OPTIMISATION OF STRATEGIC DECISIONS IN MAINTENANCE JOBSHOPS

BY

KAREEM, SULIAMINU

(B.Eng., M.Eng. Akure)

MEE/88/1488

A THESIS IN
THE DEPARTMENT OF MECHANICAL ENGINEERING
SUBMITTED TO
THE SCHOOL OF POSTGRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD
OF DOCTOR OF PHILOSOPHY (PhD) IN MECHANICAL ENGINEERING
(INDUSTRIAL ENGINEERING OPTION)
THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, NIGERIA

SEPTEMBER, 2004

CERTIFICATION

We certify that this thesis was the work of Kareem, Buliaminu in the Department of Mechanical Engineering, School of Postgraduate Studies, Federal University of Technology, Akure, Nigeria, and to the best of our knowledge it has not been submitted elsewhere for the award of any degree.

Prof. A. A. Aderoba
Major Supervisor

B. Kareem
Project Student

DEDICATION

Dedicated to:

The Owner of the heavens and earth and whatsoever it contains.

My Parents – Mr. & Mrs. Abdul-Kareem and well wishers.

ACKNOWLEDGEMENT

I thank Allah, the Owner of the heavens and earth and, the Cherisher, the Sustainer of whatsoever it contains for making this work a reality.

"Whosoever unthankful to people will be unthankful to God". My profound thanks go to my able Major Supervisor and Head of Department of Mechanical Engineering – Prof. A. A. Aderoba for his invaluable advice, thorough supervision and for painstaking to read through and correct this thesis. I also express my gratitude to my Minor Supervisor – Dr. O. P. Fapetu for his support and useful suggestions.

I owe a special debt of gratitude to the entire staff of the Department of Mechanical Engineering and Prof. C. O. Adegoke, Dean, School of Engineering and Engineering Technology for his support.

I also acknowledge the assistance rendered by the management and staff of various maintenance centres and industries in Nigeria in obtaining necessary data/information used in this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The study has developed an integrated set of algorithms, heuristics and models for optimising maintenance service demand, crew Gang, maintenance tools/equipment, personnel interaction, spare parts inventory, job scheduling and costing, which are strategic in the establishment and running of a maintenance jobshop. The model was developed using an encompassing single-channel, multi-server queueing system. The developed package named **Computer Aided Maintenance Strategic Decisions Optimisation and Planning (CAMSOP-2003)** was validated with Akure, Osogbo, Ibadan, Ajaokuta and Lagos in Nigeria as case studies. Nonetheless, the database and structure of the software is flexible but robust enough to accommodate as many jobshops/cities as the storage capacity of the computer allows. The software always facilitates a comparison of alternative methods of carrying out maintenance functions. Besides, post-optimality analyses such as benefit-cost and sensitivity analyses were done to determine the most cost-effective maintenance policy and to recommend effective service rates for various service demands.

NOMENCLATURE

N_{it}, total number of industrial machines in plant i

G_{it}, age of plant i at time t (in yr.)

n_t, number of maintenance centres within the operating region

θ_t, proportional constant between the arrival rate and the influencing factors.

N_m, number of errors obtained.

e_t, forecast error at period, t

α, smoothing parameter

θ_{t+1}, forecast factor at period, t+1 (yr.)

λ_{t+1}, forecast at period, t+1 (yr.)

a, the value of the forecast θ_t when period, t is equals zero

b, slope of the forecasting trend line

t, period at which forecast is made (yr.)

S_t, smoothed level for linear trend

T_t, smoothed trend for linear trend

α_1, smoothed parameter for level

α_2, smoothed parameter for trend

S^h_t, smoothed level for non-linear trend

T^h_t, smoothed trend for non-linear trend

β, trend modification parameter.

MSE, Mean Square Error

ω, is the change in maintenance centre in the following year.

F (a_t), random number in the range 0< F (a_t)<1 for arrival time.

K, proportionality constant which is equivalent to number of jobs served.

t_{en}, expected service time (wk.).

γ, Change in maintenance personnel

P, number of maintenance personnel in a crew (gang size)

Ω_{nt}, the utilization factor for maintenance policy, n at a given period t.

λ_t, arrival rate of jobs to maintenance centre at a given period, t (/wk.)

μ_{nt}, service rate for maintenance policy, n at a given period, t (/wk.)

S_{nt}, the crew Gang for maintenance policy, n at a period, t

W_{qt}, average waiting time for the jobs on queue for maintenance policy, n at a period, t (wk.)

W^{*}_{ip}, average acceptable waiting time of customers for each policy (wk.)

nq, total number of jobs in queue

a_i, cumulative arrival time from time $t = 0$ (wk.)

clock, previous cumulative value of time before the next event (arrival or departure) (wk.)

twt, total waiting time of jobs (wk.)

s_i, cumulative service time of maintenance calls (wk.)

$F(s_i)$, random number in the range $0 < F(s_i) < 1$ for service time

.tidt, total idle time of maintenance crew (wk.)

tnn, total number of maintenance call

etm, total engage time of maintenance crew (wk.)

Q_{nt}, the number of set of tools/equipment required for maintenance policy, n at period, t (yr.)

ψ_{an}, set of tools required to pustain for maintenance policy, n

ξ, change in tools/Equipment

N_m, optimum number of units (spare parts) per order

λ_{ri}, receipt rate (that is, units received in a given period) or supply rate (/wk.)

λ_{u}, use rate (in unit) in a period (/wk.)

Y, annual usage of the spare part in units (/yr.)

p, ordering cost of the spare part per period ((#/wk)

t_u, use time of the spare part (wk.)

$F(t_u)$, random number between 0 and 1 for use time

t_r, receipt time of the spare part (wk.)

$F(t_r)$, random number between 0 and 1for receipt time

ns, number of spare part in stock

tst, total stock time of spare part (wk.)

tost, total out of stock time of spare part (wk.)

mns, maximum stock capacity

N_o, optimum number of order per period (/wk.)

T_o, optimum time per order (wk)

S_{ie}, optimum number of crew

N_p, number of interactions

y, change in crew gang

P_{ij}, the level of interaction of personnel i to other personnel j in the group

P_w, weighted value of interaction for each personnel

tmt, $TC(S_{it})$, total maintenance cost (#)

C_l, average cost of a maintenance gang per unit time (#/hr.)

C_u, the utility cost per period of a crew Gang engagement (#/hr.)

C_l, cost of electricity per period of a crew Gang engagement (#/hr.)

C_w, cost of water used by a crew Gang per period (#/hr.)

C_a, Tools/equipment maintenance cost at a given period (Yr.)

σ, Failure rate of the maintenance equipment (/Yr.)

C_c, cost of communication in a crew interaction per period (#/min.)

i, interest rate (%), and

s, inflation rate (%).

d_p, depreciation rate on tools/equipment (%)

P_p, cost of maintenance week performance index (#/wk)

∂A_{nj}, incremental cost of switch over from one maintenance policy, n-1 to another, n when a full-time/permanent staff j is engaged (#)

∂A_{ni}, incremental cost of switch over from one maintenance policy, n-1 to another, n when a full-time/permanent staff i is engaged (#)

BCR_j, Benefit-Cost Ratio for contract staff

BCR_i, Benefit-Cost Ratio for full-time staff

$\bar{\gamma}$, Adekar factor or Reduction Coefficient

CHAPTER ONE

1.0 INTRODUCTION

Economic development of any country depends on how best she is maintaining its rival and non-rival infrastructure facilities (Deparkar, 1999). Electricity, roadways, transport services, telecommunication etc. which individuals are free to use seem to satisfy the property of non-rivalry while most of industrial production machines and ancillary equipment which require some protocols before individuals can use it (in form of goods and services) fall under rival facilities. The response rate to these rival facilities depends on how effective they are in the production of goods and services. As a result of this, effective maintenance of these facilities is necessary to keep them in operable condition.

Generally, productivity of any sector depends on how well her infrastructures are maintained. A well maintained facility will not only ensure minimum waiting time in the production process but will also promote efficiency (Felix, 1999). Therefore, in developed countries, a colossal sum of money had been spent on maintenance of facilities to keep them in operable condition so that man-hour loss will be reduced to a minimum (Ray, 1979). In developing countries most of the maintenance departments set up by privately or publicly owned companies are not effective enough to properly execute all categories of repairs and maintenance. Their works are limited to routine maintenance. Therefore, to improve maintenance culture, there is a need to establish maintenance centres where all categories of repairs can be executed at minimum cost and maximum efficiency. To achieve this, maintenance personnel with experience and high level of skills must be available (Bourn, 1989, IHUPDS, 2004) or , if not, tangible vocational training programmes should be established to get these maintenance skills (Mwewa, 1999) or a foreign manpower planning consulting firm should be contacted (ORM, 1992; SPMC, 2003). Such maintenance centres will be viable only if they can establish reasonable response rates. Management of such centres can achieve this by proper costing and scheduling of repair jobs so that they can meet up the due dates. This entails having the requisite facilities. Besides, computer software application (Alhamdan, 2003) and software aid (MacMillian et al, 1998) will also assist in this direction.

Researchers have done a lot in the establishment of sustainable maintenance systems. Majority of their works are based on in-house maintenance system evaluation, and their evaluations are unilateral (that is, evaluating one strategic decision). Among them are Richard (1976), Priel (1974), Tacaks (1976), Olorunniwo (1989) and Michael (1996). The following factors/constraints among others are inhibiting effective maintenance operations in Nigeria industries (Lawal and Adeyemo, 2002, Offiong and Okokon, 2003, Lawal, 2000 and Inegbenebor and Adeniji, 2002):

(i) Inadequate spare parts,

(ii) Budget allocation,

(iii) Maintenance equipment and tools,

(iv) Incompetent maintenance staff,

(v) Transportation,

(vi) Epileptic power supply,

(vii) Incentive scheme,

(viii) Job documentation, and

(ix) Workspace and security

To improve the situation, Kareem and Aderoba (2003) streamlined these constraints by assessing it along the line of category of maintenance jobshops (a centre where industrial machinery and other infrastructural facilities are restored to operable condition), for easy identification of critical decision(s) or strategic decisions (the decisions that influence or determine the effectiveness, efficiency or sustainability of a system) that need immediate attention. However, Aderoba and Lawal (1997) discussed various strategic decisions often made in maintenance planning and suggested optimization procedures. This study, deals with improvement, integration and practical implementation of the strategic decisions suggested in Aderoba and Lawal's work.

1.1 Essence of Maintenance

In many sectors of industry, maintenance has been regarded as an activity, which needs to be carried out in a planned way (Andrew *et al*, 1996). Maintenance is so important that in U.K., national expenditure on maintenance is about 5% of the value of the sales of goods and services which exceeds the amount invested in new plant and equipment. Modern management practice regards maintenance as an integral function in achieving efficient and productive operation, high quality products and high levels of equipment reliability. Therefore, the need for maintenance in most engineering operations is self evident. Without maintenance the plant and equipment used will not survive over the required life of the system without degradation or failure. The design and operation of a maintenance system must usually meet one of two objectives:

(i) Minimize the chance of failure and

(ii) Minimize overall cost or maximize overall profit of an operation. This requires striking a balance between the cost of setting up and running the maintenance operation and savings generated by increased efficiency, prevention of downtime, etc.

1.2 Plant Deterioration and Failure

Plant deterioration and expected failure rate, H(t) is fundamental to design of a maintenance operation. The failure rate [or hazard rate, H(t)] for components, equipment or plant is normally expressed in failure per hour (or failure per thousand or even per million hours).

This failure rate can be taken as synonymous to the rate of need of maintenance service or arrival rates of maintenance job. The figures represent an average for the type of equipment and the expected number of failures in any time period can only be expressed in terms of probabilities.

Three phases may be observed during the life of a component, although in practice the boundaries are often unclear or ill defined. In the first phase, the failure rate is initially high but it reduces over a short time. Failures in this phase are due to flaws and weakness in material or faults in manufacture. The wear-in characteristics have implications on the provision of warranties for new equipment, but of greater significance is that it will result in a high initial failure rate. Second phase is the useful-life phase; the failure rate is low and approximately constant, representing random failures. The length of this phase sometimes referred to as durability varies with the type of equipment. In this phase the Mean Time to Failure; (MTTF) is the reciprocal of the (constant) failure rate. The third phase, called the wear-out phase, the failure rate increases due to ageing, wear, erosion, corrosion and related processes. The rate at which the failure rate increases varies with the type of equipment. Wear-out has an influence on maintenance policy. If an item has distinct wear-out characteristics it can be replaced before failure is likely to occur. For example, the break pads on a car has a distinct wear-out characteristics, therefore it can be replaced before the actual failure. Three phases of failure are shown in Fig 1.1a which represents failure rate of electrical components.

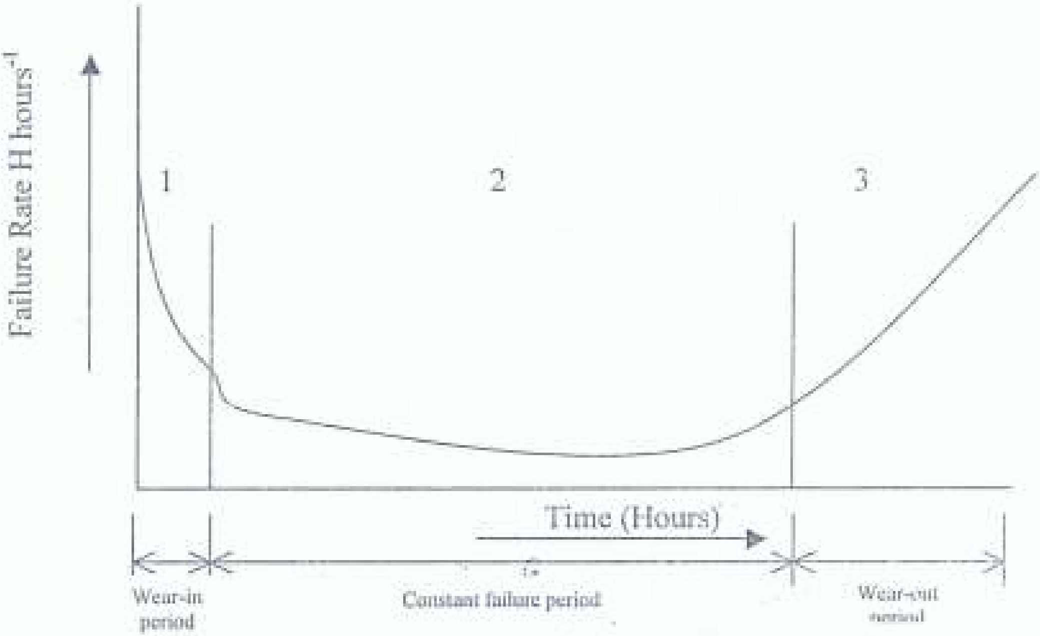


Fig. 1.1a: General Form of Failure Rate –The Bathtub Curve

Source: Andrew et al, 1996

Reliability, R(t) on the other hand, is the probability that an item will perform a required function without failure under stated conditions for a stated period of time. It is related to failure rate by the relation $R = e^{-(Ht)}$-where H is failure rate and t is time. When the equipment is new the reliability is high, and eventually it will tend to zero (when in use), as all engineering systems will eventually fail or deteriorate to such an extent that they can no longer perform their intended functions. Fig. 1.1b shows typical reliability functions. The area beneath the reliability curve is the Mean Time to Failure (MTTF) of the item.

Published data sources generally give failure rate figures for phase 2 of the failure rate curve. Data on wear-in and wear-out characteristics are often not available (Andrew et al, 1996).

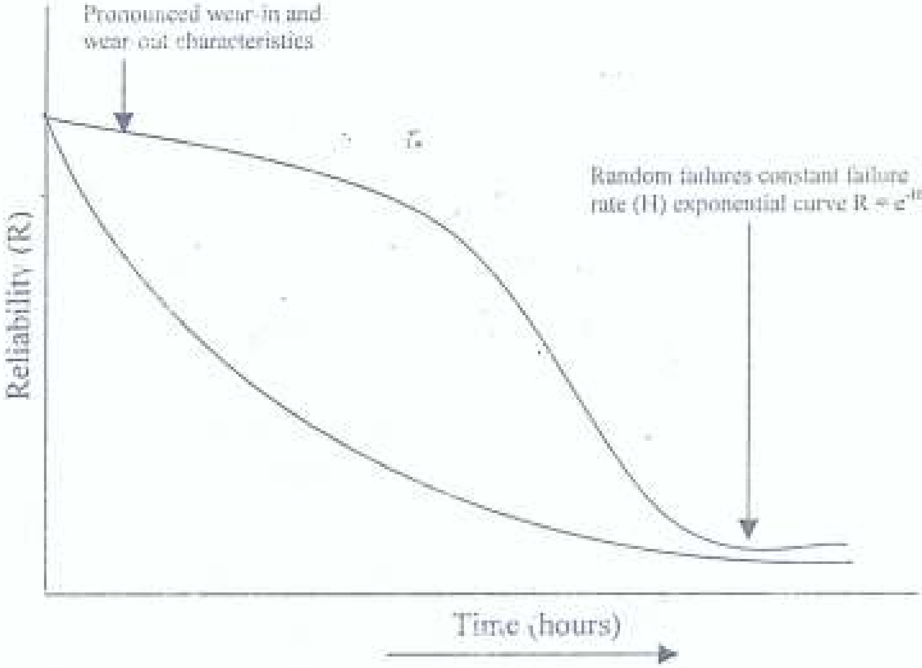


Fig. 1.1b: Reliability curve

Source; Andrew et al, 1996

1.3 Scope of Study

Generally, industrial machinery can be grouped into five. These groups are production machinery, ancillary equipment, materials handling equipment, transport equipment and office equipment. Production machinery such as lathes, milling machines, grinders and many other special purpose production machinery in manufacturing sectors as diverse as textiles, automobile, food processing, agricultural machineries, oil exploration, refineries, marines, aeronautics etc., are directly required for manufacturing. These set of machineries are the most critical and contributes most to the productivity of an industry. Efforts at reducing machine down time (waiting time) are often concentrated on this set of machineries. Therefore, commercial maintenance centres have roles to play in reducing these down times the more, to enhance productivity of the industries through establishment of effective response rate.

Ancillary equipment such as generators, compressors, ventilation equipment, blowers etc., are not directly engaged in manufacturing but are supportive of the process. Generally, the breakdown of ancillary equipment may not result in stoppage of production but may reduce productivity. The effort towards getting the latter set into operable condition is lower as compared with the former. This set of equipment is expected in commercial industrial maintenance centre after a fruitless effort in restoring it back to operable condition in the in-house maintenance department. Sometimes, these equipment could be hired pending the time the solution is found for faulty ones. Standby replacement for standard items and repair of damaged parts strategy could improve maintenance of these equipment. Therefore, patronage of these equipment are fairly critical in maintenance centre. On the other hand, materials handling equipment are also ancillary but are more critical than general ancillary machines in that production may stop if these sets of equipment are not operable. In this category a specialised maintenance centre is also required for the repair to reduce down time (waiting time).

In case of office equipment such as personal computers, typewriters, photocopiers etc., and transport equipment, such as trucks, cars, buses, etc., many industrial establishments tend to contract these equipment out (Ikhwan and Burney, 1994). The maintenance services of the last two sets of equipment are widely available and competitive in most of both developed and developing countries (Ray, 1979, Ikhwan and Burney, 1994)). Hence, there is no grave anxiety over the maintenance of these sets in many industries. The area of critical need is often in the categories of production machineries, ancillary equipment and material handling equipment for which specialised industrial maintenance centres are required (Table 1.1).

This study focused on the optimisation of the strategic decisions stated in sections 1.5 and 1.6 for effective planning of maintenance of industrial machinery in maintenance jobshops.

Table 1.1: Categories of Industrial Machinery

Categories	*Examples*
(i) Production machinery	Lathes, milling machines, grinder, extruders, planners, etc.
(ii) Ancillary equipment	Generators, compressors, ventilation equipment etc.
(iii) Material handling equipment	Forklifts, conveyors, hoists etc.
(iv) Transport equipment	Trucks, trailers, lorries, etc.
(v) Office equipment	Personal computers, typewriters, photocopiers, shredding machine etc.

1.4 Interrelationships Between Maintenance Policies and Industrial Machinery

The established specialized industrial maintenance centre should be capable of diagnosing the following maintenance problems:

(i) Preventive maintenance, which involves inspection, periodic changes of running parts, such as fuses, bearing etc, adjustments of machines and alignment tests.

(ii) Repair activity, which involves change of damaged parts and components such as gears, shafts, pulleys, belts, electric motors, etc.

(iii) Overhaul, also involves total replacement of the moving parts, machine realignment and testing.

However, maintenance departments should be capable to execute all forms of routine maintenance activities. The interrelationships between types of industrial machine, mode of maintenance and the expected sector where the diagnoses should be done is given in Fig.1.2

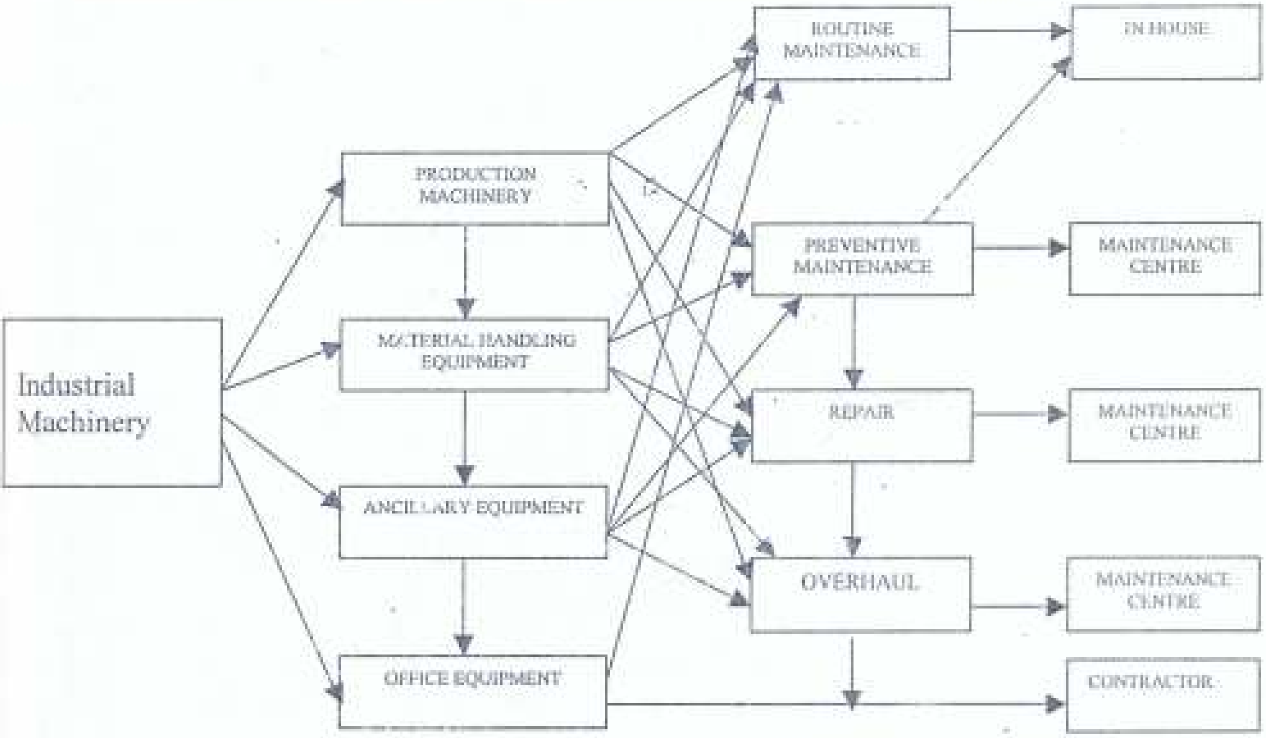


Fig.1.2 Interrelationships Between Maintenance Policies and Industrial Machinery

Also, the type of maintenance policy employed determines the extent of tools/equipment procurement for maintenance activities. For instance, preventive maintenance and general repairs may require general maintenance tool kits, electrical maintenance tool kits, portable tools and equipment, inspection equipment, while in heavy repairs and general overhaul, filters' benches, metal fabrication units and drafting departments may be included.

1.5 Strategic Decisions in Maintenance Jobshops

The decisions that influence or determine the effectiveness, efficiency, or sustainability of maintenance jobshops are termed strategic decisions. The following strategic decisions are often made in maintenance planning:.

i. Service demand forecast.

ii. Crew size determination.

iii. Tools and equipment planning (degree of capital investment).

iv. Spare parts planning and level of stock to be maintained.

v. Maintenance scheduling (operations planning)

Appropriate and effective decision must be taken for effective operations of the maintenance centre. Fig. 1.3 shows the interrelationships between these aforementioned strategic decisions.

