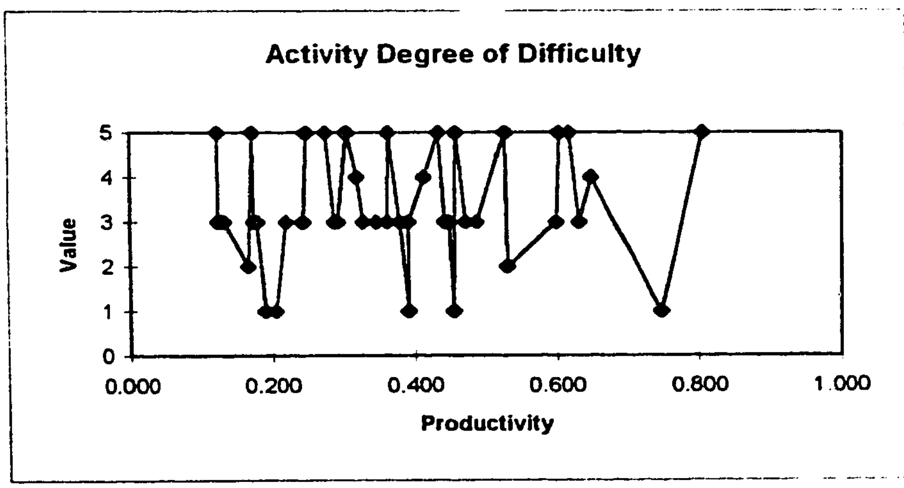


Figure B-6 Degree of Difficulty versus Productivity Plot

Table B-4 Activity Superintendent Score

Name of Parameter:	Activity Superintendent Score
Description:	Ranking of Superintendent based on HP Data
Classification:	Activity Factor - Activity Staff Group
Source:	Database
Qualitative/Quantitative:	Quantitative
Calculation Method:	Average Index of Activity Prod Rate / Corporate Activity Average Calculated for Specific Formwork Activity in HP Database
Scale of Parameter:	Score <1 is Better than Average, >1 is worse than average
Name of Neural Network Input:	A_SUPER_SCORE
Type of Input to Network:	Standard

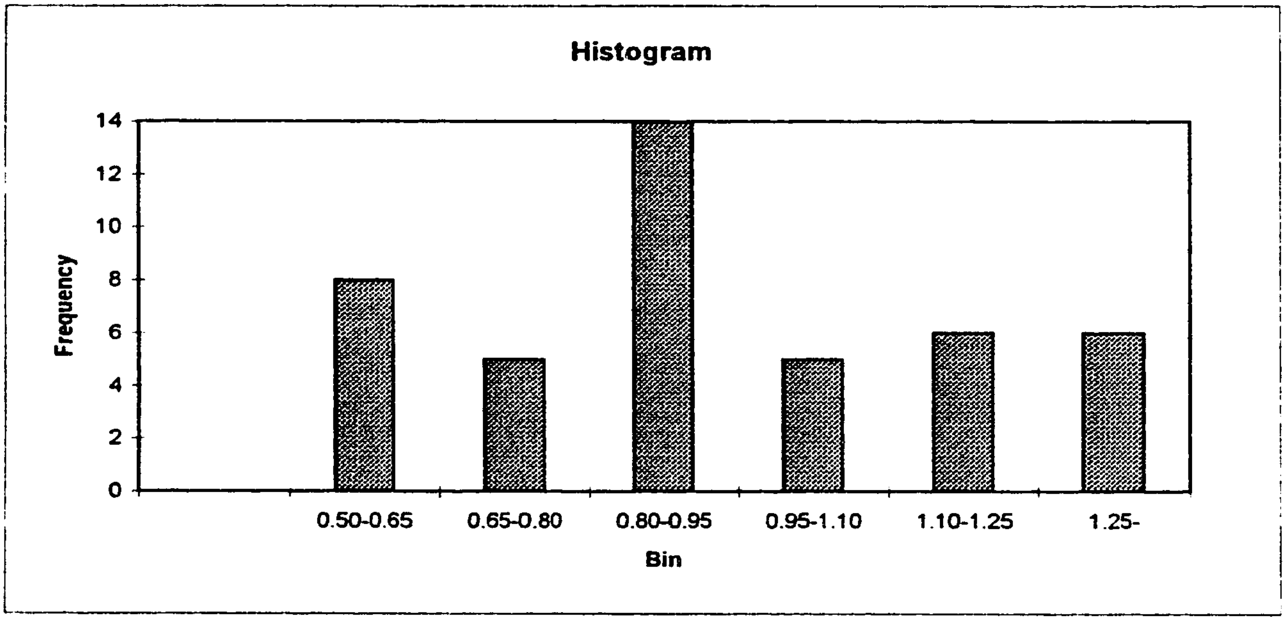


Figure B-7 Activity Superintendent Score Histogram

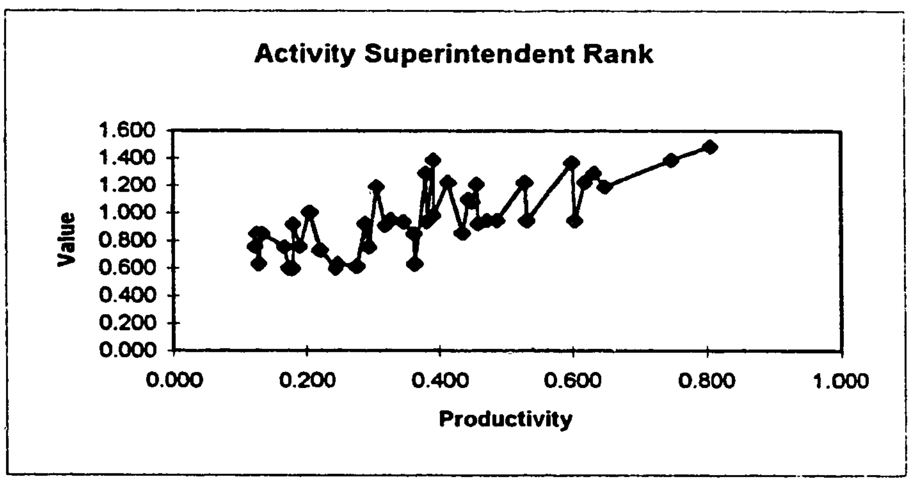


Figure B-8 Activity Superintendent Score versus Productivity Plot

Table B-5 Activity District Performance

Name of Parameter:	Activity District Performance
Description:	District Performance based on Historical Statistics
Classification:	Activity Factor - Activity Staff Group
Source:	Database (Corporate Mode)
Qualitative/Quantitative:	Quantitative
Calculation Method:	Index Based on District Activity Average / Corporate Activity Average For Specific Formwork Items in Analysis
Scale of Parameter:	Score <1 is Better than Average, >1 is worse than average
Name of Neural Network Input:	A_DISTRICT_PERF
Type of Input to Network:	Single

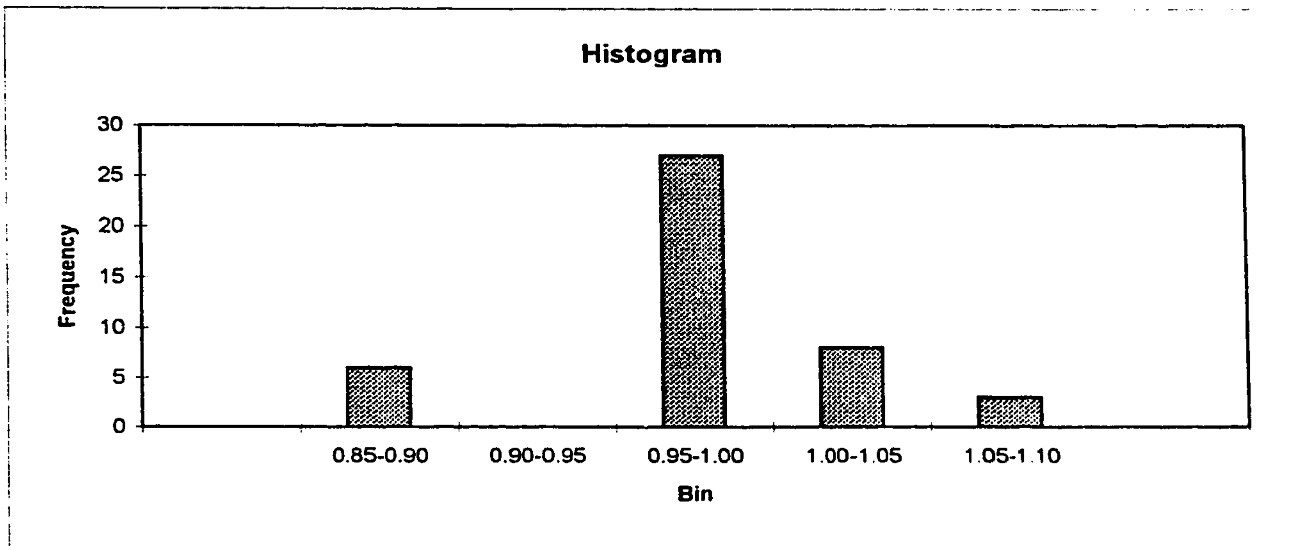


Figure B-9 Activity District Performance Histogram

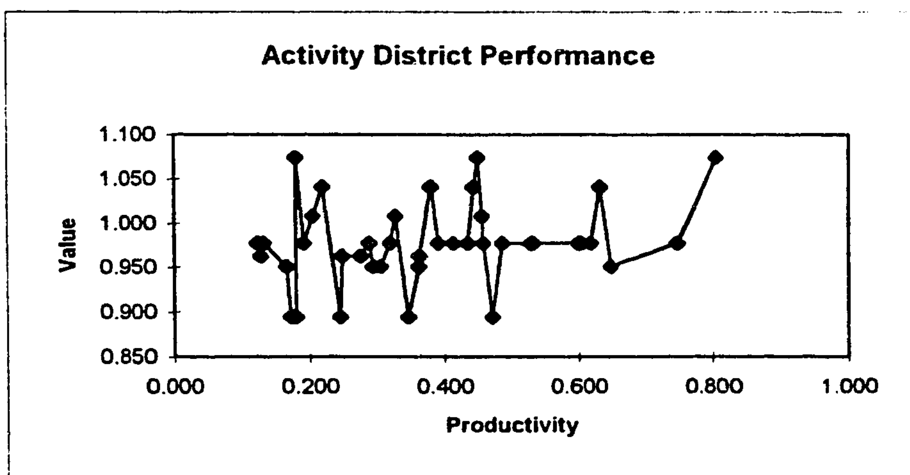


Figure B-10 Activity District Performance versus Productivity Plot

Table B-6 Crew Skill Rating

Name of Parameter:	Crew Skill Rating
Description:	Crew Performance given the circumstances
Classification:	Activity Factor - Activity Crew Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	1 (Poor) - 5 (Good)
Name of Neural Network Input:	CREW_SKILL
Type of Input to Network:	Standard

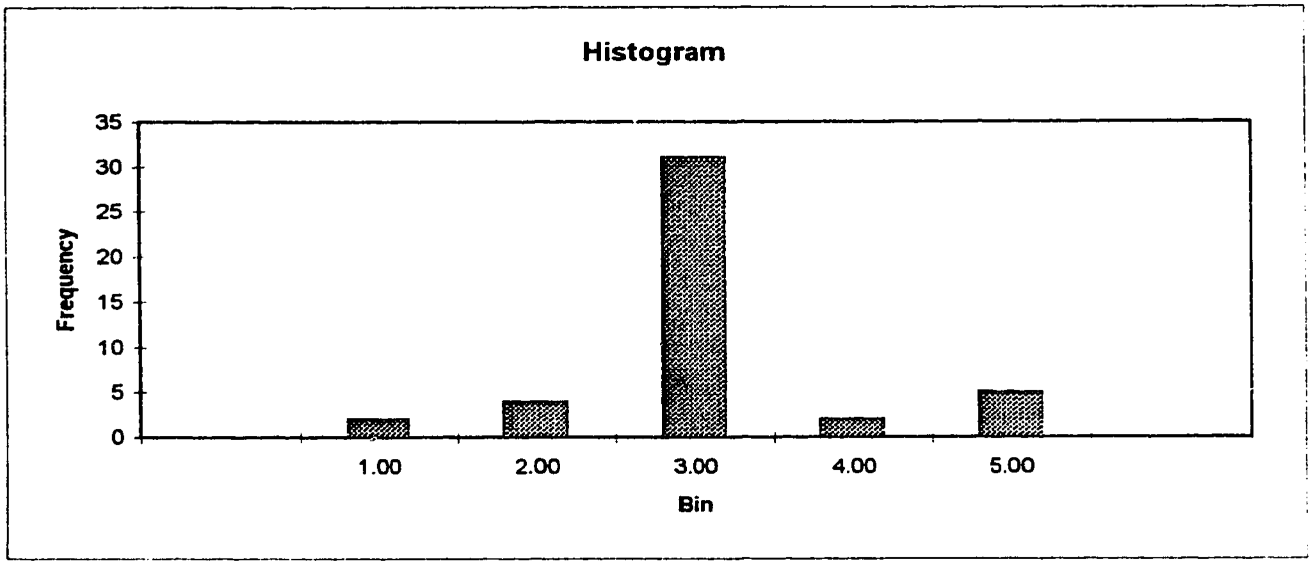


Figure B-11 Crew Skill Rating Histogram

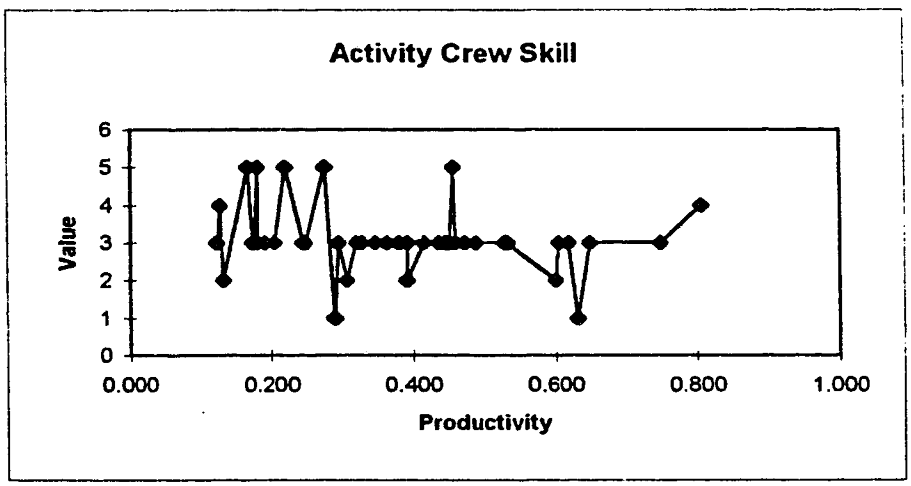


Figure B-12 Crew Skill Rating versus Productivity Plot

Table B-7 Crew Size

Name of Parameter:	Crew Size
Description:	Number of men on the work crew
Classification:	Activity Factor - Activity Crew Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Quantitative
Calculation Method:	Grouped by common ranges of values 1 - x<=5 2 - 8<x<=10 3 - 10<x<=20 4 - 20<x
Scale of Parameter:	1-4
Name of Neural Network Input:	CREWSIZE_INPUT_?
Type of Input to Network:	1 of N

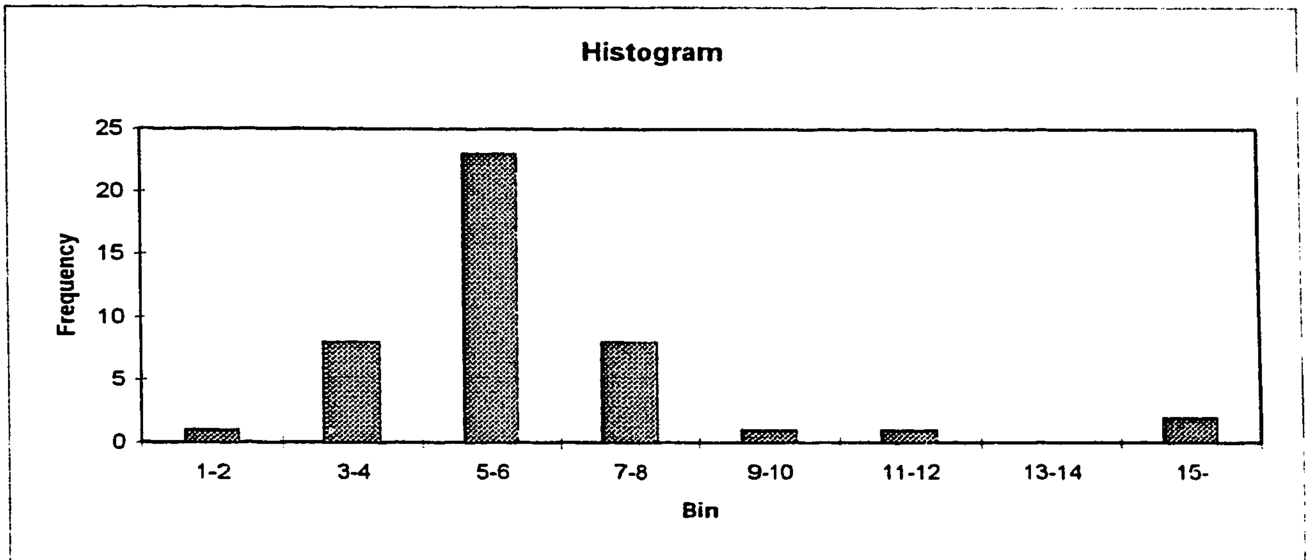


Figure B-13 Crew Size Histogram

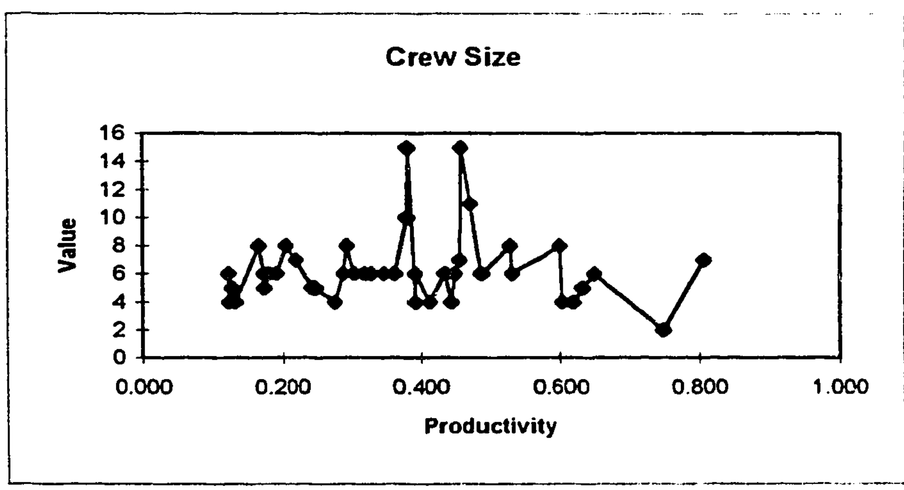


Figure B-14 Crew Size versus Productivity Plot

Table B-8 Union

Name of Parameter:	Union
Description:	Was there a labour union or not?
Classification:	Activity Factor - Activity Crew Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	Yes (4), or No (2)
Name of Neural Network Input:	UNION
Type of Input to Network:	Standard

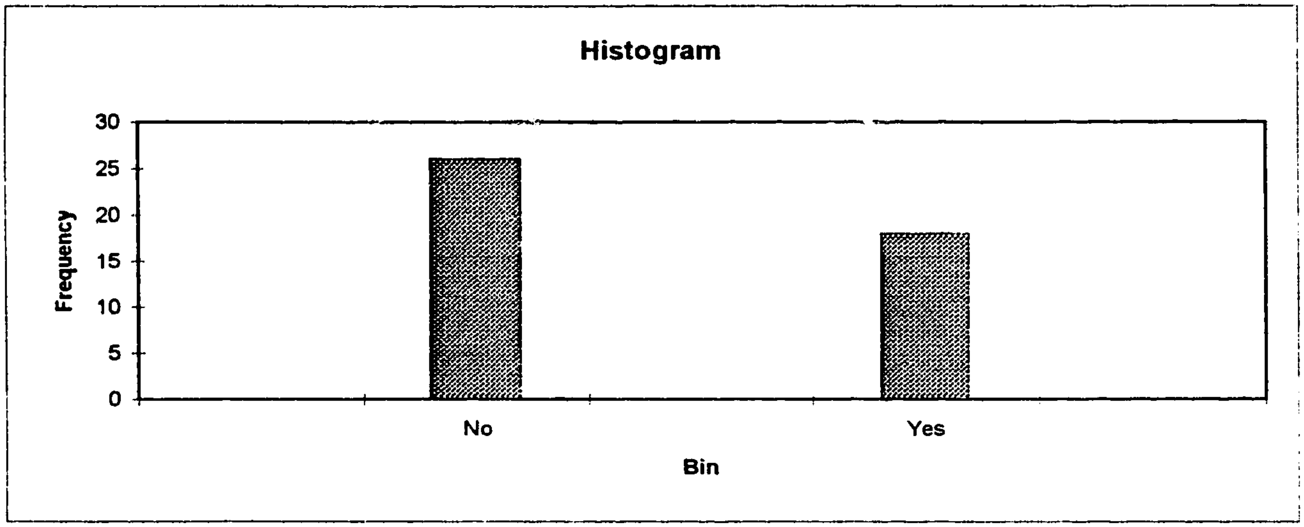


Figure B-15 Union Histogram

Table B-9 Cost Code

Name of Parameter:	Cost Code
Description:	Spectific Type of Formwork
Classification:	Activity Factor - Actitivity Design Group
Source:	Data Sheet Question - Standard Cost Code
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	0 - 1
Name of Neural Network Input:	COSTCODE_?
Type of Input to Network:	1 of N (030300 or 030310)

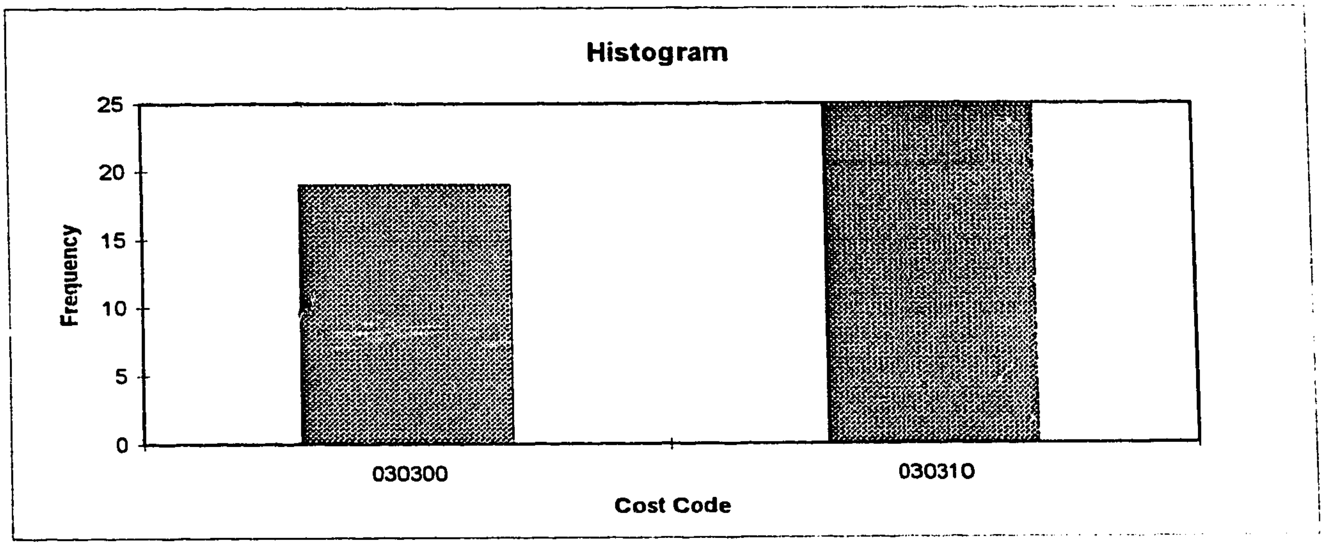


Figure B-16 Cost Code Histogram

Table B-10 Formwork Duty

Name of Parameter:	Formwork Duty
Description:	Type of Formwork (Handset or Semi-Panelized)
Classification:	Acitivity Factor - Activity Design Group
Source:	Data Sheet question
Qualitative/Quantitative:	Qualitative
Calculation Method:	12 = Handset, 13 = Semi - Panelized A 1 of N translation was used for the 2 types
Scale of Parameter:	0 - 1
Name of Neural Network Input:	FORMWORKDUTY_?
Type of Input to Network:	1 of N