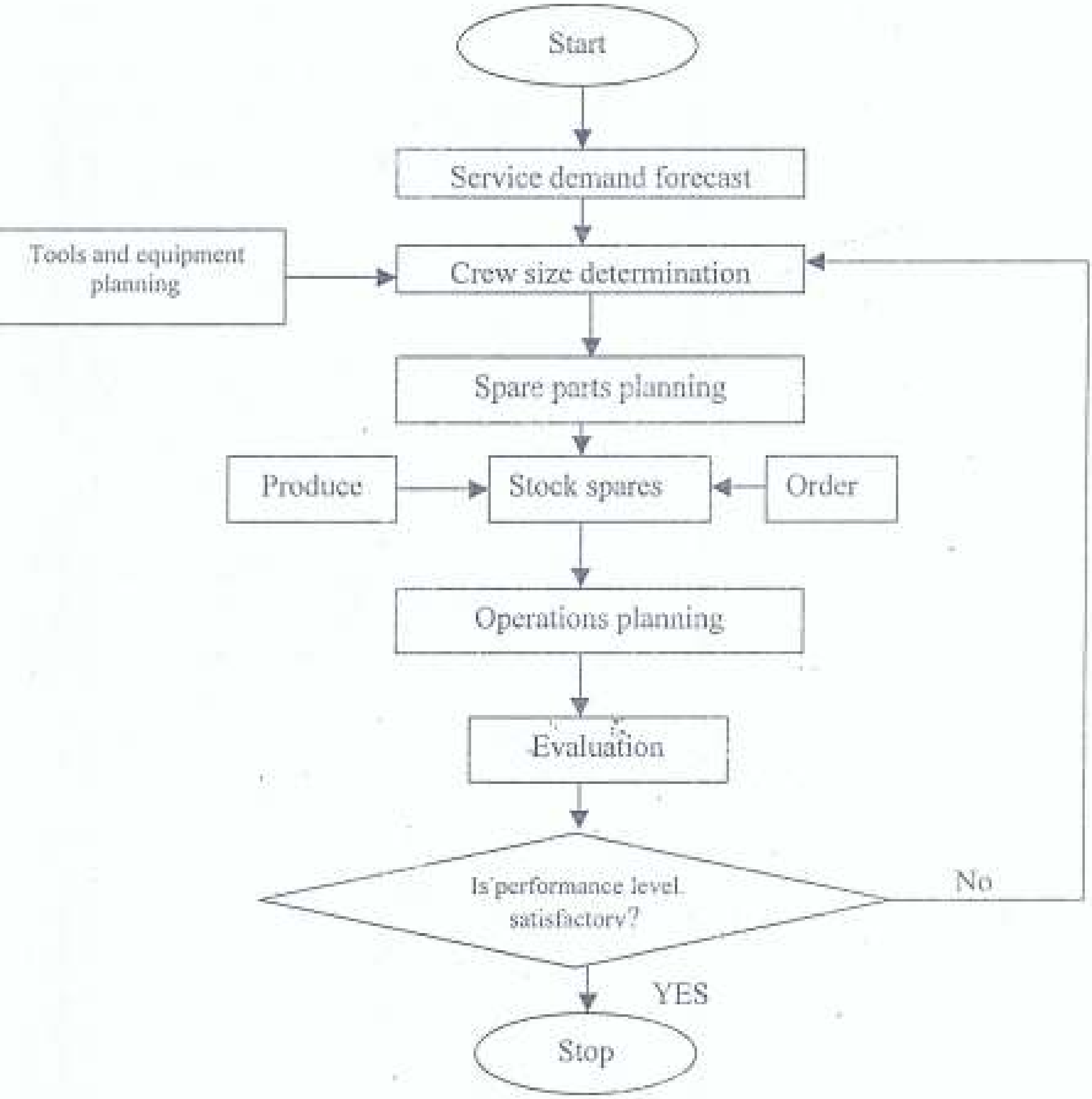


Fig. 1.3: Interrelationship between strategic decisions
Source: Aderoba and Lawal (1997)

1.6 Modification to the Strategic Decisions Interrelationship

Based on the literature survey, it was noticed that one could quantitatively assess the communication effectiveness between crews or maintenance personnel. Therefore, communication planning, which is very vital to effective operation of maintenance system could be introduced to the interrelationship. Communication is a process by which information and data are passed between individuals and/or groups by means of media (symbols or codes understood by both transmitter and the receiver and could include words, written or spoken) and channels (the means through which information are passed such as radio, memorandum, newspaper, GSM, NITEL, etc. Communication planning entails searching for simple and most cost effective communication channels(s) that allow(s) easy feedback, and/or the personnel that controls/influence the information/interaction in the gang. To achieve this goal, communication must be well planned between maintenance personnel. The modified chart is shown in Fig. 1.4.

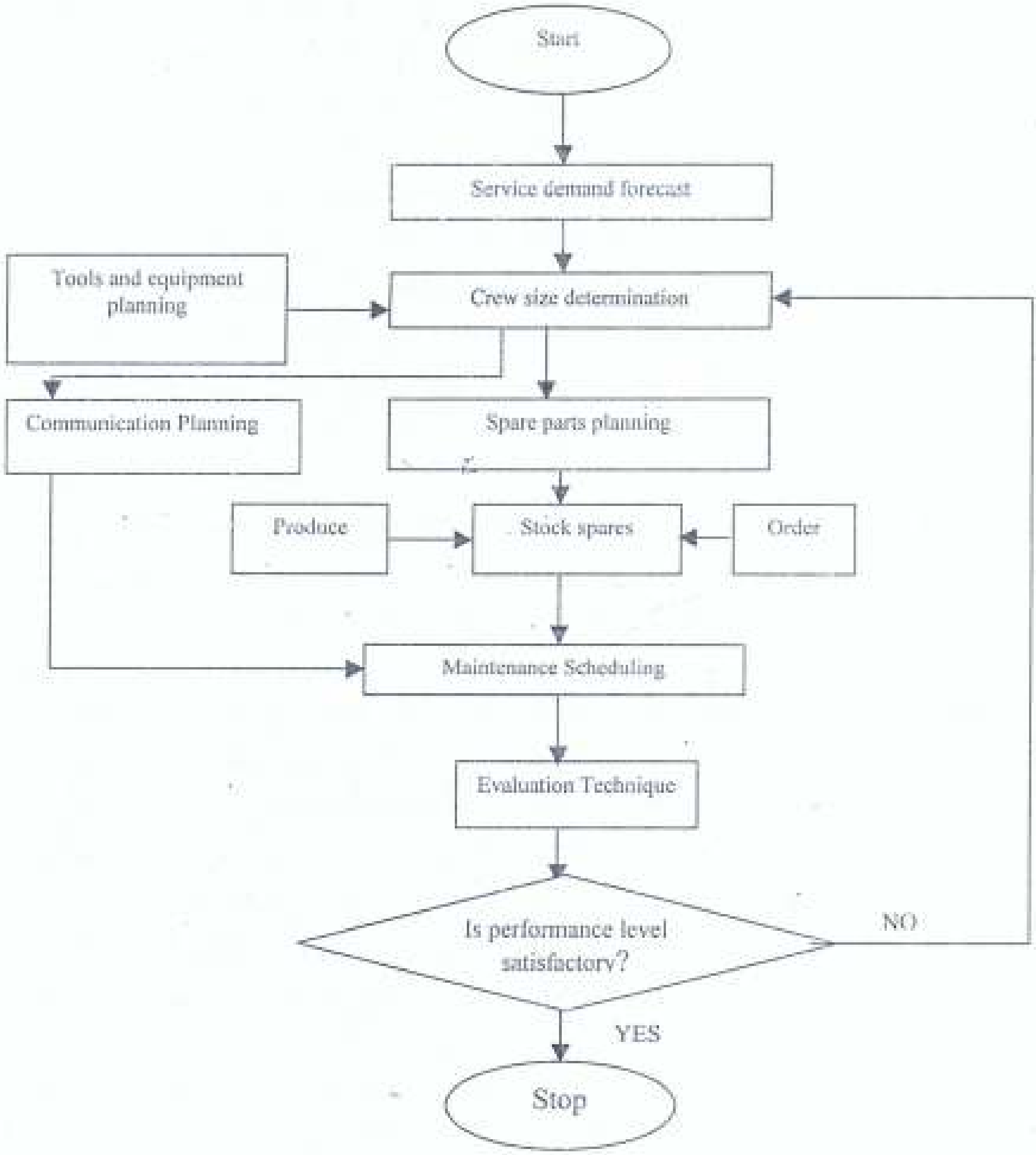


Fig. 1.4: Modification to the Strategic Decisions Interrelationship

1.7 Significance of Optimising Strategic Decisions

Problems of wrong decision making in maintenance management are evidenced both in developed and developing worlds. But concerted efforts put in solving these problems in the former are better than in the latter (Ray, 1979). In developing countries in which Nigeria is one, slow pace of maintenance improvement has caused a lot of havoc to industrial development, which directly affects the economy. Hence, the optimisation of aforementioned strategic decisions will give a green light to the dwindling maintenance jobshops operating locally or abroad as to how to operate effectively, efficiently and profitably. The effectiveness of maintenance operation could be further enhanced by providing a framework that integrates the strategic decisions and by developing a software program to satisfy the present need of computer technology.

1.8 Scope of Maintenance Jobshop Services

Maintenance jobshop is a centre where defective machineries, equipments and other facilities are brought back to operable condition. Maintenance jobshop services entail: road maintenance (this involves maintenance of roads, culvert, drainage, etc.); sewage maintenance (it involves maintenance of sewage, refuse, etc.); electrical/electronics maintenance (its services involves maintenance of electrical and electronics appliances and facilities such as computers, television set, radio set, etc.); structure maintenance (its services cover maintenance of buildings and its facilities such as plumbing, air-conditioning system, fridge and general facilities maintenance); automobile maintenance (its services deal with maintenance of various brands of automobiles such as lorries, forklifts, buses, cars, etc); and industrial machinery maintenance (which covers the maintenance of industrial machinery and equipment such as lathes, milling, grinding machines, etc.).

Examples of Maintenance jobshops are Federal Road Maintenance Agency (FERMA), John Holt Engineering Limited, Lagos, Leventis Power System Limited, Lagos, L. W. Lambourn Limited, Lagos, Afolabi Dehinde Maintenance Shop, Akure, Focus Engineering Limited, Akure, Joe Mike Engineering Services Osogbo and Fadlas Engineering Services, Osogbo. There are thousands of road side mechanics, electrician, plumbers, etc., which are other examples of maintenances jobshops on a small scale.

1.9 Modelling Concept

The mathematical modelling in this study will be based on an encompassing single-channel, multi-server queueing system with sub-models for optimising response rate as well as the various strategic decisions.

1.10 Research Objectives

The aim of this study is to develop a quantitative method for determining the sustainability of maintenance jobshops and/or sustainability of establishing additional centre, subject to employed maintenance policy, maintenance costs, as well as response rates of customers. The specific objectives of this research are to:

(i) optimise strategic decisions in maintenance systems for effective and profitable operations in maintenance job-shops.

(ii) develop a quantitative approach of establishing a cost effective maintenance centre, this could be implementable in developed and developing countries.

(iii) determine the response rates to such maintenance centres and evaluate their sustainability.

CHAPTER TWO

2.0 LITERATURE REVIEW

Effectiveness of various strategic decisions in many maintenance organisations is being viewed, as an important factor that deserves evaluation. Majority of the current works focused on optimisation of individual strategic decisions. Hence, there is need for integration. Current works on maintenance planning in the areas of service demand forecast, crew size determination, tools and equipment planning, spare parts inventory, job scheduling and communication planning are reviewed below:

2.1 Service Demand Forecast

Lawal and Lawal (2001)'s work on the use of forecasting techniques in Nigerian industries has revealed that many organizations in Nigeria are deeply involved in the use of quantitative forecasting techniques to forecast their service demand. The only problem identified from the results of Lawal and Lawal's work was that each organization is familiar with the use of only one forecasting technique. By this, evaluation of effectiveness of service demand forecast becomes difficult since other forecasting techniques may prove more efficient.

In another work of Lawal and Lawal (2002), they made use of the moving average to forecast for the sales force in a local bottling plant. In this work, effectiveness of the employed technique was tested using Mean Absolute Deviation (MAD) and Mean Absolute Percentage Error (MAPE). The Lawal and Lawal's work failed to consider Mean Square Error (MSE) evaluation which Richard et al (1987) claimed to be more accurate than MAPE and MAD error evaluations. Aderoba and Lawal (1997) suggested a formula, which may be useful in service demand evaluation. The formula could be effective in evaluating service demand in maintenance job-shops because all necessary influencing factors associated with call for maintenance were appropriately combined in the forecasting equation. The demerit of the model is in the part of non-evaluation of cumulative forecasting errors.

2.2 Crew Gang Determination

Effectiveness of crew gang in maintenance operations had been receiving attention in the past years. Raymond (1988) used multiple activity process chart to minimise the operation time subject to a reasonable number of personnel. The approach assumed equal efforts contribution from each personnel and the additional personnel works in parallel with the former. These assumptions were rejected by Lester (1988) in his work who ascertained that it is not the size of the personnel that is important but the technical competence, cooperation of the crew members and the group dynamics. Therefore, reliability is very important in determination of effective crew gang. In Shaw (1976), preventive maintenance requisition and repair requisitions were separated. One crew is expected to execute preventive maintenance requisition while another crew is empowered to work on repair requisition. The maintenance crew shift is made at time, t, when the repair backlog is sufficiently big, W (t) > θ (threshold value), but when backlog has vanished, that is, W(t) < θ, the maintenance crew is shifted back to his main duty. This can be effectively used for crew gang determination by translating threshold value θ to be repair capacity of the existing crew, and W(t) to be jobs reported at time t. Therefore, number of maintenance gang to accomplish all orders at time t can be obtained from:

$$S = W(t)/\theta \qquad \ldots \qquad (2.1)$$

Where,

S = crew gang

W(t) = quantity of jobs reported at time t, and

θ = Maximum jobs that can be executed at time t by the existing crews.

Similarly, in Sodiki (2001), manpower determination was done by replacing repair/maintenance backlog, W(t) by expected maintenance man-hour, t_e while a maintenance crew capacity, θ was replaced by number of hours available for maintenance during the period, t_v

That is,

$$S = t_e/t_v \qquad \ldots \qquad (2.2)$$

Aderoba (2000), considered manpower requirement in job-shops in line of full time staff and overtime staff, but the principle used was similar to workload method but a realistic job demand forecasting was included. However, Fapetu and Kareem (2003) developed a workload approach to crew size determination by introducing use factor f, to account for the uncertainty in the performance of maintenance crew (Richard, 1976).

Number of crew(s) for a particular skill is given as;

$$S = t_e/(t_v.f) \qquad \ldots \qquad (2.3)$$

Where f = use factor, which ranges from $0 < f \leq 1$.

In Aderoba and Lawal (1997), a heuristic was used to determine crew gang based on queuing model, using, an approach similar to Shaw (1976),in which waiting time W_q of jobs replaced repair/maintenance backlogs and response rate W_q^* replaced the expected repair/maintenance capacity of the engaged crew.

That is,

$$S = W_q/W_q^* \qquad \ldots \qquad (2.4)$$

Since the crew may not be 100% efficient, then used factor, f, which can be reasonably termed "Reliability factor", should be included.

Therefore, $S = W_q/(W_q^*.f) \qquad \ldots \qquad (2.5)$

2.3 Equipment Planning

Equipment/machine planning for production activities had been receiving attention by researchers in the past. In earlier works, a model, which established number of machine required, was derived, by dividing the capacity required by the available capacity (Aderoba, 2003).

$$n_i = C_i/C_m \quad \ldots \quad (2.6)$$

where,

n_i = number of machines required for operation i

C_i = the capacity required for ith operation (units/hr)

C_m = the capacity of the available machine i (units/hr).

This model can be effectively used in a system where capacity utilization can be predetermined. Due to Stochastic nature of service demand in maintenance jobshops, equipment/tools utilization rate becomes unstable; hence, the model becomes inapplicable. Queuing model (Richard et al, 1987) had been adapted for determining the number of machine/equipment required for production activities. This was done by considering a machine/equipment as a service facility, while the jobs processed through it were considered as customers, each arriving at random with their job characteristics of processing times. The number of machines required was determined for a particular operation by making use of waiting time of jobs in queue when the service facility is busy, leading to a complex multi-server queuing system. In the case of maintenance job-shops equipment planning is not only depends on the arriving jobs but also depends on maintenance policy employed by the management. Also, Aderoba (1997) and Idris and Aderoba (2000), planned for equipment by developing a model for sequential investment in machineries. In this model, machinery next for investment based on the available capital (after periodical augmentation from ploughed back earning) was selected using rate of return on investment. In maintenance job-shops, necessary tools/equipment for the selected maintenance policy must be available at a single-stage. Therefore, augmentation of revenue if required may be done along the various maintenance policies line.

2.4 Spare Parts Planning

It is not worthwhile to stock all the parts necessary for maintenance activities in maintenance job-shops. Instead, most important, costly or scarce spare parts must be given priority (to reduce spare parts inventory cost and to enhance response rate), while the less expensive; non-scarce spare parts could be bought immediately when needed. The former process is similar to Just-In-Time (JIT)-inventory system. In literature the inventory items are divided into 3 classes (Richard et al, 1987 and Andrew et al, 1996).

A- items; These items are very scarce and expensive. Based on Paretos optimality criteria as stated in Richard et al (1987), it can be roughly interpreted as 80% of a problem comes from 20%

of the possible causes. The A-class items are few in number, usually less than 10%, but account for about 70% of the total cost value of the stock.

B- items; Less frequent orders are placed for these items. B-Class items are about 20% of the total number of items but accounts for about 25% of the total cost value.

C- items; These classes of items are cheap and readily available. The 70% items of category C amount to only 5% of the total cost value.

The A- B- C analysis allows most attention to be paid to A- class items while the least attention is paid to C items. Therefore, it is pertinent for the management of maintenance job-shops to direct their attention on A- class of spare parts which needs to be ordered frequently but in small quantities so as to reduce tied down capital, and allows the customers to procure readily available and relatively cheap items of categories B and C. The Economic Order Quantity (EOQ) (that is, quantity of order which will result to the least cost of inventory) of the A-class spare parts is given as in classical inventory model (Martin, 1988).

$$EOQ = L = \sqrt{(2pY/CI)} \quad \ldots \quad (2.7)$$

where,

Y = number of pieces used for a year.

p = total cost of purchasing and receiving one order quantity.

C = cost per piece, including freight.

L = number of parts in a single order

I = yearly inventory carrying cost (in percentage of Naira value).

The frequency of order of a spare part per year, N is given as:

$$N = Y/EOQ \quad \ldots \quad (2.8)$$

Further modification was done by Buzacott (1975) on the classical inventory model by incorporating constant inflation rates, Akanbi et al (2001) incorporated both inflation and interest rates and Richard et al (1987) introduced use-and receipt rates.

However, Bello et al, (2000) described how principles of interchangeability of parts can be used to reduce the excess stock by identifying spare parts (through survey) that can be substituted for another. This development would prevent duplication of order with attendant hike in inventory cost.

2.5 Communication Planning

Communication is a mechanism for effective control of a system. Without communication, comprehensive presentation of salient ideas would be impossible. Therefore, effective communication is needed for improved productivity and performance. Knight (1988) stated and analysed the problem of communications. He found out that effective information channel should be:

(i) Up through the supervisory organisation;

(ii) Down through the supervisory organisation; and

(iii) Laterally across the same level of organisation.

Andrew et al (1996) stated mathematical formula relating group interactions as

$$N = P(P-1) \qquad \ldots \qquad (2.9)$$

where,

N = is number of interactions

P = is number of members of the group

The formula given by Andrew et al (1996) can be effectively adapted for maintenance crew/team interactions. Further work of Stephen (2001) employed all channel patterns of communication with Social Network Analysis (SNA) to measure and analyse how communication occurs between individuals and groups. His analyses can be put into mathematical form as:

$$P_{ij} \begin{cases} = 0, & i=j \\ > 0, & i \neq j \end{cases} \qquad \ldots \qquad (2.10)$$

Pij can be termed the matrix of communication among the individuals that make up a crew/team. Subscripts i and j denote personnel, i communicates with another personnel j during maintenance operation. The aim of the maintenance centre is to reduce communication cost and at the same time maintain effective interaction. Therefore, modification to the above should be done to include degree/level of interaction of individual, allowable time of interaction and the means of interaction.

2.6 Maintenance Scheduling and Costing

Many researchers had done a lot on how best to effectively schedule maintenance activities. Some of the works of those researchers are discussed here:

Kenne and Gharbi (1999) developed a simulation model, to effectively schedule maintenance activities on a production machine. In this model, the following quantities were determined:

(i) The age of the machine at which one can plan to do preventive maintenance. At this age,the machine is sent for preventive machine,

(ii) The age of the machine at which it is necessary to stock parts (breakdown maintenance). Before this age, the machine is supposed to be new, and at this time production is optimal, and

(iii) Value of the threshold or number of parts to maintain in stock to hedge against machine breakdowns.

Kenne and Gharbi's work would be useful in scheduling maintenance activities of a production organisation that operates maintenance department. In the case of maintenance job-shops, varieties of jobs are expected from customers, hence its magnitude cannot be predetermined easily (Cohen, 1985). Therefore, jobs scheduling of this kind based on the balancing of production with maintenance may be impossible. Instead, arrival rate magnitude at a particular period could be taken as independent variable while maintenance rates could be referred to as dependent variables.

Meanwhile, Matsui et al (1999) scheduled activities based on switch over and order selection such that, when backlog was too much, the system was switched over to high service rate; at less orders, low service rate was shifted to. This scheduling system could be adopted in maintenance job-shops by choosing service rate based on the magnitude of repair jobs at hand.

Other works done are: Azadivar and Shu (1999) scheduled activities based on maintenance policy; Swanson (1999) scheduled maintenance activities based on production technologies: that is, Advance Manufacturing Technology (AMT) and Just-In-Time (JIT) manufacturing technologies; Offiong (2002) scheduled maintenance jobs based on the age and functions of the machines by determining group maintenance scheduling of the machines; Ikpo (2000) used maintenance cost analysis to determine whether to schedule machines for repair or replace; and Charles-Owaba (2002), scheduled preventive maintenance activities using Gantt Charting method. Most of these works (in literature) found ready application in production systems operating a maintenance department where the magnitude of jobs can be easily pre-determined. In the same vain, the activity-based costing (ABC) method (Cooper, 1990 and Brimson, 1991) in the recent times could be well adapted to maintenance costing to guard against underestimation of maintenance cost.

O' Donovan et al (1999) described maintenance and repair as one of the factors militating against fulfilment of job shop scheduling and it must be well planned for, to minimise waiting time. In line with this, they carried out a research on predictable scheduling of a single machine with breakdowns and sensitive jobs. They also took other factors such as resources, set ups, personnel scheduling, future dilemmas etc, into consideration. The model developed was based on 'known uncertainty' out of the three types of uncertainties described in this work.

(i) Known uncertainties, are those about which some information is available when the predictive schedule is generated. An example is machine breakdowns whose frequency and duration may be characterised by probability distributions. The probability of breakdowns or repair difficulties can be determined from historical data.

(ii) Suspicious about the future; this is based on intuition and experience, and it is difficult to quantify. Decision support systems can be used in these cases to develop alternative algorithms, evaluation schemes, mutation generated option (genetic algorithms), and provide a more interactive what – if scheduling tool.

(iii) Complete unknown, are unpredictable events, such as a sudden strike, about which no advance information is available. Little can be done about these except react. The development of schedules for system in the face of this type of uncertainty is difficult.

Out of these three uncertainties, only known uncertainty can be used for easy and comprehensive modelling. Therefore, known uncertainty will form the basis of the current study.

The work of Azadiar and Shu (1999) on the maintenance policy selection for just-in-time (JIT) production system, described various policies often adopted in maintenance system; such as, preventive, predictive, reactive or breakdown, opportunist, time based and MTBF (Mean Time Between Failure) based. These policies were tested by simulation technique using the following characteristics factors such as job routing complexity, breakdown severity, production load, coefficient of variation of MTBF, coefficient of variation of Mean – Time To Repair (MTTR), repair load, ratio of preventive and repair maintenance (PM/RM), and probability of PM correctness, range limited factors which are demand urgency (that is, due dates and buffer size) and insignificant factors such as number of end product types, number of operation per product, MTBF, resource availability, probability distribution types and performance constraints. The basic definitions of aforementioned factors are as follows:

(i) Job routing complexity, the complexities involved in multiple pass through a machine, part and/or machine sharing etc. It indicates the complexity of a maintenance system configuration.

(ii) Resource availability, is defined as MTBF/(MTBF + MTTR) where MTTR represents mean time to repair.

(iii) Breakdown severity as defined by MTTR demand rate. It indicates the breakdown severity in terms of the amount of demand during the down time.

(iv) Production load, is defined as the ratio of the busy time over the up-time. It is an indication of the traffic density in the system. It is obtained by dividing the average work content of the demand to the average available production time.

(v) Constraint with respect to required level of performance. Possible performance constraints are the level time and the bound on the average inventory levels in the system.

(vi) Coefficient of variation of MTBF, as an indication of the variability of MTBF.

(vii) Coefficient of variation of MTTR, as an indication of the variability of MTTR.

(viii) Repair load, in terms of the ratio of production resources/repair resources, as an indication for the potential traffic density for the repair process.

(ix) Demand urgency, in terms of the ratio of due date/work content of the job, as an indicator for the tightness of the schedule.

(x) Allowed buffer size, as a factor that reduces the effect of breakdown.

(xi) Ratio of PM/RM efforts is when a combined preventive and reactive maintenance policies are used.

(xii) Probability of PM correctness, as an indication of the quality of the maintenance process.

Among these factors, system complexity requires additional explanations. Fig. 2.1 shows two systems each with two product types and two operations per product. The nodes in this picture represent the states of the product while arcs indicate the process. The letter on arcs represents the name of the resource needed for the process. The figure at left represents the simplest routing, while the right hand side picture shows a much more complex routing. Sharing of the resources among different process has further complicated this system.

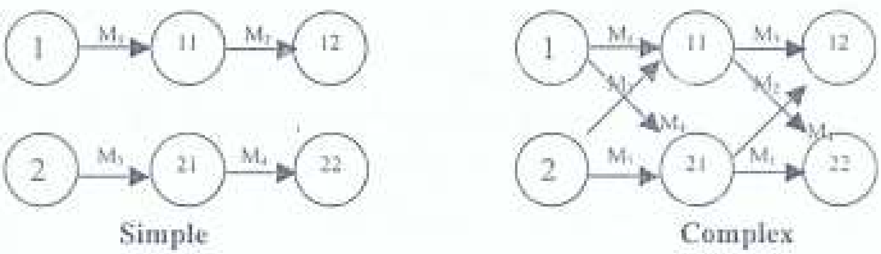


Fig. 2.1: Example of Routing Complexity

Source: Azadivar and Shu (1999)

When simulation runs were conducted the results showed that reactive or breakdown policy failed in almost all the factors considered, therefore, it can be concluded that it is not worthwhile to carry out reactive maintenance policy in a production organization. In view of this establishment of a specialised commercial maintenance centre is required to enhance the sustainability of the reactive/breakdown maintenance policy.

Swanson (1999) also based his work on the impact of new production technologies on the maintenance function. He empirically assessed the impact of two new production systems; Advance Manufacturing Technology (AMT) and Just-in-Time (JIT) manufacturing, on the maintenance practices. Swanson used the following three hypotheses to analyse the impact of maintenance practices on AMT and JIT.

(i) The use of maintenance practices that improve communication and coordination including decentralisation, use of teams and use of computerized maintenance management systems would be higher for plants reporting more extensive use of AMT and JIT.

(ii) The use of maintenance practices that increase technical expertise including training, use of professional maintenance staff, and operator involvement in maintenance tasks will be higher for plants reporting more extensive use of AMT and JIT; and

(iii) The use of maintenance practices that reduce the frequency and duration of equipment failure including preventive maintenance programs and maintenance spare parts control will be higher for plants reporting more extensive use of AMT and JIT.

He tested aforementioned hypotheses using hierarchical regression analysis, and the results revealed that, AMT supported the use of computerized maintenance management systems, training professional staff, preventive maintenance and spare parts control while JIT supported only operator involvement in maintenance tasks. Hence, AMT, requires more of maintenance practices (because of its complexity) than JIT manufacturing system. Since AMT supported majority of decisions stated above, the current study will find its customers in a manufacturing system using AMT.