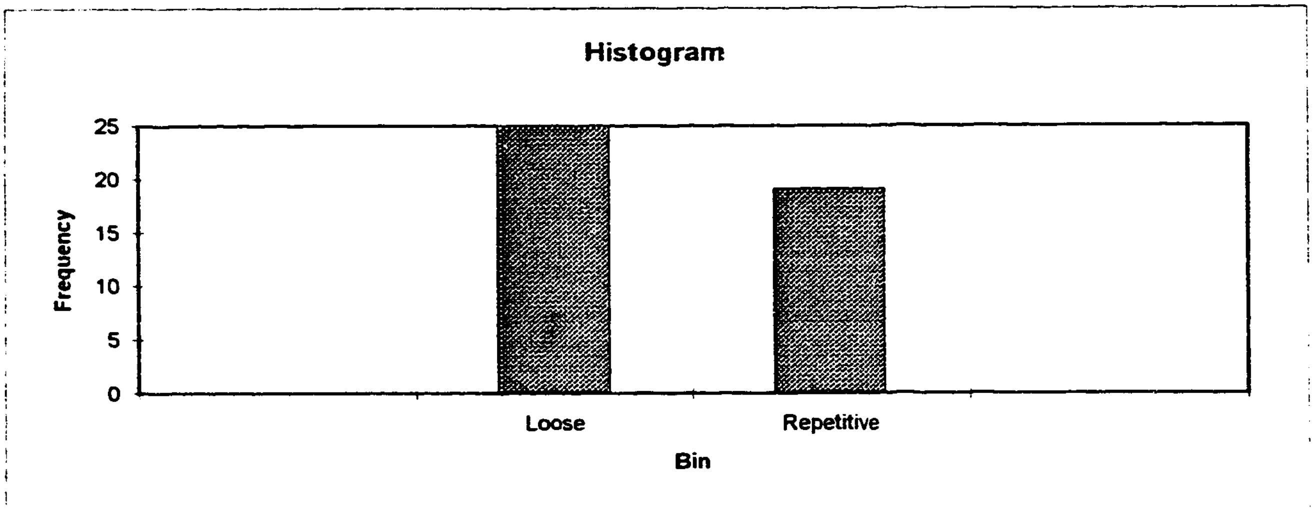


Figure B-17 Formwork Duty Histogram

Table B-11 Formwork Tie Type

Name of Parameter:	Formwork Tie Type
Description:	The type of ties used on the formwork
Classification:	Acitivity Factor - Activity Design Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	0 - 1
Name of Neural Network Input:	TIE_TYPE_WALL_?
Type of Input to Network:	1 of N

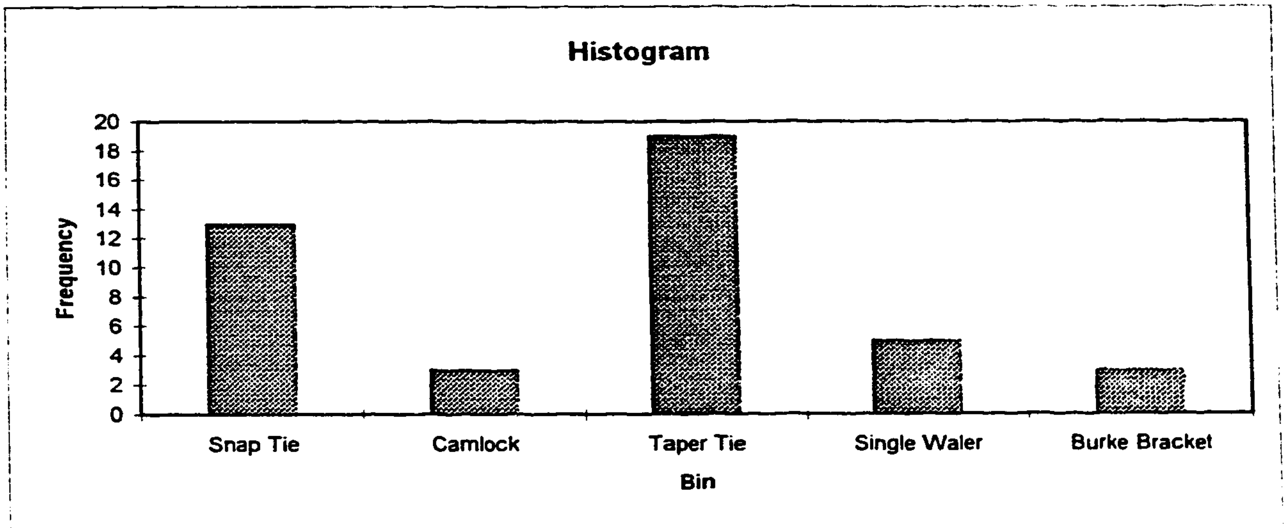


Figure B-18 Formwork Tie Type Histogram

Table B-12 Formwork Tie Spacing

Name of Parameter:	Formwork Tie Spacing
Description:	Tie Spacing Group
Classification:	Activity Factor - Activity Design Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Quantitatve
Calculation Method:	
Scale of Parameter:	5 - Spacing > 54
	3 - 35<Spacing<54
	1 - Spacing <35
Name of Neural Network Input:	TIE_SPACING_HORIZONTAL, TIE_SPACING_VERTICAL
Type of Input to Network:	Standard

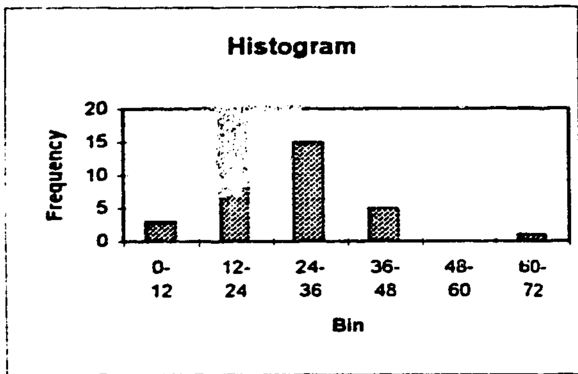


Figure B-19 Vertical Tie Spacing Histogram

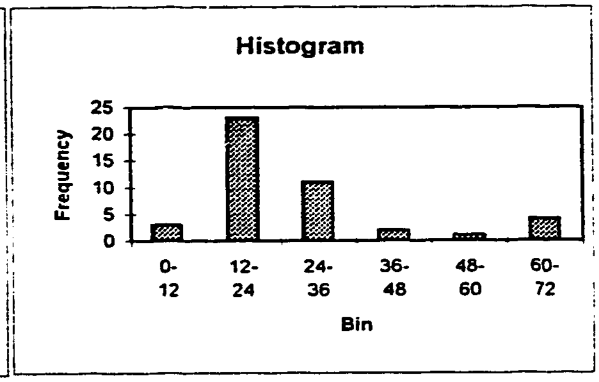


Figure B-20 Vertical Tie Spacing Histogram

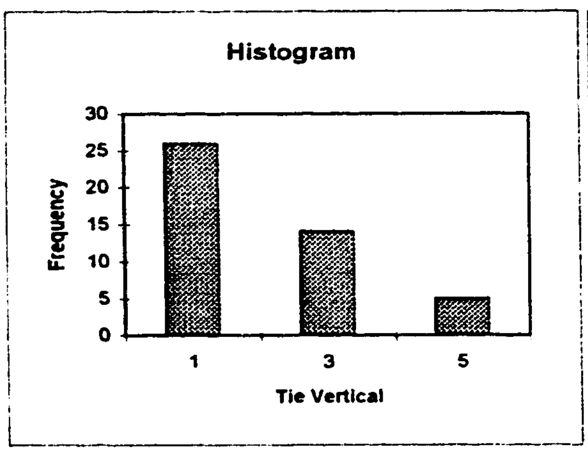


Figure B-21 Vertical Tie Spacing Group Histogram

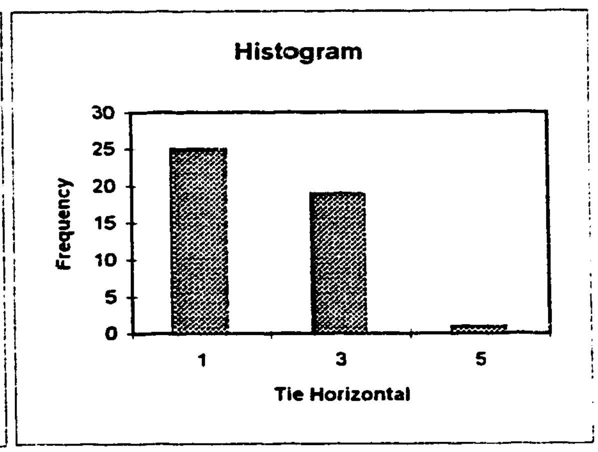


Figure B-22 Horizontal Tie Spacing Group Histogram

Table B-13 Activity Design Accuracy Rating

Name of Parameter:	Activity Design Accuracy Rating
Description:	Accuracy of Design for the Activity
Classification:	Activity Factor - Activity Design Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	1 (Poor) - 5 (High)
Name of Neural Network Input:	DESIGN_RATING
Type of Input to Network:	Standard

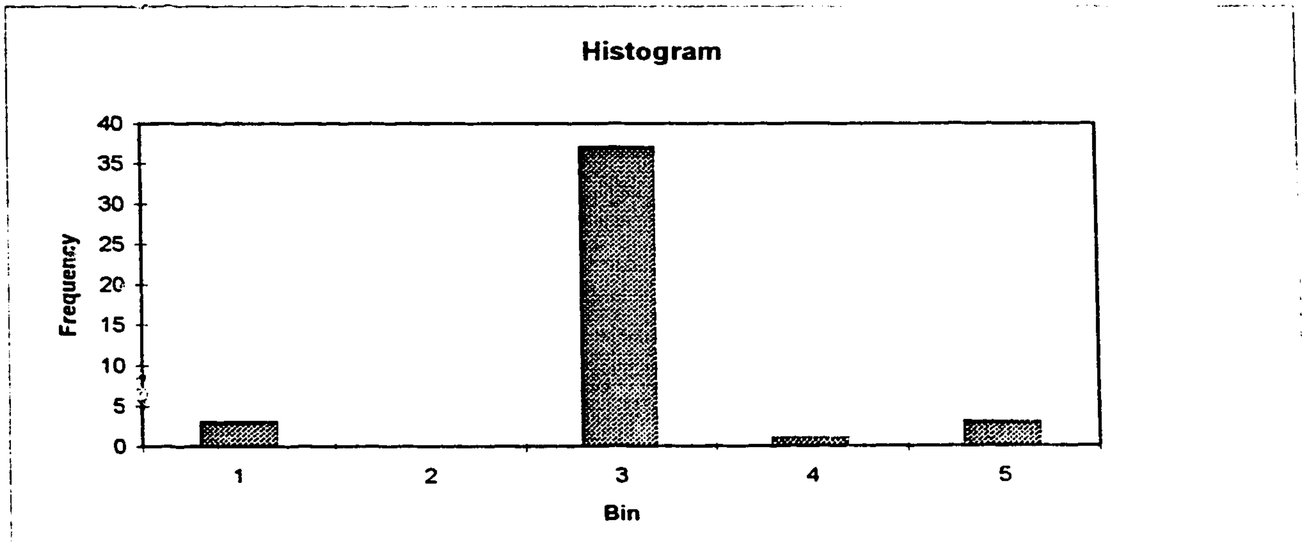


Figure B-23 Design Accuracy Histogram

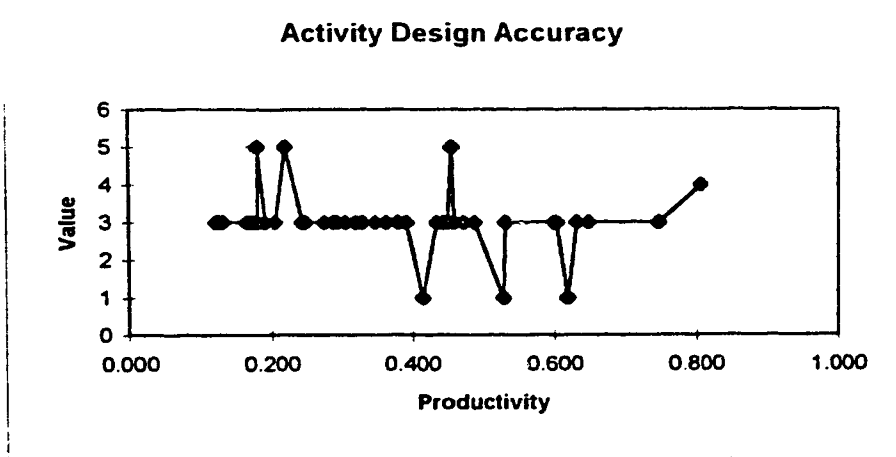


Figure B-24 Design Accuracy versus Productivity Plot

Table B-14 Formwork Quantity

Name of Parameter:	Formwork Quantity
Description:	Log of Formwork quantity in imperial units
Classification:	Activity Factor - Activity Dimensions Group
Source:	From Cost Reports
Qualitative/Quantitative:	Quantitative
Calculation Method:	Log of Formwork quantity in imperial units
Scale of Parameter:	3 - 5
Name of Neural Network Input:	LOG_QUANTITY
Type of Input to Network:	Standard

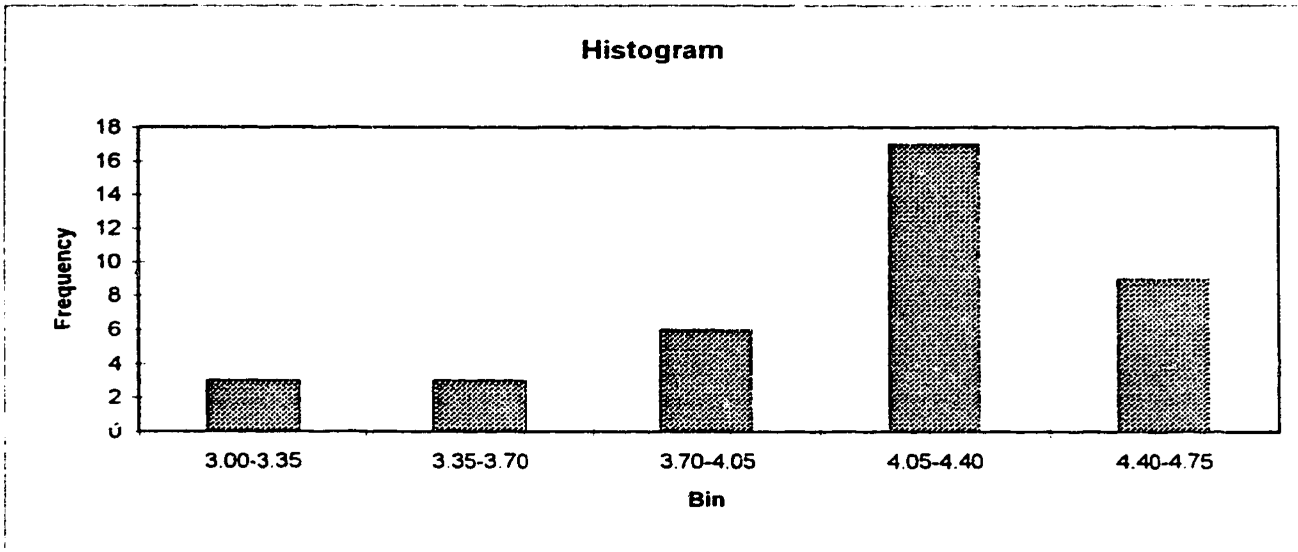


Figure B-25 Formwork Quantity Histogram

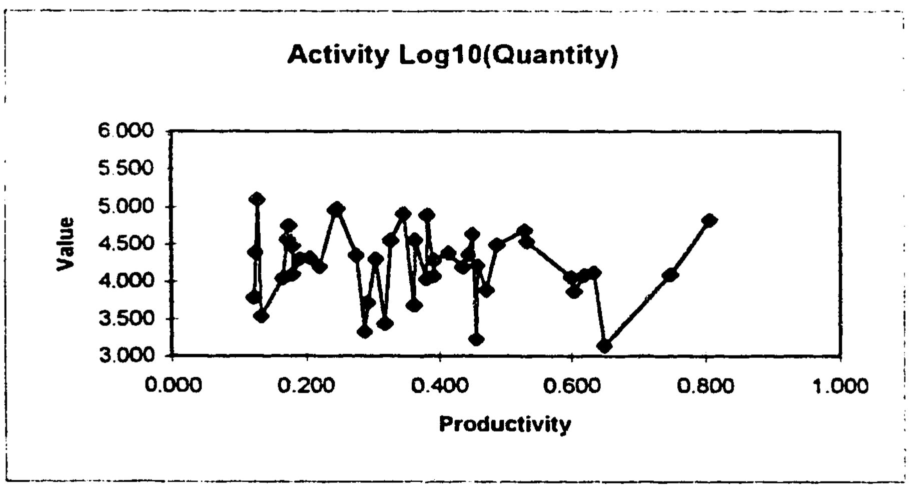


Figure B-26 Logarithm of Formwork Quantity versus Productivity Plot

Table B-15 Wall Height

Name of Parameter:	Wall Height
Description:	Height of Wall
Classification:	Activity Factor - Activity Dimensions Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Quantitative
Calculation Method:	Walls classified as: shorter than 12 ft were classified as short taller than 12 ft were classified as tall
Scale of Parameter:	0 - 1
Name of Neural Network Input:	WALL_HEIGHT
Type of Input to Network:	1 of N

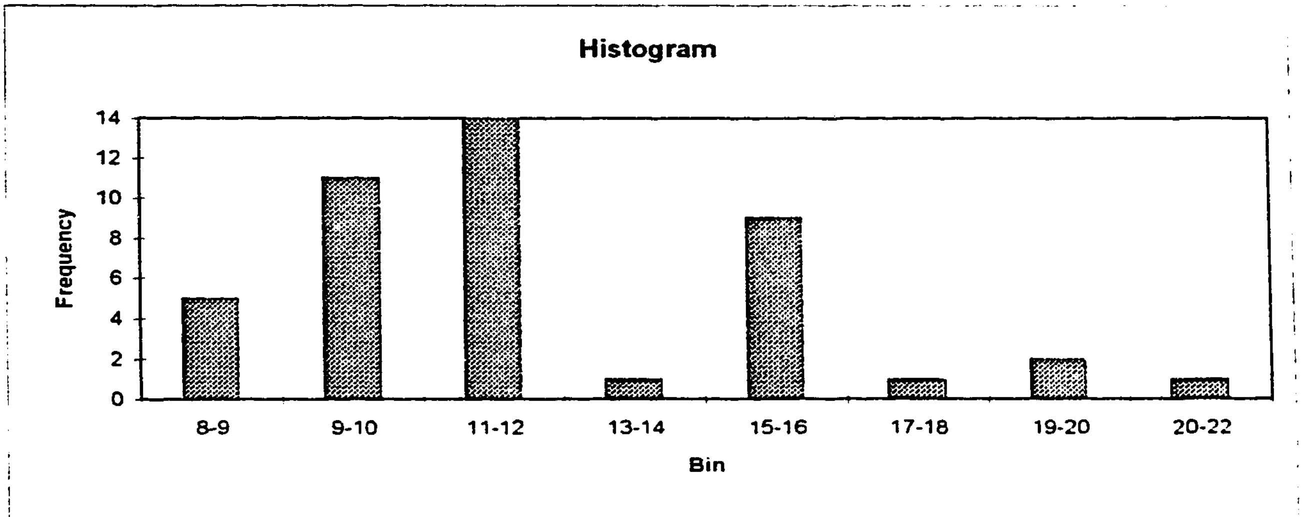


Figure B-27 Wall Height Histogram

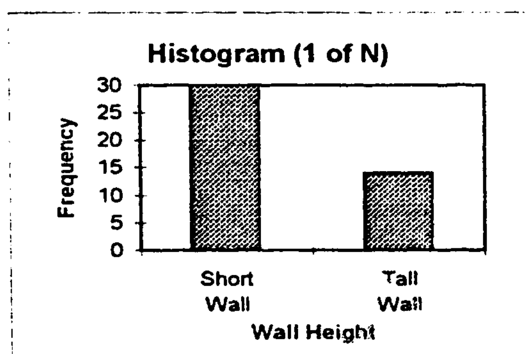


Figure B-28 Wall Height Group Histogram

Table B-16 Wall Thickness

Name of Parameter:	Wall Thickness
Description:	Thickness of Wall
Classification:	Activity Factor - Activity Dimensions Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Converted to Qualitative
Calculation Method:	Walls thinner than 10in are classified as thin walls, while walls thicker than 10in are classified as thick walls.
Scale of Parameter:	Either thick wall or thin wall
Name of Neural Network Input:	WALL_THICK
Type of Input to Network:	1 of N