The heuristics procedure developed by Offiong (2002) for the determination of group maintenance scheduling frequencies has some characteristics, which can be utilized in the effective operation of the proposed maintenance centre. The results of the heuristics showed that group maintenance scheduling is favourable for new machines (minor preventive maintenance is maximal at a given cycle of major preventive maintenance). And both group and individual preventive maintenance strategies could be adopted when there is moderation in the level of minor preventive maintenance within a given major preventive maintenance cycle. Since maintenance centre should be able to cater for all forms of repair jobs, group maintenance schedule may be adopted for similar jobs and dissimilar jobs should be maintained individually. Also, Nigerian industries are characterized by old and fairly used machineries which involves excessive (breakdown) maintenance activities (Inegbenebor and Adeniyi, 2002), there is possibility of using more of individual maintenance scheduling than group maintenance scheduling in the operation of the maintenance centre. Backlog of repairable machines and equipment waiting for repair in Nigerian industries is also evidenced in the study of Lawal and Adeyemo (2002) on maintenance performance appraisal in local production organisations. These scenarios call for the need for formidable and effective maintenance centres in Nigeria. In another work of Offiong (2001), an efficient method was developed to determine optimal replacement period for a group of machines. In this model, optimal replacement period for a group of machine parts was better than repairs. Another version of this work is the work of Ikpo (2000) on optimal economic criteria for the maintenance of repairable building component. His model helped to choose better alternatives, to repair or replace based on the cost analysis of the repair jobs. This work is different from that of Offiong (2001) because it dealt with only replacement schedule.

Efforts toward effective maintenance jobs scheduling can also be witnessed in the work of Charles-Owaba (2002) on Gantt charting multiple machines' preventive maintenance activities. In this study, a Gantt charting problem was formulated for scheduling M machines on Gantt charts for T alternative operation and maintenance periods. The system was formulated and solved as a linear programming transportation model. This model achieved the minimization of preventive maintenance cost by making use of operation and machine idle periods as variables, and maintenance activities duration and Unit cost as parameters. The model finds ready application in production systems operating a maintenance department.

2.7 Performance Evaluation

Maintenance performance measures are used generally to evaluate maintenance performance. This can be done manually or by the use of computer. Certain selected factors (as applicable to any maintenance organization that wants to measure its effectiveness) must be regularly plotted on a chart in order to determine the trends based on monthly, quarterly, semi annually or annually. From these trends, it can be discovered how the values computed vary along a time-scale and a rising or falling trend in one variable affect the other. These results will help to discover in what way measures taken in one area effect results in another, either favourable or unfavourable, confusing or useful. Since simulation and "modelling" are well accepted techniques, those indices could be fed into program of assessment by indicating high or low effectiveness range to the computer, e.g, 87: 6%, high: low, good bad of indifferent. From these results, the aspect of effectiveness measurement, which needs improvement, can be easily identified, and implemented. Table 2.1 shows twenty of such maintenance performance measures. Numerous performance measures are being used by management to relate the performance of maintenance to other factors.

Priel (1974) has written authoritatively on maintenance organization particularly on maintenance ratios. The ratios are useful for effective maintenance planning. Table 2.1 shows twenty of such maintenance ratios. In the same vain, Nwachukwu (2000) listed the criteria relating to maintenance performance measures. Among them are:

(i) Maintenance labour productivity

(ii) Downtime – Preventive Maintenance

(iii) Budgeted Expenses

(iv) Condition of Equipment

He also stated nine maintenance performance indices based on maintenance ratios. These are shown in Table 2.2. Each maintenance sector is to select the most appropriate combination based on the objectives of the measurement and peculiarity of the maintenance sector.

Table 2.1: Twenty Maintenance Performance Ratios

- Maintenance Department
  - Manpower
    - 1. Manpower efficiency = $\frac{\text{Total man-hours allowed}}{\text{Total man-hours worked on same jobs}}$
    - 2. Incentive coverage = $\frac{\text{Man-hour on bonus}}{\text{Total direct hours available}}$
    - 3. Craft civilization = $\frac{\text{Total craft hours worked}}{\text{Total craft hours clocked}}$
  - Operation of the Work order progress
    - 4. Work-done turnover = $\frac{\text{Number of jobs completed}}{\text{Total number of jobs handled}}$
    - 5. Completion delays = $\frac{\text{Job-weeks of delays}}{\text{Number of jobs handled}}$
  - Departmental economy
    - 6. Cost of maintenance hour = $\frac{\text{Total maintenance costs}}{\text{Total direct maint. Hours applied}}$
    - 7. Department overhead = $\frac{\text{Total overhead costs}}{\text{Total maintenance expenditure}}$
- ...ssessment of ...e service
  - Plant & equipment performances
    - 8. Downtime due to main = $\frac{\text{Total downtime for services}}{\text{Total shift hours worked}}$
    - 9. Breakdown frequency = $\frac{\text{Units produced of hours worked}}{\text{Number of breakdown}}$
  - Degree of planning
    - 10. Routine service worked = $\frac{\text{Total hours on regular service}}{\text{Total direct applied main hours}}$
    - 11. Breakdown workload = $\frac{\text{Total hours spend on breakdown repairs}}{\text{Total direct production hours}}$
  - The amt. of services
    - 12. Maintenance to prod. ratio = Total maintenance direct hours
    - 13. Maintenance of mechanism = $\frac{\text{Total clocked maintenance hrs}}{\text{Total hrs connected horsepower}}$

Table 2.1 contd.

Category	Index	Expression
Cost of services provided	14. Maintenance cost component	= Total maintenance expenditure / Number of units produced
	15. Cost of schedule service	= Cost of schedule services / Total production cost
	16. Cost of supplies and spares	= Cost of supplies and spares / Total investment value
	17. Maintenance cost on investment	= Total mainienanace expenditure / Total investment value
Expense justification	18. Cost of reduction	= Index No. 10 = Routine service worked / Index No. 6 Cost of maintenance hours
	19. Maintenance intensity	= Index No. 12 = Maintenance/production hrs / Mechanization hour per direct production worked
	20. Overall rate of expense	= Index No. 14 = Maintenance cost comp / Index No. 13 Maintenance of mechanization

Source: Priel, 1974

Table 2.2: Maintenance Performance Indices

1	Manpower utilisation	Total man hours worked
		Total man hours available
2	Work order turnover	No. of jobs completed during a period
		No. of jobs on hand during the period
3	Cost of maintenance hour	Total maintenance costs
		Total direct maintenance hours
4	Downtime due to maintenance	Total downtime for service
		Total maintenance hours worked
5	Machine availability	Downtime during a period x 100%
		Available machine hours during the period
6	Routine service work load	Total hours of regular service
		Maintenance hours
7	Maintenance to production ratio	Total maintenance direct hours
		Total production direct hours
8	Maintenance cost component	Total maintenance expenditure
		No of units produced
9	Cost of reduction efforts	Routine service work load
		Cost of maintenance hours.

Source: Nwachukwu 2000

Harlin (1979) also gives some productivity and efficiency expressions (Table 2.3) and Corder (1957) developed maintenance efficiency index, found to give good results in some type of industry and partly applicable in some others. The index is given as:

$$E = K/(XC + YL + Z) \quad \ldots \quad (2.11)$$

where;

E, maintenance efficiency index.

C, the total pure maintenance cost including preventive, corrective and emergence maintenance expressed as a percentage of the replacement value of the plant and equipment.

Y, total cost of lost time due to maintenance causes in base year.

L, the total down time due to maintenance expressed as percentage of the scheduled production Hours.

X, total cost of maintenance in base year

Z, total cost of waste due to maintenance cause in base year

K, Constant, chosen so that it has value of 100 for the base year

Table 2.3: Maintenance Productivity Measures

1	Productivity =	Units of production / Maintenance Hours
2	Productivity =	Units of production / Replacement cost of investment
3	Productivity =	Units of production / Replacement cost of investment
4	Efficiency of Preventive Maintenance =	Emergency maintenance hours / Preventive maintenance hours
5	Efficiency of Machine Utilisation =	$\frac{(A - B) - (C - D)}{(A - B)}$

where,

A, Total available operating hours (that is 24 hrs / day).

B, Scheduled operating downtime hours

C, Scheduled mechanical downtime hours

D, None scheduled mechanical downtime hours

Olorunniwo (1986, 1989) classified several other maintenance productivity measures that have been suggested in literature and used in practice (see Table 2.4).

Table 2.4: Typical Maintenance Productivity Improvement Measurement Ratios

	Performance Measures	Unit	Expression
EQUIPMENT			
1.	Equipment Available	%	$\frac{\text{Equipment Running Time}}{\text{Running Time + Down Time}}$
2	Trends in Downtime	Hours	Monthly downtime by equipment time
3	Equipment Shutdown Ratio	%/time	$\frac{\text{Number of Shutdown} \quad \text{X 100}}{\text{Active Time}}$
4	Equipment Shutdown Intensity	%	$\frac{\text{Downtime from Shutdown} \quad \text{X 100}}{\text{Active Time}}$
5	Emergency Failure Frequency Ratio	No/time	$\frac{\text{Number of emergency Failures} \quad \text{X 100}}{\text{Operating Time}}$
6	Emergency Failure Intensity Ratio	%	$\frac{\text{Downtime from Frequency Failures} \quad \text{X 100}}{\text{Operating Time}}$
LABOUR			
7	Manpower Efficiency	%	$\frac{\text{Total Man-Hours allowed for job}}{\text{Actual Man-hours spent on same jobs}}$
8	Craft Utilization	%	$\frac{\text{Total Craft-Hours work} \quad \text{X 100}}{\text{Total Craft-Hours Clocked}}$
9	Average Work-order Completion Time	Days/No	$\frac{\text{(Issue Date-Completion Date) for job i} \quad \text{X 100}}{\text{Total number of jobs studied}}$
10	Work-Order Turn over	%	$\frac{\text{No of Jobs Completed} \quad \text{X 100}}{\text{No of Jobs Handled}}$
PLANNING AND SCHEDULE			
11	Not Maintenance Work Ratio	%	$\frac{\text{PM (hr) + CM (hr) + BM (hr)} \quad \text{X 100}}{\text{Total working Time of Maintenance man}}$
12	Planned Maintenance Work ratio	%	$\frac{\text{PM (hr) + CM (hr)} \quad \text{X 100}}{\text{Total Maintenance working Time}}$
13	Actual Backlog	%	$\frac{\text{Hours of Maintenance on open Orders}}{\text{Weekly Maintenance Crew Hours}}$
14	Forecasting Effectiveness	%	$\frac{\text{Hours of Maintenance on Open Work Orders}}{\text{Weekly Maintenance Crew Hours}}$

Table 2.4 Contd.

15	Completion Delays	Weeks/ Job	$\frac{\text{Job-weeks of Delays}}{\text{Number of Jobs Handle}}$	
16	Overtime Ratio	%	$\frac{\text{Total Overtime Hours X 100}}{\text{Total Maintenance Hours}}$	
17	Maintenance Productivity Ratio	%	$\frac{\text{Total Direct Maintenance Hour X 100}}{\text{Total Direct Production (Hrs)}}$	
18	Number of Equipment per Maintenance Man	Size No		
MATERIALS & SPARES				
19	Oil Consumption Ratio		$\frac{\text{Litres of Oil Consumed}}{\text{Total No of Machinery}}$	
20	Material Cost Ratio	₦/Hr	$\frac{\text{Repair Material Costs}}{\text{Total man-hours of repair work}}$	
21	Parts Stock Turnover	%	$\frac{\text{Parts issued for the period X 100}}{\text{Stocks of parts at the end of period}}$	
22	Inventory Shrinkage Ratio	%	$\frac{\text{Inventory investment verified X 100}}{\text{Inventory investment expected}}$	
23	Parts Order Processing Ratio	No/Hours	$\frac{\text{Equivalent Orders picked}}{\text{Labour Hours Required}}$	
24	Inventory fill Ratio	%	$\frac{\text{Item Demands filled X 100}}{\text{Items Demand}}$	
25	Storage Space Utilization	%	$\frac{\text{Storage Space Occupied by Materials X 100}}{\text{Total Storage Space}}$	
26	Aisle Percentage of Space	%	$\frac{\text{Space Occupied by Aisles X 100}}{\text{Total Space}}$	
27	Material Handling Labour Ratio	%	$\frac{\text{Assigned to Handling Duties X 100}}{\text{Total Maintenance Workforce}}$	
28	Parts Handling Time Ratio	%	$\frac{\text{Materials Handling Time by Direct Labour X 100}}{\text{Total Maintenance Direct Labour time}}$	
29	Cost of Maintenance Hour	₦/Hr	$\frac{\text{Cost of Maintenance}}{\text{Total man-hour spent on work-order}}$	

Table 2.4 Contd.				
30	Maintenance cost per operating time	₦/ Hr	$\frac{\text{Total Maintenance cost}}{\text{Equipment Operating time}}$	
31	Maintenance cost Component	₦/No	$\frac{\text{Total Maintenance cost}}{\text{Production Volume}}$	
32	Breakdown Cost to Total Production Cost	%	$\frac{\text{Cost of Breakdowns} \times 100}{\text{Total production Cost}}$	
33	Overall Maintenance Cost Effectiveness	%	$\frac{\text{Maintenance Cost + Cost of Downtime} \times 100}{\text{Equipment Investment}}$	
34	Maintenance Improvement Justification	%	$\frac{\text{(Maintenance Cost + Cost of Downtime) for Last (base) period}}{\text{(Maintenance Cost + Cost of Current Downtime) for current period}}$	
35	Maintenance Breakdown Severity	₦/No	$\frac{\text{Cost of Breakdown Repair}}{\text{Total Number of Breakdown}}$	
36	Extent of Breakdown Repair	%	$\frac{\text{Direct Cost of Breakdown Repair x 100}}{\text{Direct Cost of Maintenance}}$	
37	Direct Maintenance	%	$\frac{\text{Total Direct Maintenance Cost} \times 100}{\text{Total Maintenance Expenditure}}$	
38	Contract Maintenance	₦ %	$\frac{\text{Total Cost of Contract Maintenance} \times 100}{\text{Total Cost of Maintenance}}$	
39	Cost of Supplies and Spares	%	$\frac{\text{Cost of Spares Use} \times 100}{\text{Initial Cost of Maintenance}}$	
40	Progress in Cost Reduction	%	$\frac{\text{Schedule Job} \times \text{(1/Index 32)}}{\text{Total man-hours Available}}$	

Source: Olorunniwo, 1989

Aderoba and Banerjee (1993), also gave different methodologies and approaches to measure the effectiveness and performance of maintenance in public sector. Some of these approaches are the use of system analysis, operation research, production management methods and management science. There are well tested methods and techniques in industrial engineering such as work-study and systems Approach which can also be used in maintenance effectiveness measurement.

Maintenance performance measurement involves defining what measurement criteria are to be used. The few sets of performance measurement criteria to be used should appropriately reflect the goals of maintenance effectiveness and completely assessed maintenance activities and also at the same time enjoying wide acceptability by management and maintenance department. Unfortunately, there is little agreement among industrial executives as to what are the relevant criteria in designing productivity indices. The theorists are also equally divided.

Olorunniwo (1986) also buttresses this fact by stating that there are several surrogate maintenance productivity measures which have been suggested and used in practice but which are not entirely acceptable to either the management and or the maintenance department. Also, those whose performance is to be evaluated by the use of these productivity ratios have not been adequately involved in the definition of these criteria and the development of the appropriate scale of measurement. He suggested that the involvement could be encouraged by the use of proven techniques to ensure participation in any program planning is the Nominal Group Technique (NGT).

However, Aderoba and Lawal (1997) suggested a good performance index for a commercial maintenance centre. It is the ratio of response rate to the cost of a maintenance gang. Also, for the effective costing of the job, Aderoba (2001) enumerated various elements (activity based) of cost in jobshop operations. These activity based cost (labour, space, utility) elements will be useful for effective evaluation of centre performance.

Maintenance Performance had been measured by using maintenance ratios especially maintenance-cost- hour (Priel, 1974), productivity ratio (Olorunniwo, 1989), response rate to cost ratio (Aderoba and Lawal, 1997). Out of these performance measures stated, only response rate to cost and maintenance cost hours could be useful for maintenance centre performance measure.

Also, further performance measures based on post-optimality analyses such as benefit-cost, sensitivity, etc could also be used to obtain the best maintenance policy. The summary of quantitative tools that had been used in literature to optimise strategic decisions and their limitations is presented in Table 2.5.

Table 2.5: Quantitative Tools for Optimising Strategic Decisions

Strategic Decision	Proposed tools	Limitations	Sources
Service demand Forecast	Forecasting techniques: - Moving averages with an empirical relationship - Moving averages - Forecast errors analysis	No Error Evaluation No Mean Square Error No integration	Aderoba and Lawal (1997) Lawal and Lawal (2001) Richard *et al* (1989)
Crew size determination	Queuing model – Heuristics Queuing model – Heuristics Multiple-activity process chart Queuing model Maintenance work loads Maintenance work loads Maintenance work loads Maintenance time analysis Dynamic programming	No Reliability concept No Reliability concept No Reliability concept No Reliability concept (NR) Predetermined & (NR) Predetermined & (NR) Predetermined & (NR) Predetermined & (NR) No Part-time staff & (NR)	Aderoba and Lawal (1997) Kareem and Aderoba (2000) Raymond (1988) Shaw (1976) Richard (1976) Priel (1974) Oloruniwo (1989) Sodiki (2001) Aderoba (2000)
Tools and equipment planning	Capacity utilisation method Queuing method Sequential investment	Predetermined No Set Theory Equip. procurement not based on maintenance policy	Aderoba (2001) Richard *et al* (1989) Aderoba (1997), Idris and Aderoba (2000)
Spare parts planning	Inventory model Inventory model Inventory model Interchangeable	No use and receipt rate No use and receipt rate No use and receipt rate No use and receipt rate	Martin (1988) Andrew *et al* (1996) Aderoba and Lawal (1997) Bello *et al* (2000)
Operations planning/ Maintenance scheduling	Simulation technique Simulation technique Gantt-charting (LP transportation model) Activities based costing Failure/Reliability Model Salvage and maintenance cost functions Maintenance frequency	No Part-time &Full-time Staffers No Part-time &Full-time Staffers No Probability distribution. No Inflation &Interest rate. No Part-time &Full-time Staffers No Inflation &Interest rate. No Probability distribution	Azadivar and Shu (1999) Swanson (1999) Charles – Owaba (2002) Aderoba (2001), Brimson (1991) & Cooper (1990) Kenne & Gharbi (1999) Offiong (2001) Offiong (2002)
Communication planning	Social network analysis (SNA) Interaction model	No weighted ratings No weighted ratings	Stephen (2001), Knight (1988) Andrew *et al* (1996)
Performance Evaluation	Maintenance ratios Maintenance ratios Response rate / maintenance gang cost Efficiency index Benefit-cost ratio	Predetermined Predetermined No Part-time Staffers Predetermined No Part-time Staffers, No Equipment failure.	Oloruniwo (1989) Priel (1974) Aderoba & Lawal (1997) Hamlin (1979) John et al (1989)

2.8 Distinguishing Features of Current Study

The major differences between past works and current study are:

(i) Most of the studies in the past on maintenance management dealt with in-house maintenance system where maintenance departments are part of production system while the new study can be applied to external system.

(ii) Most of the past works were based on the optimisation of individual maintenance strategic decision. This study will integrate all the maintenance strategic decisions in order to achieve integrated optimisation of these decisions using appropriate techaiques.

(iii) Performance evaluation has direct link with production system in most of the past works; hence maintenance performance ratio between cost expended and savings on down times can be easily assessed. In the present study response rate of maintenance jobs (which is independent of maintenance centre) and the cost of maintenance gang play a vital role in evaluating the performance of the centre.

CHAPTER THREE

3.0 MODEL FORMULATION

In this section, optimisation models were developed for the salient strategic decisions often made in maintenance centre by exploiting the versatility of the existing quantitative techniques and the current works of the operations researchers. These strategic decisions include; service demand forecast, crew size determination, tool and equipment planning, spare parts management, and shop/customers communication planning. Optimisation strategy for each decision is discussed in the following sections. However, in formulating this model the following assumptions are made:

(i) Service calls are attended to based on First Come First Served (FCFS).

(ii) Service calls came from a single source (i.e. industrial machinery).

(iii) Service calls are served by a single source (i.e. maintenance jobshop).

(iv) Effectiveness and reliability of maintenance crew(s) are constant for the period considered.

(v) Maintenance crews are equally competent to diagnose all categories of repairs.

3.1 Service Demand Forecast

It has been known and it must be known that service demand forecast for external maintenance operation is very difficult to estimate by the maintenance managers. Unlike the internal maintenance system, that can be easily estimated because the management has become familiar with the condition of the machines. Hence, management of maintenance job-shops should critically study and understand the behaviour of the external variables relevant to effective forecast of service calls (Cohen, 1985). However, in Aderoba and Lawal's work, 1997, it was explicitly stated that major external factors influencing service demand in maintenance centres are:

(i) Total number of industrial machines,

(ii) Age of the plant

(iii) Number of maintenance centres within the operating region

These influencing factors were related empirically by:

$$\lambda_t = \theta_t \Sigma [N_i G_{it}/n_t] \qquad \ldots \qquad (3.1)$$

where,

λ_t, service demand rate at time t

N_i, total number of industrial machines in plant i

G_{it}, age of plant i at time t

n_i, number of maintenance centres within the operating region

θ_t, proportional constant between the arrival rate and the influencing factors.

By critically looking at Equation 3.1, it may be noticed that it resembles linear equation in which λ_t is ordinates, the factors $N_t G_{it}/n_t$ is in abscissa and the θ_t represents the gradient of the straight line passing through origin (having zero intercept in ordinate).

Using Equation 3.1 verbatim can lead to a cumbersome data collection and analysis. To simplify the system, there is need to modify the model along the line of category of equipment/machines the maintenance centres are specialised on (Kareem and Aderoba, 2003). With this modification, Equation 3.1 can be re-written as

$$\lambda_t = \theta_t\,[N_t\,G_{it}/n_t\,] \quad \ldots \quad (3.2)$$

where,

N_{it} total number of equipment/industrial machines expected in maintenance centre of category i at time t

G_{it}, average age of equipment/industrial machines expected in maintenance centre of category i at time t

n_{it}, number of maintenance centres of category i operating within the region considered

λ_t actual failure rate (arrival rate) of equipment/industrial machines. That is, actual service demand in maintenance centre of category i .

θ_{it} proportional constant between the arrival rate and the influencing factors.

The value θ_{it}, for the previous years can be obtained from

$$\theta_t = (\lambda_t\,n_t\,) / (N_t\,G_{it}) \quad \ldots \quad (3.3)$$

Then, the value of θ_{it}, for one period ahead is given as

$$\theta_{t+1} = (\lambda_{t+1}\,n_{t+1}\,) / (N_{it+1}\,G_{it+1}) \quad \ldots \quad (3.4)$$

The value of θ_t varies, depending on the values of N_t, G_{it}, n_t, and λ_t at a particular period. The previous values of N_t, G_{it}, n_t, and λ_t can be obtained through administration of questionnaire and interview among the existing maintenance centres and industrial plants. The value of θ_t varies, depending on the values of N_t, G_{it}, n_t, and λ_t at a particular period.

After obtaining values of the θ_t for the past years, the values can be used to predict the value of service demand in the future. In doing this, accurate error measurement of Mean Square Error, MSE (Richard et al 1987) must be considered with various forecasting techniques. Technique with least MSE gives optimum service demand rate for the following year.

For various forecasting techniques, accuracy is obtained and compared with benchmark model called 'naïve model' as follows.

Naïve model

Naïve model can be expressed as

$\theta^{a}_{t+1} = \theta^{n}_{t}$ ... (3.5)

where,

$\theta^{a}_{t+1,}$ forecast for next period, t+1

$\theta_{t,}$ observed value in each period t,

Forecast error (in naïve model) in each period is given below ... (3.6)

$e^{a}_{t} = \theta_{t}{}^{n} - \theta^{n}_{t+1}$

The mean square error, MSE_n, can be calculated from:

$MSE_n = \Sigma(e^{n})^{2}_{t} / N_n$ ... (3.7)

where,

N_m, number of errors obtained.

Moving Average Technique (MA).

Moving average for the θ_ts' previous data values is the mean of the last N data points. For instance, moving average for N periods is given as:

$\theta^{m}_{t+1} = (\theta_t + \theta_{t-1} + \theta_{t-2} \ldots\ldots\ldots + \theta_t - _{(N-1)})/N$ ... (3.8)

where,

θ^{m}_{t+1}, moving average forecast at period t+1.

θ_t, the observed data at period t

The best number of period N is three as suggested by Richard et al (1989).

The moving average forecast error can be obtained from:

$e^{m}_{t} = \theta_t - \theta^{m}_{t+1}$ ... (3.9)

The average cumulative sum of the squares of these errors can be gotten to obtain the value of MSE_m.

$MSE_m = \Sigma(e^{m}_{t})^{2}/N_m$ ... (3.10)

where,

$e^{m}_{t,}$ moving average forecast error

N_m, number of errors obtained

Exponential Smoothing Model

The exponential smoothing model is given by

$\theta^{s}_{t+1} = \theta^{s}_{t} + \alpha e^{s}_{t}$ ... (3.11)

where,

θ^s_{t+1}, forecast at period, t+1

θ^s_t, forecast at period, t

α, smoothing parameter

e^s_t, error in period, t

The fraction α, smoothing parameter lies between 0 and 1. The best fitting α is the one that gives the minimum MSE in the sample after testing nine adequate trial values 0.1, 0.2, ..., 0.9.(Cohen, 1985).

Forecasting error, e^s_t, can also be obtained from

$$e^s_t = \theta_t^s - \theta^s_{t+1} \qquad \ldots \qquad (3.12)$$

where,

θ_t, observed values at period, t

θ^s_t, forecast at period, t

θ^s_{t+1}, forecast at period, t+1

The simple smoothing in Equation 3.11 is equivalent to Equation 3.13 by substituting e^s_t in Equation.3.12 into it

That is,

$$\theta^s_{t+1} = \alpha\theta_t + (1-\alpha)\,\theta^s_t \qquad \ldots \qquad (3.13)$$

Similarly, mean square error MSE, can also be calculated from:

$$MSEs = \Sigma(e^s_t)^2 / Ns \qquad \ldots \qquad (3.14)$$

where,

e^s_t exponential smoothing errors at period, t

N_s, number of errors obtained.

Time Series Regression Model with Linear Trend

To fit a straight line, Equation 3.15 could be used.

$$\theta^l_t = a + bt \qquad \ldots \qquad (3.15)$$

where,

θ^l_t, forecast at period t

a, the value of the forecast θ_t when period, t is equals zero

b, slope of the forecasting trend line

t, periods at which forecast is made

By the use of least-square method,

$$b = (\Sigma t\ \theta_t - nt\theta_t) / (\Sigma t^2 - nt^2) \qquad \ldots \qquad (3.16)$$

and

$$a = \bar{\theta}_t - b\,\bar{t} \quad \ldots \quad (3.17)$$

where,

b, slope of the equation of best fit

t, time or period

θ_t, observed values

$\bar{t}$, mean of periods, t

$\bar{\theta}_t$, mean of observed values

a, interception of best fitting line with the forecast value θ^l_t.