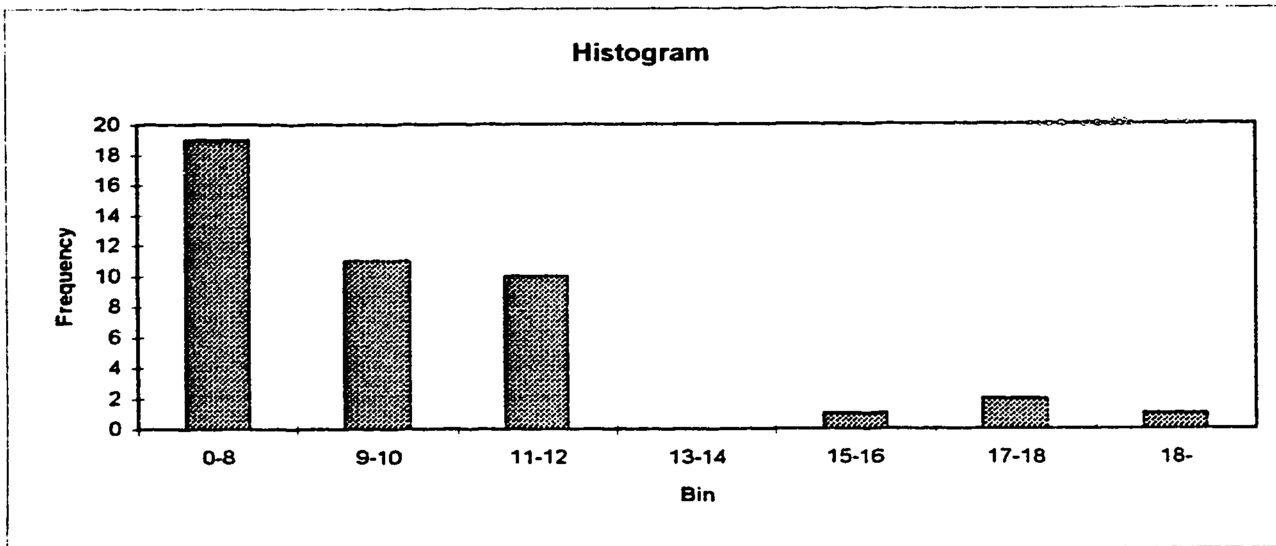


Figure B-29 Wall Thickness Histogram

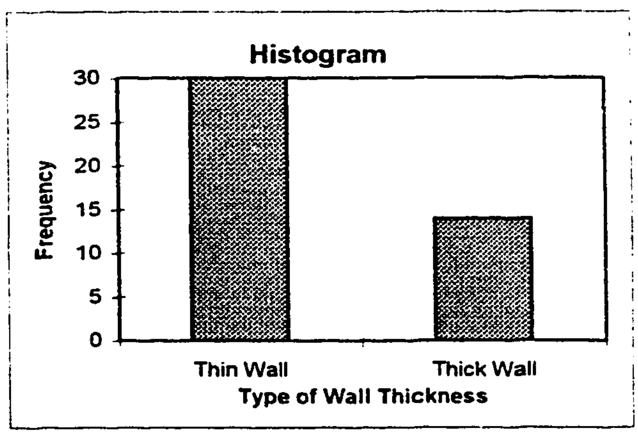


Figure B-30 Wall Thickness Group Histogram

Table B-17 Activity Repetition Rating

Name of Parameter:	Activity Repetition Rating
Description:	Typical or Similar Construction (Consistency)
Classification:	Activity Factor - Activity Repetition Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	1(Low) - 5 (High)
Name of Neural Network Input:	REPETITION_RATING
Type of Input to Network:	Standard

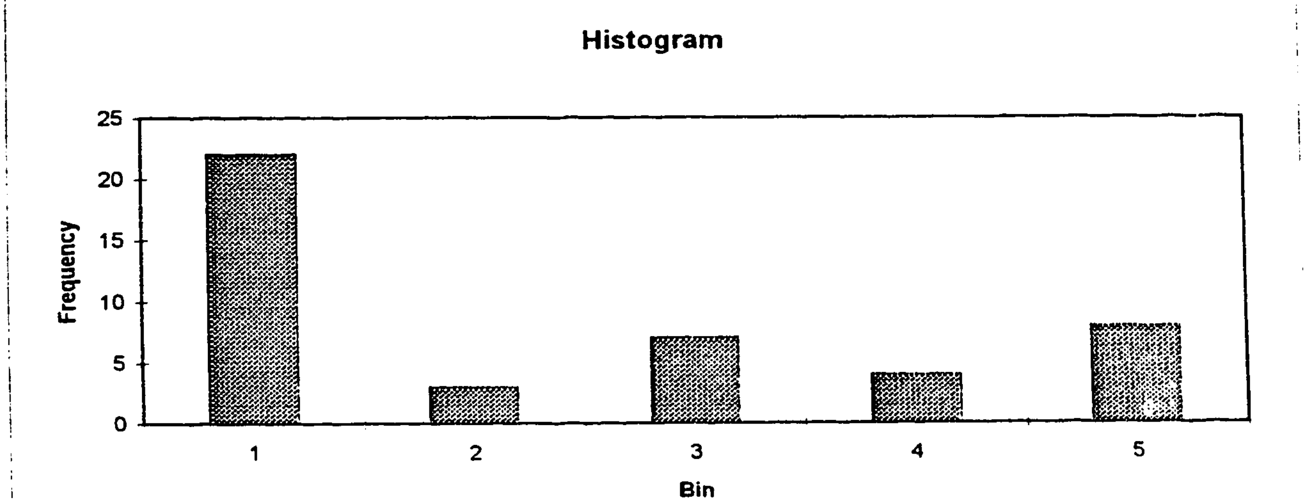


Figure B-31 Activity Repetition Histogram

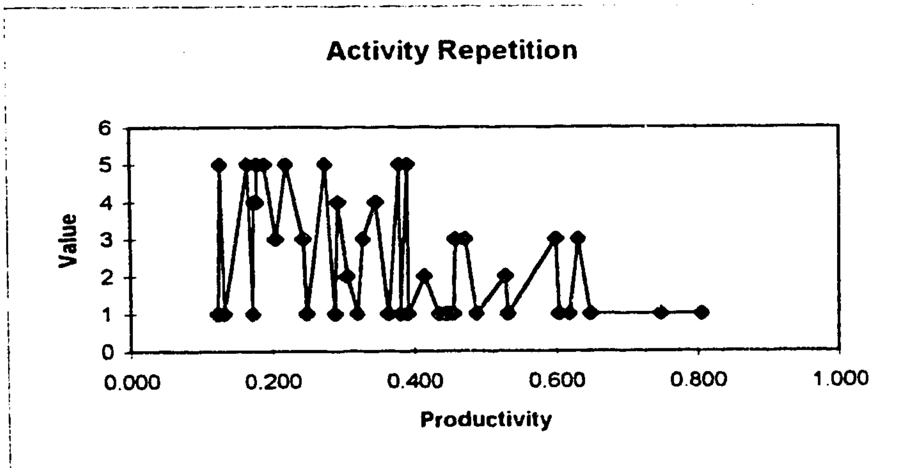


Figure B-32 Activity Repetition versus Productivity Plot

Table B-18 Number of Reuses

Name of Parameter: Number of Reuses
Description: Number of Reuses
Classification: Activity Factor - Activity Repetition Group
Source: Data Sheet Question
Qualitative/Quantitative: Quantitative
Calculation Method: Group by common Ranges
1 - x<=8
2 - 8 < x <=15
3 - 15<x<=25
4 - 25<x
Scale of Parameter: 1-4
Name of Neural Network Input: NUMBER_OF_REUSE_?
Type of Input to Network: 1 of N

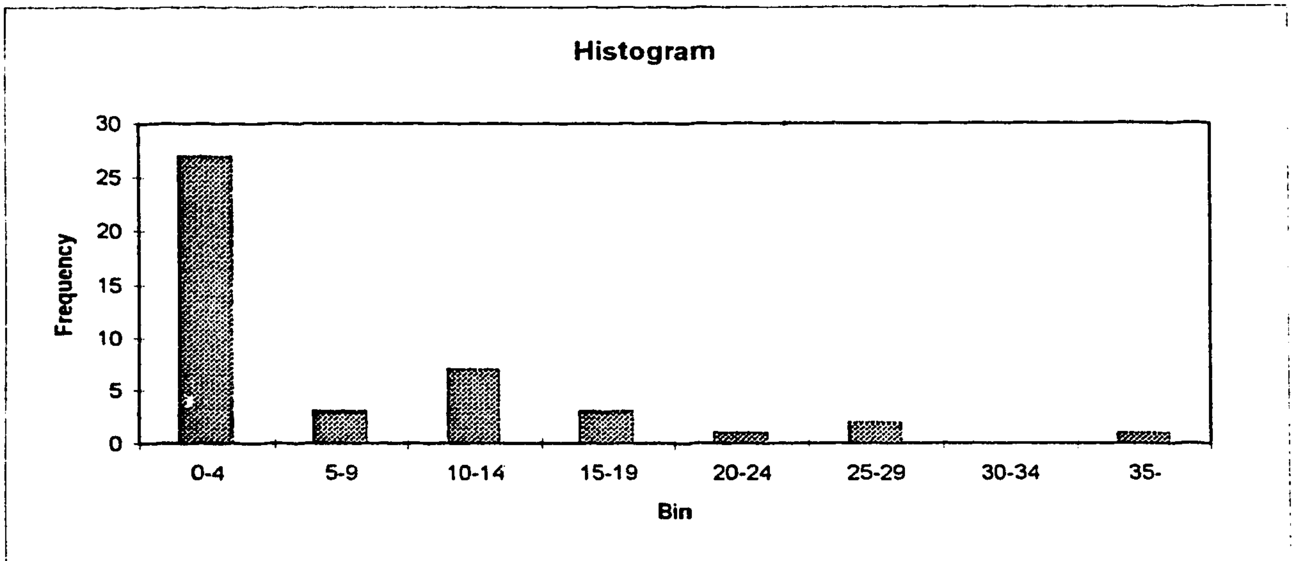


Figure B-33 Number of Reuses Histogram

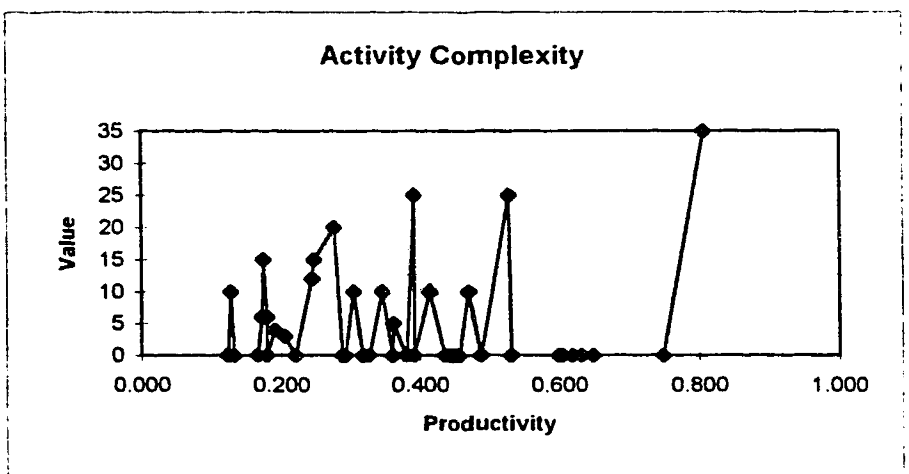


Figure B-34 Number of Reuses versus Productivity Plot

Table B-19 Panel Area

Name of Parameter:	Panel Area
Description:	Repetitive Panel Area
Classification:	Activity Factor - Activity Repetition Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Quantitative
Calculation Method:	Panel Length * Panel Width
Scale of Parameter:	5 - >275 sf
	3 - 175 < X < 275 sf
	1 - < 175 sf
	0 - Panel Area = 0 sf
Name of Neural Network Input:	PANEL_AREA_INPUT_?
Type of Input to Network:	Standard

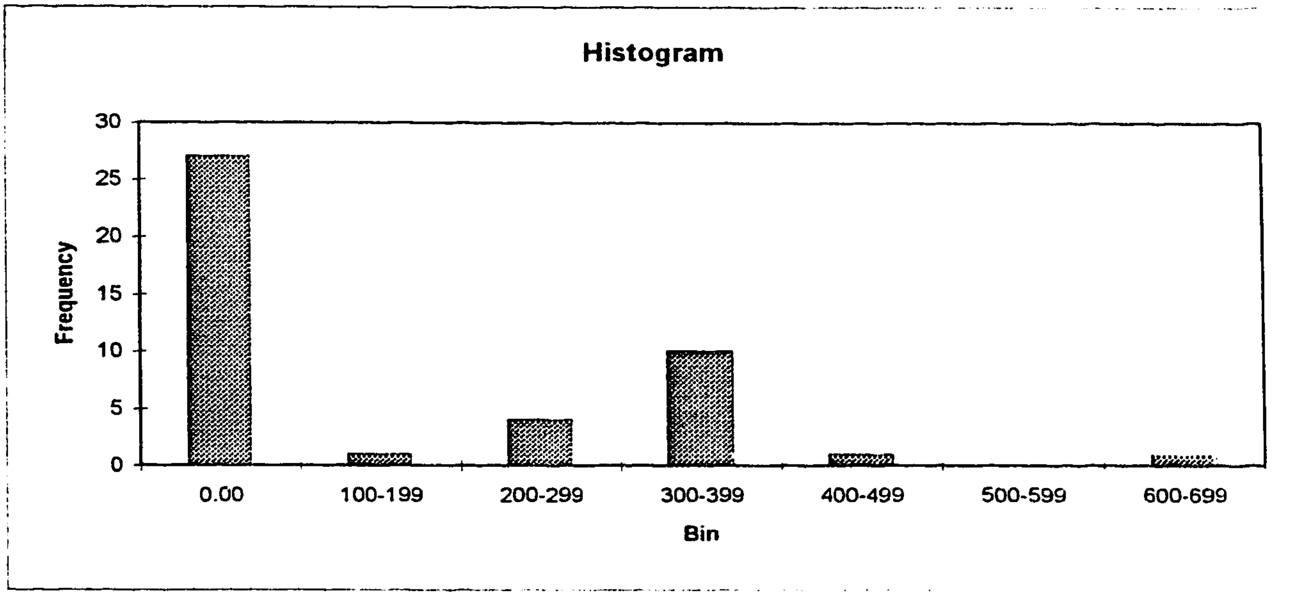


Figure B-35 Panel Area Histogram

Table B-20 Material Handling Problems

Name of Parameter:	Material Handling Problems
Description:	Problems with crane time or material handling
Classification:	Activity Factor - Activity Working Conditions Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	1 (Yes) - 5 (No)
Name of Neural Network Input:	MATERIAL_HANDLE_PROBLEM
Type of Input to Network:	Single

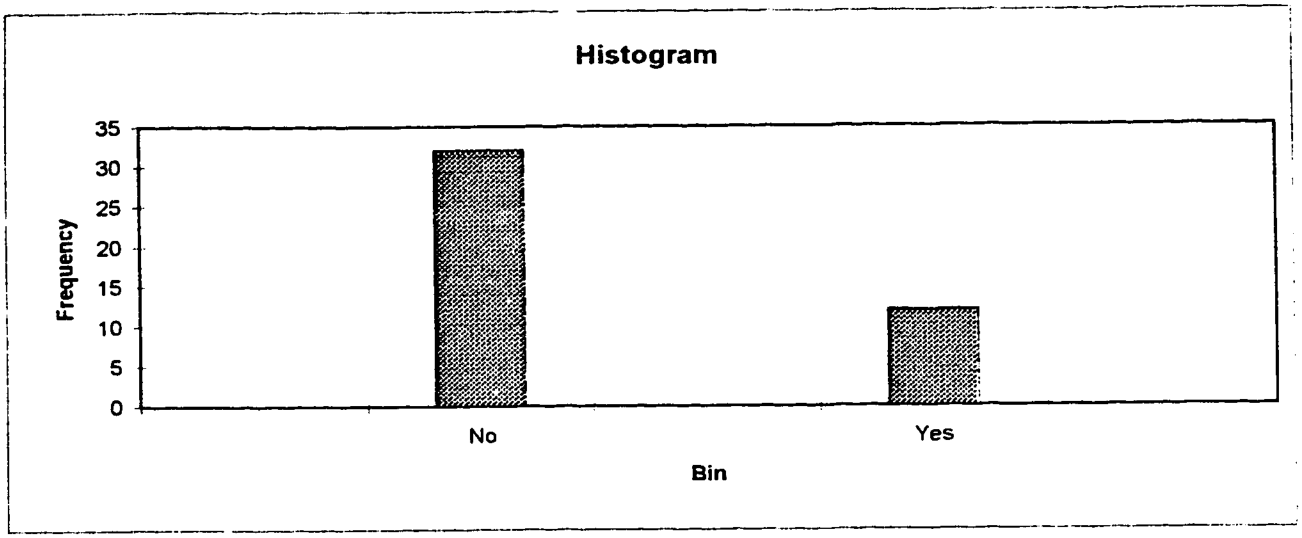


Figure B-36 Material Handling Histogram

Table B-21 Maintain Continuity of Cycle

Name of Parameter:	Maintain Continuity of Cycle
Description:	Was Continuity of Cycle Maintained?
Classification:	Activity Factor - Activity Working Conditions Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	Yes (4) or No (2)
Name of Neural Network Input:	CYCLE_CONTINUITY
Type of Input to Network:	Single

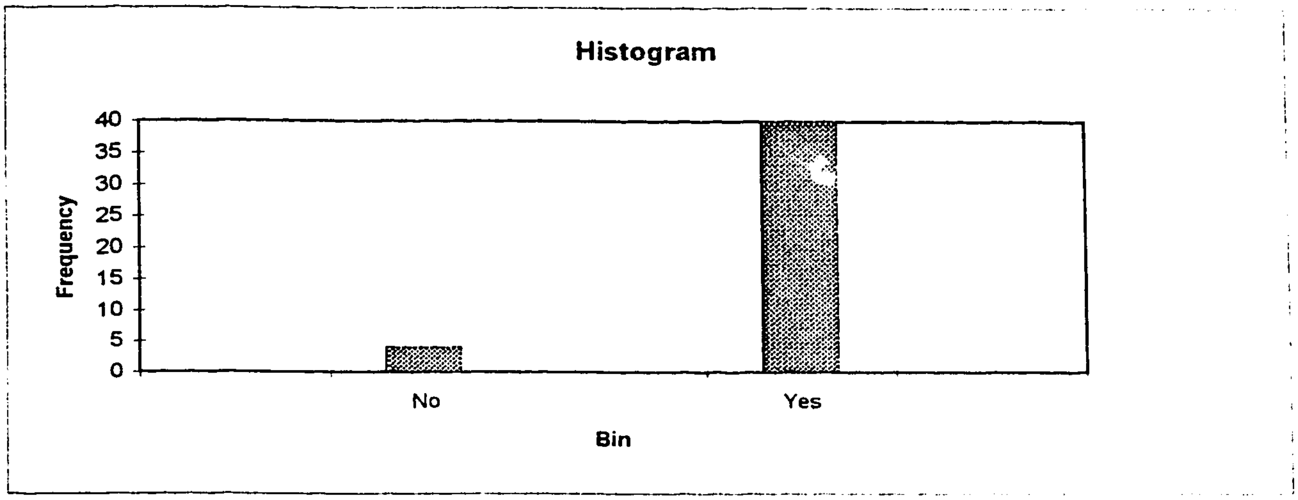


Figure B-37 Maintain Continuity of Cycle Histogram

Table B-22 Extended Shift Duration

Name of Parameter:	Extended Shift Duration
Description:	Were there Extended work hours?
Classification:	Activity Factor - Activity Working Conditions Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	No (0) or Yes (1)
Name of Neural Network Input:	SHIFT_DURATION
Type of Input to Network:	Single

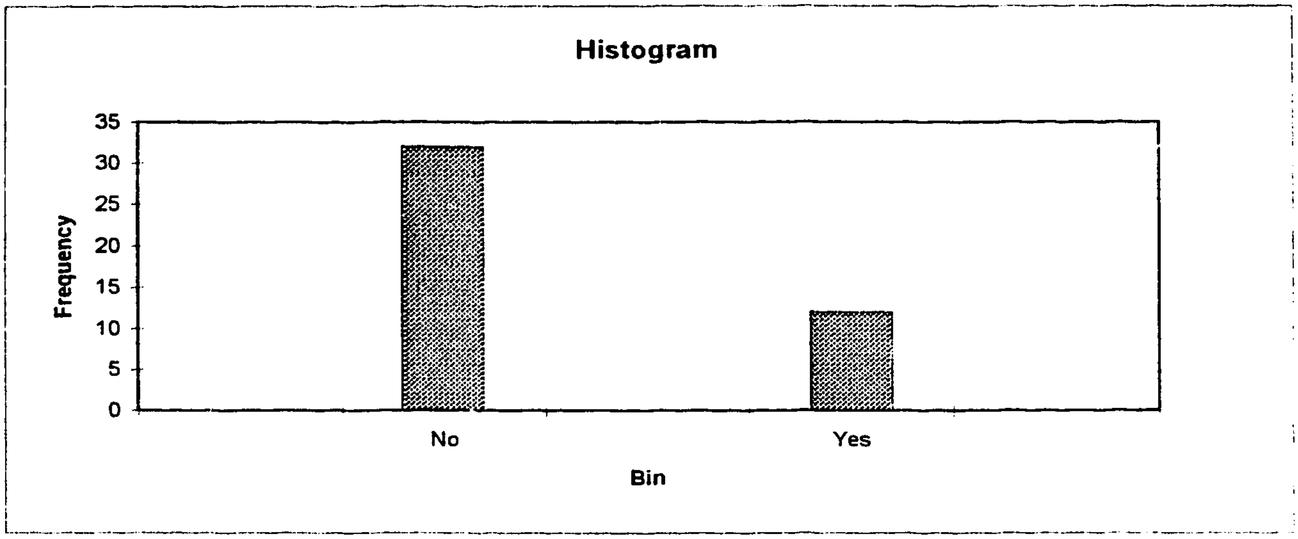


Figure B-38 Extended Shift Duration Histogram

Table B-23 Project Complexity

Name of Parameter:	Project Complexity
Description:	Supplement to Overall Project Degree of Difficulty
Classification:	Project Factor - Project Performance Group
Source:	Calculated from HP Database
Qualitative/Quantitative:	Quantitative
Calculation Method:	Index based on all Formwork and Concrete Index is Actual Productivity / Budget Productivity
Scale of Parameter:	
Name of Neural Network Input:	P_COMPLEXITY
Type of Input to Network:	Standard

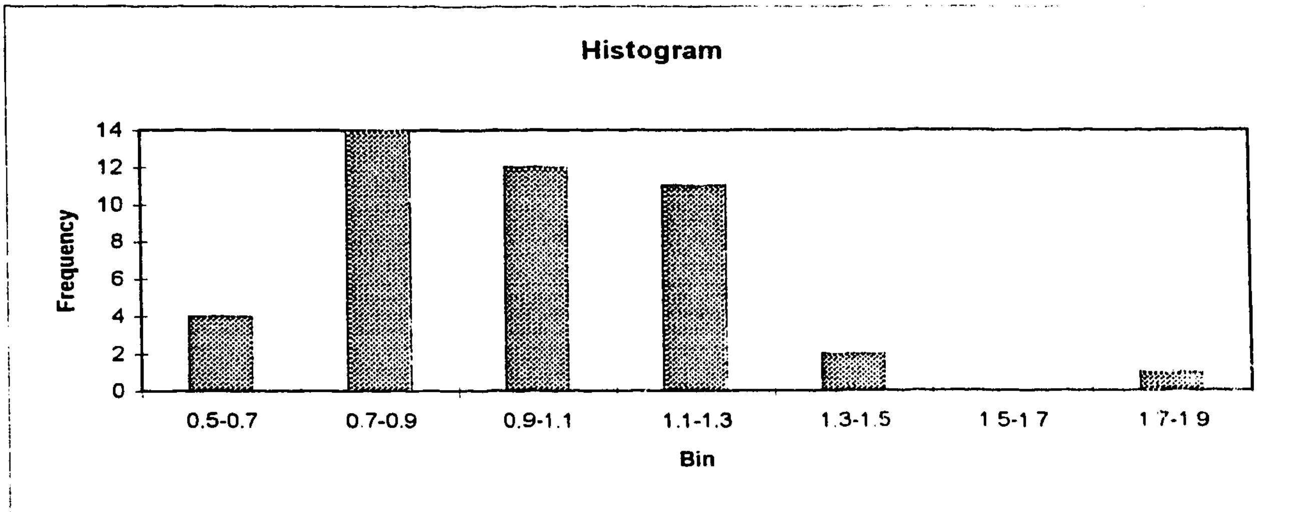


Figure B-39 Project Complexity Factor Histogram

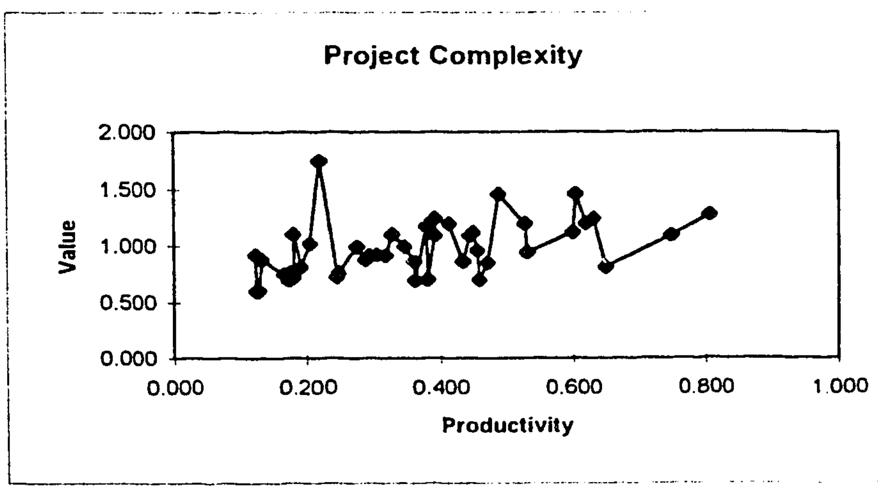


Figure B-40 Project Complexity versus Productivity Plot

Table B-24 Project Superintendent Score

Name of Parameter:	Project Superintendent Score
Description:	Ranking of Superintendent based on HP Data
Classification:	Project Factor - Project Staff Group
Source:	Database
Qualitative/Quantitative:	Quantitative
Calculation Method:	Average Index of Actual Prod Rate / Corporate Average Calculated for All Formwork Activities in HP Database
Scale of Parameter:	Score <1 is Better than Average, >1 is worse than average
Name of Neural Network Input:	P_SUPER_SCORE
Type of Input to Network:	Standard