The regression model (Equation 3.15) assigns equal weight to all observation. Therefore, smoothing method should be introduced so that recent data would be assigned more weight, than old data. With the introduction of this concept, the following equations could be derived.

$$S_t = \theta^l_t + \alpha_1 e^l_t \quad \ldots \quad (3.18)$$

$$T_t = T_{t-1} + \alpha_2 e^l_t \quad \ldots \quad (3.19)$$

$$\theta^l_{t+1} = S_t + T_t \quad \ldots \quad (3.20)$$

where,

θ^l_{t+1}, forecast value for linear trend at period, t+1

S_t, smoothed level for linear trend

T_t, smoothed trend for linear trend

α_1, smoothed parameter for level

α_2, smoothed parameter for trend

The values of α_1, and α_2 which will give the best combination correspond to the minimum MSE_L, which were experimentally put at 0.10 and 0.01 respectively (Richard et al, 1987)

Initial value of θ^l_{t+1} can be obtained

when, t = 0, that is

$$\theta^l_1 = S_0 + T_0 \quad \ldots \quad (3.21)$$

where,

S_0, smoothed level when t = 0

T_0, smoothed trend when t = 0

Similarly, the errors are calculated from

$$e^l_t = \theta_t - \theta^l_t \quad \ldots \quad (3.22)$$

where,

e^l_t, error in period, t for linear regression.

θ_t, observed data in period, t

θ'_{tt}, forecast values in period, t.

The MSE_l values can also be gotten from

$$MSE_l = \Sigma(e^l_t)^2 / N_l \qquad \ldots \qquad (3.23)$$

where,

e^l_t, error in period, t for linear regression

N_l, number of errors obtained in linear regression.

Time Series Regression Model with Non-Linear Trend

The two popular non-linear trend found useful are the exponential trend' (which predicts that the amount of growth in each period will increase, and the damped trend' (which predicts that the amount of growth will decline. Both non-linear trends can be generated by simple modification to the linear-trend model.

The exponential smoothing model for non-linear trend is:

$$S^n_t = \theta^l_t + \alpha_1 e^l_t \qquad \ldots \qquad (3.24)$$

$$T^n_t = \beta T_{t-1} + \alpha_2 e^l_t \qquad \ldots \qquad (3.25)$$

$$\theta^n_{t+1} = S^n_t + \beta T^n_t \qquad \ldots \qquad (3.26)$$

where,

S^n_t, smoothed level for non-linear trend

T^n_t, smoothed trend for non-linear trend

β, trend modification parameter.

α_1, α_3, θ^l_t and e^l_t, are as defined earlier

θ^n_{t+1}, forecast value for non-linear trend at period , t + 1

The effect of β is to accelerate or decelerate the trend. When $\beta>1$, the model is called an exponential trend (since the amount of growth each period increases), and when $0<\beta<1$, growth decreases and the model is called a damped trend. If $\beta = 1$, the non-linear model is the same as linear trend.

The values of α_1, α_2, α_3 and β should be selected by a computer search similar to one for the linear trend. Practically, the best combination of the parameters were given to be 0.10, 0.01 and 1.1 respectively for exponential trend, and 0.20, 0.01 and 0.9 respectively for damped version (Richard et al, 1987).

Similarly, error e^n_t can be got using Equation 3.27 of the linear regression model that is

$$e^n_t = \theta_t - \theta_{t-1}{}^l \qquad \ldots \qquad (3.27)$$

The MSE_n for non-linear trend can also be obtained from

$MSE_b = \Sigma(e^b_t)^2/N_b$ ... (3.28)

where,

MSE_b, Mean Square error for non-linear trend

N_b, number of errors in non-linear trend.

The values of MSE_m, MSE_L, MSE_s, and MSE_b are compared with the value obtained from naive model MSE_o. The best of these forecasting models for the observed values of θ_t correspond to the one having the least value of MSE. Therefore, the value of service demand forecast for the next period in future can be written as

$\lambda_{t+1} = \theta^{best}_{t+1} N_t G_{it}/n_t$ ... (3.29)

The service demand rate, λ_{t+1}, would assist the management in planning for manpower (crews), tools and equipment, spare parts, operations and communication in the following year. To cater for any increase or decrease in number of maintenance centre in the following year, the service demand forecast equation can be re-written as:

$\lambda_{t+1}^* = \theta^{best}_{t+1} N_t G_{it}/(n_t \pm \omega)$ ... (3.30)

Where ω is the increase or decrease in maintenance centre in the following period.

The arrivals of these maintenance jobs into the centre are random thereby followed Poisson distribution (Kareem and Aderoba, 2000). Therefore inter-arrival times followed negative exponential distribution (Taha, 1988).

Hence,

$f(a_t) = \lambda_t \varepsilon^{-\lambda t a t}$ ... (3.31)

The associated Cumulative Probability Distribution Function (CDF) is given by

$$F(a_t) = \int_0^{a_t} \lambda_t \varepsilon^{-\lambda t a t}$$

From which

$F(a_t) = 1 - \varepsilon^{-\lambda t a t}$ ... (3.32)

Taking Logarithm of both sides

$a_t = -(1/\lambda_t) \, Log\,[F(a_t)]$ ... (3.33)

where,

$F(a_t)$ is a random number in the range $0 < F(a_t) < 1$.

However every computer system has a random number generator.

3.2 Crew Gang Determination

The maintenance centre should be able to engage crew size that would be competent to diagnose all categories of repairs to sustain response rate of customers. Time and work-studies have shown that longevity in duration of an activity depends on complexity or severity of such an activity. Hence, it is possible to have different times of service for different category of service demand. This development would also affect the number of manpower (crew gang) to be engaged. The activities in maintenance jobshops include preventive, repair, overhaul as well as the combinations of these activities.

The time to complete various tasks (in the past) could be obtained by administering questionnaire, oral interviews and personal observation of the activities in the maintenance centres. Since technology employed varies from one centre to the other then, three-time estimate from β–distribution become necessary (Aderoba, 1995).

Hence,

Let t_{e1}, be the expected time to complete a preventive maintenance.

t_{e2}, be the expected time to complete a repair

t_{e3}, be the expected time to complete an overhaul

From the β–distribution, an expected activity duration t_e is given as (Fig. 3.1)

$$t_e = (t_o + 4t_m + t_p)/6 \qquad \ldots \qquad (3.34)$$

Where,

t_e = Expected time,

t_o = Optimistic time,

t_m = Most likely time, and.

t_p = Pessimistic time of completion

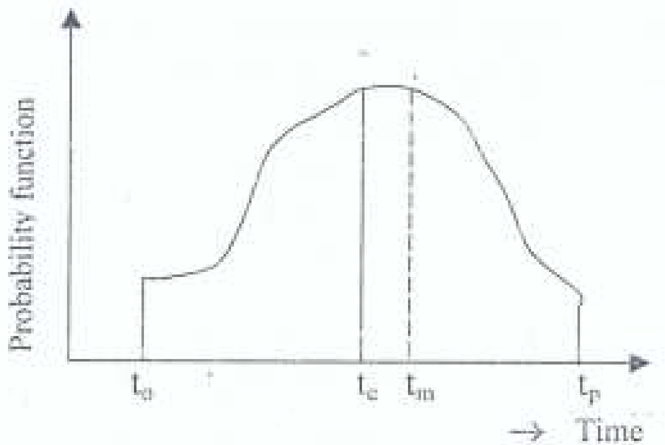


Fig. 3.1: β-Probability Distribution Curve

Source: Aderoba (1995)

The expected time for various policies can be estimated as in Table 3.1.

Table 3.1: Possible Maintenance Policy

Policy, n	Maintenance Policy	Expected Time
1	Preventive maintenance only	t_{e1}
2	Repair only	t_{e2}
3	Overhaul only	t_{e3}
4	Preventive and repair only	t_{e4}= Average of t_{e1}, t_{e2}
5	Preventive and overhaul only	t_5 = Average of t_{e1}, t_{e3}
6	Repair and Overhaul only	t_6 = Average of t_{e2}, t_{e3}
7	Preventive, Repair and Overhaul only	t_7 = Average of t_{e1}, t_{e2}, t_{e3}

As a result of these expected service times, for different maintenance policy, the service rate for each policy must be proportional to the service time. However, service time and service rate exhibit inverse proportionality relationship.

$$\mu_{nt} \propto 1/t_{en} \qquad \ldots \qquad (3.35)$$

$$\mu_{nt} = K/t_{en} \qquad \ldots \qquad (3.36)$$

where,

μ_{nt} = the service rate for policy, n at a period t.

K = proportionality constant which is equivalent to number of jobs served.

t_{en} = expected service time.

Then, for a unit job (K = 1),

$$\mu_{nt} = 1/t_{en} = t_{en}^{-1} \qquad \ldots \qquad (3.37)$$

The service rate, μ_{nt} may be accomplished by a group of maintenance personnel working as a team called "maintenance crew" whose size is equal to the number of personnel in the team called "gang size". The increase or decrease in number of maintenance personnel (in the following year) would surely affect service rate.

Hence,

$$\mu_{nt}^* = \mu_{nt}(1 \pm (\gamma/P)) \qquad \ldots \qquad (3.38)$$

where,

γ = Increase or decrease in maintenance personnel

P = Number of maintenance personnel in a crew

This system is a queuing problem, which can be solved by a tractable single channel model (Kareem and Aderoba, 2000). Employing this model (single channel).

Average waiting time, W_{qt} is given (at a given period, t) as

$W_{qt} = \Omega_{nt} / (\mu_{nt} - \lambda_t)$ ... (3.39)

where,

Ω_{nt} = the utilization factor on maintenance policy, n at a given period t.

λ_t = arrival rate of jobs to maintenance centre at a given period, t

μ_{nt} = service rate on maintenance policy, n at a given period, t.

The utilisation factor is a measure of

$\Omega_{nt} = \lambda_t / \mu_{nt}$ ... (3.40)

In case of multi-channel (in parallel) queueing system as expressed by Equation 3.1, the resulting complex equation for average waiting time of job in a given period, W_{qt} is as follows:

$W_{qt} = \{[\mu_{nt}(\Omega_{nt})^{Snt} P_0] / [(S_{nt} - 1)!(S_{nt}\mu_{nt} - \lambda_t)^2]\}$ ... (3.40a)

Where, P_0 is the probability that all channels are idle. However, various values of P_0 can be seen in Richard et al (1987).

The effective crew number to perform the tasks can be heuristically calculated from (Aderoba and Lawal, 1997)

$S_{nt} = W_{qt} / W^{*}_{qt}$ ... ... (3.41)

where,

S_{nt}- the crew gang for maintenance policy, n at a period, t

W_{qt}- waiting time for the jobs on maintenance policy, n at a period, t.

The W^{*}_{qt}- acceptable waiting time for each policy can be obtained in the same way as in expected service time, t_e.

Since maintenance crew cannot be 100% efficient, as a result of influencing factors (Lester, 1988), reliability factor, r should be included. Hence, Equation 3.41 becomes

$S_{nt} = W_{qt} / (rW^{*}_{qt})$ ... (3.41')

In Equation 3.41, if $W_{qt} \le W^{*}_{qt}$, single crew is optimum and if $W_{qt} > W^{*}_{qt}$, number of optimum crew is to the higher nearest integer (since fractions of human beings are impossible).

The corresponding value of crew size P* can be obtained from

$P^* = S_{nt}(P \pm y)$ ... (3.42)

However, Equation 3.39 may not be appropriate, as there is tendency that service rate could be lower than arrival rates due to stochastic nature of the system that may result to a negative crew size. To this end, simulation model based on event scheduling approach (Taha, 1988) would be useful to cater for stochastic nature of service time and arrival time.

Similarly, the studies of the process of departure of jobs are random in nature. That is Poisson distribution (Aderoba and Kareem, 2000). Hence, probability distribution follows negative exponential distribution.

Hence,

$f(s_i) = \mu_i \varepsilon^{-\mu_i s_i}$ ... (3-43)

The associated Cumulative Probability Distribution Function (CDF) is given by

$F(s_i) = \int_0^{\mu_i} \mu_i \varepsilon^{-\mu_i s_i}$

From which

$F(s_i) = 1 - \varepsilon^{-\mu_i s_i}$ ... (3-44)

Taking logarithm of both sides

$s_i = -(1/\mu_i) \, \mathrm{Log}\,[F(s_i)]$ ... (3-45)

where,

$F(s_i)$ is a random number in the range $0 < F(s_i) < 1$

Random numbers are called as in arrival time.

The following conditions are possible at a particular period of operating a maintenance policy

If, $s_i \geq a_i$

At this stage total waiting time, twt of jobs is updated

$twt = twt + nq\,(a_i - clock)$

and, $nq = nq + 1$

where,

nq = total number of jobs in queue

a_i = cumulative arrival time from time $t = 0$

clock = previous cumulative value of time before the next event (arrival or departure).

If, $s_i < a_i$ and $nq = 0$, then $s_i = clock$

At this stage the maintenance crew is idle. Therefore, total idle time, tidt is updated

$tidt = tidt + (a_i - clock)$

During the idle time the crew will be waiting for next arrival. Therefore total arrivals, tna will be increased by 1

$tna = tna + 1$

If, $nq > 0$ then $a_i = clock$

At this stage total waiting time, twt of jobs is updated

$twt = twt + nq\,(s_i - clock)$

If,

$s_i = a_i$ and the maximum simulation time is reached,

Then,

the average waiting time in queue, W_{qt} can be obtained from

$$W_{qt} = twt / tna \qquad \ldots \qquad (3.46)$$

Number of crew and crew size can be obtained in the same way as depicted in Equations (3.41 and 3.42 respectively)

Total busy time of the crew, etm is given as

$$etm = clock - tidt \qquad \ldots \qquad (3.47)$$

3.3 Tools and Equipment Planning

The maintenance centre will operate effectively if and only if each maintenance crew is provided with necessary maintenance tools. The number of set of tools/equipment required at a given time depends on maintenance policy employed and the corresponding number/size of maintenance crew obtained from Equation 3.41. That is,

$$Q_{nt} = S_{nt} \qquad \ldots \qquad (3.48)$$

where,

Q_{nt}, the number of set of tools and equipment required for maintenance policy, n at a given period, t.

However, tools and equipment for maintenance activities need to be well planned to guard against its excessive procurement. In planning for tools/equipment, there should be no room for duplication. This can be achieved through application of Set Theory (ST).

Let,

A, be the set of tools/equipment for preventive activities only without repetition.

B, be set of tools/equipment for repair activities only without repetition.

C, be set of tools/equipment for overhauling activities only without repetition.

Then,

Tools for preventive and repair activities only, D could be obtained as

$$D = A \cup B = g(A) + g(B) - g(A \cap B) \qquad \ldots \qquad (3.49)$$

Tools for preventive and overhauling only, can be obtained from

$$E = A \cup C = g(A) + g(C) - g(A \cap C) \qquad \ldots \qquad (3.50)$$

Tools for repair and overhauling only, can also be obtained as

$$F = B \cup C = g(B) + g(C) - g(B \cap C) \qquad \ldots \qquad (3.51)$$

Tools for all operations, can be got using

$$G = A \cup B \cup C = g(A) + g(B) + g(C) - g(A \cap C) - g(A \cap B) - g(B \cap C) +$$

$g(A \cap B \cap C)$ ... (3.52)

The initial values of A, B & C can be obtained through questionnaire analysis. With Equations 3.49, 3.50, 3.51 and 3.52 optimum number of tools and equipment can be obtained for different maintenance policy, n at a given period, t.

That is,

$Q^*_{n} = S_{n}\psi_{n}$ ... (3.53)

where,

ψ_{n} = set of tools used for maintenance policy, n

In case of increase or decrease in number of set of tools/Equipment in future, Equation 3.53 can be modified as

$Q^*_{n} = S_{n}(\psi_{n} \pm \xi)$ ... (3.54)

where,

ξ = Increase or decrease in tools/Equipment at a given period, t.

3.4 Spare Parts Planning

Since the inventory costs add to the cost of operation, it will be economical to apply effective inventory management to the scarce and expensive items (A-class). In maintenance centre, the A-class spare parts may be received in piece-meal by making sure that supplier supply at a time, what is enough for smooth operation of the centre. Classical inventory model was modified by Richard et al (1987) to include use rate and receipt rate:

Let,

N_{u} be optimum number of units per order

λ_{r}, be receipt rate (that is, units received in a given period) or supply rate.

Therefore, N_{u}/λ_{r}, number of periods required to receive order.

If,

λ_{u} is use rate (in unit) in a period

Then,

$(N_{u}/\lambda_{r})\lambda_{u}$ is number of units used during receipt period.

Hence,

Largest inventory which can accumulate is,

$N_{u} - N_{u}\lambda_{u}/\lambda_{r}$ ... (3.55)

Let R represent cost per unit, and let C represent carrying costs (Which includes, interest in money invested on inventory, obsolescence, storage space cost, store operations cost, taxes, insurance and pilferage costs) expressed as a percentage of average inventory.

Carrying costs is given as,

$(N_s/2)(1 - \lambda_u/\lambda_r)$ RC per period $= (RCN_u/2)(1 - \lambda_u/\lambda_r)$ ... (3.56)

If annual usage in units is symbolised as Y and ordering cost as p

Number of lots (orders) per year is Y/N_u

and total ordering cost is

Yp/N_u ... (3.57)

The total ordering and carrying costs are minimal when the cost to order per year equals the cost to carry the same inventory per year.

Equating Equations 3.56 and 3.57 to obtain Economic Order Quantity (EOQ), N_u

$Yp/N_u = (RCN_u/2)(1 - \lambda_u/\lambda_r)$

From which,

$N_u = [(2Yp/RC)(1 - \lambda_u/\lambda_r)]^{1/2}$ ... (3.58)

The supplier controls the receipt rate; to avoid the store being empty; the maintenance centre should seek for a reliable supplier. However, Equation 3.58 cannot be true for real life problem in that receipt rate cannot always be greater than use rate because of the random nature of supply times and use times. To this end, it will be difficult to estimate N_u at a time when $\lambda_u \geq \lambda_r$ as the result will either give zero or negative quantity Therefore, an acceptable solution could be achieved through simulation, by assuming one supplier as the controller of the receipt rate and one maintenance gang as the user of the spare parts supplied by that single supplier. This is a single channel queuing problem, which can be solved using event scheduling simulation approach.

These conditions are similar to that of crew gang determination but with different application. Therefore the following relations are valid for inventory planning:

The use time, t_u can be obtained as

$t_u = -(1/\lambda_u)\text{Log}\,[F(t_u)]$ ... (3.59).

If there is any increase/decrease, γ in personnel this would definitely affect the use rate, as the service rate would also change. Hence, use rate, λ_u in Equation (3.59) would change to the new use rate, λ_u'.

$\lambda_u' = \lambda_u(1 \pm \gamma/P)$. ... ($3.59^1$)

The use time, t_u becomes,

$t_u = -(1/\lambda_u')\text{Log}\,[F(t_u)]$,

where,

$F(t_u)$ is a random number between 0 and 1.

Similarly, receipt time, t_r can be obtained from

$t_r = -(1/\lambda_r)\text{Log}\,[F(t_r)]$ ... (3.60).

where,

$F(t_r)$ is a random number between 0 and 1.

Increase/decrease, γ in personnel does not affect the receipt rate, λ_r unless the maintenance centre requests the spare parts vendor to review its present supply rate, otherwise, it will remain as it was. The event scheduling approach is applied such that at the beginning of the planning horizon it was assumed that the first spare part is being received and used for the operation and the next receipt is being expected. That is, if t_u (use time) of the spare part received is greater than the next receipt time, t_r, the stock is increased by one then number of spare parts in stock is updated, otherwise, the store is empty. At this point, total out of stock time, tost, is updated, thereby expecting the next receipt.

That is,

If,

$t_u \geq t_r$, then update the number of spare part in stock, ns as well as total stock time ,tst

$tst = tst + ns(t_u - clock)$ ... (3.61)

$ns = ns + 1$ ... (3.62)

If the current number in stock, ns is greater than the maximum store capacity, mns then

$Mns = ns$ ... (3.63)

$tns = tns + 1$ ... (3.64)

tns = total number of receipts which enter the store.

If,

$t_u < t_r$ then total out of stock time is updated, and the time is set to the time of next receipt.

$ns = 0$

$tost = tost + (t_r - clock)$ ... (3.65)

$ns = ns + 1$

Obtain total stock time, tst of all receipts

$tst = tst + ns\,(t_u - clock)$ ... (3.66)

Then,

$ns = ns - 1$ ... (3.67)

The process of event scheduling simulation will continue until the maximum simulation time is reached. If not the time of next use and/ or the time of next receipt is generated and the process continues. The following statistics can also be obtained:

Total number of spare parts enter the stock up to the end of the planning horizon = tns

The maximum stock capacity at the end of the planning period (i.e. spare parts left) = mns

Average number of spare parts used at the end of the planning period,

$$Y = (tns - mns) / tst \quad \ldots \quad (3.68)$$

Using Equation 3.68, the effective optimum values for inventory could be obtained.

$$N_e = S_{at}[(2Yp/RC)]^{1/2} \quad \ldots \quad (3.69)$$

$$N_o = Y / N_e \quad \ldots \quad (3.70)$$

$$T_o = tst / N_o \quad \ldots \quad (3.71)$$

where,

N_e = optimum number of spare parts to order at a time.

N_e = optimum number of order.

T_o = optimum time per order.

S_{at} = optimum number of crew gang.

It could be seen that continuous maintenance operations are not hindered only by the arrival of jobs but also by the supply of spare parts. Therefore, actual busy period of maintenance crew could be obtained by taking minimum value between engage time (obtained from service rate) and total stock time (obtained from receipt rate). The optimum value of etm can be obtained from the relation:

If,

tidt $\geq$ tost, etm = clock – tidt; and if,

tost $\geq$ tidt, then, etm = clock – tost ... (3.72)

3.5 Communication Planning

Andrew et al (1996) stated that, in a group, numbers of interactions (N_p) within the group is given as:

$$N_p = P(P-1) \quad \ldots \quad (3.73)$$

where,

N_p = number of interactions

P = number of members of the group.

Equation (3.73) cannot be effectively used to analyse any change in interaction in future as a result of increase/decrease in crew size, γ.

Thus, by induction/enumeration,

$$N_{p\pm\gamma} = (P \pm \gamma)[(P \pm \gamma) - 1]$$

If there is increase in gang size then interaction will be

$$N_{p+\gamma} = N_p + \gamma(2P + \gamma - 1) \quad \ldots \quad (3.74)$$

Also,

If there is decrease in gang size, then interaction will be

$$N_{p-\gamma} = N_p + \gamma(-2P + \gamma - 1) \qquad \ldots \qquad (3.75)$$

Equation 3.73 gives equal weight to every member of the crew. However, Stephen (1999), analysed the level of interaction of individual in the group by the use of Equation 3.76

$$N_L = \sum_j P_{ij} \qquad \ldots \qquad (3.76)$$

where;

P_{ij} = the level of interaction of personnel i to other personnel j in the group.

The various values of P_{ij} can be obtained through questionnaire analysis.

Total level of interaction for all personnel in the group, N_a can also be obtained as

$$N_a = \sum_i \sum_j P_{ij} \qquad \ldots \qquad (3.77)$$

The weighted value of interaction for each personnel, P_w could be developed from Equations 3.76 and 3.77 as

$$P_w = N_L (N_p) / N_a \qquad \ldots \qquad (3.78)$$

If there is change in personnel, the weighted value becomes

$$P_w = N_L (N_{p\pm\gamma})/N_a \qquad \ldots \qquad (3.79)$$

Equation (3.79) shows that communication level depends on crew size. If the optimum number of crew is S_m, then Equation (3.79) becomes

$$P_w = S_M \; N_L (N_{p\pm\gamma}) / N_a \qquad \ldots \qquad (3.80)$$

The communication model will assist to know the personnel who control communication system of the maintenance centre (that is, one that has highest weighted value of interaction). That position should be given to well learned and articulate personnel for effective flow of information.

3.6 Maintenance Scheduling and Costing

The essence of operation planning is to ensure that all maintenance works are completed within a reasonable period and minimum maintenance cost. The effective operation planning will minimise both waiting time cost incurred by the customers and the cost of maintenance incurred by the maintenance centre. Taha, (1987), gave a typical relation for calculating total maintenance cost in which its adapted version is given as

$$TC(S_M) = S_M C_1 + C_2 L(S_m) \qquad \ldots \qquad (3.81)$$

TC (S_M), is the total maintenance cost.

C_1, average cost of a maintenance gang per unit time,

C_2, average cost of waiting per unit

However, the acceptable response rates (acceptable waiting time) of customers obtained from response to the administered questionnaire for all categories of repair works would solve the problem of waiting time cost incurred by the customers to the acceptable level. Hence, waiting time cost element in Equation (3.81) should be neglected, and cost of maintenance operations should be estimated.

Therefore,

$$TC\ (S_M) = (S_M)\ C_1 \qquad \ldots \qquad (3.82)$$

Equation (3.82) can be used to obtain the value of maintenance cost for various maintenance policies.

Cost of a maintenance crew gang, C_m per period can be obtained from the salary/allowance of the engaged crew. Cost of a set of tools/equipment, C_e per period can be obtained from the cost per period used of the set. Cost of inventorying spare parts, C_s at a given period is given as

C_s = ordering cost + carrying cost

$$C_s = Yp/N_o + (RCN_o/2) \qquad \ldots \qquad (3.83)$$

The utility cost, C_u entails the cost of electricity, C_t, cost of water supply, C_w and cost of communication, C_c.

That is,

$$C_u = C_t + C_w + C_c \qquad \ldots \qquad (3.84)$$

where,

C_u= is the utility cost per period of a crew gang engagement

C_t= cost of electricity per period of a crew gang engagement.

C_t can be calculated from monthly NEPA bill and/or the timely cost of diesel burnt in generator operation.

C_w = cost of water used by a crew gang per period.

C_c = is the cost of communication in a crew interaction per period.

C_c depends on the means of communication such as GSM, NITEL, MEMO, etc.

Another cost element is the cost of building/floor space, C_b. This can be calculated from the depreciation cost of building. Cost of maintaining tools/equipment used for maintenance, C_q cannot be neglected. Using poison distribution with necessary cost element;

$$C_q = C_b\ [1-(e^{-\sigma t} + e^{-\sigma t}(\sigma t)^1/1! + e^{-\sigma t}(\sigma t)^2/2! + \ldots + e^{-\sigma t}(\sigma t)^r/r!)\ ] \qquad \ldots \qquad (3.84a)$$

Due to low capital outlay in developing countries, indigenous maintenance centre may not be able to have more than one stand-by maintenance tools/equipment. However, three cases are possible at a given period of jobshop operation:

C_q = 0, when there is no equipment failure during the time frame considered.

C_q = $C_{tt}\,[1 - e^{-\sigma t}]$, when there is a failure but no stand-by equipment.