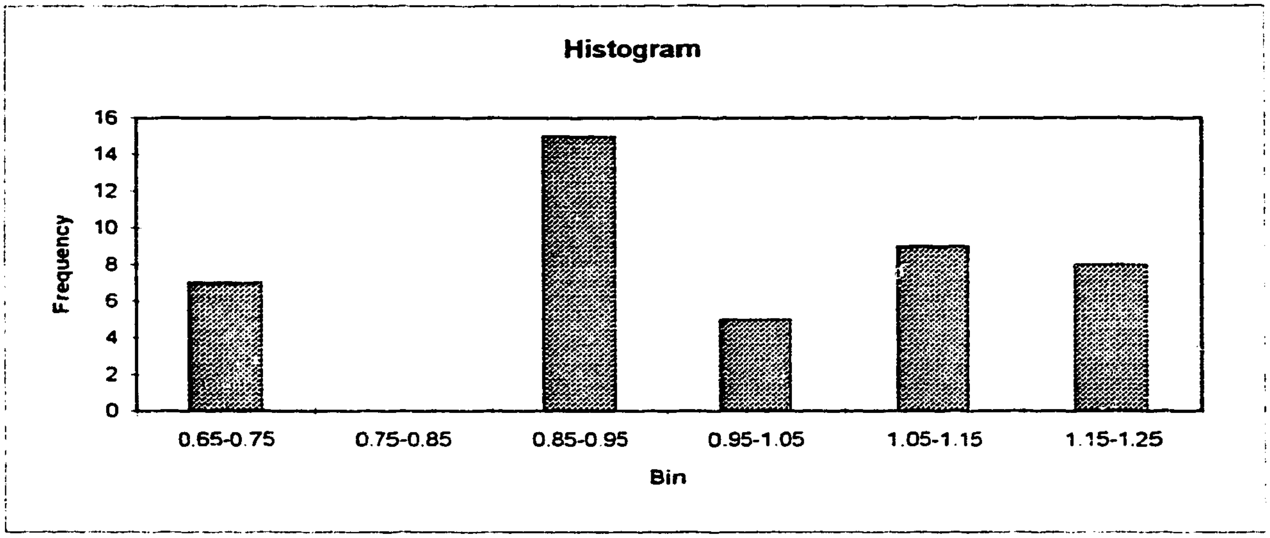


Figure B-41 Project Superintendent Score Histogram

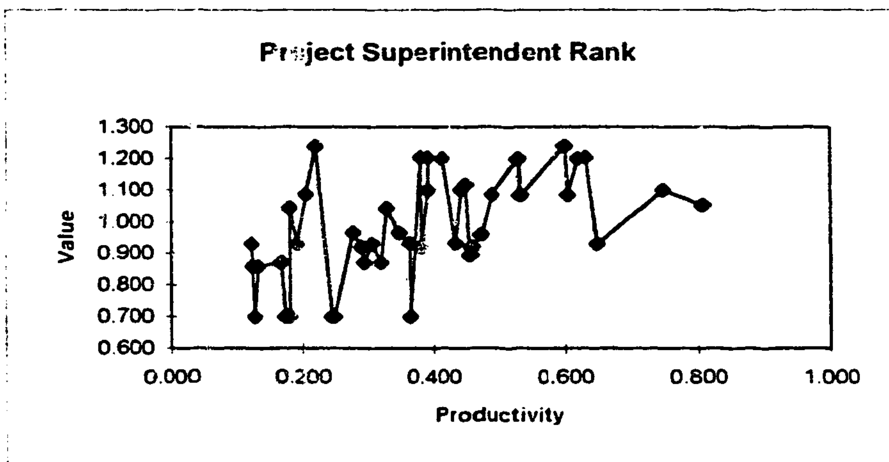


Figure B-42 Project Superintendent Score versus Productivity Plot

Table B-25 Project District Performance

Name of Parameter:	Project District Performance Score
Description:	District Performance based on historical statistics
Classification:	Project Factor - Project Staff Group
Source:	Database (Corporate Mode)
Qualitative/Quantitative:	Quantitative
Calculation Method:	Index Based on District Average / Corporate Average For All Formwork Items
Scale of Parameter:	Score <1 is Better than Average, >1 is worse than average
Name of Neural Network Input:	P_DISTRICT_PERF
Type of Input to Network:	Single

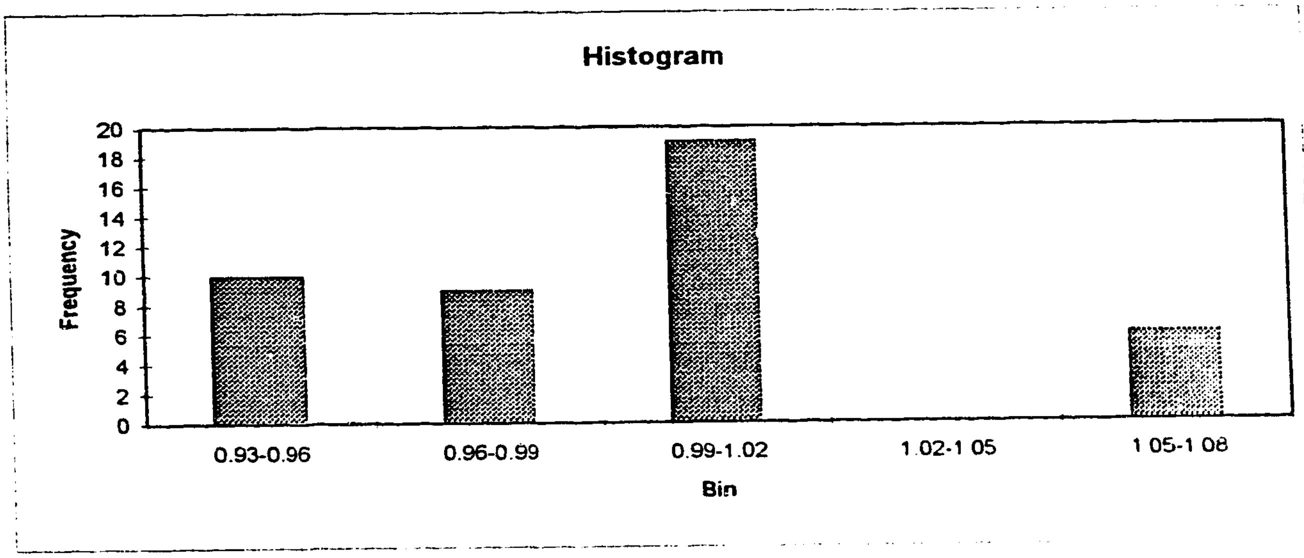


Figure B-43 Project District Performance Histogram

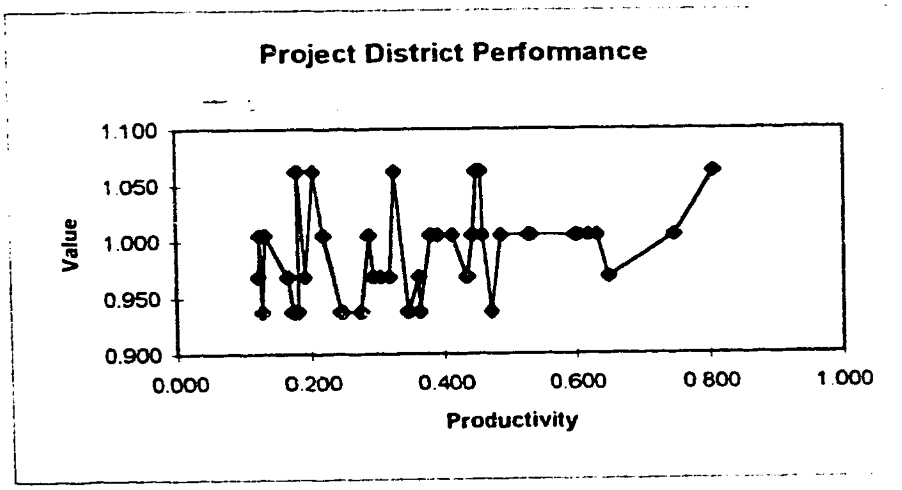


Figure B-44 Project District versus Productivity Histogram

Table B-26 Gross Building Area

Name of Parameter:	LOG Gross Building Area
Description:	Log of Gross building area
Classification:	Project Factor - Project Structure Group
Source:	Database information
Qualitative/Quantitative:	Quantitative converted to Quantitative
Calculation Method:	Log of Gross building area then grouped <4.75 = 1 4.75 to 5.25 = 2 5.25 to 5.5 = 3 5.5 to 5.75 = 4 >5.75 = 5
Scale of Parameter:	1 - 5
Name of Neural Network Input:	LOG_GROSS_BUILDING_AREA
Type of Input to Network:	Standard

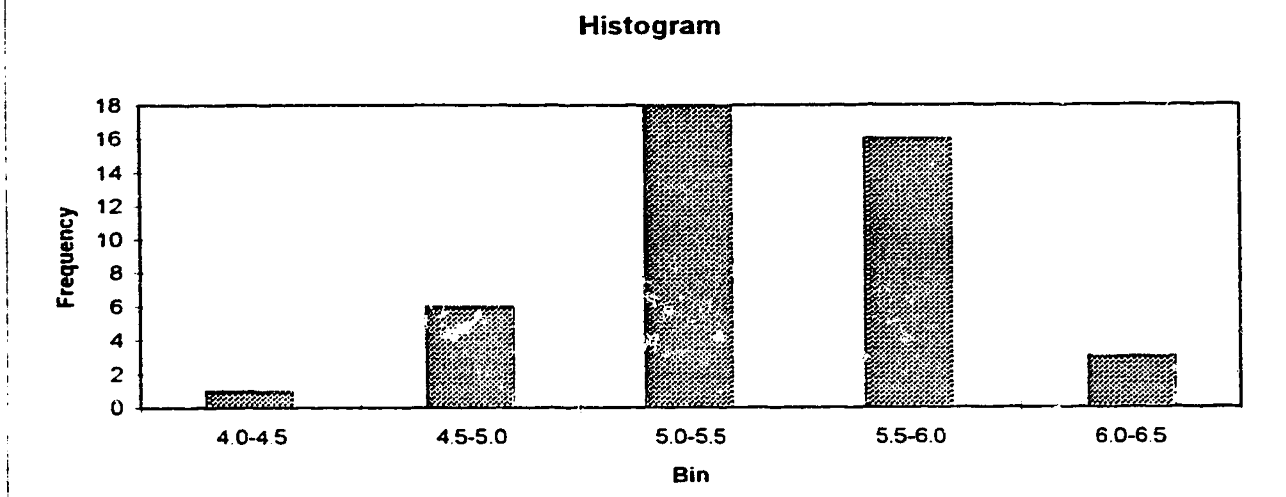


Figure B-45 Gross Building Area Histogram

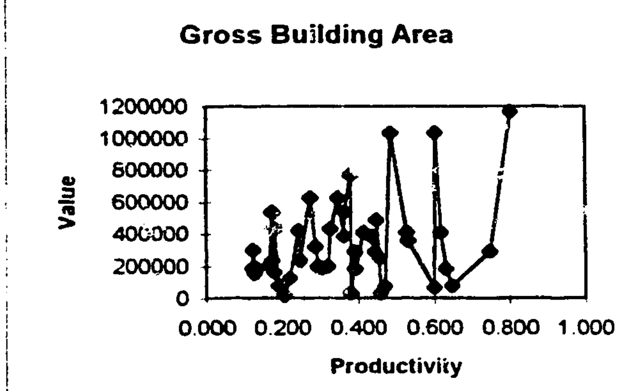


Figure B-46 GBA versus Productivty Plot

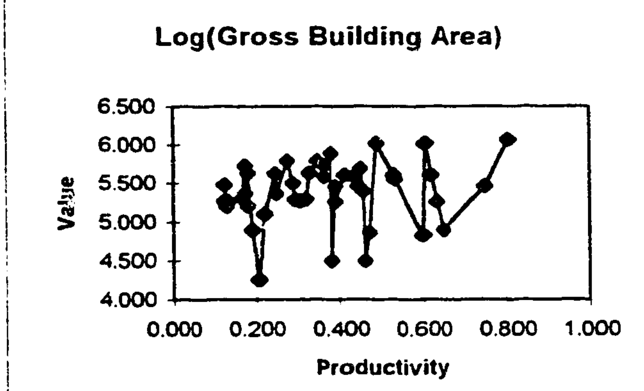


Figure B-47 Log(GBA) versus Productivty Plot

Table B-27 Number of Floors Above Grade

Name of Parameter:	Number of Floors Above Grade
Description:	Number of Floors Above Grade
Classification:	Project Factor - Project Structure Group
Source:	Data Base Info
Qualitative/Quantitative:	Quantitative converted to Qualitative
Calculation Method:	Less than 3 floors = Low Floor 4 to 10 = Med Floor More than 10 floors = High Floor
Scale of Parameter:	0 - 1
Name of Neural Network Input:	#_FLOORS_ABOVE_?
Type of Input to Network:	1 of N

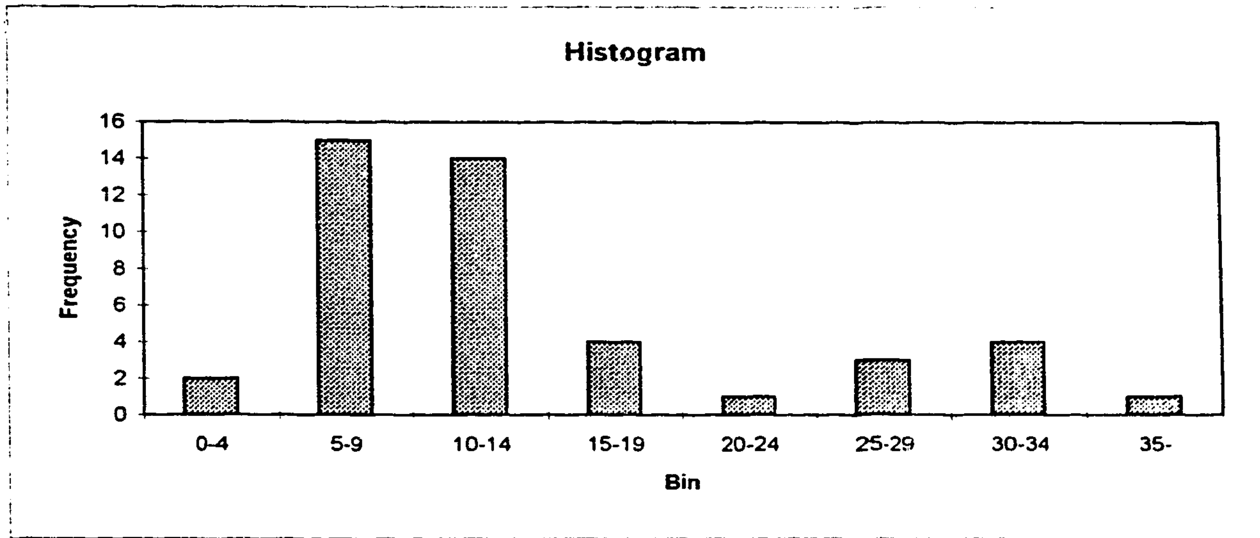


Figure B-48 Floors Above Grade Histogram

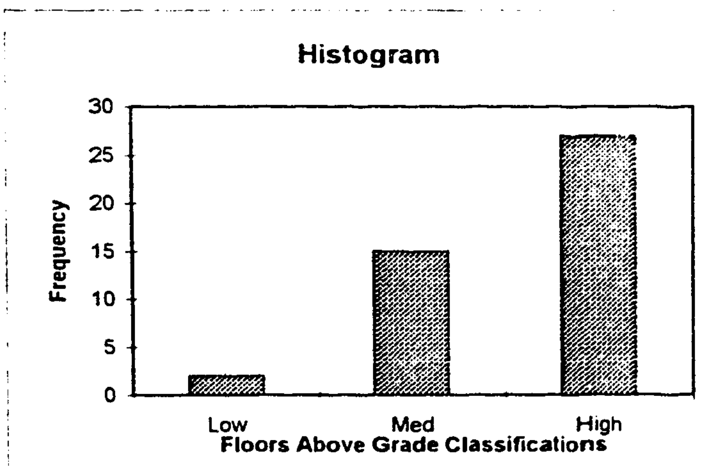


Figure B-49 Floor Above Grade Group Histogram

Table B-28 Number of Floors Below Grade

Name of Parameter:	Number of Floors Below Grade
Description:	Number of Floors Below Grade
Classification:	Project Factor - Project Structure Group
Source:	Data Base Info
Qualitative/Quantitative:	Quantitative converted to Qualitative
Calculation Method:	Shallow basements (2 or fewer levels) = 0 Deeper basements (more than 2 levels) = 1
Scale of Parameter:	0 - 1
Name of Neural Network Input:	#_FLOORS_BELOW_?
Type of Input to Network:	Binary

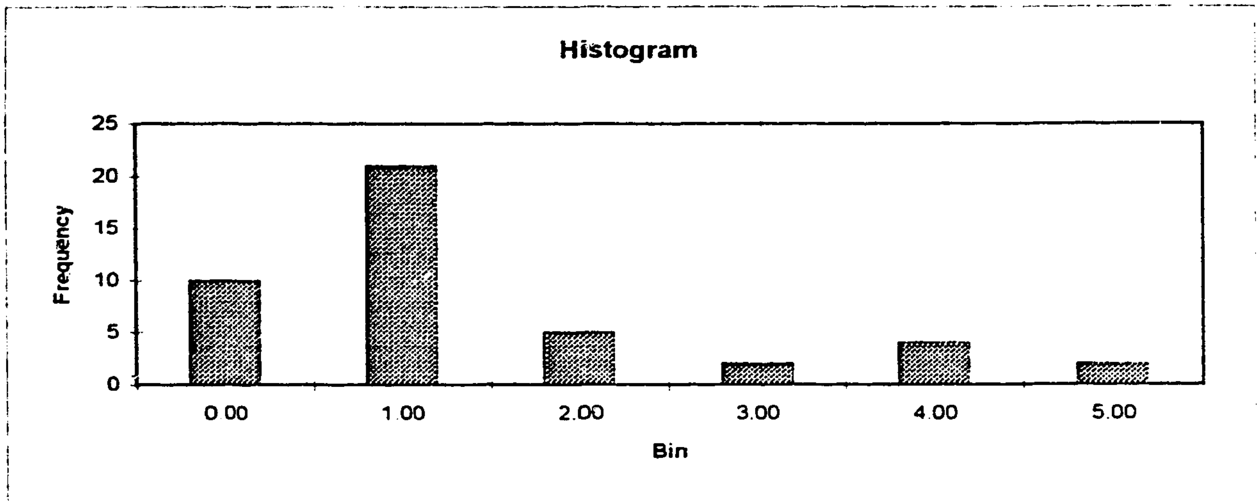


Figure B-50 Floors Below Grade Histogram

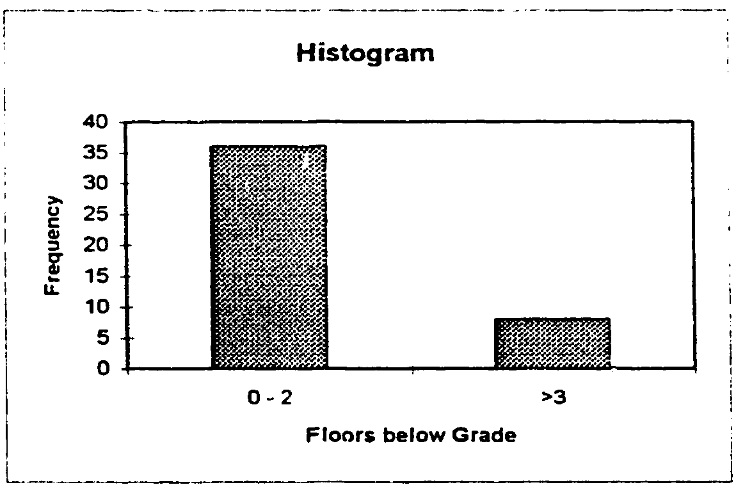


Figure B-51 Floors Below Grade Group Histogram

Table B-29 Company Contract Cost

Name of Parameter:	Company Contract Cost
Description:	Log of Cost for portion of contract that was done by Company
Classification:	Project Factor - Project Size Group
Source:	Database Info
Qualitative/Quantitative:	Quatitative
Calculation Method:	Log(PCL Percentage * Contract Amount)
Scale of Parameter:	6 to 7.4
Name of Neural Network Input:	LOG_COMPANY_CONTRACT
Type of Input to Network:	Simple