C_q = $C_{tt}[1-(e^{-\sigma t} + e^{-\sigma t}(\sigma t)^1/1!)]$, when there is a failure and a stand-by equipment is in place.

C_{tt} = Tools/equipment maintenance cost at a given period.

σ = Failure rate of the maintenance equipment.

t = Period considered

Summarily, the total maintenance cost at a unit period for maintenance policy, n is given as

$$TC\,(S_{nt}) = S_{nt}\,(C_m + C_{tt} + C_e + C_q) + C_b + C_s \qquad \ldots \qquad (3.85)$$

The maintenance cost computational methods would help the centre to forecast the best maintenance policy to adopt presently or in the future so that the expected maintenance cost could be minimal, and at the same time enhance sustainability of the centre by satisfying the response rate of the service calls.

If engage time of the crew (contract/temporary staff) during planning period is etm, total maintenance cost incurs during this period is given as

$$TC\,(S_{nt}) = S_{nt}\,C_l\,etm \qquad \ldots \qquad (3.86)$$

Which is equivalent to

$$TC\,(S_{nt}) = S_{nt}[\,(C_m + C_u + C_e)\,etm + C_q)] + C_b d_s + C_s \qquad \ldots \qquad (3.86')$$

where,

d, % depreciation

In the case of full-time/permanent staff, their idle time, tidt will still be paid for. Hence, total maintenance cost is given as

$$TC\,(S_{nt}) = S_{nt}\,C_l(etm + tidt) \qquad \ldots \qquad (3.87)$$

Similarly,

$$TC\,(S_{nt}) = S_{nt}[\,(C_m + C_u + C_e)\,(etm + tidt) + C_q)] + C_b d_s + C_s \qquad \ldots \qquad (3.87')$$

As a result of economy problem in developing countries it may be impossible to get enough funds to solving maintenance problem. If b% (of Equation (3.87)) is the percentage amount available for maintenance during planning period, then

$$TC\,(S_{nt}) = S_{nt}\,C_l(\,etm + tidt\,)b\% \qquad \ldots \qquad (3.88)$$

Discounted maintenance cost, tmt (if there is inflation and/or interest) can be obtained from,

$tmt = TC(S_{nt})/ [1/(1+i)(1+s)]$ ... (3.89)

where,

i = interest rate, and

s = inflation rate.

From Equations (3.86 and 3.88), budget surplus /shortage, B_s can be obtained

$B_s = TC(S_{nt}) = Snt\ C_1\ (etm + tidt)\ b\% - S_{nt}\ C_1\ etm$ ... (3.90)

If Equation (3.90) gives positive value, it indicates budget surplus, if otherwise, it indicates budget shortage.

If the actual amount released for maintenance is B, then,

$b\% = B/[TC(S_{nt})']$ ... (3.91)

3.7 Performance Evaluation

The key objective of establishing a commercial industrial maintenance centre is to maximise profit. This can be achieved by minimizing the cost of maintenance operations at an acceptable response rate. The cost incurred by the centre is the cost of operating the maintenance gang(s), which should be minimized as possible without affecting the response rates for various maintenance policies. The response-cost performance index, P_e for commercial maintenance centre could be obtained from

Performance index,

$P_e = W^*_{qt} / TC(S_{nt})$ ... (3.92)

where,

W^*_{qt}, is the response rate of service calls at a period t

Other performance indices that also proved useful include:

Crew utilisation performance index,

P_e = etm/ clock .. (3.93)

Cost of maintenance hour performance index,

$P_e = TC(S_{nt})/ etm$ ... (3.94)

Increase in value of Equation 3.93, indicates increase in performance. In case of Equation 3.94 decrease in value indicates better performance.

3.8 Post Optimality Analysis and Benefit-Cost Analysis

Benefit-cost analysis could be done by adapting the work of John et al (1989) to maintenance operations:

Let,

∂A_{nj} = incremental cost of switch over from one maintenance policy, n-1 to another, n when a contract/temporary staff j is engaged

∂A_{ni} = incremental cost of switch over from one maintenance policy, n-1 to another, n when a full-time/permanent staff i is engaged.

Then,

$\partial A_{nj} = TC(S_{nt})_j - TC(S_{(n-1)t})_j$

$\partial A_{ni} = TC(S_{nt})_i - TC(S_{(n-1)t})_i$

The benefit (savings) of engaging contract staff over full-time staff during switchover episode can be given as, ∂X_j

$\partial X_j = \partial A_{ni} - \partial A_{nj}$ ... (3.95)

The benefit (savings) of engaging full-time staff over contract staff during switchover episode can be given as, ∂X_i

$\partial X_i = \partial A_{nj} - \partial A_{ni}$ ... (3.96)

Hence,

Benefit-Cost Ratio (BCR) = Savings/Cost expended

Then,

For contract staff (part time staff),

$BCR = \partial X_j / \partial A_{nj}$ ... (3.97)

For full-time staff,

$BCR = \partial X_i / \partial A_{ni}$ ... (3.98)

The best alternative is the one with positive highest ratio.

3.9 Sensitivity Analysis

Recall that

$s_t = -(1/\mu_t) \text{Log} [F (s_t)]$

$a_t = -(1/\lambda_t) \text{Log} [F (a_t)]$

At a particular point in tim

$[F (a_t)] = [F (s_t)]$

Dividing,

$a_t/s_t = \mu/\lambda$

Making λ, the subject

$\lambda = (s_t/ a_t)\, \mu$

To prevent backlog of maintenance job

$s_i < a_i$

Introducing a Reduction Coefficient, $\bar{\gamma}$ termed Adekar factor,

$$\lambda = \bar{\gamma}\mu \qquad \ldots \qquad (3.99)$$

$\bar{\gamma}$ can be best obtained at the maximum possible service demand rate λ^* that the available service rate, μ can cope with.

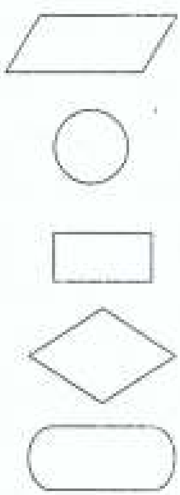
Therefore,

$$\gamma = \lambda^*/\mu \qquad \ldots \qquad (3.100)$$

With this Adekar factor, various λ can be plotted against μ. Hence, effective μ_{max} that prevents backlog can be obtained through the graph. $\bar{\gamma}$ varies from one maintenance policy/city to the other.

3.10 Computer Software Development

The algorithm developed for the integrated model (Appendix I), and its flow-chart (Appendix II) helped in computer software design/coding of the systems (Appendix III). The following are the keys to flow chart development:



Data input

Connector

Process

Decision

Terminator

Computer Aided Maintenance Strategic Decisions Optimisation & Planning named CAMSOP-2003 was developed using Visual Basic 6.0. CAMSOP-2003 was designed in the familiar Microsoft Windows environment to be interactive and user-friendly: through the use of controls such as text boxes, command buttons, frames and other appropriate message boxes. The database and structure of the software is flexible but robust enough to accommodate as many jobshops/cities as the storage capacity of the computer allows.

The design/coding of CAMSOP-2003 software involved the following phases (Appendix IV): namely, title, data entry, operation / execution and report phases.

Title Phase

This interface welcomes the software user into the system. It contains the names of the software, developer, the supervisor, the essence of the study and the department to which the developer belongs (Appendix IVa).

Data Entry Phase

This interface enters data into the database. It contains the following sub-interfaces (Appendix IVb).

City registration; this enters cities/maintenance jobshops used as case studies (Appendix IVbi):

Maintenance jobshop selection; this selects type of maintenance jobshops in question (Appendix IVbii).

Data entry for service demand; this enters data on service calls into the database. The data entry system is very flexible as shown in (Appendix IVbiii), and it gives room for data updating.

Maintenance policy data; this enters data related to maintenance policy into the database. It enters 3-times estimated (based on technological difference) for finishing the jobs and the acceptable waiting times for customers. This entering device is also flexible and the data can be updated (Appendix IVbiv).

Constant values data; this enters the smoothing parameters (Alphas) for various jobshops and it can be updated (Appendix IVbv).

Spare parts registration; this registers spare parts that maintenance jobshops are keeping. It gives room to deletion of spare parts that are no longer in use (Appendix IVbvi):

Spare parts planning data; it enters necessary data needed for effective spare parts planning. The basic elements of data required are as depicted in (Appendix IVbvii). This data can also be updated.

Tools registration; it registers the tools/equipment used for respective maintenance activities in the identified maintenance jobshops used as case studies. Tools/equipment are registered with their costs based on maintenance types and it can further be updated (Appendix IVbviii).

Communication means; it enters various media through which information can be passed from one personnel to the other with their unit time cost. This data can also be updated (Appendix IVbix).

Personnel per crew; this enters total number of personnel making a crew. The design gives room to changes in crew size (Appendix IVbx).

Personnel interaction record; this records the ratings of communication between maintenance personnel (Appendix IVbxi).

Maintenance cost entry; this submenu records a unit cost of electricity, water, crew and building/floor-space with its percentage depreciation. There is room for data updating (Appendix IVbxii)

Discounted cost data; this submenu enters into the database embedded into the software the inflation and interest rates (%). The database allows changes in inflation and interest rates (Appendix IVbxiii).

Operation/Execution Menu

This is the programme execution menu. It leads to the following submenu:

Forecasting; it forecasts for service demands in maintenance jobshops in the various towns based on the clicked forecasting method (Appendix IVc). This will lead to sub-interface (Appendix IVci-vii) where next forecast, mean errors and a button that leads to various maintenance policies can be seen. Optimum forecast button can also be clicked to obtain overall optimal forecast. This submenu compares MSEs for various forecasting methods and overall optimal forecast is chosen based on least MSE (Appendix IVcviii).

Maintenance policy unit; this submenu is entered into by clicking "maintenance policy" command in the aforementioned forecasting sub-interface and the optimal service demand rate appeared as shown in (Appendix IVcix). In this interface crew size and crew no are computed by clicking various policies indicated after inputting the simulation time and reliability factor. Other measures can also be carried out such as engage time of crew, idle time, waiting time of job etc.. This interface leads to submenu named "communication and inventory unit " by clicking required buttons".

Communication unit; this interface gives the total ratings and weighted level of interactions (Appendix IVcx). Note that optimal crew number at the top left side transferred from maintenance policy submenu. This helps in calculating optimal level of communication of maintenance crew(s).

Spare parts inventory unit; this submenu computes the optimal spare parts, time of order and other stated parameters with respect to optimal maintenance crews and service demands as indicated in Appendix IVcxi. This submenu leads to total cost interface by clicking command "Total Cost".

Total cost unit; in this interface various cost elements in Appendix IVcxii can be computed for various maintenance policies. This interface also selects appropriate tools/equipment required to carry out a specified maintenance activity. It also contains performance measures such as unit cost of maintenance as well as response-cost performance index. It also takes care of budgetary aspect based on part-time and full-time staff operation system. Decision of either to review strategic decision or not can be taken in this place. Clicking command "Report" can enter to sub-interface of Benefit-cost analysis. This leads to Appendix IVcxiii, where Benefit-cost analysis for various policies can be computed.

Report Menu

This interface reports the results of each and every modules of operation currently in use. However, the developed software is flexible and works in modules that are integrated into a composite whole. The software can effectively validate users input.

3.11 Computer Requirements

The computer hardware requirements for the developed CAMSOP 2003 are a personal computer with at least Pentium 166Hz, 32MB RAM, 1.5GB free Hard Disk. It can also be run on computer systems of higher grade like Pentium-2, Pentium-3 etc.

CHAPTER FOUR

4.0 MODEL VALIDATION

In an attempt to validate the model, some cities in Nigeria were used based on the information demands of the formulated model. In the chosen cities, questionnaires (Appendix Va,b) were circulated to every potential and prosperous maintenance centre (especially one engaging in maintenance of industrial machinery), as well as to every industry that demands for service of the centre. Besides, interview through phone call and direct contact with the management of the concerned organisations were conducted for further clarification on their responses. The responses after analysis served as input data for the model and also assist to know the level of acceptability of the developed CAMSOP-2003. The results obtained from the model assisted to know both sustainability of the existing maintenance centres and sustainability of establishing additional centre, subject to maintenance policy, maintenance costs and response rates of customers.

4.1 Data Collection and Analysis

Data were collected by questionnaire administration, direct interviews and by extracting relevant information from the works of past researchers. The collected data were analysed using statistical methods, such as sampling, grouping, mean, median and mode. The data (related to machinery maintenance) collected from identified maintenance jobshops in five cities in Nigeria namely, Akure, Osogbo, Ibadan, Ajaokuta and Lagos, were analysed and the results are shown in Tables 4.1 to 4.56:

4.2 Case Study 1: Maintenance Centres in Akure

This entails identified maintenance jobshops that are operating in Akure. These jobshops are maintaining, rotary parts of industrial machines like camshafts, crankshafts, gears and gearboxes, etc. and generating sets. The pattern of service demand, time of service, response rate and others are stated and analyzed in Tables 4.1 - 4.11.

Table 4.1: Maintenance Centre (Akure)

Maintenance centre*	Code	Age (as at 2003)
AMS	M_{c1}	31
SOMS	M_{c2}	15
FEL	M_{c3}	22
JMEW	M_{c4}	22

*The names of these centres are concealed to protect their identities and information.

Source: Survey, 2003

Table 4.2: Service Demand Data (Akure)

Year	Total no. of equip.	Ave. Age of plant	Ave. Maintenance call per week	Total no. of Mtce. Centre	Maintenance Call/Centre per week
1991	13	3	1.042	4	0.26
1992	13	4	1.063	4	0.27
1993	13	5	2.021	4	0.50
1994	13	6	3.021	4	0.76
1995	9	7	2.000	4	0.50
1996	9	8	3.000	4	0.75
1997	15	9	4.000	4	1.00
1998	24	6	3.188	4	0.80
1999	25	7	2.146	4	0.54
2000	27	8	3.146	4	0.80
2001	34	13	4.146	4	1.04
2002	34	14	3.188	4	0.80
2003	32	15	4.125	4	1.00

Source: Survey, 2003

Table 4.3: Average Time (in weeks) Spent in Maintenance (Akure)

Maintenance centre	Preventive			Repair			Overhaul			No of Gangs
	t_m	t_p	t_o	t_m	t_p	t_o	t_o	t_m	t_p	
M_{c1}	0.1	0.2	0.2	0.2	0.2	0.6	0.4	0.2	0.5	1
M_{c2}	0.1	0.2	0.2	0.2	0.2	0.8	0.6	0.4	0.6	1
M_{c3}	0.1	0.2	0.2	0.2	0.2	0.8	0.6	0.4	0.6	1
M_{c4}	0.1	0.2	0.2	0.2	0.2	1.0	0.8	0.6	0.7	1
Mean	0.1	0.2	0.2	0.2	0.2	0.8	0.6	0.4	0.6	1

t_o = Optimistic time, t_m = Most likely time, t_p = Pessimistic time

Source: Survey, 2003

Table 4.4: Average Acceptable Waiting Time (in weeks) in Maintenance Jobshops (Akure)

Maintenance center	Preventive			Repair			Overhaul		
	q_o	q_m	q_p	q_o	q_m	q_p	q_o	q_m	q_p
M_{c1}	1	1	1	1	2	2	2	2	2
M_{c2}	1	1	1	1	2	2	2	2	2
M_{c3}	1	1	1	1	2	2	2	2	2
M_{c4}	1	1	1	1	2	2	2	2	2
Mean	1	1	1	1	2	2	2	2	2

q_o = Optimistic acceptable waiting time, q_m = Most likely acceptable waiting time, q_p = Pessimistic acceptable waiting time

Source: Survey, 2003

Table 4.5: Tools/Equipment Used for Maintenance (Akure)

Preventive	Repair	Overhaul
Complete tool box, measuring instruments and small gadgets see (CAMSOP 2003)	Complete toolbox, measuring instruments and other maintenance equipment. (CAMSOP 2003)	As in repair but includes filters' benches and drafting facilities.

Source: Survey, 2003

Table 4.6: Spare Parts Stocked and Cost (Akure)

Spare Part	Preventive		Repair		Overhaul		Unit Cost ₦	Carrying cost ₦	Ordering Cost ₦
	Use rate No/ week	Received Rate (no/week)	Use rate (No/ week)	Receipt rate (No/week)	Use rate (No/ week)	Receipt rate (No/week)			
Diamond Cutter	0.5	2	1	2	1.5	2	3,000	200	1000
Bearing	0.5	2	1	2	1.5	2	2,000	200	1000

Source: Survey, 2003

Table 4.7: Average Cost of a Maintenance Gang (Akure)

Code	Cadre	Gross Salary/Month (₦)	Gross Salary/Hour (₦)
I	Director	60,000	500
II	Supervisor	25,000	208
III	Technical Officer	20,080	167
IV	Fore-man	18,000	150
V	Craftsman	15,000	125
VI	Attendant	10,000	833
	Total	148,000	1,233

Source: Survey, 2003

Table 4.8: Means and Cost/Unit Time of Communication (Akure)

Means	Cost/min. ₦	Mc_1	Mc_2	Mc_3	Mc_4	Common
MEMO	10	✓	✓	✓	✓	MEMO
NITEL	30	X	X	X	X	-
GSM	35	X	X	X	X	-
PABX	20	X	X	X	X	-
Face To Face (FTF)	2.1	✓	✓	✓	✓	FTF
✓ = Available X = Not Available						

Source: Survey, 2003

Table 4.9: Degree of Communication of Maintenance Personnel (Akure)

	I	II	III	IV	V	VI	Total Score
I	0	5	4	3	2	1	15
II	5	0	5	4	3	2	19
III	4	5	0	5	4	3	21
IV	3	4	5	0	5	4	21
V	2	3	4	5	0	5	19
VI	1	2	3	4	5	0	15
TOTAL	15	19	21	21	19	15	110

Key: Daily communication = 5 points
Every 2 days = 4 points
Every 3 days = 3 points
Every 4 days = 2 points
Weekly = 1 point
No communication = 0 point

Source: Survey, 2003

Table 4.10: Average Cost of Utility (Akure)

Utility	Cost/hr-₦	Source
Cost of Water	12	(Survey, 2003)
Cost of Electricity	24	(Survey, 2003)
Annual Depreciation Cost on Building	5% of Building Cost	(Aderoba, 1995)
Equipment maintenance cost/annum	200,000	(Survey, 2003)
Equipment failure rate/annum	9	(Survey, 2003)

Table 4.11: Inflation and Interest Rates (Akure)

	Percentage	Source
Inflation	25%	(Akanbi, et al, 2001)
Interest rate	25%	Survey, 2003

4.3 Case Study 2: Maintenance Centres in Osogbo

Maintenance jobshops currently operating in Osogbo were identified. These jobshops were grossly engaged in maintenance of industrial machinery such as; extruders, machine tools, stranding and wire drawing machines, generating sets and other related machines. The data on service demand from various industries, times of service, response rate, and maintenance crew are given in Table 4.12 - 4.22

Table 4.12: Maintenance Centres (Osogbo)

Maintenance Centre *	Code	Age (as at 2003)
JMES	M_{ca}	13
MAL	M_{cb}	13
FAES	M_{cc}	8
NMTO	M_{cd}	24

*The names of these centres are concealed to protect their identities and information.

Source: Survey, 2003

Table 4.13: Service Demand Data (Osogbo)

Year	Total no of serviceable equip.	Ave. Age of plant	Ave. Maintenance call per week	No. of maintenance centre	Maintenance Call /Centre per week
1991	27	10	1.625	3	0.54
1992	30	11	2.188	3	0.73
1993	29	9	1.375	3	0.46
1994	33	10	2.438	3	0.81
1995	33	11	1.875	3	0.63
1996	33	12	2.125	4	0.53
1997	15	8	2.50	4	0.62
1998	13	9	2.50	4	0.62
1999	14	10	1.5	4	0.38
2000	14	12	2.50	4	0.62
2001	14	13	1.5	4	0.38
2002	14	14	2.25	4	0.56
2003	27	15	2.5	4	0.63

Source: Survey, 2003

Table 4.14: Average Time of Service (in weeks) Spent in Maintenance (Osogbo)

Maintenance centre	Preventive			Repair			Overhaul			No of Gang
	t_o	t_m	t_p	t_o	t_m	t_p	t_p	t_o	t_m	
M_{cu}	0.1	0.2	0.3	0.2	0.3	0.4	0.3	0.3	0.5	1
M_{ch}	0.1	0.2	0.3	0.2	0.3	0.4	0.3	0.3	0.5	1
M_{cr}	0.1	0.2	0.3	0.2	0.3	0.4	0.3	0.3	0.5	1
M_{cd}	0.1	0.2	0.3	0.2	0.3	0.4	0.3	0.3	0.5	1
Mean	0.1	0.2	0.3	0.2	0.3	0.4	0.3	0.3	0.5	1

Source: Survey, 2003 .

Table 4.15: Average Acceptable Waiting Time in Maintenance Jobshop (Osogbo)

Maintenance centre	Preventive			Repair			Overhaul		
	t_o	t_m	t_p	t_o	t_m	t_p	t_o	t_m	t_p
M_{cu}	1	1	1	1	2	2	2	3	3
M_{ch}	1	1	1	1	2	2	2	3	3
M_{cr}	1	1	1	1	2	2	2	3	3
M_{cd}	1	1	1	1	2	2	2	3	3
Mean	1	1	1	1	2	2	2	3	3

Source: Survey, 2003

Table 4.16: Tools/Equipment Used for Maintenance (Osogbo)

Preventive (week)	Repair (week)	Overhaul (week)
Complete tool box, measuring instruments and small gadgets see (CAMSOP 2003)	Complete toolbox, measuring instruments and other maintenance equipment. (CAMSOP 2003)	As in repair but includes filters' benches and drafting facilities.

Source: Survey, 2003

Table 4.17: Spare Parts Stocked and Cost (Osogbo)

Nature / Parts	Preventive		Repair		Overhaul		Unit cost (₦)	Carrying cost (₦)	Ordering cost (₦)
	Use rate (No/week)	Receipt rate (No / week)	Use rate (No/ week)	Receipt rate (No/ week)	Use rate (No/ week)	Receipt rate (No/ week)			
Piston & ring	-	-	-	-	0.2	0.3	13100	13100	65500
Injector pump	0.1	0.5	0.2	0.5	0.4	0.5	18000	54000	270000
Bearing	0.5	2	1.2	2	1.5	2	2000	200	1000

Source: Survey, 2003

Table 4.18: Average Cost of Maintenance Crew (Osogbo)

Code	Cadre	Gross Salary/Month(₦)	Gross Salary/Hour(₦)
I	Manager	50,000	417
II	Engineer	35,000	292
III	Supervisor	25,000	208
IV	Foreman	19,000	158
V	Craftsman	17,000	142
VI	Filter Mechanics	14,000	117
VII	Attendant	7,000	58
	Total	167,000	1,392

Source: Survey, 2003

Table 4.19: Means and Cost/Unit Time of Communication (Osogbo)

Means	Cost/Min. (₦)	M_{cs}	M_{cls}	M_{cc}	M_{cd}	Common
MEMO	10	✓	✓	✓	✓	MEMO
NITEL	30	X	X	X	X	-
GSM	35	X	X	X	X	-
PABX	20	X	X	X	X	-
INTERNET	15	X	X	X	✓	-
Face To Face (FTF)	23	✓	✓	✓	✓	FTF
✓ = Available X = Not Available						

Source: Survey, 2003

Table 4.20: Degree of Interaction of Maintenance Crew (Osogbo)

Personnel	I	II	III	IV	V	VI	VII	Total
I	0	5	5	4	3	2	1	15
II	5	0	5	4	3	2	1	20
III	5	5	0	5	4	3	2	24
IV	4	4	5	0	5	4	3	25
V	3	3	4	5	0	5	4	24
VI	2	2	3	4	5	0	5	21
VII	1	1	2	3	4	5	0	16
Total	15	20	24	25	24	21	16	150

Source: Survey, 2003

Table 4.21: Average Cost of Utility (Osogbo)

Utility	Cost/hr(₦)	Source
Cost of Water	12	(Survey, 2003)
Cost of Electricity	24	(Survey, 2003)
Dep. Cost on Building	5%	(Aderoba, 1995)
Equipment maintenance cost/annum	200,000	(Survey, 2003)
Average equipment failure/annum	10	(Survey, 2003)

Table 4.22: Inflation and Interest Rates (Osogbo)

	Percentage	Source
Inflation	25%	(Akanbi et al, 2001)
Interest rate	25%	Survey, 2003

4.4 Case Study 3: Maintenance Centre in Ibadan

Identified maintenance jobshop currently operating in Ibadan was used. The maintenance jobshop is NTL. It specialises on the maintenance of generating sets, air compressors, gear system and pumps. The necessary maintenance related data are analysed and given in Table 4.23-4.33.

Table 4.23: Maintenance Centre (Ibadan)

Maintenance Centre*	Age
NTL	13

*The name of the centre is concealed to protect its identity and information.
Survey, 2003

Table 4.24: Service Demand Data (Ibadan)

Year	Total number of machinery	Ave. 'age' of industrial plant	Total maintenance call/week	Total no. of maintenance centre	Average maintenance call/week
1991	5	1	1	1	1
1992	5	2	1	1	1
1993	20	2	2	1	2
1994	20	3	2	1	2
1995	25	3	2	1	2
1996	30	4	2	1	2
1997	30	5	3	1	3
1998	30	6	3	1	3
1999	35	7	3	1	3
2000	35	7	3	1	3
2001	35	8	3	1	3
2002	35	9	3	1	3
2003	35	10	3	1	3

Source: Survey, 2003

Table 4.25: Average Time (Weeks) of Service in NTL Ibadan

Preventive			Repair			Overhaul			No of Gangs
t_o	t_m	t_p	t_o	t_m	t_p	t_o	t_m	t_p	
0.2	0.2	0.3	0.2	0.3	0.4	0.3	0.4	0.5	2

Source: Survey, 2003

Table 4.26: Acceptable Waiting Time in Weeks in NTL

Preventive			Repair			Overhaul		
q_o	q_m	q_p	q_o	q_m	q_p	q_o	q_m	q_p
1	2	2.5	2	2	2.5	2	2.5	3

Source: Survey, 2003

Table 4.27: Tools/Equipment Used for Maintenance in NTL

Preventive	Repair	Overhaul
Complete tool box, measuring instruments and small gadgets see (CAMSOP 2003)	Complete toolbox, measuring instruments and other maintenance equipment. (CAMSOP 2003)	As in repair but includes filters' benches and drafting facilities.