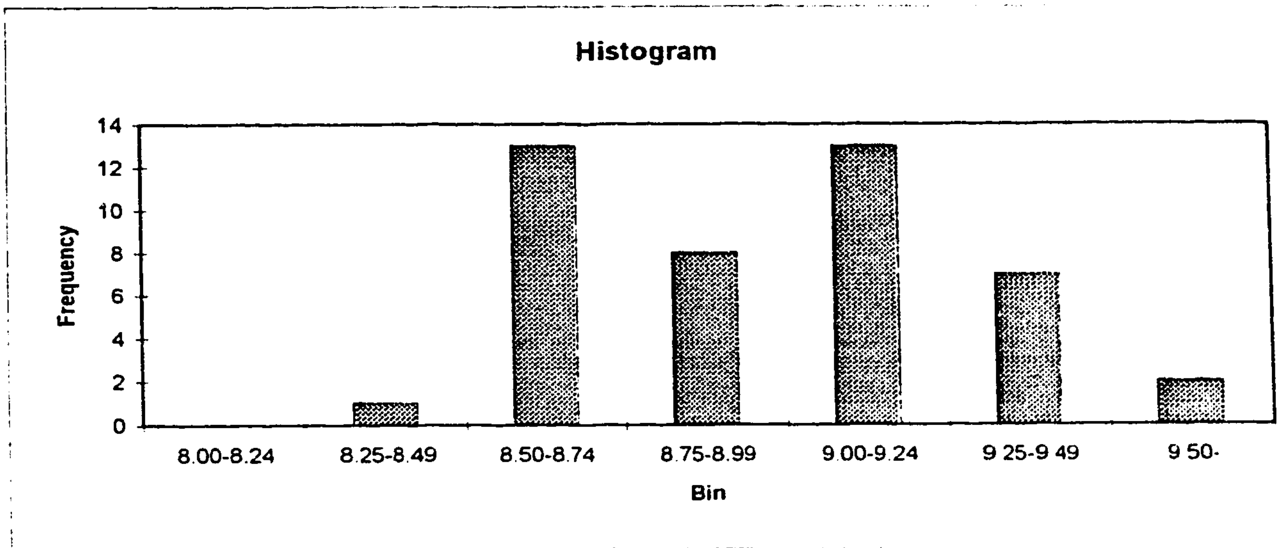


Figure B-52 Logarithm of Company Contract Cost Histogram

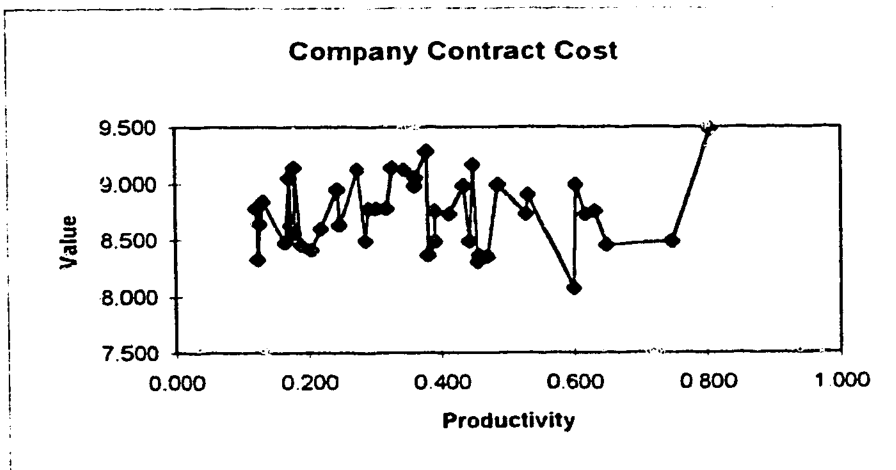


Figure B-53 Logarithm of Company Contract Cost versus Productivity Plot

Table B-30 Total Contract

Name of Parameter: Total Contract
Description: Log of Original Contract Amount
Classification: Project Factor - Project Size Group
Source: Data Sheet Question
Qualitative/Quantitative: Quatitative converted to qualitative
Calculation Method: Log of Contract Amount
Scale of Parameter: 6 to 8
Name of Neural Network Input: LOG_TOTAL_CONTRACT
Type of Input to Network: Simple

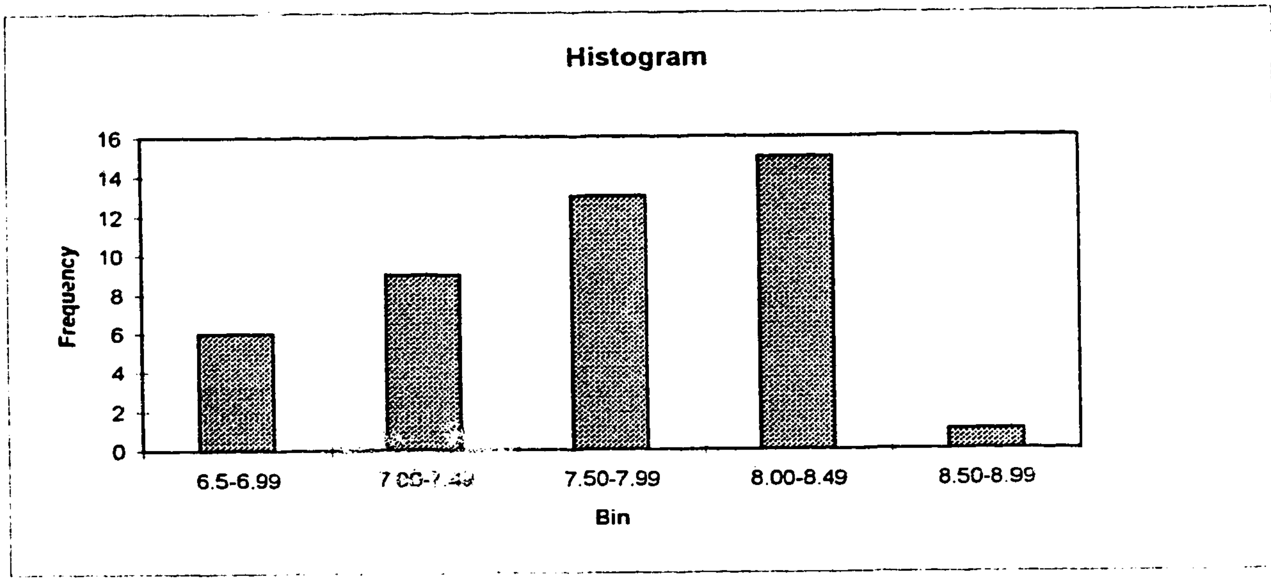


Figure B-54 Logarithm of Total Contract Cost Histogram

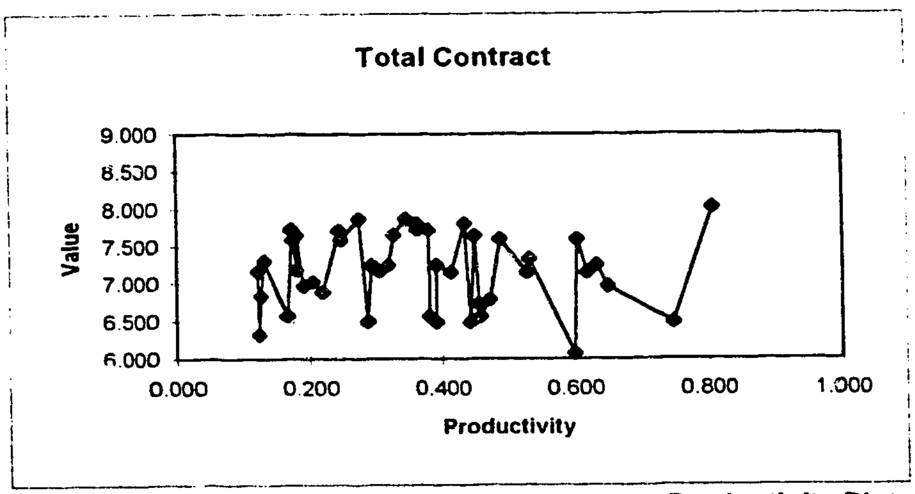


Figure B-55 Logarithm of Total Contract Cost versus Productivity Plot

Table B-31 District

Name of Parameter:	Company District
Description:	District or Region
Classification:	Project Level - Project Location Group
Source:	Database
Qualitative/Quantitative:	Qualitative
Calculation Method:	From Database
Scale of Parameter:	4,5,6,11 (Calgary, Edmonton, Regina, Vancouver - Respectively)
Name of Neural Network Input:	DISTRICT_?_INPUT
Type of Input to Network:	1 of N

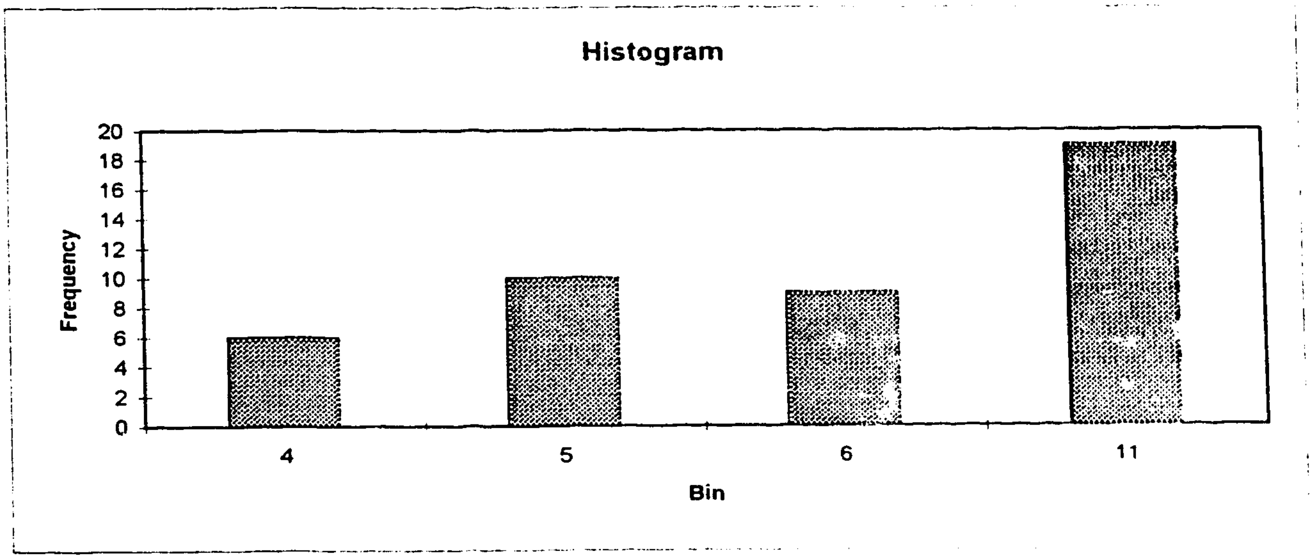


Figure B-56 District Histogram

Table B-32 Temperature

Name of Parameter: Season Mean Temperature
Description: Season Mean Temperature
Classification: Project Factor - Project Location Group
Source: Statistics Canada
Qualitative/Quantitative: Quantitative
Calculation Method:
Name of Neural Network Input: SEASON_MEAN_TEMPERTATURE
Type of Input to Network: Standard

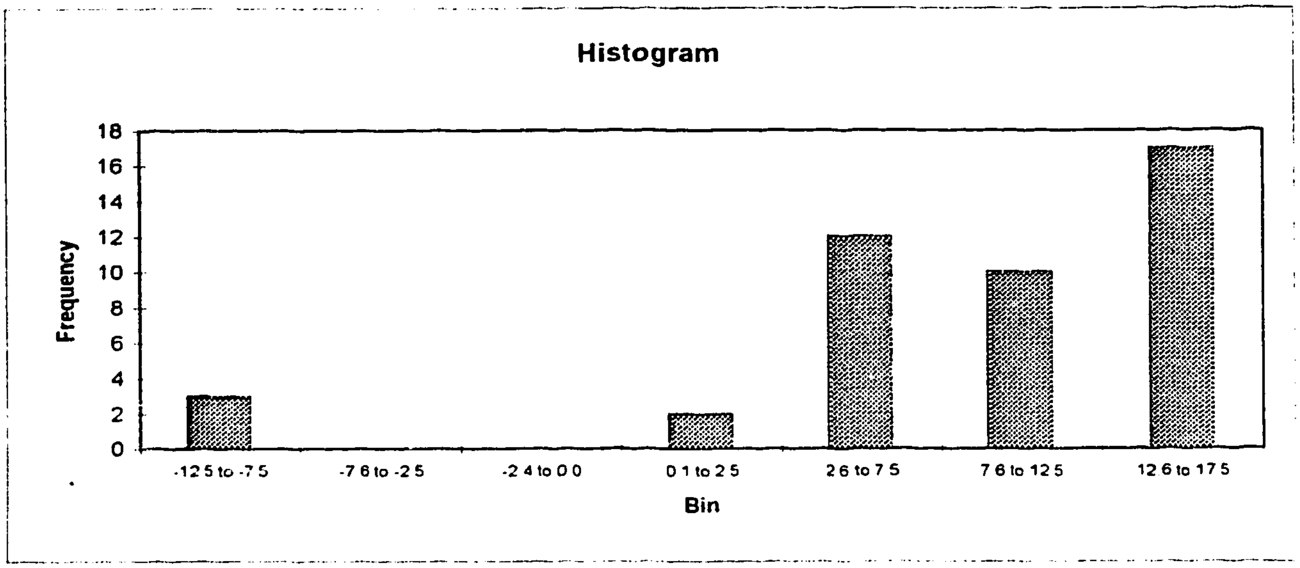


Figure B-57 Temperature Histogram

Table B-33 Project Site

Name of Parameter:	Project Site Problems
Description:	Combines Project Site Congestion, Access and Conditions
Classification:	Project Factor - Project Site Group
Source:	Calculated from other factors
Qualitative/Quantitative:	Quantitative
Calculation Method:	
Scale of Parameter:	
Name of Neural Network Input:	PROJECT_SITE
Type of Input to Network:	Standard

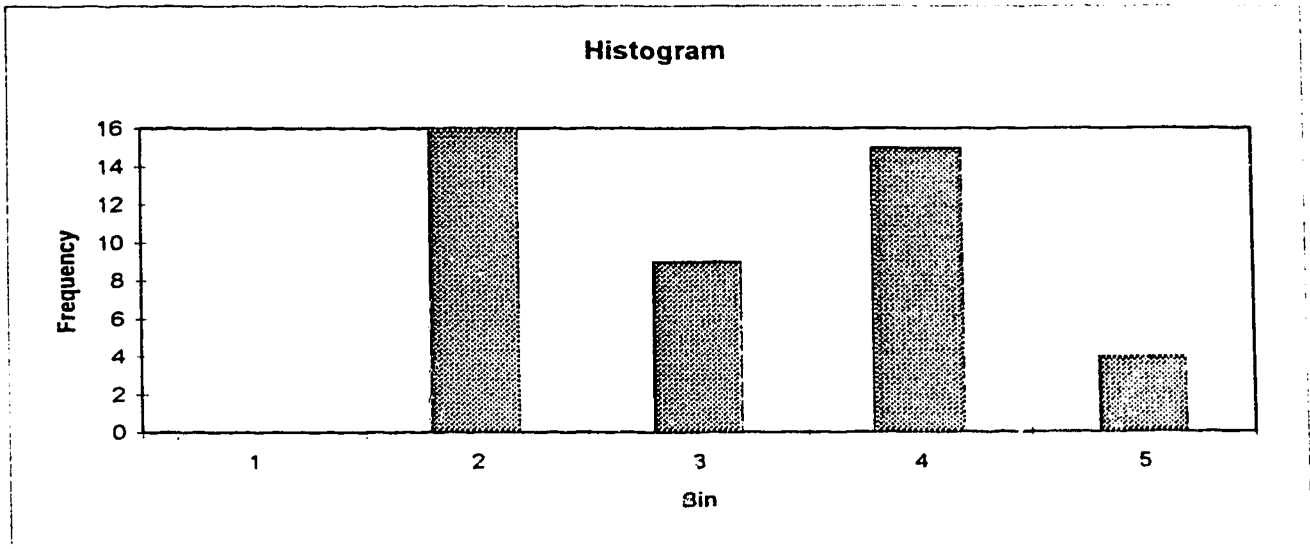


Figure B-58 Project Site Factor Histogram

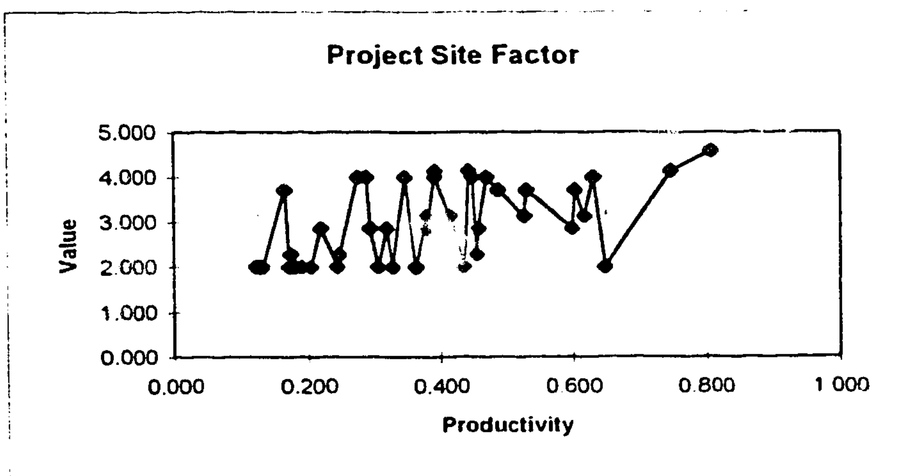


Figure B-59 Project Site Factor versus Productivity Plot

Table B-34 Site Congestion Problems

Name of Parameter:	Site Congestion Problems
Description:	Problems with congestion
Classification:	Project Factor - Project Site Group
Source:	Data Sheet question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	1(Significant), 2 (Yes), 4 (No)
Name of Neural Network Input:	
Type of Input to Network:	Simple

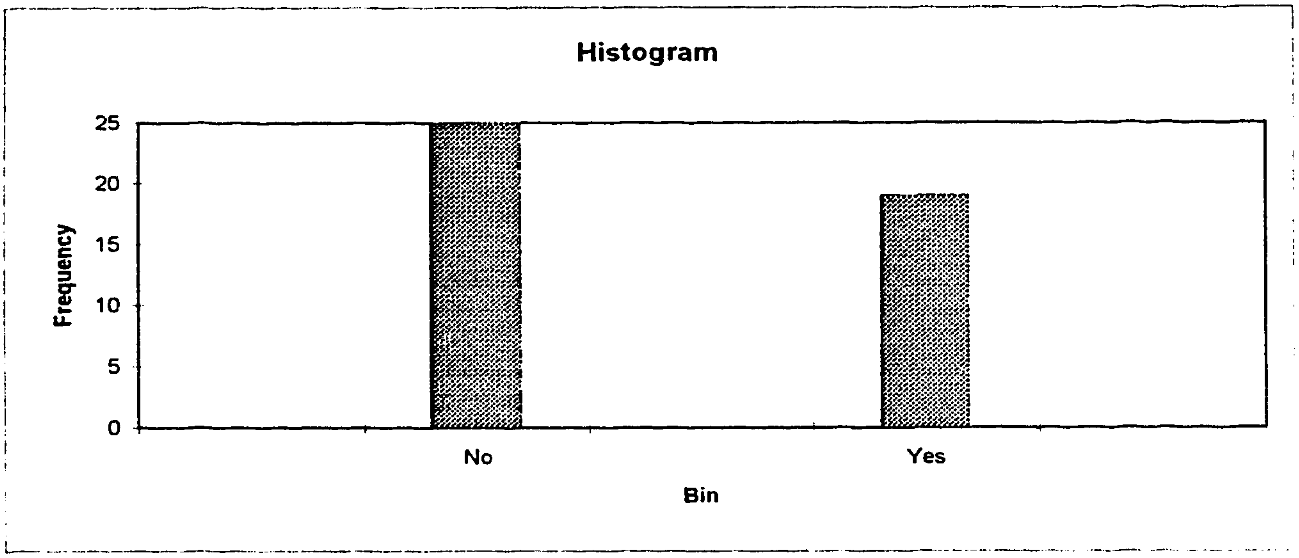


Figure B-60 Site Congestion Problems Histogram

Table B-35 Site Access Problems

Name of Parameter:	Site Access Problems
Description:	Problems with Access to the Site
Classification:	Project Factor - Project Site Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	1(Significant), 2 (Yes), 4 (No)
Name of Neural Network Input:	
Type of Input to Network:	Simple

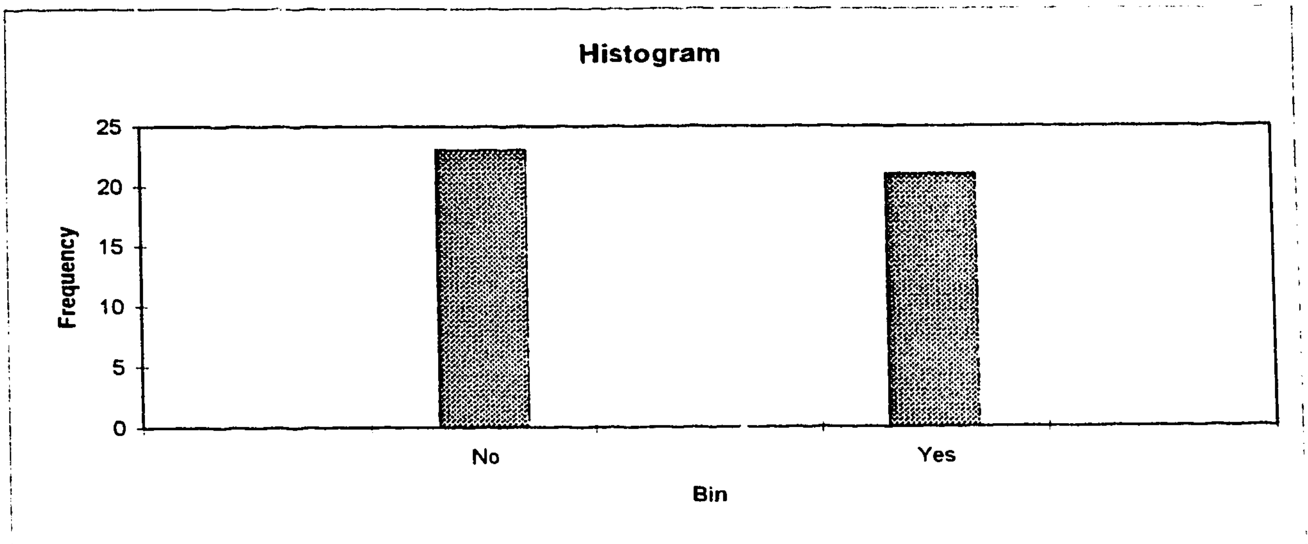


Figure B-61 Site Access Problems Histogram

Table B-36 Site Conditions Problems

Name of Parameter:	Site Conditions Problems
Description:	Were there Problems with site conditions?
Classification:	Project Factor - Project Site Group
Source:	Data Sheet Question
Qualitative/Quantitative:	Qualitative
Calculation Method:	
Scale of Parameter:	1(Significant), 2 (Yes), 4 (No)
Name of Neural Network Input:	
Type of Input to Network:	Simple

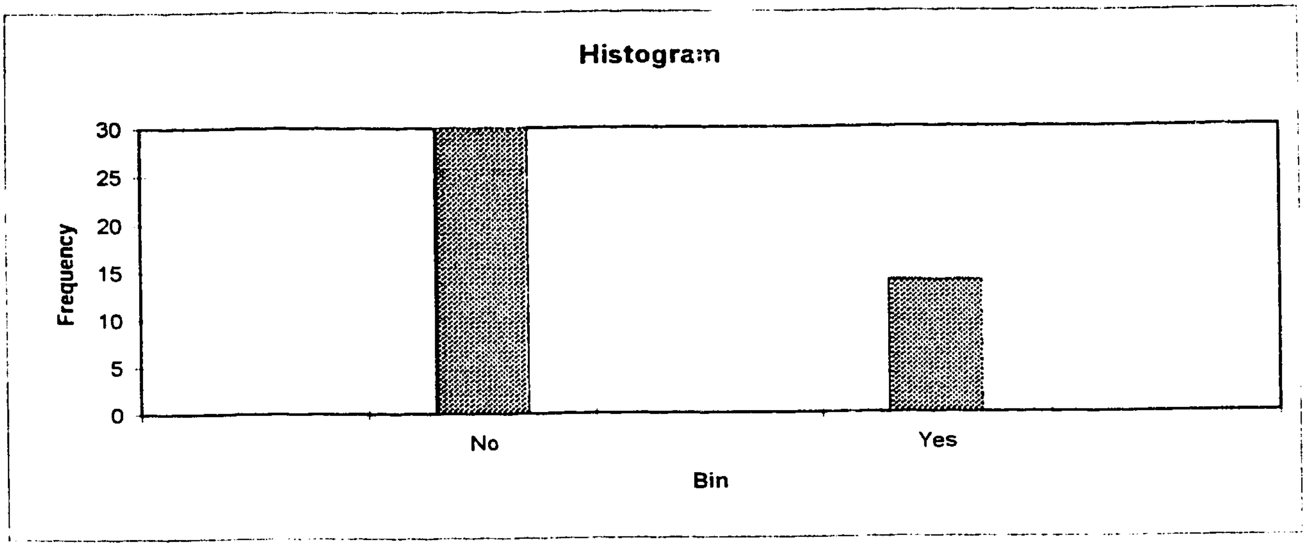


Figure B-62 Site Conditions Problems Histogram

Appendix C Experimentation

The following is the developed neural network experimentation procedure.