Source: Survey, 2003

Table 4.28: Spare Parts Stocked in NTL and Costs

Spare parts	Preventive		Repair		Overhaul		Unit cost (₦)	Carry-ing cost /unit (₦)	Ordering cost (₦)
	Use rate (/wk)	Receipt rate (/wk)	Use rate (/wk)	Receipt rate (/wk)	Use rate (/wk)	Receipt rate (/wk)			
Main bearing	1	3	2	3	2	3	2000	200	1000
Slip Rings	_	_	3	4	3	4	1000	100	500

Source: Survey, 2003

Table 4.29: Cost of Maintenance Crew in NTL

Maintenance Personnel	Code	Gross salary/month (₦)	Gross salary/hr (₦)
Engineer	1	20,000	166.67
Technologist	11	16,000	133.33
Technician	111	10,000	83.33
Craftsman	1V	7,000	62.50
Attendant	V	6,000	50.00
Total		59,000	495.83

Source: Survey, 2003

Table 4.30: Means of Communication and Costs in NTL

Means	Common ✓ Not common X	Cost / call/min.
MEMO	✓	10
NITEL	X	30
GSM	X	35
PABX	✓	20
FACE TO FACE	X	2.5
WALKIE TALKIE	✓	10

Source: Survey, 2003

Table 4.31: Rating of Communication in NTL

	I	II	III	IV	V	Total
I	0	5	5	5	5	20
II	5	0	5	5	5	20
III	5	5	0	5	5	20
IV	5	5	5	0	5	20
V	5	5	5	5	0	20
Total	20	20	20	20	20	100

Source: Survey, 2003

Table 4.32: Cost of Utility in NTL

Utility	Cost (₦)	Source
Water	12/hr	Survey, 2003
Electricity	24/hr	Survey, 2003
Dep. On Building	5%	Aderoba, 1995
Annual tool/ Equipment maintenance cost.	200,000	Survey, 2003
No. of Equipment failure/ annum	10	Survey, 2003

Source: Survey, 2003

Table 4.33: Inflation and Interest Rates

	Percentage	Source
Inflation	25%	(Akanbi, 2000)
Interest rate	25	Survey; 2003

Source: Survey, 2003

4.5 Case Study 4: Maintenance Centres in Ajaokuta

The maintenance jobshops specialised only on the maintenance of industrial machinery in ASCL was used. Their jobs covered among others maintenance of power plants, repair of machine tools, forged products, cyclones, de-mineralising water plants and related machinery. Data related to service demand and others are analysed and stated in Tables 4.34 - 4.44.

Table 4.34: Maintenance Centres In ASCL (Ajaokuta)

	Maintenance Centre*	Code	Age (as at 2003)
1	MRS	Mc^1	16
2	PERS	Mc^2	20

*The names of these centres are concealed to protect their identities and information.

Survey.2003

Table 4.35: Service Demand Data (Ajaokuta) ASCL.

Year	Total no of Equip.	Average Age of Industrial Plant	Total maintenance call/week	Total no of maintenance centre	Average maintenance call/centre/week
1991	12	4	2	2	1
1992	12	5	2	2	1
1993	12	6	2	2	1
1994	12	7	2	2	1
1995	15	6	2	2	1
1996	21	6	2	2	1
1997	28	6	2	2	1
1998	32	6	3	2	1.5
1999	32	7	3	2	1.5
2000	35	7	3	2	1.5
2001	35	8	3	2	1.5
2002	35	9	3	2	1.5
2003	35	10	4	2	2

Source: Survey, 2003

Table 4.36: Average Time of Service (in weeks) in ASRL (Ajaokuta)

Maintenance Centre	Preventive			Repair			Overhaul			No of Gang
	t_o	t_m	t_p	t_o	t_m	t_p	t_o	t_m	t_p	
mc^1	0.2	0.3	0.4	0.3	0.5	0.5	0.3	0.4	0.6	1
mc^2	0.2	03.	0.4	0.3	0.5	0.5	0.3	0.4	0.6	1
mean	0.2	0.3	0.4	0.3	0.5	0.5	0.3	0.4	0.6	1

Source: Survey, 2003

Table 4.37: Acceptable Waiting Time in Weeks

Maintenance Centre	Preventive			Repair			Overhaul		
	q_o	q_m	q_p	q_o	q_m	q_p	q_o	q_m	q_p
mc^1	1	1	2	1	2	2	2	2	3
mc^2	1	1	2	1	2	2	2	2	3
mean	1	1	2	1	2	2	2	2	3

Source: Survey, 2003

Table 4.38: Tools/Equipment Used for Maintenance Activities

Preventive (week)	Repair (week)	Overhaul (week)
Complete tool box, measuring instruments and small gadgets see (CAMSOP 2003)	Complete toolbox, measuring instruments and other maintenance equipment. (CAMSOP 2003)	As in repair but includes filters' benches and drafting facilities.

Source: Survey, 2003

Table 4.39: Spare Parts Stocked and Costs (Ajaokuta)

Spare parts	Preventive		Repair		Overhaul		Unit cost (₦)	Carrying cost/unit (₦)	Ordering cost/unit (₦)
	Use rate (/wk)	Receipt rate (/wk)	Use rate (/wk)	Receipt rate (/wk)	Use rate (/wk)	Receipt rate (/wk)			
Main bearin g	1	2	1.5	2	1.5	2	2000	200	1000
Slip Rings	–	–	2	3	2	3	10000	1000	5,000

Source: Survey, 2003

Table 4.40: Average Cost of Maintenance Gang (Ajaokuta)

Maintenance Personnel	Code	Gross salary/month (₦)	Gross salary/hr (₦)
Manager	1	85,000	708.33
Supervisor	11	52,000	433.33
Foreman	111	45,000	375.00
Craftsmen	1V	25,000	208.33
Attendant	V	15,000	125.00
Total		222,000	1,850

Source: Survey, 2003

Table 4.41: Means of Communication and Cost.

Means	Cost/min	Mc[1]	Mc[2]	Common
MEMO	10	✔	✔	MEMO
NITEL	30	X	X	-
GSM	35	X	X	-
PABX	20	✔	✔	PABX
FACE TO FACE	2.1	X	X	-
WALKIE TALKIE	10	✔	✔	WALKIE TALKIE

Source: Survey, 2003

Table 4.42: Rating of Communication

	I	II	III	IV	V	Total
I	0	5	5	5	5	20
II	5	0	5	5	5	20
III	5	5	0	5	5	20
IV	5	5	5	0	5	20
V	5	5	5	5	0	20
Total	20	20	20	20	20	100

Source: Survey, 2003

Table 4.43: Cost of Utility

Utility	Cost (₦)	Source
Water	12/hr	Survey, 2003
Electricity	24/hr	Survey, 2003
Dep. Cost On Building	5%	Aderoba, 1997
Average Annual Equipment maintenance cost.	200,000	Survey, 2003
Ave. Equipment failure/ annum	7	Survey, 2003

Source: Survey, 2003

Table 4.44: Inflation and Interest Rates

	Percentage	Source
Inflation	25%	(Akanbi et al, 2001)
Interest rate	25%	Survey, 2000)

Source: Survey, 2003

4.6 Case Study 5: Maintenance Centres in Lagos

The majority of maintenance jobshops identified in Lagos were involved in maintenance of generating sets. This entails servicing, repairing and overhauling. The characteristics of the identified jobshops are depicted as in Tables 4.45 - 4.55. The data related to service demand at the peak period of December of every year in the past is given in Table 4.56.

Table 4.45: Maintenance centre (Lagos)

	Maintenance Centre*	Code	Age (as at 2003)
1	LWLL	Mc^a	13
2	UTCN	Mc^b	40
3	LPSL	Mc^c	43
4	JHEL	Mc^d	41
5	MIL	Mc^e	35

*The names of these centres are concealed to protect their identities and information.

Source: Survey, 2003

Table 4.46: Service Demand Data (Lagos)

Year	Total no of serviceable machines	Average Age of Industrial Plant	Total maintenance call/week	Total no of maintenance centre	Average maintenance call/week
1991	14	3	6	5	1.2
1992	14	4	6	5	1.2
1993	14	5	6	5	1.2
1994	16	5	6	5	1.2
1995	16	6	6	5	1.2
1996	16	7	6	5	1.2
1997	16	8	6	5	1.2
1998	18	7	6	5	1.2
1999	18	8	7	5	1.4
2000	18	9	7	5	1.4
2001	18	10	10	5	2.0
2002	18	11	11	5	2.2
2003	18	12	11	5	2.2

Source: Survey, 2003

Table 4.47: Average Time (in Weeks) of Service in Maintenance Centres (Lagos)

Maintenance Centre	Preventive			Repair			Overhaul			No of Gang
	t_o	t_m	t_p	t_o	t_m	t_p	t_o	t_m	t_p	
mc^a	0.1	0.2	0.3	0.2	0.3	0.5	0.3	0.3	0.6	1
mc^b	0.1	0.2	0.3	0.2	0.3	0.5	0.3	0.3	0.6	1
mc^c	0.1	0.2	0.3	0.2	0.3	0.5	0.3	0.3	0.6	1
mc^d	0.1	0.2	0.3	0.2	0.3	0.5	0.3	0.3	0.6	1
mc^e	0.1	0.2	0.3	0.2	0.3	0.5	0.3	0.3	0.6	1
Mean	0.1	0.2	0.3	0.2	0.3	0.5	0.3	0.3	0.6	1

Source: Survey, 2003

Table 4.48: Acceptable Waiting Time in Weeks (Lagos)

Maintenance Centre	Preventive			Repair			Overhaul		
	q_o	q_m	q_p	q_o	q_m	q_p	q_o	q_m	q_p
mc^a	1	1	1	1	2	2	2	3	3
mc^b	1	1	1	1	2	2	2	3	3
mc^c	1	1	1	1	2	2	2	3	3
mc^d	1	1	1	1	2	2	2	3	3
mc^e	1	1	1	1	2	2	2	3	3
Mean	1	1	1	1	2	2	2	3	3

Source: Survey, 2003

Table 4.49: Tools/Equipment Used for Maintenance Activities (Lagos)

Preventive (week)	Repair (week)	Overhaul (week)
Complete tool box, measuring instruments and small gadgets see (CAMSOP 2003)	Complete toolbox, measuring instruments and other maintenance equipment. (CAMSOP 2003)	As in repair but includes filters' benches and drafting facilities.

Source: Survey, 2003

Table 4.50: Spare Parts Stocked and Cost (Lagos)

Spare parts	Preventive		Repair		Overhaul		Unit cost (₦)	Carrying cost/unit (₦)	Ordering cost/unit (₦)
	Use rate (/wk)	Receipt rate (/wk)	Use rate (/wk)	Receipt rate (/wk)	Use rate (/wk)	Receipt rate (/wk)			
Main bearing	1	2	1.5	1.5	1.8	2	2000	200	1000
Slip Rings	–	–	2	2	1.5	2	28,000	1200	6,000

Source: Survey, 2003

Table 4.51: Average Cost of Maintenance Gang (Lagos)

Maintenance Personnel	Code	Gross salary/month (₦)	Gross salary/hr (₦)
Maintenance Manager	1	85,000	708.33
Maintenance Engineer	11	60,000	500.00
Foreman	111	38, 000	316.67
Craftsmen	1V	25,000	208.33
Attendant	V	15,000	125.00
Total		223,000	1858.33

Source: Survey, 2003

Table 4.52: Means of Communication and Cost (Lagos)

Means	Cost/min	Mc^a	Mc^b	Mc^c	Mc^d	Mc^e	Common
NITEL	30	✓	X	✓	✓	✓	-
MEMO	10	✓	✓	✓	✓	✓	MEMO
GSM	35	✓	X	✓	✓	✓	-
INTERNET	10	X	✓	✓	✓	✓	
PABX	20	✓	✓	✓	✓	✓	PABX
FACE TO FACE	2.1	X	X	X	X	X	-
WALKIE TALKIE	20	X	X	X	X	X	-

✓, Available, X, Not Available

Source: Survey, 2003

Table 4.53: Degree of Communication

	I	II	III	IV	V	Total
I	0	5	5	5	5	20
II	5	0	5	5	5	20
III	5	5	0	5	5	20
IV	5	5	5	0	5	20
V	5	5	5	5	0	20
Total	20	20	20	20	20	100

Source: Survey, 2003

Table 4.54: Average Cost of Utility

Utility	Cost (₦)	Source
Water	12/hr	Survey, 2003
Electricity	24/hr	Survey, 2003
Dep. Cost On Building	5%	Aderoba, 1996
Average Equipment maintenance cost.	₦200,000	Survey, 2003
Ave. Equipment failure/annum	10	Survey, 2003

Source: Survey, 2003

Table 4.55: Inflation and Interest Rates

	Percentage	Source
Inflation	25%	(Akanbi et al, 2001)
Interest rate	25%	Survey, 2003

Source: Survey, 2003

Table 4.56: Service Demand Data for December (Ave. Calls/week)

Year	Akure	Osogbo	Ibadan	Ajaokuta	Lagos
1991	0.5	1.0	1.5	1.5	1.6
1992	0.5	1.1	1.5	1.5	1.6
1993	0.7	0.9	3	1.5	1.6
1994	0.9	1.2	3	1.5	1.6
1995	0.8	1.2	3	1.5	1.8
1996	1.2	1.0	3	1.5	2.0
1997	2	1.1	3	2.0	2.0
1998	1.3	1.1	3.5	2.0	2.0
1999	0.9	0.8	3.5	2.0	2.2
2000	1.4	0.8	3.5	2.5	2.6
2001	2.0	0.8	3.5	2.5	2.8
2002	1.4	1.1	4	2.5	3.0
2003	1.8	1.5	4	2.5	3.0

Source: Survey, 2003.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

We present here the results obtained when model was tested using the data obtained from maintenance job-shops operating in Akure, Osogbo, Ibadan, Ajaokuta and Lagos metropolis, under a simulation run of 52000 weeks (of CAMSOP – 2003). These results are discussed based on each strategic decision.

5.1 Service Demand Forecast

Optimal service demand forecast was obtained based on minimum "Mean Square Forecast Error" whereas the latter was obtained through "computer search" for the best smoothing parameters or factors α_1, α_2 and α_3 (Tables 5.1-5.10). Tables 5.11 and 5.12 summarises the values of the overall optimal service demand forecast for each of maintenance jobshops identified. Generally, optimal service demand was achieved through "Exponential Smoothing Forecasting" technique. Each maintenance centre in Akure, Osogbo, Ibadan, Ajaokuta and Lagos is having (on average) a demand of 1.08, 0.9, 2.39, 1.42 and 2.02 jobs/week respectively (Table 5.11). This shows that service demands for year 2004 are generally low except in Ibadan and Lagos where there is a little improvement. Service calls towards the end of the year (December, 2004) show an appreciable improvement over the normal periods (Table 5.12), except in Ibadan where there is no change in demand. The optimal demands are 2.06, 0.99, 2.39, 1.56 and 2.81 for each maintenance jobshop in Akure, Osogbo, Ibadan, Ajaokuta and Lagos respectively.

Table 5.1: Optimal Service Demand Forecast for 2004 (Akure)

Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecast 2004	Overall optimal forecast
	α_1	α_2	α_3			
1. Three period moving average	-	-	-	0.000069	1.08	-
2. Exponential smoothing	0.9	-	-	0.000001	1.08	1.08
3. Naive model	-	-	-	0.000131	1.08	-
4. Linear Regression model	-	-	-	0.002200	9.68	-
5. Smoothing Linear Trend	0.9	0.01	-	0.000438	2.15	-
6. Smoothing Non-linear Trend						
(i). Exponential	0.9	0.01	1.1	0.000452	2.15	-
(ii) Damped	0.9	0.01	0.9	0.000448	2.15	-

Table 5.2: Optimal Service Demand Forecast (2004) Osogbo

Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecast 2004	Overall optimal forecast
	α_1	α_2	α_3			
1. Three period moving average	-	-	-	0.000031	0.9	-
2. Exponential smoothing	0.9	-	-	0.000001	0.9	0.9
3. Naive model	-	-	-	0.000023	0.9	-
4. Linear regression model	-	-	-	0.006392	14.37	-
5. Smoothing Linear Trend	0.9	0.01	-	0.000985	2.69	-
6. Smoothing Non-linear Trend						
(i). Exponential	0.9	0.01	1.1	0.0001403	3.59	-
(ii) Damped	0.9	0.01	0.9	0.001013	2.69	-

Table 5.3: Optimal Service Demand Forecast (2004) Ibadan

Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecast 2004	Overall optimal forecast
	α_1	α_2	α_3			
1. Three period moving average	-	-	-	0.000762		-
2. Exponential smoothing	0.9	-	-	0.000011	2.39	2.39
3. Naive model	-	-	-	0.004100	2.39	-
4. Linear regression model	-	-	-	0.115485	2.39	-
5. Smoothing Linear Trend	0.9	0.09	-	0.043372	11.74	-
6. Smoothing Non-linear Trend						
(i). Exponential	0.9	0.09	1.1	0.063185	4.11	-
(ii) Damped	0.9	0.09	0.7	0.038258	4.79	-

Table 5.4: Optimal Service Demand Forecast (2004) Ajaokuta

Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal Forecast 2004	Overall Optimal Forecast
	α_1	α_2	α_3			
1. Three period moving average	-	-	-	0.000031	1.42	-
2. Exponential smoothing	0.9	-	-	0.000000	1.42	1.42
3. Naive model	-	-	-	0.000162	1.42	-
4. Linear regression model	-	-	-	0.054408	5.45	-
5. Smoothing Linear Trend	0.9	0.59	-	0.013554	5.59	-
6. Smoothing Non-linear Trend						-
(i). Exponential	0.9	0.09	1.1	0.023269	18.48	
(ii) Damped	0.9	0.09	0.8	0.011925	2.84	-

Table 5.5: Optimal Service Demand Forecast (2004) Lagos

Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal Forecast 2004	Overall Optimal Forecast
	α_1	α_2	α_3			
1. Three period moving average	-	-	-	0.000238	2.24	-
2. Exponential smoothing	0.9	-	-	0.000002	2.02	2.02
3. Naive model	-	-	-	0.001700	1.98	-
4. Linear regression model	-	-	-	0.143954	6.42	-
5. Smoothing Linear Trend	0.9	0.09	-	0.323777	7.12	-
6. Smoothing Non-linear Trend						
(i). Exponential	0.9	0.09	1.1	0.492166	22.54	-
(ii) Damped	0.9	0.09	0.7	0.270817	2.37	-

Table 5.6: Optimal Service Demand Forecast for December 2004 (Akure)

	Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecast (Dec. 2004)	Overall Optimal forecast (Dec. 2004)
		α_1	α_2	α_3			
1	Three period moving average	-	-	-	0.000223	1.79	-
2	Exponential smoothing	0.9	-	-	0.000001	2.06	2.06
3	Naive model	-	-	-	0.000338	2.15	-
4	Linear Regression Model	-	-	-	0.008608	10.44	-
5	Smoothing L. Regression Model	0.9	0.01	-	0.001338	4.30	-
6	Smoothing Non-linear Trend						
	(i) Exponential	0.9	0.01	1.1	0.001800	5.38	-
	(ii) Damped	0.9	0.01	0.5	0.001069	2.15	-

Table 5.7: Optimal Service Demand Forecast for December 2004 (Osogbo)

	Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecast (Dec. 2004)	Overall Optimal forecast (Dec. 2004)
		α_1	α_2	α_3			
1	Three period moving average	-	-	-	0.000131	1.50	-
2	Exponential smoothing	0.9	-	-	0.000001	0.99	0.99
3	Naive model	-	-	-	0.000115	0.90	-
4	Linear Regression Model	-	-	-	0.012423	9.75	-
5	Smoothing L. Regression Model	0.9	0.01	-	0.002631	3.59	-
6	Smoothing Non-linear Trend						
	(i) Exponential	0.9	0.01	1.1	0.003193	4.49	-
	(ii) Damped	0.9	0.01	0.7	0.002091	1.80	-

2

Table 5.8: Optimal Service Demand Forecast for December 2004 (Ibadan)

	Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecast (Dec. 2004)	Overall Optimal forecast (Dec. 2004)
		α_1	α_2	α_3			
1	Three period moving average	-	-	-	0.0001615	2.39	-
2	Exponential smoothing	0.9	-	-	0.000024	2.39	2.39
3	Naive model	-	-	-	0.009131	2.39	-
4	Linear Regression Model	-	-	-	0.261885	8.18	-
5	Smoothing L. Regression Model	0.9	0.04	-	0.091169	8.74	-
6	Smoothing Non-linear Trend (i) Exponential	0.9	0.06	1.1	0.127673	9.87	-
	(ii) Damped	0.9	0.04	0.7	0.078584	4.79	-

Table5.9: Optimal Service Demand Forecast for December 2004 (Ajaokuta)

	Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecast (Dec. 2004)	Overall Optimal forecast (Dec. 2004)
		α_1	α_2	α_3			
1	Three period moving average	-	-	-	0.000062	2.37	-
2	Exponential smoothing	0.9	-	-	0.0000001	1.56	1.56
3	Naive model	-	-	-	0.000315	1.42	-
4	Linear Regression Model	-	-	-	0.122046	8.05	-
5	Smoothing L. Regression Model	0.9	0.07	-	0.032838	9.95	-
6	Smoothing Non-linear Trend (i) Exponential	0.9	0.08	1.1	0.053409	7.02	-
	(ii) Damped	0.9	0.07	0.8	0.028050	2.84	-

Table 5.10: Optimal Service Demand Forecast for December 2004 (Lagos)

	Forecasting Techniques	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecast (Dec. 2004)	Overall Optimal forecast (Dec. 2004)
		α_1	α_2	α_3			
1	Three period moving average	-	-	-	0.000292	3.03	-
2	Exponential smoothing	0.9	-	-	0.000003	2.81	2.81
3	Naive model	-	-	-	0.003069	2.77	-
4	Linear Regression Model	-	-	-	2.318131	9.29	-
5	Smoothing L. Regression Model	0.9	0.06	-	0.665431	13.45	-
6	Smoothing Non-linear Trend (i) Exponential	0.9	0.09	1.1	0.012200	10.45	-
	(ii) Damped	0.9	0.07	0.8			-

Table 5.11: Overall Optimal Service Demand Forecast for 2004

Town/ Maintenance centre	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecasting Technique	Optimal forecast 2004
	α_1	α_2	α_3			
Akure	0.9	-	-	0.000001	Exponential smoothing	1.08
Osogbo	0.9	-	-	0.000001	Exponential smoothing	0.9
Ibadan	0.9	-	-	0.000011	Exponential smoothing	2.39
Ajaokuta	0.9	-	-	0.000001	Exponential smoothing	1.42
Lagos	0.9	-	-	0.000002	Exponential smoothing	2.02

Table 5.12: Overall Optimal Service Demand Forecast for December 2004

Town/ Maintenance centre	Optimal smoothing factor			Optimal Mean Square Error (MSE)	Optimal forecasting Technique	Optimal forecast Dec. 2004
	α_1	α_2	α_3			
Akure	0.9	-	-	0.000001	Exponential smoothing	2.06
Osogbo	0.9	-	-	0.000001	Exponential smoothing	0.99
Ibadan	0.9	-	-	0.000024	Exponential smoothing	2.39
Ajaokuta	0.9	-	-	0.000001	Exponential smoothing	1.56
Lagos	0.9	-	-	0.000003	Exponential smoothing	2.81

5.2 Crew Gang Determination

The optimal results of maintenance crew obtained from CAMSOP-2003 for each of maintenance centres identified in each city are shown in Tables 5.13 -5.17 for various reliability factors. At an acceptable reliability of 0.7, the results showed that the identified maintenance centres in Akure, Osogbo, Ibadan, Ajaokuta and Lagos can operate effectively with only one crew due to the low level of service demands (Table 5.18). In Akure and Osogbo, gang size can be further reduced from 6 and 7 to 4 and 5 respectively without affecting their level of operation. In peak period (December, 2004), one crew would be enough for the maintenance centres with its various sizes except in Lagos, which requires more personnel for its sustainability (Tables 5.19-5.23). Table 5.24 summarises the overall optimal crew at a reliability of 0.7 for each of maintenance centres. For instance, in Akure, 6 maintenance personnel are needed instead of 4 proposed, in Osogbo only 5 is required as proposed under normal condition, Ibadan and Ajaokuta still retain their level of gang size of 5, and in Lagos the existing crew needs to be increased by 1, for effective operation of the centre.