1. Examine all inputs from data collection, electronic sources and calculated sources. (Refer to Table C-1 Original Raw Neural Network Data Table Example)
    a) Fill in any missing data, making necessary assumptions or eliminate the record.
    b) Perform input collection, compiling, and consolidation.
2. Combine and compile all inputs for the network and convert for Neural Works. (Refer to Table C-2 Final Neural Network Data Table Example)
3. Train and test all records and analyze the results. (Refer to Table C-3 Results Summary Table - Step 3 Train and Test all Records and Table C-4 Zone Comparison Results - Step 3 Train and Test all Records)
    a) Examine the testing results of the records. Prediction accuracy should be within 10-15%. Eliminate or edit up to 10% of the records to increase training accuracy. (Refer to Table C-5 Results Summary Table - Step 3a Eliminate Records and Retrain and Table C-6 Zone Comparison Results - Step 3a Eliminate Records and Retrain)
    b) Examine the weights connecting each input to the hidden layer. Determine the relative importance of each input and consider elimination of unimportant inputs. (Refer to Table C-7 Network Weight Analysis - Step 3b)
4. Train and test the records.
    a) Either train with 70-80% of the records, test with 20-30% of the records. (Refer to Table C-8 Results Summary Table - Step 4a Train with 80% of Records and Table C-9 Results Summary Table - Step 4b Test with 20% of Records and Table C-10 Output Zone Analysis - Step 4b Test with 20% of Records)
    b) Train with all but 1 of the records and, test with 1 record for 20-30% of the records.
5. Evaluate the accuracy of the network. (Refer to Table C-11 Graphical Output Zone Analysis - Step 5)
    a) Predicts the proper output zone.
    b) Within 15 % of the actual productivity.

Table C-1 Original Raw Neural Network Data Table Example

Field Name	Example	Meaning
District Number	5	
District	Edmonton	
Project Number	0500029	
Project Name		
Cost Code	030300	
Cost Code Description	Fdn/Retaining Walls	
Unit of Measure - Imperial	SF	
Split #	1	
Season	Winter	
Formwork Type Code	11	
Formwork Type Description	Loose Wall Formwork	
Formwork Duty Code	13	
Formwork Duty Description	Semi-Panelized	
Formwork Support System Code	10	
Formwork Support System Description	Not Applicable	
Component Height	16	
Component Height UoM	FT	
Reshore Included	NOT Applicable	
Formwork Tie System Used	14	
Formwork Tie System Description	Taper Tie	
Tie Horizontal Spacing	36	
Tie Vertical Spacing	36	
Tie Spacing UoM	INCH	
Panel Length	16	
Panel Width	16	
Panel UoM	FT	
Beam Depth	0	
Beam Width	0	
Beam UoM	NAP	
Slab Thickness	0	
Slab Thickness UoM	NAP	
Wall Thickness	8	
Wall Thickness UoM	INCH	
Column Width	0	
Column Depth	0	
Column UoM	NAP	
Percent Prefabricated	10	
Number of Reuses	12	
Typical Cycle Duration	1	
Typical Cycle Duration UoM	DAY	
Total Crew Size	5	
Degree of Difficulty	3	Average
Degree of Repetition	3	Average
Degree of Repetition - Percentage	70	
Degree of Rework	1	Low
Rating of Crew Skill	3	Average
Rating of Design	3	Average

Table C-1 Original Raw Neural Network Data Table Example Continued

Field Name	Example	Meaning
Rating of Constructability	3	Average
Rating of Estimate	3	Average
Shift Duration	1	Overtime
Material Handling and Crane Time Problems	2	Medium-Low
Continuity of Cycle	4	Yes
Project Factors.Rating of Labor Skill	3	Average
Project Factors.Rating of Employee Turnover	3	Average
Project Factors.Rating of Subcontractor Performance	3	Average
Project Factors.Weather Conditions Problems	2	No
Project Factors.Access to Work Area Problems	2	No
Project Factors.Site Conditions Problems	2	No
Project Factors.Site Congestion Problems	2	No
Project Factors.Sequencing Problems	2	No
Project Factors.Reassignment Problems	2	No
Project Factors.Inspection/Quality Problems	2	No
Project Factors.Material Supply Problems	2	No
Project Factors.Equipment Supply Problems	2	No
Project Factors.Union	2	No
Project Factors.Walkouts/Strikes	2	No
Project Factors.Change Problems	2	No
Project Factors.Claims	2	No
Project Factors.Rating of Design	3	Average
Project Factors.Rating of Constructability	3	Average
Project Factors.Rating of Estimate	3	Average
Project Factors.Rating of Degree of Difficulty	3	Average
Project Factors.Rating of Degree of Repetition	3	Average
Project Factors.Rating of Degree of Rework	3	Average
Imperial Quantity	90000	
Total Man hours		
Imperial Productivity Rate		
Budget Imperial Quantity	88000	
Budget Man hours		
Budget Imperial Productivity Rate		

Table C-2 Final Neural Network Data Table Example

Field Name	Example
ACTIVITY PERFORMANCE	3
Activity - Superintendent Score	0.60
Activity - District Performance Score	0.89
Crew Skill Rating	3
CREWSIZE INPUT 1	0
CREWSIZE INPUT 2	1
CREWSIZE INPUT 3	0
CREWSIZE INPUT 4	0
CREWSIZE INPUT 5	0
Union	2
CostCode1	1
CostCode2	0
CostCode3	0
FORMWORK DUTY_LOOSE	0
FORMWORK DUTY_REPETITIVE	1
TIE TYPE_WALL_SNAP TIE	0
TIE TYPE_WALL_ANCHOR&CAMLOCK	0
TIE TYPE_WALL_TAPER TYPE&BURKE	1
TIE TYPE_WALL_WALER	0
TIE SPACING_HORIZONTAL	3
TIE SPACING_VERTICAL	3
Design Rating	3
LOG_QUANTITY	4.95
HEIGHT_WALL_1	0
WALL_THICK	1
Degree of Repetition Rating	3
NUMBER OF REUSE INPUT 1	0
NUMBER OF REUSE INPUT 2	1
NUMBER OF REUSE INPUT 3	0
NUMBER OF REUSE INPUT 4	0
PANEL AREA INPUT 1	0
PANEL AREA INPUT 2	1
PANEL AREA INPUT 3	0
Material Handling and Crane Time Problems	2
Continuity of Cycle	4
Shift Duration	1
Project Complexity	0.72
Project Superintendent Score	0.70
Project District Performance Score	0.94
LOG_GROSS BUILDING AREA	5.62
# FLOORS_ABOVE_LOW	0
# FLOORS_ABOVE_MEDIUM	1
# FLOORS_ABOVE_HIGH	0
# FLOORS_BELOW_LOW	1
# FLOORS_BELOW_HIGH	0
LOG_COMPANY_CONTRACT	9.00
LOG_TOTAL_CONTRACT	7.75

Table C-2 Final Neural Network Data Table Example Continued

Field Name	Example
DISTRICT_4_INPUT	0
DISTRICT_5_INPUT	1
DISTRICT_6_INPUT	0
DISTRICT_11_INPUT	0
Season Mean Temperature	-8.88
PROJECT_SITE_FACTOR	2
Output Zone1	0
Output Zone2	0.8
Output Zone3	1
Output Zone4	0.8
Output Zone5	0
Output Zone6	0
Output Zone7	0
Output Zone8	0
Output Zone9	0
Output Zone10	0
Output Zone11	0
Output Zone12	0
Output Zone13	0
Imperial Productivity Rate	
Project #	0500029
Cost Code	030300
Split #	1

Table C-3 Results Summary Table - Step 3 Train and Test all Records

Record	Actual Productivity (AP)	Predicted Productivity (PP)	Weighted Average Actual Productivity (WAAP)	Weighted Average Predicted Productivity (WAPP)	PP/AP	WAPP/AP	PP/AP	WAPP/AP	(WPP-AP)/R
1	0.450	0.439	0.460	0.462	98%	103%	Hit	Hit	-2%
2	0.206	0.224	0.220	0.220	109%	107%	Hit	Hit	-2%
3	0.456	0.684	0.460	0.459	150%	101%	Miss	Hit	0%
4	0.344	0.728	0.380	0.381	212%	111%	Miss	Hit	-5%
5	0.807	0.817	0.780	0.780	101%	97%	Hit	Hit	3%
6	0.244	0.180	0.220	0.217	74%	89%	Miss	Hit	3%
7	0.175	0.196	0.140	0.150	112%	86%	Hit	Hit	3%
8	0.248	0.239	0.220	0.202	96%	82%	Hit	Miss	6%
9	0.182	0.120	0.220	0.219	66%	120%	Miss	Miss	-5%
10	0.117	0.246	0.140	0.141	210%	120%	Miss	Miss	-3%
11	0.128	0.147	0.140	0.143	115%	112%	Hit	Hit	-2%
12	0.173	0.161	0.140	0.141	93%	82%	Hit	Miss	4%
13	0.364	0.391	0.380	0.379	108%	104%	Hit	Hit	-2%
14	0.472	0.490	0.460	0.458	104%	97%	Hit	Hit	2%
15	0.347	0.316	0.380	0.379	91%	109%	Hit	Hit	-4%
16	0.276	0.238	0.300	0.298	86%	108%	Hit	Hit	-3%
17	0.180	0.180	0.140	0.137	100%	76%	Hit	Miss	5%
18	0.294	0.245	0.300	0.302	83%	103%	Miss	Hit	-1%
19	0.319	0.382	0.300	0.300	120%	94%	Miss	Hit	2%
20	0.306	0.280	0.300	0.302	92%	99%	Hit	Hit	0%
21	0.123	0.151	0.140	0.144	123%	117%	Miss	Miss	-3%
22	0.167	0.120	0.140	0.141	72%	85%	Miss	Miss	3%
23	0.380	0.335	0.380	0.382	88%	100%	Hit	Hit	0%
24	0.133	0.096	0.140	0.148	72%	112%	Miss	Hit	-2%
25	0.488	0.491	0.460	0.459	101%	94%	Hit	Hit	4%
26	0.604	0.554	0.620	0.617	92%	102%	Hit	Hit	-2%
27	0.632	0.705	0.620	0.619	112%	98%	Hit	Hit	2%
28	0.392	0.334	0.380	0.397	85%	101%	Hit	Hit	-1%
29	0.220	0.259	0.220	0.221	118%	100%	Miss	Hit	0%
30	0.414	0.368	0.380	0.377	89%	91%	Hit	Hit	5%
31	0.529	0.527	0.540	0.541	100%	102%	Hit	Hit	-2%
32	0.619	0.616	0.620	0.621	99%	100%	Hit	Hit	0%
33	0.600	0.659	0.620	0.618	110%	103%	Hit	Hit	-2%
34	0.444	0.399	0.460	0.454	90%	102%	Hit	Hit	-1%
35	0.392	0.402	0.380	0.379	102%	97%	Hit	Hit	2%
36	0.748	0.773	0.780	0.779	103%	104%	Hit	Hit	-4%
37	0.381	0.390	0.380	0.384	102%	101%	Hit	Hit	0%
38	0.459	0.398	0.460	0.459	87%	100%	Hit	Hit	0%
39	0.289	0.278	0.300	0.305	96%	105%	Hit	Hit	-2%
40	0.553	0.644	0.540	0.537	117%	97%	Miss	Hit	2%
41	0.124	0.127	0.140	0.140	103%	113%	Hit	Hit	-2%
42	0.328	0.354	0.300	0.296	108%	90%	Hit	Hit	4%
43	0.180	0.228	0.220	0.222	127%	123%	Miss	Miss	-5%
44	0.363	0.398	0.380	0.406	110%	112%	Hit	Hit	-5%
45	0.435	0.402	0.460	0.434	92%	100%	Hit	Hit	0%
46	0.649	0.576	0.620	0.619	89%	95%	Hit	Hit	4%
47	0.191	0.239	0.220	0.221	125%	116%	Miss	Miss	-4%
48	0.532	0.512	0.540	0.536	96%	101%	Hit	Hit	-1%

Table C-4 Zone Comparison Results - Step 3 Train and Test all Records

	Record	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12
Actual	1	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	1	0.00	0.00	0.00	0.00	0.71	1.02	0.78	0.00	0.00	0.00	0.00	0.00
Actual	2	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	2	0.00	0.79	0.92	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	3	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	3	0.00	0.00	0.00	0.00	0.75	0.88	0.73	0.00	0.00	0.00	0.00	0.00
Actual	4	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	4	0.00	0.00	0.00	0.63	0.86	0.67	0.00	0.00	0.00	0.00	0.00	0.00
Actual	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00
Predicted	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.97	0.78	0.00
Actual	6	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	6	0.00	0.76	0.85	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	7	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	7	0.61	1.04	0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	8	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	8	0.22	0.78	0.91	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	9	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	9	0.00	0.77	1.01	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	10	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	10	0.73	0.96	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	11	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	11	0.72	1.02	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	12	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	12	0.77	0.99	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	13	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	13	0.00	0.00	0.00	0.79	0.94	0.76	0.00	0.00	0.00	0.00	0.00	0.00
Actual	14	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	14	0.00	0.00	0.00	0.00	0.84	0.94	0.76	0.00	0.00	0.00	0.00	0.00
Actual	15	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	15	0.00	0.00	0.00	0.83	0.95	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Actual	16	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	16	0.00	0.00	0.80	0.98	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	17	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	17	0.82	1.03	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	18	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	18	0.00	0.00	0.80	0.95	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	19	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	19	0.00	0.00	0.76	1.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	20	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	20	0.00	0.00	0.73	1.02	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	21	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	21	0.74	0.96	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	22	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	22	0.79	1.01	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	23	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	23	0.00	0.00	0.00	0.77	1.06	0.83	0.00	0.00	0.00	0.00	0.00	0.00
Actual	24	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	24	0.67	1.01	0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	25	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	25	0.00	0.00	0.00	0.00	0.76	0.91	0.72	0.00	0.00	0.00	0.00	0.00
Actual	26	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	26	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.87	0.76	0.00	0.00	0.00
Actual	27	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	27	0.00	0.00	0.00	0.00	0.00	0.00	0.81	1.00	0.77	0.00	0.00	0.00
Actual	28	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	28	0.00	0.00	0.00	0.71	1.04	0.86	0.23	0.00	0.00	0.00	0.00	0.00
Actual	29	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	29	0.00	0.75	0.99	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	30	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	30	0.00	0.00	0.00	0.83	1.03	0.74	0.00	0.00	0.00	0.00	0.00	0.00

Table C-4 Zone Comparison Results - Step 3 Continued

	Record	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12
Actual	31	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00
Predicted	31	0.00	0.00	0.00	0.00	0.00	0.76	0.91	0.79	0.00	0.00	0.00	0.00
Actual	32	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	32	0.00	0.00	0.00	0.00	0.00	0.00	0.81	1.01	0.83	0.00	0.00	0.00
Actual	33	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	33	0.00	0.00	0.00	0.00	0.00	0.00	0.79	1.03	0.74	0.00	0.00	0.00
Actual	34	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	34	0.00	0.00	0.00	0.00	0.81	0.93	0.64	0.00	0.00	0.00	0.00	0.00
Actual	35	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	35	0.00	0.00	0.00	0.85	0.96	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Actual	36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00
Predicted	36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.93	0.75	0.00
Actual	37	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	37	0.00	0.00	0.00	0.72	1.02	0.85	0.00	0.00	0.00	0.00	0.00	0.00
Actual	38	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	38	0.00	0.00	0.00	0.00	0.77	0.97	0.75	0.00	0.00	0.00	0.00	0.00
Actual	39	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	39	0.00	0.00	0.67	1.03	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	40	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00
Predicted	40	0.00	0.00	0.00	0.00	0.00	0.79	0.99	0.70	0.00	0.00	0.00	0.00
Actual	41	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	41	0.81	1.03	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	42	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	42	0.00	0.00	0.80	1.02	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	43	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	43	0.00	0.70	1.03	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	44	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	44	0.00	0.00	0.00	0.54	0.95	0.84	0.27	0.00	0.00	0.00	0.00	0.00
Actual	45	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	45	0.00	0.00	0.00	0.26	0.84	0.96	0.53	0.00	0.00	0.00	0.00	0.00
Actual	46	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	46	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.93	0.76	0.00	0.00	0.00
Actual	47	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	47	0.00	0.81	0.94	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	48	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00
Predicted	48	0.00	0.00	0.00	0.00	0.00	0.84	0.99	0.72	0.00	0.00	0.00	0.00

Table C-5 Results Summary Table - Step 3a Eliminate Records and Retrain

Record	Actual Productivity (AP)	Predicted Productivity (PP)	Weighted Average Actual Productivity (WAAP)	Weighted Average Predicted Productivity (WAPP)	PP/AP	WAPP/AP	PP/AP	WAPP/AP	(WPP-AP)/R
1	0.450	0.434	0.460	0.462	97%	103%	Hit	Hit	-1%
2	0.206	0.219	0.220	0.219	106%	106%	Hit	Hit	-2%
3	0.456	0.456	0.460	0.460	100%	101%	Hit	Hit	-1%
4	0.807	0.785	0.780	0.779	97%	97%	Hit	Hit	3%
5	0.244	0.203	0.220	0.217	83%	89%	Miss	Hit	3%
6	0.175	0.175	0.140	0.149	100%	86%	Hit	Hit	3%
7	0.248	0.220	0.220	0.217	89%	88%	Hit	Hit	4%
8	0.128	0.148	0.140	0.144	116%	112%	Miss	Hit	-2%
9	0.173	0.170	0.140	0.138	98%	80%	Hit	Miss	4%
10	0.364	0.378	0.380	0.377	104%	104%	Hit	Hit	-2%
11	0.472	0.480	0.460	0.459	102%	97%	Hit	Hit	2%
12	0.347	0.381	0.380	0.379	110%	109%	Hit	Hit	-4%
13	0.276	0.283	0.300	0.300	103%	109%	Hit	Hit	-3%
14	0.180	0.168	0.140	0.137	94%	76%	Hit	Miss	5%
15	0.294	0.277	0.300	0.303	94%	103%	Hit	Hit	-1%
16	0.319	0.325	0.300	0.298	102%	93%	Hit	Hit	3%
17	0.306	0.307	0.300	0.303	101%	99%	Hit	Hit	0%
18	0.123	0.154	0.140	0.143	125%	116%	Miss	Miss	-3%
19	0.167	0.158	0.140	0.140	95%	84%	Hit	Miss	3%
20	0.380	0.374	0.380	0.381	98%	100%	Hit	Hit	0%
21	0.133	0.132	0.140	0.147	100%	111%	Hit	Hit	-2%
22	0.488	0.473	0.460	0.459	97%	94%	Hit	Hit	4%
23	0.604	0.592	0.620	0.618	98%	102%	Hit	Hit	-2%
24	0.632	0.660	0.620	0.620	105%	98%	Hit	Hit	2%
25	0.392	0.392	0.380	0.384	100%	98%	Hit	Hit	1%
26	0.220	0.200	0.220	0.221	91%	101%	Hit	Hit	0%
27	0.414	0.383	0.380	0.378	92%	91%	Hit	Hit	5%
28	0.529	0.529	0.540	0.541	100%	102%	Hit	Hit	-2%
29	0.619	0.617	0.620	0.622	100%	100%	Hit	Hit	0%
30	0.600	0.615	0.620	0.618	102%	103%	Hit	Hit	-2%
31	0.444	0.451	0.460	0.455	102%	102%	Hit	Hit	-1%
32	0.392	0.377	0.380	0.380	96%	97%	Hit	Hit	2%
33	0.748	0.759	0.780	0.779	101%	104%	Hit	Hit	-4%
34	0.381	0.409	0.380	0.382	107%	100%	Hit	Hit	0%
35	0.459	0.439	0.460	0.459	96%	100%	Hit	Hit	0%
36	0.289	0.297	0.300	0.303	103%	105%	Hit	Hit	-2%
37	0.553	0.568	0.540	0.537	103%	97%	Hit	Hit	2%
38	0.124	0.151	0.140	0.141	122%	113%	Miss	Hit	-2%
39	0.328	0.327	0.300	0.297	100%	91%	Hit	Hit	4%
40	0.180	0.199	0.220	0.220	110%	122%	Hit	Miss	-5%
41	0.363	0.377	0.380	0.405	104%	112%	Hit	Hit	-5%
42	0.435	0.442	0.460	0.436	102%	100%	Hit	Hit	0%
43	0.649	0.625	0.620	0.619	96%	95%	Hit	Hit	4%
44	0.191	0.187	0.220	0.221	98%	115%	Hit	Miss	-4%
45	0.532	0.518	0.540	0.538	97%	101%	Hit	Hit	-1%

Table C-6 Zone Comparison Results - Step 3a Eliminate Records and Retrain

	Record	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12
Actual	1	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	1	0.00	0.00	0.00	0.00	0.76	1.04	0.81	0.00	0.00	0.00	0.00	0.00
Actual	2	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	2	0.00	0.81	0.95	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	3	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	3	0.00	0.00	0.00	0.00	0.80	0.97	0.82	0.00	0.00	0.00	0.00	0.00
Actual	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00
Predicted	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.98	0.78	0.00
Actual	5	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	5	0.00	0.80	0.88	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	6	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	6	0.62	1.02	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	7	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	7	0.00	0.78	0.91	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	8	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	8	0.73	1.03	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	9	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	9	0.80	0.96	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	10	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	10	0.00	0.00	0.00	0.81	0.93	0.72	0.00	0.00	0.00	0.00	0.00	0.00
Actual	11	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	11	0.00	0.00	0.00	0.00	0.83	0.96	0.79	0.00	0.00	0.00	0.00	0.00
Actual	12	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	12	0.00	[illegible]	[illegible]	0.82	0.95	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Actual	13	0.00	[illegible]	[illegible]	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	13	0.00	0.00	0.77	0.96	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	14	0.80	1.00	0.80	0.00	0.00	[illegible]	[illegible]	[illegible]	0.00	0.00	0.00	0.00
Predicted	14	0.83	1.02	0.75	0.00	0.00	[illegible]	0.00	0.90	0.00	0.00	0.00	0.00
Actual	15	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	15	0.00	0.00	0.79	1.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	16	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	16	0.00	0.00	0.82	1.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	17	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	17	0.00	0.00	0.72	0.98	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	18	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	18	0.74	0.97	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	19	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	19	0.81	0.99	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	20	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	20	0.00	0.00	0.00	0.80	1.06	0.83	0.00	0.00	0.00	0.00	0.00	0.00
Actual	21	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	21	0.70	1.00	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	22	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	22	0.00	0.00	0.00	0.00	0.75	0.95	0.73	0.00	0.00	0.00	0.00	0.00
Actual	23	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	23	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.87	0.77	0.00	0.00	0.00
Actual	24	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	24	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.03	0.79	0.00	0.00	0.00
Actual	25	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	25	0.00	0.00	0.00	0.70	1.00	0.84	0.00	0.00	0.00	0.00	0.00	0.00
Actual	26	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	26	0.00	0.77	1.00	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	27	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	27	0.00	0.00	0.00	0.82	1.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00
Actual	28	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00
Predicted	28	0.00	0.00	0.00	0.00	0.00	0.76	0.92	0.80	0.00	0.00	0.00	0.00
Actual	29	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	29	0.00	0.00	0.00	0.00	0.00	0.00	0.77	1.00	0.82	0.00	0.00	0.00
Actual	30	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	30	0.00	0.00	0.00	0.00	0.00	0.00	0.84	1.02	0.77	0.00	0.00	0.00