Table 5.13: Optimal Number of Maintenance Crew for 2004 (Akure)

Maintenance Centre	Observed parameters		Optimal Crew Number for various reliability factor (r)									
	Crew No.	Gang size	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
			P									
mc_1	1	6	1	1	1	1	1	1	1	1	1	1
mc_2	1	6	1	1	1	1	1	1	1	1	1	1
mc_3	1	6	1	1	1	1	1	1	1	1	1	1
mc_4	1	6	1	1	1	1	1	1	1	1	1	1
			R									
mc_1	1	6	1	1	1	1	1	1	1	1	1	1
mc_2	1	6	1	1	1	1	1	1	1	1	1	1
mc_3	1	6	1	1	1	1	1	1	1	1	1	1
mc_4	1	6	1	1	1	1	1	1	1	1	1	1
			O									
mc_1	1	6	1	1	1	1	1	1	1	1	1	1
mc_2	1	6	1	1	1	1	1	1	1	1	1	1
mc_3	1	6	1	1	1	1	1	1	1	1	1	1
mc_4	1	6	1	1	1	1	1	1	1	1	1	1
			A									
mc_1	1	6	1	1	1	1	1	1	1	1	1	1
mc_2	1	6	1	1	1	1	1	1	1	1	1	1
mc_3	1	6	1	1	1	1	1	1	1	1	1	1
mc_4	1	6	1	1	1	1	1	1	1	1	1	1
			P/R									
mc_1	1	6	1	1	1	1	1	1	1	1	1	1
mc_2	1	6	1	1	1	1	1	1	1	1	1	1
mc_3	1	6	1	1	1	1	1	1	1	1	1	1
mc_4	1	6	1	1	1	1	1	1	1	1	1	1
			P/O									
mc_1	1	6	1	1	1	1	1	1	1	1	1	1
mc_2	1	6	1	1	1	1	1	1	1	1	1	1
mc_3	1	6	1	1	1	1	1	1	1	1	1	1
mc_4	1	6	1	1	1	1	1	1	1	1	1	1
			R/O									
mc_1	1	6	1	1	1	1	1	1	1	1	1	1
mc_2	1	6	1	1	1	1	1	1	1	1	1	1
mc_3	1	6	1	1	1	1	1	1	1	1	1	1
mc_4	1	6	1	1	1	1	1	1	1	1	1	1

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.14: Optimal Number of Maintenance Crew for 2004 (Osogbo)

Maintenance Centre	Observed Parameters		Optimal Crew No for various reliability (r)									
	Crew No	Gang Size	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
	P											
mc_a	1	7	1	1	1	1	1	1	1	1	1	1
mc_b	1	7	1	1	1	1	1	1	1	1	1	1
mc_c	1	7	1	1	1	1	1	1	1	1	1	1
mc_d	1	7	1	1	1	1	1	1	1	1	1	1
	R											
mc_a	1	7	1	1	1	1	1	1	1	1	1	1
mc_b	1	7	1	1	1	1	1	1	1	1	1	1
mc_c	1	7	1	1	1	1	1	1	1	1	1	1
mc_d	1	7	1	1	1	1	1	1	1	1	1	1
	O											
mc_a	1	7	1	1	1	1	1	1	1	1	1	1
mc_b	1	7	1	1	1	1	1	1	1	1	1	1
mc_c	1	7	1	1	1	1	1	1	1	1	1	1
mc_d	1	7	1	1	1	1	1	1	1	1	1	1
	A											
mc_a	1	7	1	1	1	1	1	1	1	1	1	1
mc_b	1	7	1	1	1	1	1	1	1	1	1	1
mc_c	1	7	1	1	1	1	1	1	1	1	1	1
mc_d	1	7	1	1	1	1	1	1	1	1	1	1
	P/R											
mc_a	1	7	1	1	1	1	1	1	1	1	1	1
mc_b	1	7	1	1	1	1	1	1	1	1	1	1
mc_c	1	7	1	1	1	1	1	1	1	1	1	1
mc_d	1	7	1	1	1	1	1	1	1	1	1	1
	P/O											
mc_a	1	7	1	1	1	1	1	1	1	1	1	1
mc_b	1	7	1	1	1	1	1	1	1	1	1	1
mc_c	1	7	1	1	1	1	1	1	1	1	1	1
mc_d	1	7	1	1	1	1	1	1	1	1	1	1
	R/O											
mc_a	1	7	1	1	1	1	1	1	1	1	1	1
mc_b	1	7	1	1	1	1	1	1	1	1	1	1
mc_c	1	7	1	1	1	1	1	1	1	1	1	1
mc_d	1	7	1	1	1	1	1	1	1	1	1	1

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.15: Optimal Number of Maintenance Crew for 2004 (Ibadan)

Maintenance Centre	Observed		Optimal Crew No for various reliability (r)									
	Crew No	Gang Size	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
NT L.	P 2	5	1	1	1	1	1	1	1	1	1	2
NT L.	R 2	5	1	1	1	1	1	1	1	2	2	4
NT L.	O 2	5	1	1	1	1	1	2	2	2	3	6
NT L.	A 2	5	1	1	1	1	1	1	1	1	2	3
NT L.	P/R 2	5	1	1	1	1	1	1	1	1	2	3
NT L.	P/O 2	5	1	1	1	1	1	1	1	1	2	3
NT L.	R/O 2	5	1	1	1	1	1	1	1	1	2	3

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations
A, All operations

Table 5.16: Optimal Number of Maintenance Crew for 2004 (Ajaokuta ASCL)

Maintenance Centre	Observed		Optimal Crew No for various reliability (r)									
	Crew No	Gang Size	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
	P											
mc[1]	1	5	1	1	1	1	1	1	1	1	1	2
mc[2]	1	5	1	1	1	1.	1	1	1	1	1	2
	R											
mc[1]	1	5	1	1	1	1	1	1	1	1	1	2
mc[2]	1	5	1	1	1	1	1	1	1	1	1	2
	O											
mc[1]	1	5	1	1	1	1	1	1	1	1	2	3
mc[2]	1	5	1	1	1	1	1	1	1	1	2	3
	A											
mc[1]	1	5	1	1	1	1	1	1	1	1	1	2
mc[2]	1	5	1	1	1	1	1	1	1	1	1	2
	P/R											
mc[1]	1	5	1	1	1	1	1	1	1	1	1	2
mc[2]	1	5	1	1	1	1	1	1	1	1	1	2
	P/O											
mc[1]	1	5	1	1	1	1	1	1	1	1	2	3
mc[2]	1	5	1	1	1	1	1	1	1	1	2	3
	R/O											
mc[1]	1	5	1	1	1	1	1	1	1	1	1	2
mc[2]	1	5	1	1	1	1	1	1	1	1	1	2

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.17: Optimal Number of Maintenance Crew for 2004(Lagos)

Maintenance Centre	Observed		Optimal Crew No for various reliability (r)									
	Crew No	Gang Size	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
	P											
mc^a	1	6	1	1	1	1	1	1	1	1	1	2
mc^b	1	6	1	1	1	1	1	1	1	1	1	2
mc^c	1	6	1	1	1	1	1	1	1	1	1	2
mc^d	1	6	1	1	1	1	1	1	1	1	1	2
mc^e	1	6	1	1	1	1	1	1	1	1	1	2
	R											
mc^a	1	6	1	1	1	1	1	1	1	2	2	4
mc^b	1	6	1	1	1	1	1	1	1	2	2	4
mc^c	1	6	1	1	1	1	1	1	1	2	2	4
mc^d	1	6	1	1	1	1	1	1	1	2	2	4
mc^e	1	6	1	1	1	1	1	1	1	2	2	4
	O											
mc^a	1	6	1	1	1	1	1	1	1	1	2	4
mc^b	1	6	1	1	1	1	1	1	1	1	2	4
mc^c	1	6	1	1	1	1	1	1	1	1	2	4
mc^d	1	6	1	1	1	1	1	1	1	1	2	4
mc^e	1	6	1	1	1	1	1	1	1	1	2	4
	A											
mc^a	1	6	1	1	1	1	1	1	1	1	2	3
mc^b	1	6	1	1	1	1	1	1	1	1	2	3
mc^c	1	6	1	1	1	1	1	1	1	1	2	3
mc^d	1	6	1	1	1	1	1	1	1	1	2	3
mc^e	1	6	1	1	1	1	1	1	1	1	2	3
	P/R											
mc^a	1	6	1	1	1	1	1	1	1	1	1	2
mc^b	1	6	1	1	1	1	1	1	1	1	1	2
mc^c	1	6	1	1	1	1	1	1	1	1	1	2
mc^d	1	6	1	1	1	1	1	1	1	1	1	2
mc^e	1	6	1	1	1	1	1	1	1	1	1	2
	P/O											
mc^a	1	6	1	1	1	1	1	1	1	1	1	2
mc^b	1	6	1	1	1	1	1	1	1	1	1	2
mc^c	1	6	1	1	1	1	1	1	1	1	1	2
mc^d	1	6	1	1	1	1	1	1	1	1	1	2
mc^e	1	6	1	1	1	1	1	1	1	1	1	2
	R/O											
mc^a	1	6	1	1	1	1	1	1	1	1	1	1
mc^b	1	6	1	1	1	1	1	1	1	1	1	1
mc^c	1	6	1	1	1	1	1	1	1	1	1	1
mc^d	1	6	1	1	1	1	1	1	1	1	1	1
mc^e	1	6	1	1	1	1	1	1	1	1	1	1

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Tables 5.18: Operable Maintenance Policy for Various Gang Size ($r = 0.7$).

Crew Nr	Gang size	P	R	O	A	P/R	P/O	R/O
		LAGOS						
1	5*	✓	✓	✓	✓	✓	✓	✓
1	4	✓	X	X	✓	✓	✓	✓
1	3	X	X	X	X	X	X	✓
1	2	X	X	X	X	X	X	X
1	1	X	X	X	X	X	X	X
		AJAOKUTA						
1	5*	✓	✓	✓	✓	✓	✓	✓
1	4	X	✓	✓	✓	✓	✓	✓
1	3	X	X	X	X	X	X	✓
1	2	X	X	X	X	X	X	X
1	1	X	X	X	X	X	X	X
		IBADAN						
1*, 2	5*, 10	✓, ✓	✓, ✓	✓, ✓	✓, ✓	✓, ✓	✓, ✓	✓, ✓
1, 2	4, 8	X, ✓	X, X	X, X	X, ✓	✓, ✓	✓, ✓	✓, ✓
1, 2	3, 6	X, X	X, X	X, X	X, X	X, X	X, X	✓, ✓
1, 2	2, 4	X, X	X, X	X, X	X, X	X, X	X, X	X, X
1, 2	1, 2	X, X	X, X	X, X	X, X	X, X	X, X	X, X
		X, X	X, X	X, X	X, X	X, X	X, X	X, X
		OSOGBO						
1	7	✓	✓	✓	✓	✓	✓	✓
1	6	✓	✓	✓	✓	✓	✓	✓
1	5*	✓	✓	✓	✓	✓	✓	✓
1	4	X	✓	✓	✓	✓	✓	✓
1	3	X	✓	X	✓	✓	✓	✓
1	2	X	X	X	X	X	X	✓
1	1	X	X	X	X	X	X	X
		AKURE						
1	6	✓	✓	✓	✓	✓	✓	✓
1	5	✓	✓	✓	✓	✓	✓	✓
1	4*	✓	✓	✓	✓	✓	✓	✓
1	3	X	✓	X	✓	✓	✓	✓
1	2	X	X	X	X	X	X	✓
1	1	X	X	X	X	X	X	X

✓ = Operable

X = Not Operable

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.19: Optimal Number of Maintenance Crew for December 2004 (Akure) [Gang size 6*, 4, 5]

Maintenance Policy	Optimal crew number for various reliability factors (r)									
	1,1,1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
P	1,3,1	1,3,1	1,3,1	1,4,1	1,4,1	1,5,1	1,7,1	1,8,2	1,12,1	2,28,4
R	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,2,1	1,2	1,3,2	2,5,3
O	1,>3,1	1,>3,2	1,>3,2	1,>4,2	1,>4,2	1,>5,2	1,>7,3	2,>8	2,>12,5	4,>28,9
A	1,1,1	1,1,1	1,1,1	1,2,1	1,2,1	1,2,1	1,3,1	1,3	1,4,2	2,9,3
P/R	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,2	1,2,1	2,5,2
P/O	1,2,1	1,2,1	1,2,1	1,2,1	1,2,1	1,3,1	1,3,1	1,4	1,6,2	2,11,4
R/O	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1	1,2,1	1,3,2

Table5.20: Optimal Number of Maintenance Crew for December 2004 (Osogbo) [Gang size 7, 5*, 6]

Maintenance	Optimal crew number for various reliability factors (r)									
Policy	1,1,1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
P	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,2,1	1,3,2
R	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,2,1
O	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,2,1	1,3,2
A	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,2,1
P/R	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,2,1
P/O	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,2,1
R/O	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.21: Optimal Number of Maintenance Crew for December 2004 (Ibadan) [Gang size 5*]

Maintenance	Optimal crew number for various reliability factors (r)									
Policy	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
P	1	1	1	1	1	1	1	1	1	2
R	1	1	1	1	1	1	1	2	2	4
O	1	1	1	1	1	2	2	2	3	6
A	1	1	1	1	1	1	1	1	2	3
P/R	1	1	1	1	1	1	1	1	2	3
P/O	1	1	1	1	1	1	1	1	2	3
R/O	1	1	1	1	1	1	1	1	1	1

Table 5.23: Optimal Number of Maintenance Crew for December 2004 (Ajaokuta) [Gang size 5*]

Maintenance	Optimal crew number for various reliability factors (r)									
Policy	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
P	1	1	1	1	1	1	1	1	2	3
R	1	1	1	1	1	1	1	1	1	2
O	1	1	1	1	1	2	2	2	2	4
A	1	1	1	1	1	1	1	1	2	3
P/R	1	1	1	1	1	1	1	1	1	2
P/O	1	1	1	1	1	1	1	1	2	3
R/O	1	1	1	1	1	1	1	1	1	2

Table 5.24: Optimal Number of Maintenance Crew for December 2004 (Lagos) [Gang size 5, 6*]

Maintenance	Optimal crew number for various reliability factors (r)									
Policy	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
P	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	2,1	3,1
R	2,1	2,1	2,1	2,1	3,1	3,1	4,2	5,2	8,3	14,5
O	5,1	7,1	7,1	8,1	9,1	10,1	11,2	14,2	24,3	46,5
A	1,1	1,1	1,1	2,1	2,1	2,1	2,1	3,1	4,2	7,3
P/R	1,1	1,1	1,1	1,1	1,1	1,1	2,1	2,1	3,2	5,3
P/O	1,1	1,1	1,1	1,1	1,1	1,1	2,1	2,1	3,2	5,3
R/O	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	2,1

Table 5.25: Overall Optimal Crew for 2004 (r = 0.7)

Town/ Maintenance Centre	Observed		Maintenance Policy	Optimal Value 2004, Dec. 2004		Savings 2004, Dec. 2004	
	Crew No	Gang Size		Crew No	Gang Size	Crew No	Gang Size
Akure	1	6	P	1,1	4,6	-,-	2,-
			R	1,1	4,6	-,-	2,-
			O	1,1	4,6	-,-	2,-
			A	1,1	4,6	-,-	2,-
			P/R	1,1	4,6	-,-	2,-
			P/O	1,1	4,6	-,-	2,-
			R/O	1,1	4,6	-,-	2,-
Osogbo	1	7	P	1,1	5,5	-,-	2,2
			R	1,1	5,5	-,-	2,2
			O	1,1	5,5	-,-	2,2
			A	1,1	5,5	-,-	2,2
			P/R	1,1	5,5	-,-	2,2
			P/O	1,1	5,5	-,-	2,2
			R/O	1,1	5,5	-,-	2,2
Ibadan	2	10	P	1,1	5,5	1,1	5,5
			R	1,1	5,5	1,1	5,5
			O	1,1	5,5	1,1	5,5
			A	1,1	5,5	1,1	5,5
			P/R	1,1	5,5	1,1	5,5
			P/O	1,1	5,5	1,1	5,5
			R/O	1,1	5,5	1,1	5,5
Ajaokuta	1	5	P	1,1	5,5	-,-	-,-
			R	1,1	5,5	-,-	-,-
			O	1,1	5,5	-,-	-,-
			A	1,1	5,5	-,-	-,-
			P/R	1,1	5,5	-,-	-,-
			P/O	1,1	5,5	-,-	-,-
			R/O	1,1	5,5	-,-	-,-
Lagos	1	5	P	1,1	5,6	-,-	-,-1
			R	1,1	5,6	-,-	-,-1
			O	1,1	5,6	-,-	-,-1
			A	1,1	5,6	-,-	-,-1
			P/R	1,1	5,6	-,-	-,-1
			P/O	1,1	5,6	-,-	-,-1
			R/O	1,1	5,6	-,-	-,-1

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

5.3 Tools and Equipment Planning

The results in Table 5.26 shows that one set of maintenance tools/equipment (as indicate in CAMSOP- 2003) is optimal for various categories of repair in each of maintenance centres in Akure, Osogbo, Ibadan, Ajaokuta and Lagos. Besides, set theory analysis shows that Overhaul (O) tools/equipment are optimal for All operations (A), Preventive and Overhaul (P/O) and Repair and Overhaul (R/O), whereas Repair tools (R) are optimal for Preventive and Repair (P/R) activities (Table 5.27). The situation is the same for December, 2004, but each of maintenance jobshops in Ibadan should shelve one set of tools/equipment out of the two set presently using as one set is optimal based on the level of service demands.

Table 5.26: Optimal Number of Tools & Equipment (r = 0.7)

Town	Observed set of equipment							Optimal set of equipment							
	P	R	O	A	P/R	P/O	R/O	P	R	O	A	P/R	P/O	R/O	Saving
Akure	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-
Osogbo	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-
Ibadan	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1
Ajaokuta	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-
Lagos	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-

Table 5.27: Optimal Maintenance Policy and Corresponding Set of Equipment/Tools (r = 0.7)

	Akure	Osogbo	Ibadan	Ajaokuta	Lagos	Equivalent
P	1	1	1	1	1	P
R	1	1	1	1	1	R
O	1	1	1	1	1	O
A	1	1	1	1	1	O
P/R	1	1	1	1	1	R
P/O	1	1	1	1	1	O
R/O	1	1	1	1	1	O

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

5.4 Spare Parts Planning

The level of spare part (bearing) inventory is shown Table 5.28a. The model would save each of maintenance centres in Akure, Osogbo, Ibadan, Ajaokuta and Lagos from excessive procurement of "bearing" of 78, 77, 52, 51 and 51 (in case of Preventive (P) maintenance policy), 52, 41, 26, 26 and 26 (in case of Repair (R) maintenance policy), 26, 25, 26, 26 and 36 (in case of Overhaul (O) maintenance policy), 51, 49, 35, 35 and 37 (in case of All operation (A) maintenance policy), 64, 59, 38, 39 and 38 (in case of P/R maintenance policy), 52, 52, 38, 38 and 44 (in case of P/O maintenance policy), 38,33, 26, 26, and 31 (in case of R/O maintenance policy) respectively. For these policies, optimal time/order (in weeks) are round up to half a week except in Ibadan where each maintenance centre has optimal time/order round up to two-third of a week.. Besides, only one spare part should be ordered at a time (Table 5.28b).

Table 5.28a: Optimal Inventory Level (r = 0.7)

Town	Observed Average Inventory							Optimal Inventory							Inventory Savings						
	P	R	O	A	P/R	P/O	R/O	P	R	O	A	P/R	P/O	R/O	P	R	O	A	P/R	P/O	R/O
Akure	104	104	104	104	104	104	104	26	52	78	53	40	52	66	78	52	26	51	64	52	38
Osogbo	104	104	104	104	104	104	104	27	53	79	55	45	52	71	77	41	25	49	59	52	33
Ibadan	78	78	78	78	78	78	78	26	52	52	43	40	40	52	52	26	26	35	38	38	26
Ajaokuta	104	104	104	104	104	104	104	53	78	78	69	65	66	78	51	26	26	35	39	38	26
Lagos	104	104	130	112	104	117	117	53	78*	94	75	66	73	86	51	26	36	37	38	44	31

Table 5.28b: Optimal Number of Order and Time of Order

Town	Observed Average Inventory							Optimal Inventory						
	p	R	O	A	P/R	P/O	R/O	P	R	O	A	P/R	P/O	R/O
Akure	1	1	1	1	1	1	1	0.50	0.50	0.49	0.49	0.50	0.50	0.49
Osogbo	1	1	1	1	1	1	1	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Ibadan	1	1	1	1	1	1	1	0.67	0.65	0.65	0.66	0.66	0.64	0.66
Ajaokuta	1	1	1	1	1	1	1	0.50	0.50	0.49	0.50	0.49	0.50	0.50
Lagos	1	1	1	1	1	1	1	0.49	0.50	0.50	0.50	0.50	0.49	0.50

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

5.5 Communication Planning

Table 5.29a shows savings in level of interaction. Application of this model saves each of maintenance shops in Akure, Osogbo, and Ibadan, 18, 22 and 20 interactions (and its associated cost) respectively, while the present interaction level in Ajaokuta and Lagos is still optimal in year 2004. In December, 2004 each of maintenance shops in Lagos needs to increase its level of interaction by adding one more staff. Also Technical Officer and Foreman have the highest weighted level of interaction in each of maintenance centres in Akure, and Foreman have the highest weighted level of interaction in each of maintenance centres in Osogbo. All maintenance personnel in each of the maintenance centres in Ibadan, Ajaokuta and Lagos have equal weighted level of interaction (Table 5.29b)

Table 5.29a: Optimal Level of Interaction (r = 0.70)

Town	Observed				Optimal				Savings			
	No of Crew	Gang Size	No of Interaction	Total ratings of interaction	No of Crew	Gang Size	No of Interaction	Total ratings of interaction	No of Crew	Gang Size	No of Interaction	Total ratings of interaction
Akure	1	6	30	30	1	4	12	12	-	2	18	18
Osogbo	1	7	42	42	1	5	20	20	-	2	22	22
Ibadan	2	10	40	40	1	5	20	20	1	5	20	20
Abeokuta	1	5	20	20	1	5	20	20	-	-	-	-
Lagos	1	5	20	20	1	5	20	20	-	-	-	-

Table5.29b: Optimal Weighted Level of Interaction (r = 0.7)

Town	Personnel	Rating	Weighted level
Akure	Attendant	15	4.09
	Craftsman	19	5.18
	Director	15	4.09
	Foreman	21	5.73
	Supervisor	19	5.18
	Technical officer	21	5.73
Osogbo	Attendant	16	4.36
	Craftsman	24	6.55
	Engineer	20	5.45
	Filter mechanics	21	5.73
	Foreman	25	6.82
	Manager	24	6.55
	Supervisor	24	6.55
Ibadan	Attendant	20	4.00
	Craftsman	20	4.00
	Engineer	20	4.00
	Technician	20	4.00
	Technologist	20	4.00
Ajaokuta	Attendant	20	4.00
	Craftsman	20	4.00
	Foreman	20	4.00
	Manager	20	4.00
	Supervisor	20	4.00
Lagos	Attendant	20	4.00
	Craftsman	20	4.00
	Engineer	20	4.00
	Foreman	20	4.00
	Manager	20	4.00

5.6 Maintenance Scheduling and Costing

The optimal maintenance jobs scheduling costs using developed model are presented in Tables 5.30a-5.36a under various condition stated: Full- time (FT) and Part- time (PT) staff engagement on one part and No Equipment Failure (NEF), Equipment Failure with Standby (EFS) and Equipment Failure Without Standby (EFW) on the other. Performance based on the cost of maintenance week is also evaluated; this would assist in charging maintenance activities appropriately (Figures 5.30b-5.36b). However, Benefit Cost Ratio (BCR) analysis of the system (Tables 5.30b-5.36b) would assist the maintenance manager of each maintenance centre to know the most profitable maintenance policy to embark on in the year 2004 with minimum additional cost as compared to other alternative policies. For instance in Akure, Preventive/Repair policy is the best alternative for each of maintenance centres in the year 2004 with BCR of 44.51, 46.24 and 48.51 for NEF, EFS and EFW respectively, based on PT staff engagement, while Overhauling stands the best for NEF, EFS and EFW based on FT staff engagement. The former is preferable in region where competent staff is lacking. It may be disastrous to embark on PT staff under this condition. The PT staff may be encouraged in the developed countries where enough competent staff is readily available. Similarly, All Operations (A) stands the best for PT staff and Repair/Overhauling (R/O) stands the best for FT staff engagement under the three states of NEF, EFS and EFW in each of maintenance centres in Osogbo. This is similar to one at Ibadan.

In case of Ajaokuta, Preventive/Repair (P/R) is considered best alternative for PT staff while Repair/Overhaul (R/O) is the best option for FT staff engagement in the year 2004. These results are similar to one obtained for Lagos. The revised version of the results when the crew size in Akure and Osogbo maintenance jobshops are reduced to 4 and 5 respectively are presented in Tables 5.35b and 5.36b. In Osogbo, reduction of the crew size to 5 does not affect the optimal alternative course of action, but in Akure, the reduction of crew size to 4 greatly changed the situation. For PT staff engagement, Repair is the best option for NEF, Preventive/Overhaul is the best for EFW and Preventive/Repair is the best for EFS. In case of FT staff, Overhaul (O) is the best for all the three states of NEF, EFW and EFS. Also tools/equipment failure without standby incurred more maintenance cost than with standby.

Generally, maintenance cost estimated for Full-time Staffers is generally higher than that of Part-time Staffers. Results also showed that Cost estimated for each maintenance policy under Part-time Staffers are relatively close in all identified maintenance centres, and the gap is relatively wide in case of Full-time Staffers (Tables 5.30a-5.36a; Figures 5.1- 5.7).