Table C-6 Zone Comparison Results - Step 3a Continued

	Record	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12
Actual	31	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	31	0.00	0.00	0.00	0.00	0.80	0.94	0.65	0.00	0.00	0.00	0.00	0.00
Actual	32	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	32	0.00	0.00	0.00	0.81	0.99	0.79	0.00	0.00	0.00	0.00	0.00	0.00
Actual	33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00
Predicted	33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.95	0.77	0.00
Actual	34	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	34	0.00	0.00	0.00	0.77	1.00	0.85	0.00	0.00	0.00	0.00	0.00	0.00
Actual	35	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	35	0.00	0.00	0.00	0.00	0.77	0.98	0.74	0.00	0.00	0.00	0.00	0.00
Actual	36	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	36	0.00	0.00	0.71	1.00	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	37	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00
Predicted	37	0.00	0.00	0.00	0.00	0.00	0.84	1.02	0.74	0.00	0.00	0.00	0.00
Actual	38	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	38	0.77	0.98	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	39	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	39	0.00	0.00	0.81	1.04	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	40	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	40	0.00	0.76	1.02	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	41	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	41	0.00	0.00	0.00	0.56	0.95	0.82	0.28	0.00	0.00	0.00	0.00	0.00
Actual	42	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	42	0.00	0.00	0.00	0.24	0.81	0.97	0.52	0.00	0.00	0.00	0.00	0.00
Actual	43	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00
Predicted	43	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.95	0.75	0.00	0.00	0.00
Actual	44	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	44	0.00	0.79	0.96	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	45	0.00	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00
Predicted	45	0.00	0.00	0.00	0.00	0.00	0.81	0.99	0.74	0.00	0.00	0.00	0.00

Table C-7 Network Weight Analysis - Step 3b

Field Name	Minimum	Maximum	Average	Sum
ACTIVITY PERFORMANCE	0.01	1.59	0.58	17.48
Activity - Superintendent Score	0.05	1.31	0.40	12.01
Activity - District Performance Score	0.00	0.44	0.14	4.12
Crew Skill Rating	0.03	0.99	0.27	8.17
CREWSIZE INPUT 1	0.06	1.05	0.43	13.02
CREWSIZE INPUT 2	0.01	0.76	0.25	7.46
CREWSIZE INPUT 3	0.01	0.53	0.22	6.51
CREWSIZE INPUT 4	0.01	0.60	0.23	7.04
CREWSIZE INPUT 5	0.00	0.13	0.07	2.16
Union	0.01	0.62	0.18	5.39
CostCode1	0.02	0.55	0.18	5.37
CostCode2	0.03	0.45	0.15	4.37
CostCode3	0.01	0.14	0.08	2.37
FORMWORK DUTY_LOOSE	0.00	0.53	0.19	5.83
FORMWORK DUTY_REPETITIVE	0.00	0.52	0.19	5.67
TIE TYPE_WALL_SNAP TIE	0.04	0.72	0.33	9.90
TIE TYPE_WALL_ANCHOR&CAMLOCK	0.00	0.50	0.21	6.42
TIE TYPE_WALL_TAPER TYPE&BURKE	0.02	0.53	0.22	6.71
TIE TYPE_WALL_WALER	0.00	0.51	0.16	4.85
TIE SPACING_HORIZONTAL	0.01	0.61	0.18	5.55
TIE SPACING_VERTICAL	0.01	0.64	0.31	9.33
Design Rating	0.01	0.45	0.21	6.39
LOG_QUANTITY	0.00	0.69	0.21	6.25
HEIGHT_WALL_1	0.00	0.93	0.22	6.64
WALL_THICK	0.02	0.62	0.20	5.85
Degree of Repetition Rating	0.00	0.66	0.21	6.36
NUMBER OF REUSE INPUT 1	0.02	0.94	0.30	9.04
NUMBER OF REUSE INPUT 2	0.01	0.50	0.21	6.30
NUMBER OF REUSE INPUT 3	0.03	0.78	0.31	9.25
NUMBER OF REUSE INPUT 4	0.01	0.77	0.33	9.91
PANEL AREA INPUT 1	0.02	0.68	0.27	8.04
PANEL AREA INPUT 2	0.02	0.81	0.29	8.67
PANEL AREA INPUT 3	0.01	0.52	0.25	7.50
Material Handling and Crane Time Problems	0.00	0.93	0.19	5.71
Continuity of Cycle	0.00	0.45	0.17	4.96
Shift Duration	0.00	0.89	0.19	5.70
Project Complexity	0.01	0.48	0.18	5.49
Project Superintendent Score	0.00	0.69	0.20	6.14
Project District Performance Score	0.00	0.57	0.14	4.06
LOG_GROSS BUILDING AREA	0.00	0.26	0.13	3.98
# FLOORS_ABOVE_LOW	0.01	0.57	0.20	5.90
# FLOORS_ABOVE_MEDIUM	0.00	0.40	0.17	5.11
# FLOORS_ABOVE_HIGH	0.02	0.86	0.31	9.42
# FLOORS_BELOW_LOW	0.03	0.62	0.26	7.76
# FLOORS_BELOW_HIGH	0.01	0.78	0.28	8.51
LOG_COMPANY_CONTRACT	0.00	0.49	0.15	4.53
LOG_TOTAL_CONTRACT	0.00	0.58	0.22	6.71
DISTRICT_4_INPUT	0.00	0.45	0.14	4.18
DISTRICT_5_INPUT	0.01	0.38	0.14	4.17
DISTRICT_6_INPUT	0.00	0.85	0.30	8.93
DISTRICT_11_INPUT	0.01	0.64	0.19	5.70
Season Mean Temperature	0.01	0.64	0.23	6.94
PROJECT_SITE_FACTOR	0.01	0.59	0.19	5.79

Table C-8 Results Summary Table - Step 4a Train with 80% of Records

Record	Actual Productivity (AP)	Predicted Productivity (PP)	Weighted Average Actual Productivity (WAAP)	Weighted Average Predicted Productivity (WAPP)	PP/AP	WAPP/AP	PP/AP	WAPP/AP	(WPP-AP)/R
1	0.632	0.650	0.620	0.620	103%	98%	Hit	Hit	1%
2	0.381	0.406	0.380	0.381	107%	100%	Hit	Hit	0%
3	0.600	0.603	0.620	0.618	100%	103%	Hit	Hit	-2%
4	0.435	0.434	0.460	0.453	100%	104%	Hit	Hit	-2%
5	0.380	0.379	0.380	0.380	100%	100%	Hit	Hit	0%
6	0.328	0.329	0.300	0.298	100%	91%	Hit	Hit	4%
7	0.220	0.208	0.220	0.221	94%	100%	Hit	Hit	0%
8	0.456	0.456	0.460	0.461	100%	101%	Hit	Hit	-1%
9	0.180	0.195	0.220	0.220	108%	122%	Hit	Miss	-5%
10	0.276	0.273	0.300	0.300	99%	109%	Hit	Hit	-3%
11	0.347	0.379	0.380	0.379	109%	109%	Hit	Hit	-4%
12	0.191	0.188	0.220	0.220	98%	115%	Hit	Hit	-4%
13	0.206	0.214	0.220	0.219	104%	106%	Hit	Hit	-2%
14	0.180	0.158	0.140	0.141	88%	78%	Hit	Miss	5%
15	0.649	0.628	0.620	0.619	97%	95%	Hit	Hit	4%
16	0.133	0.142	0.140	0.145	107%	109%	Hit	Hit	-1%
17	0.128	0.133	0.140	0.141	104%	110%	Hit	Hit	-2%
18	0.306	0.310	0.300	0.303	102%	99%	Hit	Hit	0%
19	0.167	0.157	0.140	0.141	94%	85%	Hit	Miss	3%
20	0.392	0.386	0.380	0.380	98%	97%	Hit	Hit	2%
21	0.123	0.144	0.140	0.141	117%	115%	Miss	Hit	-2%
22	0.748	0.753	0.780	0.780	101%	104%	Hit	Hit	-4%
23	0.529	0.545	0.540	0.542	103%	102%	Hit	Hit	-2%
24	0.289	0.286	0.300	0.302	99%	105%	Hit	Hit	-2%
25	0.363	0.370	0.380	0.398	102%	110%	Hit	Hit	-4%
26	0.459	0.446	0.460	0.460	97%	100%	Hit	Hit	0%
27	0.604	0.597	0.620	0.620	99%	103%	Hit	Hit	-2%
28	0.472	0.470	0.460	0.458	100%	97%	Hit	Hit	2%
29	0.807	0.796	0.780	0.780	99%	97%	Hit	Hit	3%
30	0.124	0.156	0.140	0.141	126%	114%	Miss	Hit	-2%
31	0.414	0.393	0.380	0.380	95%	92%	Hit	Hit	4%
32	0.532	0.521	0.540	0.539	98%	101%	Hit	Hit	-1%
33	0.392	0.375	0.380	0.382	96%	98%	Hit	Hit	1%
34	0.244	0.209	0.220	0.220	85%	90%	Hit	Hit	3%
35	0.619	0.626	0.620	0.621	101%	100%	Hit	Hit	0%
36	0.553	0.547	0.540	0.538	99%	97%	Hit	Hit	2%
37	0.444	0.441	0.460	0.457	99%	103%	Hit	Hit	-2%

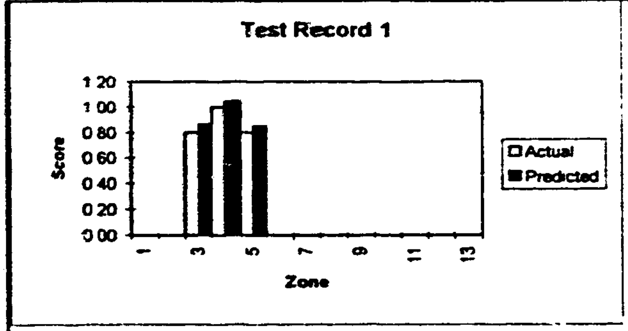
Table C-9 Results Summary Table - Step 4b Test with 20% of Records

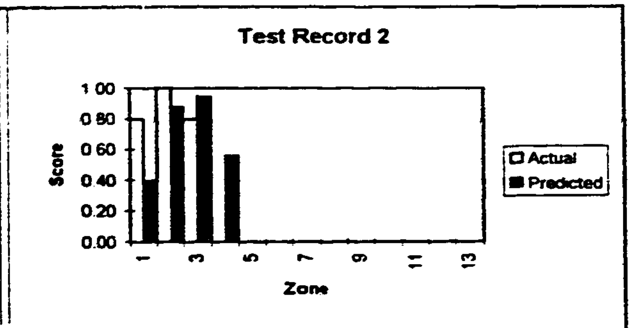
Record	Actual Productivity (AP)	Predicted Productivity (PP)	Weighted Average Actual Productivity (WAAP)	Weighted Average Predicted Productivity (WAPP)	PP/AP	WAPP/AP	PP/AP	WAPP/AP	(WPP-AP)/R
1	0.294	0.212	0.300	0.300	72%	102%	Miss	Hit	-1%
2	0.175	0.144	0.140	0.188	82%	108%	Miss	Hit	-2%
3	0.248	0.133	0.220	0.160	54%	65%	Miss	Miss	11%
4	0.364	0.292	0.380	0.226	80%	62%	Miss	Miss	17%
5	0.319	0.234	0.300	0.252	73%	79%	Miss	Miss	8%
6	0.488	0.550	0.460	0.545	113%	112%	Hit	Hit	-7%
7	0.450	0.457	0.460	0.473	102%	105%	Hit	Hit	-3%
8	0.173	0.173	0.140	0.164	100%	94%	Hit	Hit	1%

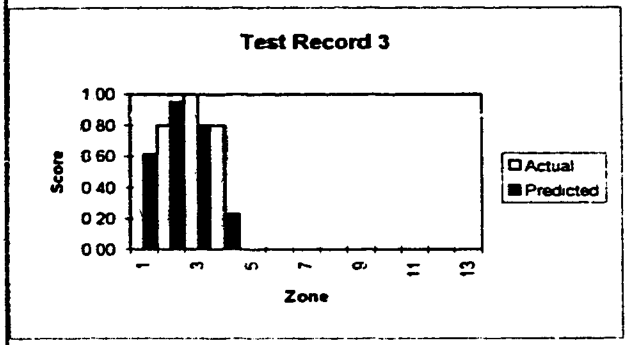
Table C-10 Output Zone Analysis - Step 4b Test with 20% of Records

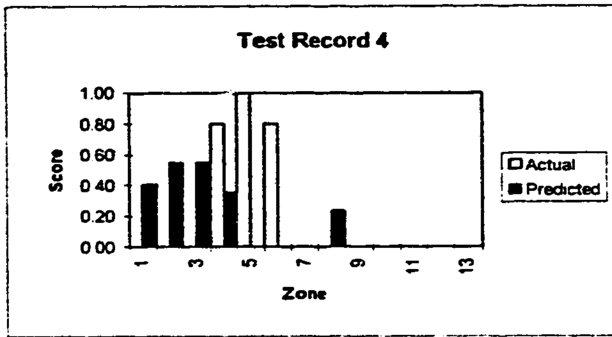
	Record	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12
Actual	1	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	1	0.00	0.00	0.87	1.05	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	2	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	2	0.40	0.88	0.95	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	3	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	3	0.62	0.95	0.80	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	4	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	4	0.41	0.55	0.55	0.35	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00
Actual	5	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	5	0.24	0.30	0.72	0.63	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual	6	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	6	0.00	0.00	0.00	0.25	0.21	0.28	0.66	0.82	0.39	0.00	0.00	0.00
Actual	7	0.00	0.00	0.00	0.00	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00
Predicted	7	0.00	0.00	0.00	0.00	0.55	1.21	1.01	0.00	0.00	0.00	0.00	0.00
Actual	8	0.80	1.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Predicted	8	0.67	0.85	0.82	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

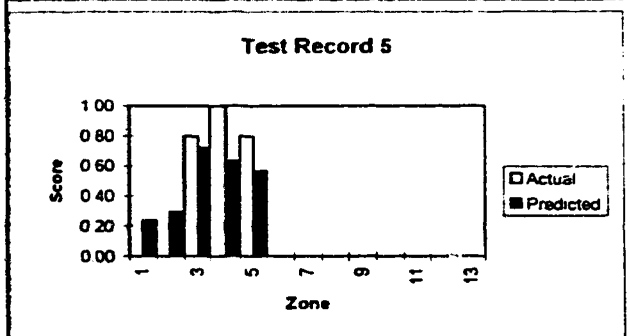
Table C-11 Graphical Output Zone Analysis - Step 5

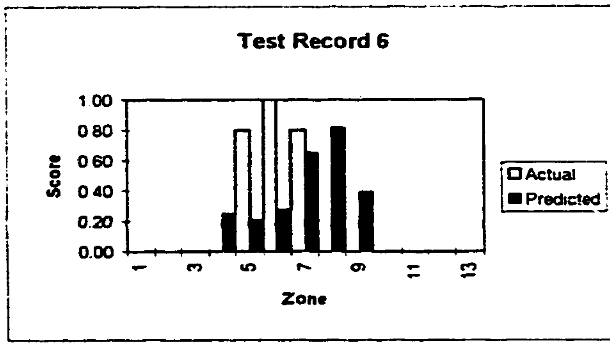


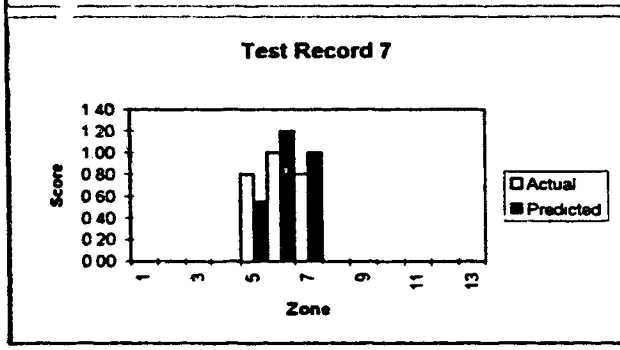


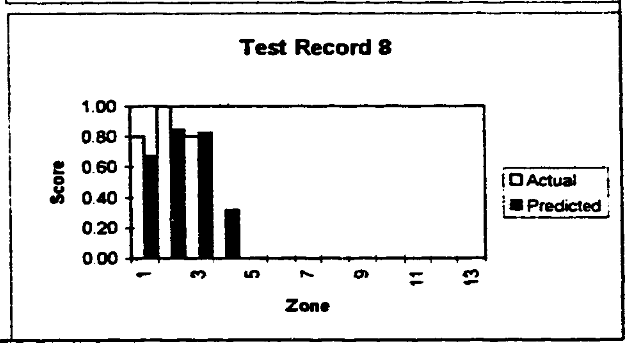












Appendix D Program User Interfaces

The following pages contain examples of user interfaces for the existing application and the new applications.

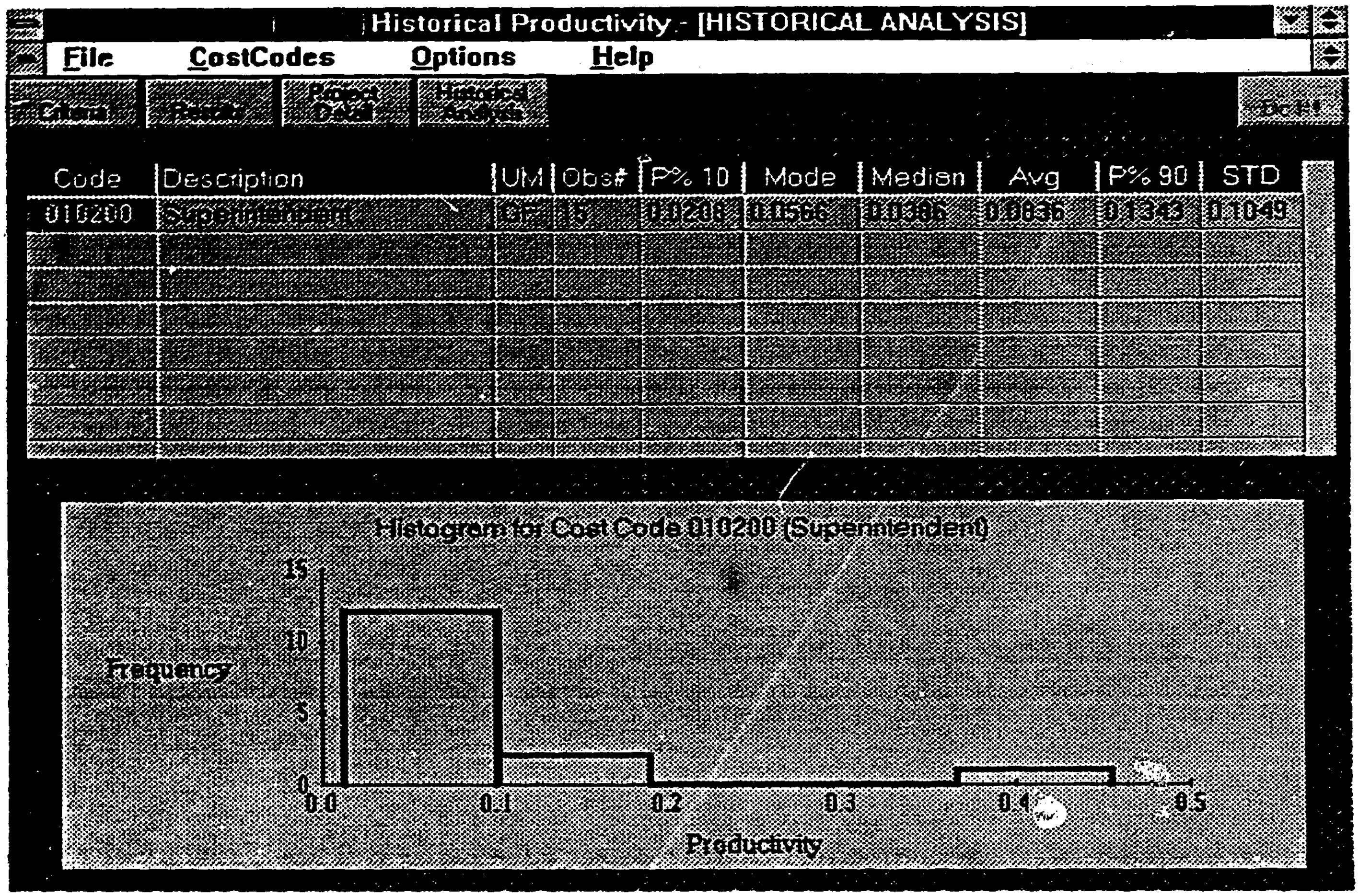


Figure D-1 Historical Productivity Analysis User Interface (Histogram)

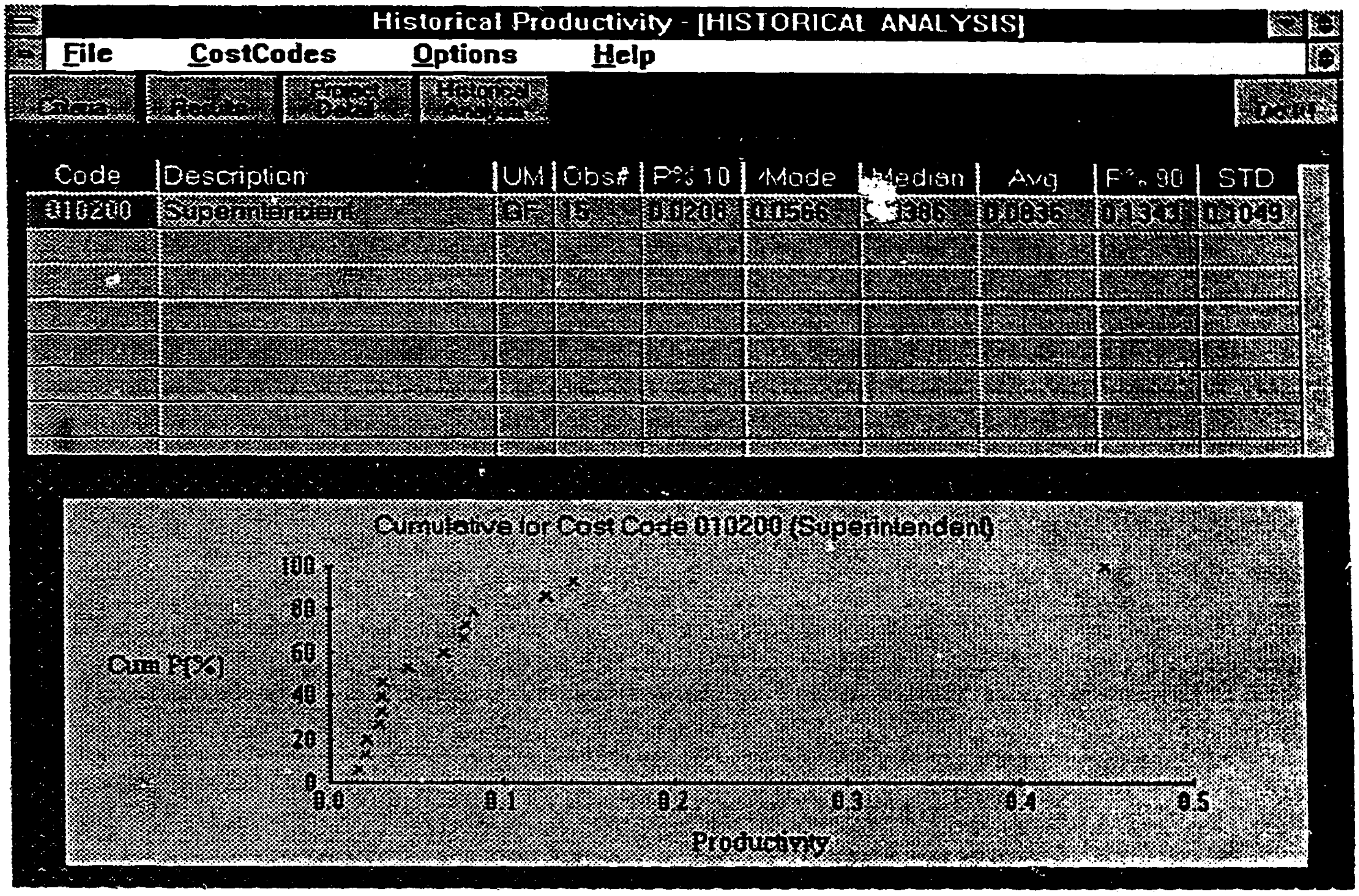
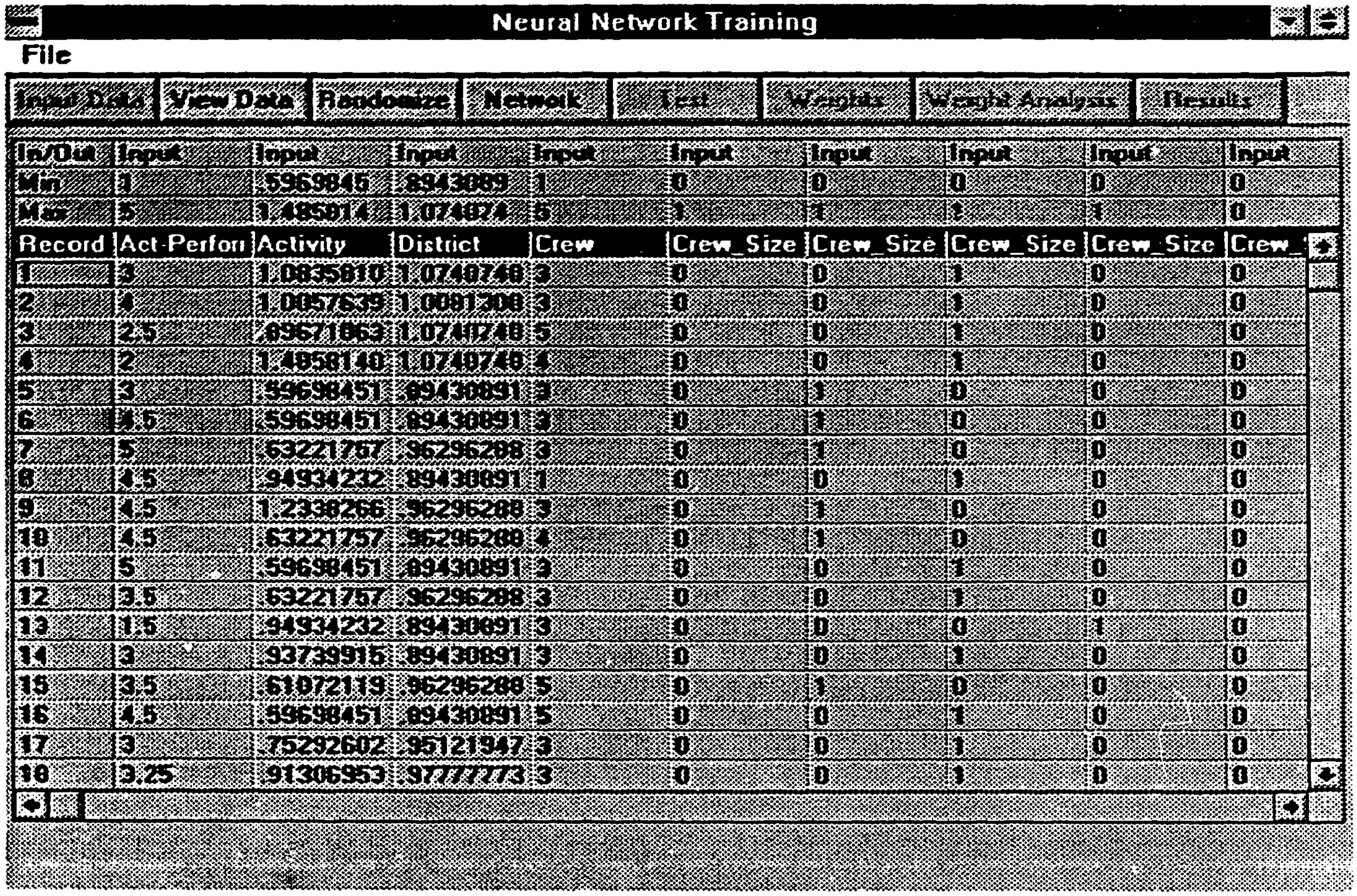


Figure D-2 Historical Productivity Analysis User Interface (Cumulative Density Plot)



Neural Network Training

File

Input Data | View Data | Randomize | Network | Test | Weights | Weight Analysis | Results

In/Out	Input	Input	Input	Input	Input	Input	Input	Input	Input
Min	1	.5969845	.8943089	1	0	0	0	0	0
Max	5	1.485814	1.074074	5	1	1	1	1	0
Record	**Act-Perfon**	**Activity**	**District**	**Crew**	**Crew_Size**	**Crew_Size**	**Crew_Size**	**Crew_Size**	**Crew_**
1	3	1.0835810	1.0740740	3	0	0	1	0	0
2	4	1.0057639	1.0081300	3	0	0	1	0	0
3	2.5	.89671063	1.0740740	5	0	0	1	0	0
4	2	1.4858140	1.0740740	4	0	0	1	0	0
5	3	.59698451	.89430891	3	0	1	0	0	0
6	4.5	.59698451	.89430891	3	0	1	0	0	0
7	5	.63221757	.96296288	3	0	1	0	0	0
8	4.5	.94934232	.89430891	1	0	0	1	0	0
9	4.5	1.2338266	.96296288	3	0	1	0	0	0
10	4.5	.63221757	.96296288	4	0	1	0	0	0
11	5	.59698451	.89430891	3	0	0	1	0	0
12	3.5	.63221757	.96296288	3	0	0	1	0	0
13	1.5	.94934232	.89430891	3	0	0	0	1	0
14	3	.93739915	.89430891	3	0	0	1	0	0
15	3.5	.61072119	.96296288	5	0	1	0	0	0
16	4.5	.59698451	.89430891	5	0	0	1	0	0
17	3	.75292602	.95121947	3	0	0	1	0	0
18	3.25	.91306953	.97777273	3	0	0	1	0	0

Figure D-3 Neural Network Experimentation Program - Data View/Edit Screen

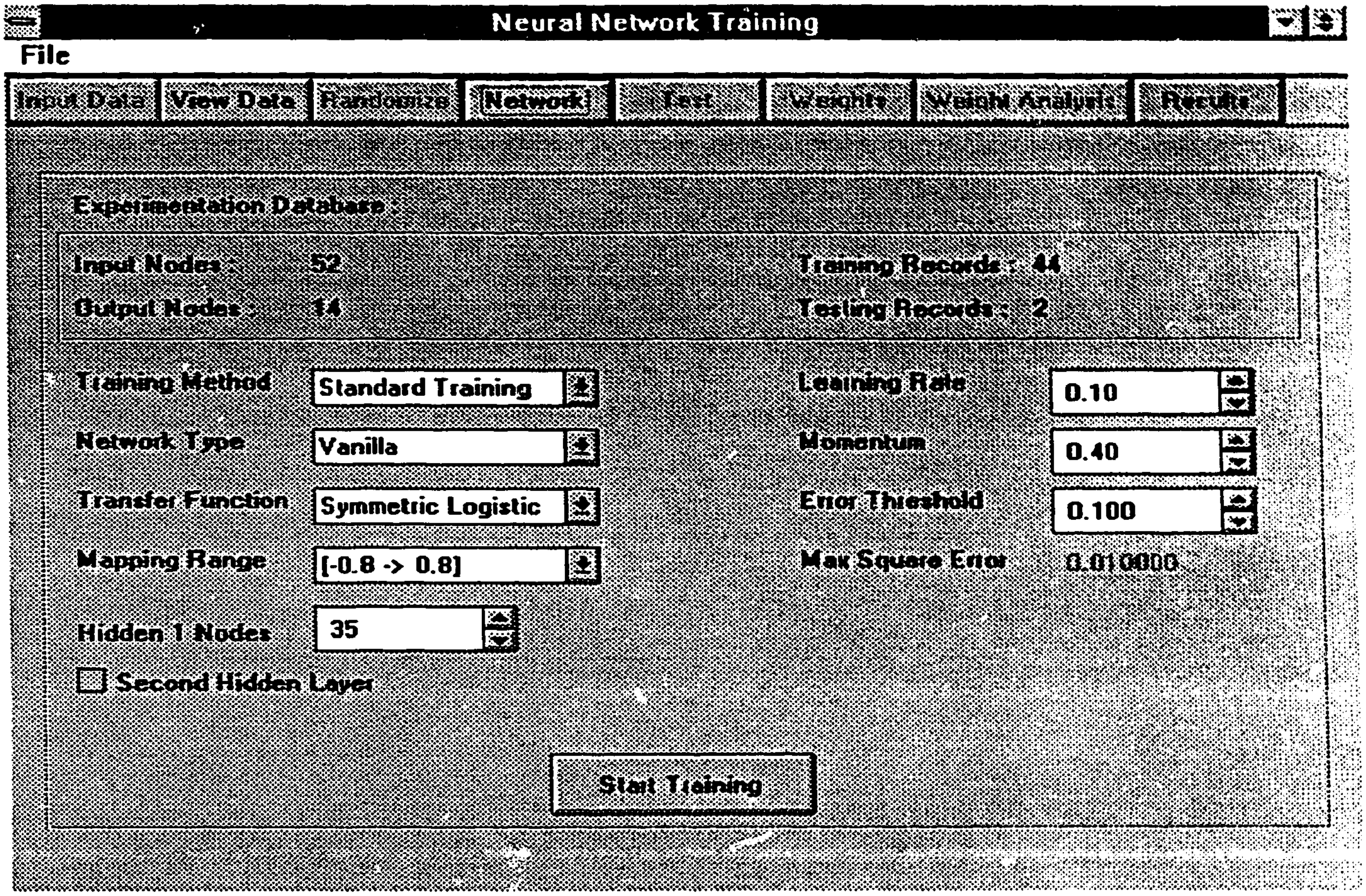


Figure D-4 Neural Network Experimentation Program - Neural Network Setup Screen

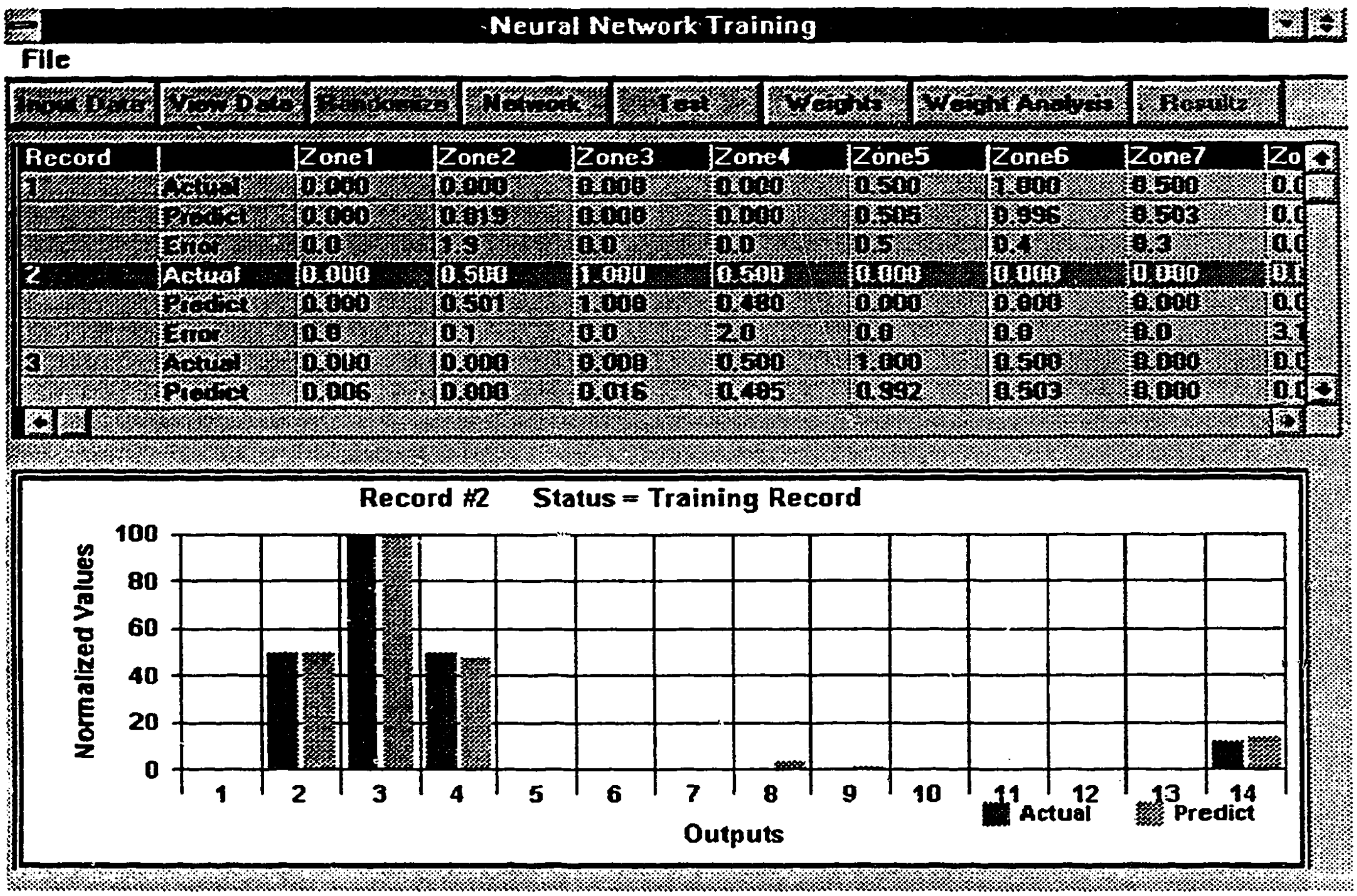


Figure D-5 Neural Network Experimentation Program - Results Screen

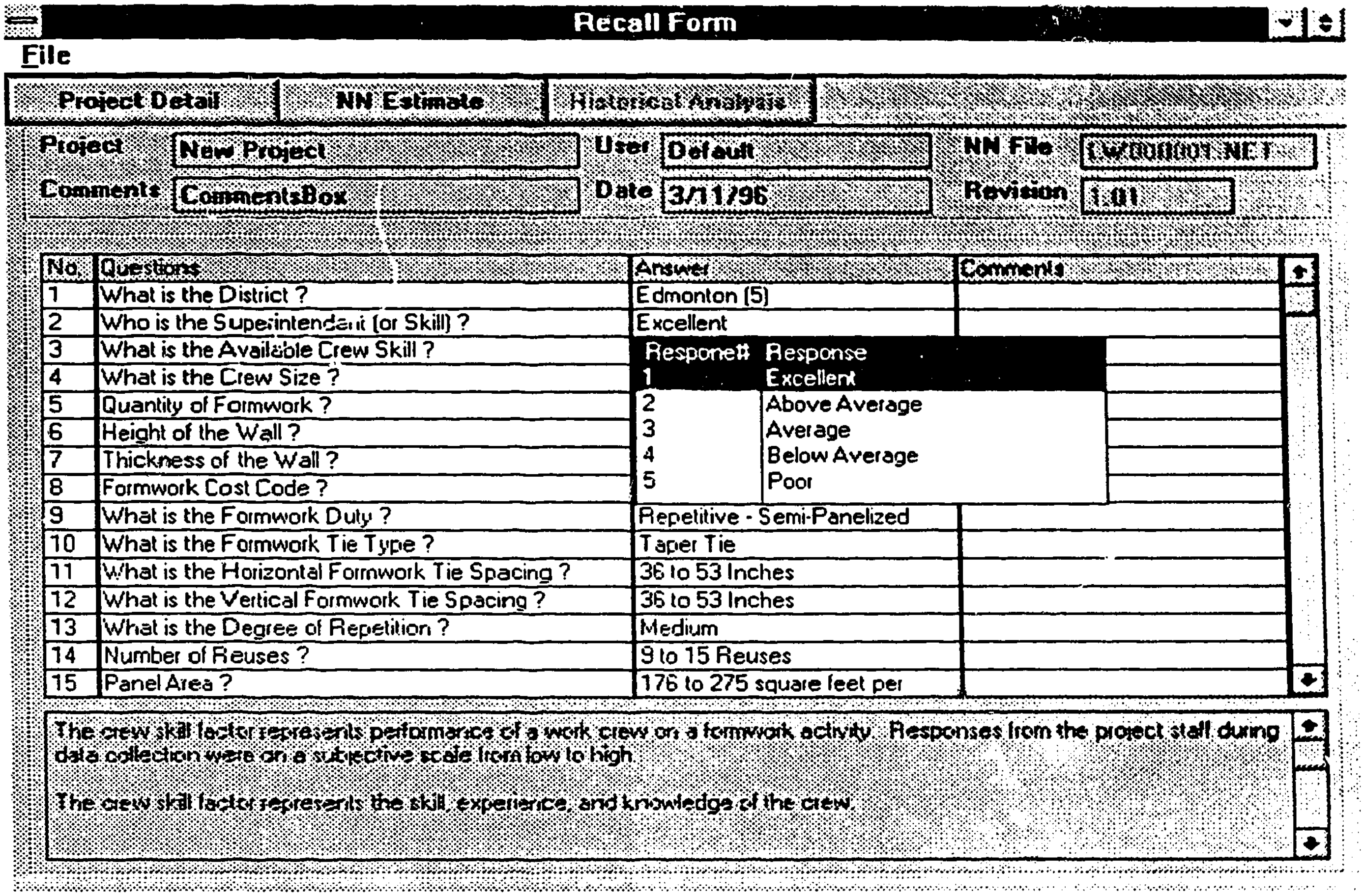


Figure D-6 Neural Network Historical Productivity Module - Factor Specification Screen

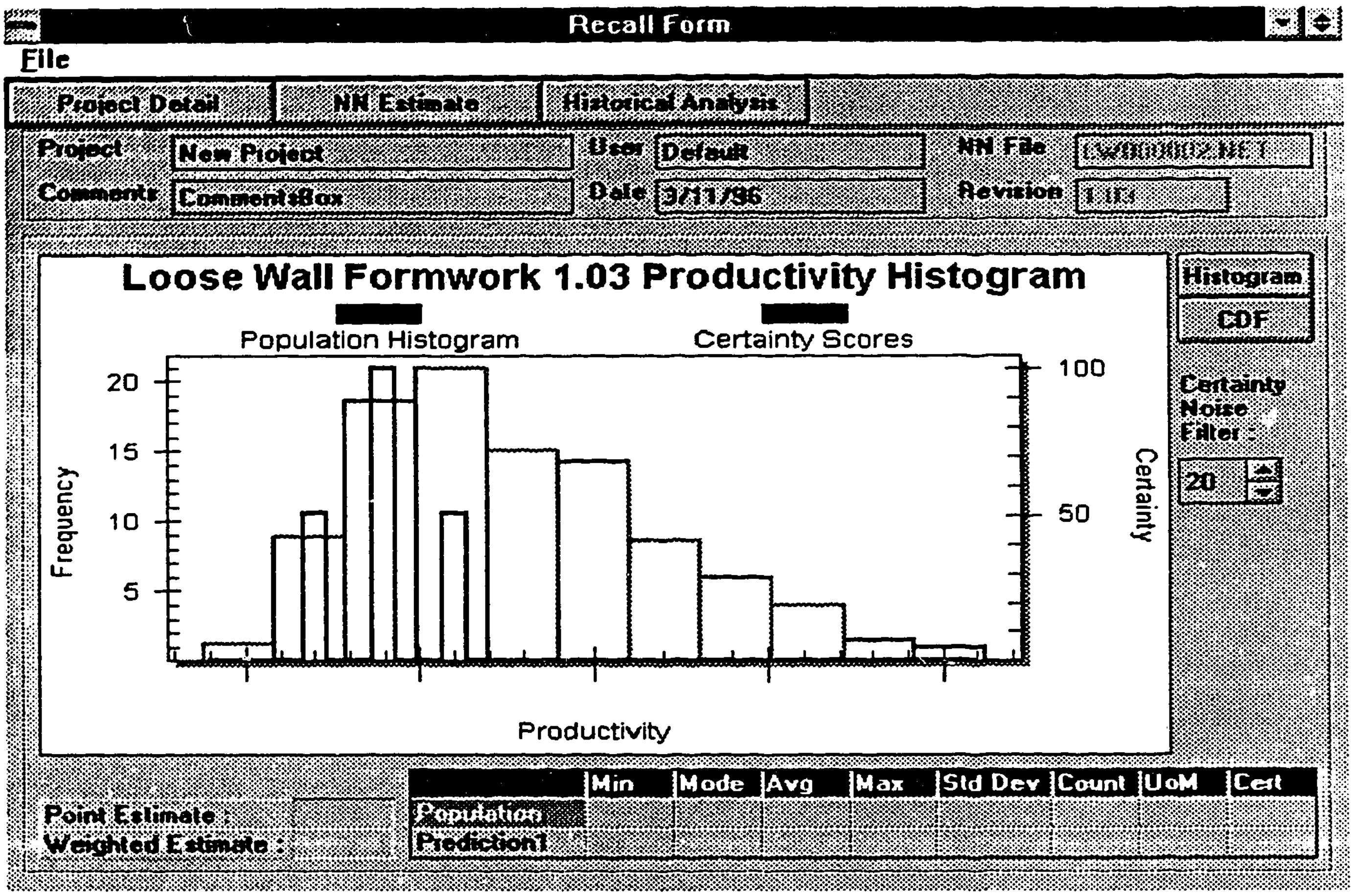


Figure D-7 Neural Network Historical Productivity Module - Analysis Screen