Table 5.30a: Optimal Total Maintenance Cost under Full-time and Part-time Staff (Memo, Akure)

Mtce Policy	Part-Time Staff Engagement				Full-Time Staff Engagement				Savings		
	No equip mtce (n)	With standby (w)	Without standby (w_o)	Mtce wk cost	No equip mtce (n)	With standby (w)	Without standby (w_o)	Mtce wk cost	No equip mtce (n)	With standby (w)	Without standby (w_o)
P	744683.24	778533.87	838680.28	32575.76	14926723.07	14926847.73	14926669.89	1154817.06	14181739.83	14179313.89	14087989.63
R	1653052.61	1073950.82	1121152.64	80693.69	15159758.98	15158223.66	15151043.80	1169988.77	14097746.37	14076872.84	14029893.16
O	1470810.05	1478412.09	1503368.06	77044.56	15187534.77	15184759.45	15184561.59	864702.43	13713924.72	13706317.36	13681613.53
A	1189530.81	1209926.14	1249407.56	84304.14	3499652.61	3499677.30	3469899.44	248043.90	2310121.81	2299751.16	2270491.88
P/R	933379.66	960146.49	1013978.71	80325.27	15156659.55	15156684.21	15156906.35	1304361.81	14223279.87	14196537.72	14142927.64
P/O	1153394.25	1169630.56	1210997.59	79121.69	15237840.66	15237865.34	15238087.48	1015119.38	14084246.41	14068234.78	14027089.89
R/O	999403.01	1017693.13	1073026.09	87537.88	15208802.28	15208826.96	5209049.10	1345911.71	14219398.27	14191131.83	14136023.05

Table 5.30b: Benefit Cost Ratio (BCR) Analysis (Akure)

B C R	P → R	R → O	O → A	A → P/R	P/R → P/O	P/O → R/O
BCR_c^n	NV	NV	40.54	44.51*	NV	NV
BCR_i^n	0.37	11.30*	NV	NV	1.71	4.65
BCR_c^{wo}	NV	NV	42.00	46.24*	NV	NV
BCR_i^{wo}	1.32	10.92*	NV	NV	1.58	4.23
BCR_c^w	NV	NV	45.10	48.51*	NV	NV
BCR_i^w	1.26	10.26*	NV	NV	1.42	3.72

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.31a: Optimal Total Maintenance Cost under Full-time and Part-time Staff (Memo, Osogbo)

Mtce Policy	Part-Time Staff Engagement				Full-Time Staff Engagement				Savings		
	No equip mtce (n)	With standby (w)	Without standby (w_o)	Mtce work cost	No equip mtce (n)	With standby (w)	Without standby (w_o)	Mtce work cost	No equip mtce (n)	With standby (w)	Without standby (w_o)
P	734068.09	789398.18	846395.99	79806.35	15370925.77	15370934.85	15371025.65	1624834.55	14613857.67	14580536.67	14524629.66
R	1214627.24	1228461.77	1265415.72	87446.17	15510268.07	15510277.15	15510367.95	1116649.97	14295640.83	14281815.94	14244952.23
O	1398280.73	1407936.43	1437260.62	88723.40	15593772.04	15593781.12	15593871.92	889455.12	14195491.31	14185844.69	14156671.30
A	1214628.10	1231267.50	1272642.33	93038.75	3904421.02	3904430.10	3904520.90	301966.85	2689792.93	2673162.51	2631878.57
P/R	1020551.74	1041755.55	1089335.31	87450.88	15499549.25	15499558.33	15499649.13	1326153.32	14478997.51	14457804.78	14410313.82
P/O	1119290.77	1137226.21	1180478.23	89257.64	15591727.82	15591736.90	15591827.70	1245359.87	14472437.05	14454510.69	14411349.47
R/O	950301.26	983081.77	1032283.77	100891.83	15619055.46	15619014.54	15619149.34	1618072.77	14668644.20	14635972.77	14586861.57

Table 5.31b: Benefit Cost Ratio (BCR) Analysis (Osogbo)

B C R	P → R	R → O	O → A	A → P/R	P/R → P/O	P/O → R/O
BCR_c^n	NV	NV	62.65*	58.75	NV	NV
BCR_i^n	2.30	1.20	NV	NV	0.07	5.18*
BCR_c^{wo}	NV	NV	65.17*	60.18	NV	NV
BCR_i^{wo}	2.15	1.15	NV	NV	3.57	4.64*
BCR_c^w	NV	NV	70.03*	62.26	1.14	NV
BCR_i^w	2.01	1.06	NV	NV	NV	4.06*

Table 5.32a: Optimal Total Maintenance Cost under Full-time and Part-time Staff (Memo, Ibadan)

Mtce Policy	Part-Time Staff Engagement				Full-Time Staff Engagement				Savings		
	No equip mtce (n)	With standby (w)	Without standby (w_o)	Mtce work cost	No equip mtce (n)	With standby (w)	Without standby (w_o)	Mtce work cost	No equip mtce (n)	With standby (w)	Without standby (w_o)
P	838287.21	839392.65	845138.79	31013.22	11764202.54	11764001.02	11764392.42	439230.95	10926005.33	10924808.79	10919253.63
R	1515937.46	1546052.04	1517169.64	40664.58	12164841.74	12164850.82	12165041.62	326489.97	10649034.28	10648888.78	10647871.98
O	1671258.37	1672327.43	1671877.88	40515.86	12243824.11	12243833.19	12243923.99	295387.80	10572565.73	10557265.78	10572046.11
A	1497725.73	1497962.62	1499558.92	42743.31	2074995.28	2075024.36	2075095.16	59217.00	577269.55	577041.74	575536.24
P/R	1304520.62	1304744.86	1307356.40	40747.29	12182981.57	12182990.65	12183081.45	390590.21	10879665.95	10878245.79	10875725.05
P/O	1391706.78	1391983.60	1393803.85	40657.52	12227725.69	12227734.77	12227825.57	357222.49	10836026.91	10835751.17	10834019.72
R/O	1106272.99	1107928.46	1115865.18	44375.17	12207521.79	12207521.86	12207612.67	68971.59	11101239.80	11099593.41	11091747.49

Table 5.32b: Benefit Cost Ratio (BCR) Analysis (Ibadan)

B C R	P → R	R → O	O → A	A → P/R	P/R → P/O	P/C → R/O
BCR_c^n	NV	NV	57.60*	51.2632	NV	NV
BCR_i^n	0.69	0.96939	NV	NV	0.95301	13.121*
BCR_c^{wo}	NV	610.363	604.63*	52.31	NV	NV
BCR_i^{wo}	0.69	NV	NV	NV	1.05	7.66*
BCR_c^w	NV	NV	57.01*	52.59	NV	NV
BCR_i^w	0.68	1.04	NV	NV	1.07	7.8*

Table 5.33a: Optimal Total Maintenance Cost under Full-time and Part-time Staff (Memo, Ajaokuta)

Mtce. Policy	Part-Time Staff Engagement				Full-Time Staff Engagement				Savings		
	No equip. mtce. (n)	With standby (w)	Without standby (w_o)	Mtce. work cost	No equip. mtce. (n)	With standby (w)	Without standby (w_o)	Mtce. work cost	No equip. mtce. (n)	With standby (w)	Without standby (w_o)
P	1995361.71	2003475.44	2038659.10	89912.57	16102608.94	16102791.32	16104467.15	726321.26	14109247.23	14099315.87	14151148.85
R	2417145.59	2424467.11	2480685.02	68377.92	16491055.97	16491617.97	16492894.60	671202.10	14074290.00	14067150.86	14014211.58
O	3009563.82	3012812.85	3026192.48	98319.60	16643771.27	16642935.03	16645230.28	505736.40	13634205.45	13631140.80	13619057.80
A	2608781.04	2610980.60	2636307.92	131076.51	4938661.94	4918621.32	4920120.95	190571.95	2309877.29	2303863.72	2283613.03
P/R	2298041.87	2306474.96	2333275.43	97789.86	16467118.22	16467300.60	16468877.23	700132.38	14169076.35	14160823.63	14135601.80
P/O	2604193.56	2609898.19	2630414.13	99977.79	16673053.00	16673065.38	16675342.21	633746.98	14069777.44	14064167.19	14044927.88
R/O	2294110.39	2303663.13	2333323.90	102233.08	16631094.70	16631277.08	16632553.73	741135.13	14336984.30	14327413.95	14299229.81

Table 5.33b: Benefit Cost Ratio (BCR) Analysis (Ajaokuta)

B C R	P → R	R → O	O → A	A → P/R	P/R → P/O	P/O → R/O
BCR_r^n	NV	NV	28.26	36.16*	NV	NV
BCR_l^n	0.09	2.89	NV	NV	0.48025	6.25*
BCR_r^{wo}	NV	NV	4.07	36.43*	NV	NV
BCR_l^{wo}	3.37	12.93	NV	NV	0.46748	6.15*
BCR_r^w	NV	NV	29.09	37.07*	NV	NV
BCR_l^w	0.08	2.79	NV	NV	0.43756	5.94*

Table 5.34a: Optimal Total Maintenance Cost under Full-time and Part-time Staff (Lagos)

Mtce. Policy	Part-Time Staff Engagement				Full-Time Staff Engagement				Savings		
	No equip. mtce. (n)	With standby (w)	Without standby (w_o)	Mtce. work cost	No equip. mtce. (n)	With standby (w)	Without standby (w_o)	Mtce. work cost	No equip. mtce. (n)	With standby (w)	Without standby (w_o)
P	1911799.65	1913311.03	1929505.12	90051.46	16212512.05	16212721.11	16212611.51	771286.02	14300712.38	14297210.08	14283106.79
R	3151368.87	3151692.98	3153775.36	94324.12	16495097.36	16495406.44	16495497.24	478726.35	13344023.49	13343713.46	13341721.88
O	3606863.85	3609028.87	3610200.52	97758.71	16677382.91	16677794.02	16677886.82	451727.71	13068923.09	13068767.15	13067686.30
A	3036343.92	3036434.48	3040374.58	100242.45	4969517.64	4969526.72	4969617.52	144060.43	1933173.72	1933092.24	1929243.02
P/R	2596220.41	2597294.41	2602908.15	95519.51	16459139.43	16459148.51	16459739.31	605560.68	13862919.02	13861854.10	13856131.16
P/O	2863044.86	2864113.43	2868087.87	99000.16	16670130.36	16670139.44	16670230.24	576422.71	13806985.50	13806026.01	13802142.37
R/O	2200522.66	2204040.80	2218255.44	104736.92	16691163.52	16691172.60	16691263.40	794439.01	14490640.86	14487131.80	14473007.96

Table 5.34b: Benefit Cost Ratio (BCR) Analysis (Lagos)

B C R	P → R	R → O	O → A	A → P/R	P/R → P/O	P/O → R/O
BCR_r^n	NV	NV	19.45	25.11*	NV	NV
BCR_l^n	*3.38	1.51	NV	NV	0.26604	124.65*
BCR_r^{wo}	NV	NV	19.47	25.13*	NV	NV
BCR_l^{wo}	*3.37	1.51	NV	NV	0.26459	30.38*
BCR_r^w	NV	NV	19.55	25.26*	NV	NV
BCR_l^w	3.33	1.50	NV	NV	0.26	29.91*

P, Preventive maintenance
R, Repair,
O, Overhaul,
A, All operations

Table 5.35a: Optimal Total Maintenance Cost under Full-time and Part-time Staff (Crew size = 4*, Akure)

Mtce. Policy	Part-Time Staff Engagement				Full-Time Staff Engagement				Savings		
	No equip. mtce. (n)	With standby (w)	Without standby (w_o)	Mtce. work cost	No equip. mtce. (n)	With standby (w)	Without standby (w_o)	Mtce. work cost	No equip. mtce. (n)	With standby (w)	Without standby (w_o)
P	1034684.02	1038355.15	1053028.81	44701.56	14032509.24	14032533.92	14032756.06	607467.93	12997824.24	12994178.77	12979727.25
R	1115012.79	1121750.64	1144593.83	56017.45	14330071.94	14330306.62	14330318.76	731499.35	13215059.14	13208345.98	13185722.93
O	1548803.06	1550343.18	1558072.94	55433.25	14385959.79	14385981.47	14386206.64	314887.61	12837154.73	12835391.30	12828133.67
A	1259807.15	1264941.79	1283746.42	59517.20	2639039.70	2639064.38	2639286.52	134718.32	1379232.55	1374122.59	1355540.10
P/R	989133.38	998061.21	1028231.13	56587.72	14312202.42	14312221.10	14312449.21	810773.88	13323069.04	13313385.89	13284218.11
P/O	1210809.92	1215699.31	1235697.19	56342.95	14374371.28	14374395.96	14374618.10	668880.52	13163561.36	13158726.65	13140928.91
R/O	1043882.70	1050541.65	5067792.70	61740.42	14343244.56	14343269.24	14343491.78	816705.68	13297362.27	13286727.59	13275699.08

Table 5.35b: Benefit Cost Ratio (BCR) Analysis (Crew size = 4*, Akure)

B C R	P → R	R → O	O → A	A → P/R	P/R → P/O	P/O → R/O
BCR_c^{n}	47.52*	NV	39.65	42.13	NV	NV
BCR_i^{n}	NV	6.76*	NV	NV	2.57	4.30
BCR_c^{wo}	2.57	NV	40.15	3.54	58.70*	NV
BCR_i^{wo}	NV	6.67*	NV	NV	NV	4.11
BCR_c^{w}	2.25	NV	41.80	44.69*	NV	NV
BCR_i^{w}	NV	6.40*	NV	NV	2.31	3.69

P, Preventive maintenan
R, Repair,
O, Overhaul,
A, All operations

Table 5.36a: Optimal Total Maintenance Cost under Full-time and Part-time Staff (Crew size = 5*, Osogbo)

Mtce. Policy	Part-Time Staff Engagement				Full-Time Staff Engagement				Savings		
	No equip mtce (n)	With standby (w)	Without standby (w_o)	Mtce wk cost	No equip mtce (n)	With standby (w)	Without standby (w_o)	Mtce wk cost	No equip mtce (n)	With standby (w)	Without standby (w_o)
P	893588.14	937959.35	958523.80	51058.02	14113864.97	14113874.05	14115164.85	773904.65	13183475.93	13177514.72	13156640.56
R	1243847.14	1248094.01	1264457.95	62099.21	14513616.88	14513625.96	14512716.76	724913.95	13269769.74	13265531.05	13249730.76
O	1496428.79	1409355.86	1423712.26	64015.88	14618691.68	14618700.75	14618791.36	663393.34	13222262.89	13209346.90	13197079.30
A	1221591.57	1229798.86	1231346.82	67731.64	2930543.27	2930552.35	2930643.15	162267.07	1708948.70	1700753.49	1679296.33
P/R	1027695.41	1036183.85	1063003.94	62549.93	14489335.40	14489344.48	14489635.28	881893.03	13461839.99	13453160.66	13426631.34
P/O	1137131.16	1149825.81	1166519.64	64318.50	14884591.71	14884600.79	14884691.59	830576.45	13547440.55	13534774.98	13518171.95
R/O	958005.83	974017.49	1014446.94	72963.13	14845134.46	14845143.56	14845234.36	1115794.86	13687128.63	13671126.07	13630787.42

Table 5.36b: Benefit Cost Ratio (BCR) Analysis (Crew size = 5*, Osogbo)

B C R	P → R	R → O	O → A	A → P/R	P/R → P/O	P/O → R/O
BCR_c^{n}	0.28	NV	62.93*	58.01	0.78	NV
BCR_i^{n}	NV	0.55	NV	NV	NV	3.55*
BCR_c^{wo}	0.28	NV	64.10*	58.70	0.81	NV
BCR_i^{wo}	NV	0.54	NV	NV	NV	3.30*
BCR_c^{w}	0.30	NV	67.61*	60.37	0.88	NV
BCR_i^{w}	NV	0.50	NV	NV	NV	2.85*

5.7 Performance Evaluation

Performance measure based on the Unit Cost of Maintenance and Maintenance Cost Week showed that 'All operations' maintenance policy has the lowest unit cost of maintenance in year 2004 for dual Part-time and Full-time Staffers in each of identified maintenance centres (Table 5.37: Figures 5.1- 5.7).

Table 5.37: Optimal Maintenance Week Cost (r = 0.7)

Mtce. Policy	Part-Time Staff Engagement					Full-Time Staff Engagement				
	Akure	Osogbo	Ibadan	Ajaokuta	Lagos	Akure	Osogbo	Ibadan	Ajaokuta	Lagos
P	72579.26	79806.35	31013.22	89912.57	90951.46	1454817.06	1624834.55	435230.95	726324.26	771289.82
R	80693.69	87446.17	40684.58	98377.92	94324.12	1160980.77	1116649.97	326489.97	671202.10	493726.35
O	77944.36	88723.40	40319.86	98319.69	97748.21	804702.43	989453.12	295387.80	543736.40	451727.71
A	84304.14	93938.75	42743.31	101076.51	100242.45	248043.90	301966.05	59217.90	190571.95	164064.63
P/R	80325.27	87450.88	40747.29	97705.86	95519.51	1304361.81	1328153.32	380599.24	700132.58	605560.69
P/O	79121.69	89257.64	40657.52	98977.79	99009.16	1045119.38	1245359.48	357222.49	633746.98	576422.21
R/O	87557.88	100891.85	44375.17	102233.08	104736.92	1345911.71	1658072.77	489671.59	741136.13	794439.01

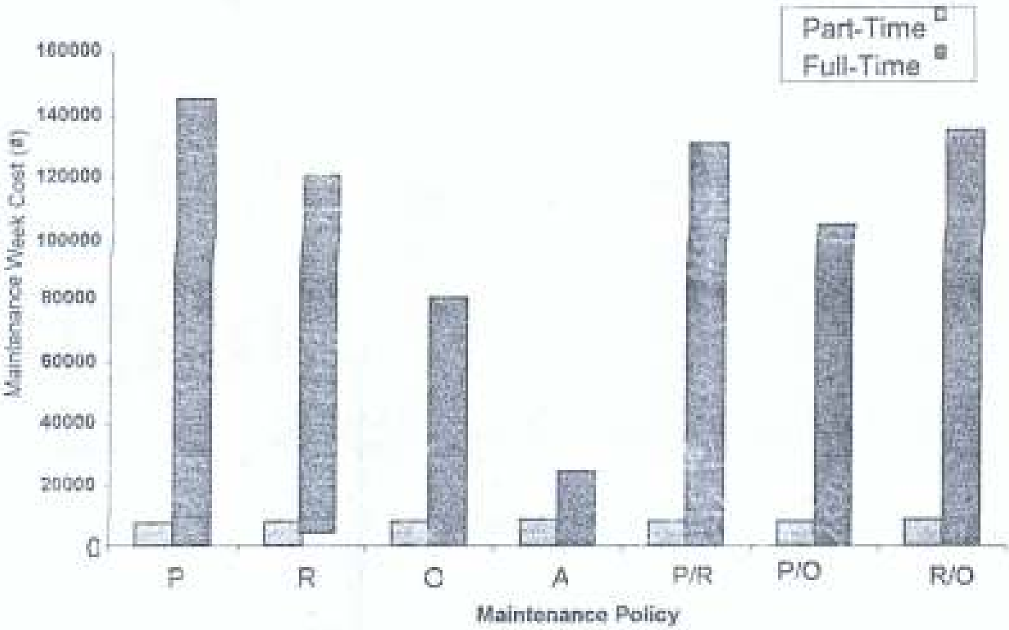


Fig. 5.1: Maintenance Week Cost for Part-Time and Full-Time Staff Engagement (Akure)

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

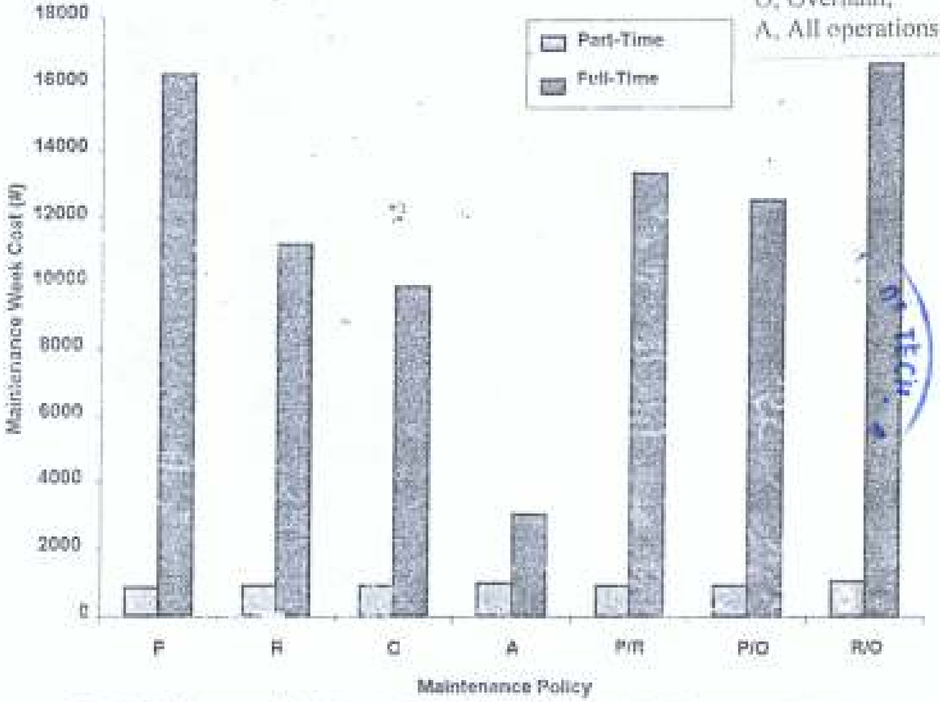


Fig. 5.2: Maintenance Week Cost for Part-Time and Full-Time Staff Engagement (Osogbo)

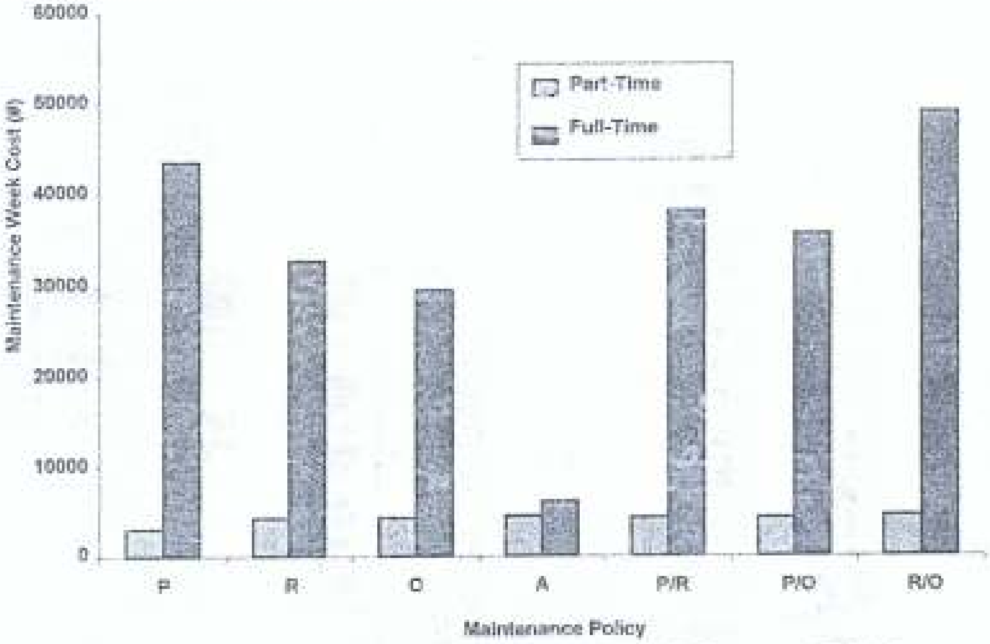


Fig. 5.3:Maintenance Week Cost for Part-Time and Full-Time Staff Engagement (Ibadan)

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

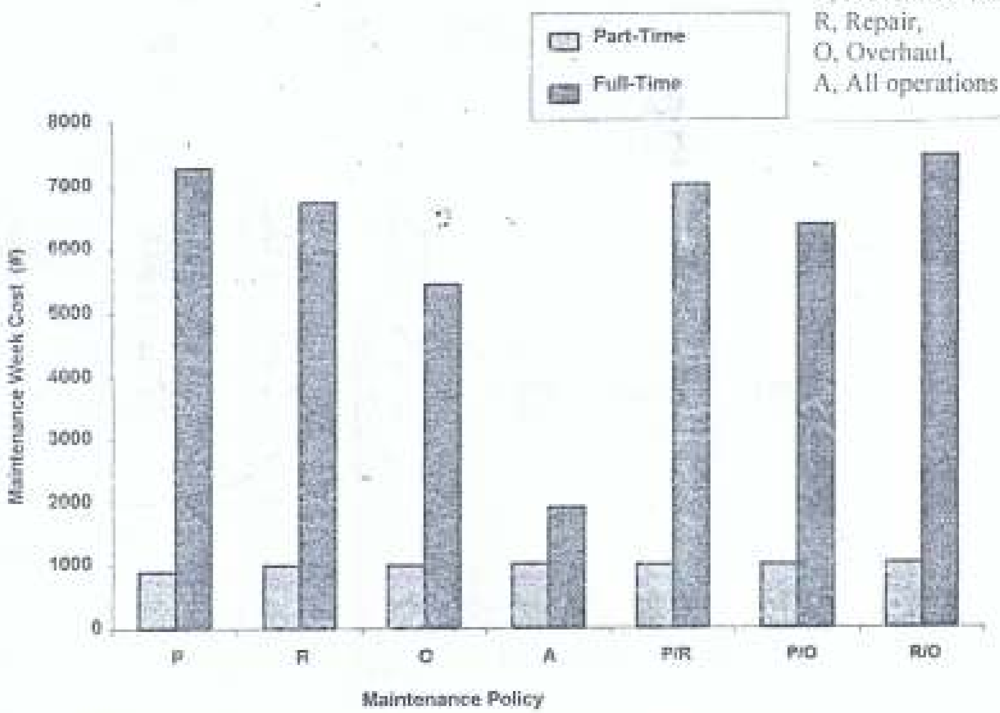


Fig. 5.4:Maintenance Week Cost for Part-Time and Full-Time Staff Engagement

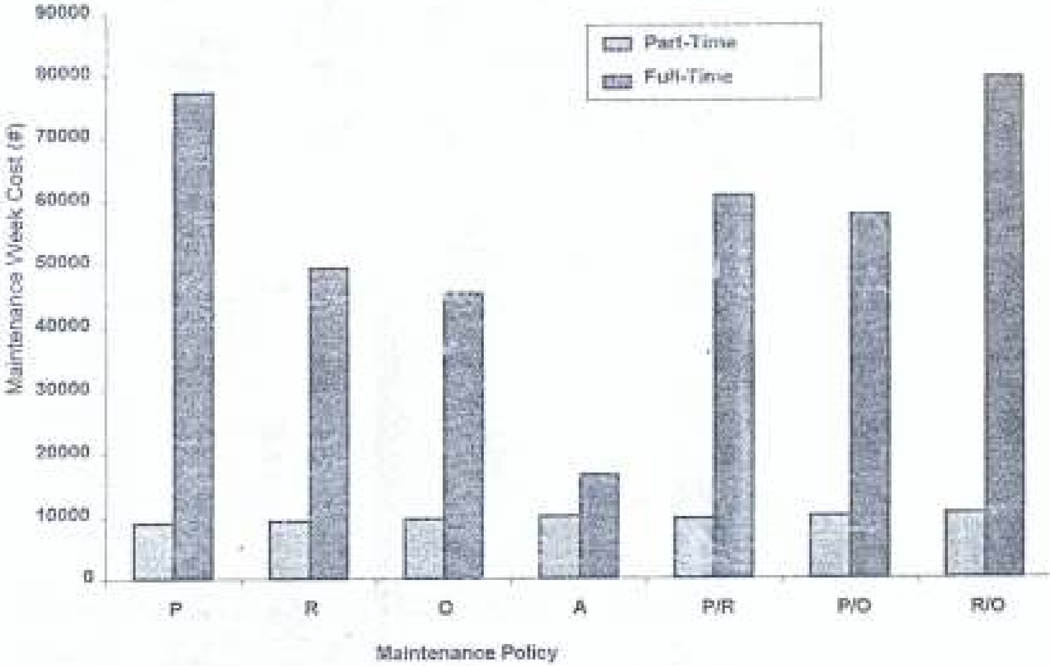
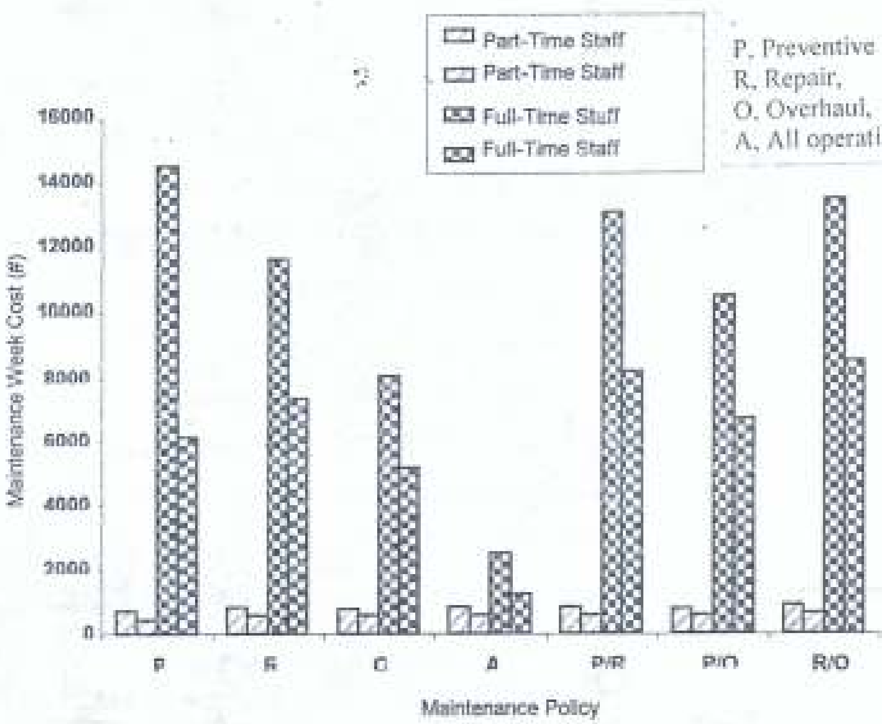


Fig. 5.5:Maintenance Week Cost for Part-Time and Full-Time Staff Engagement (Lagos)



P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Fig. 5.6: Maintenance Week Cost for Part-Time and Full-Time Staff Engagement (Crew size 6 and 4*, Akure)

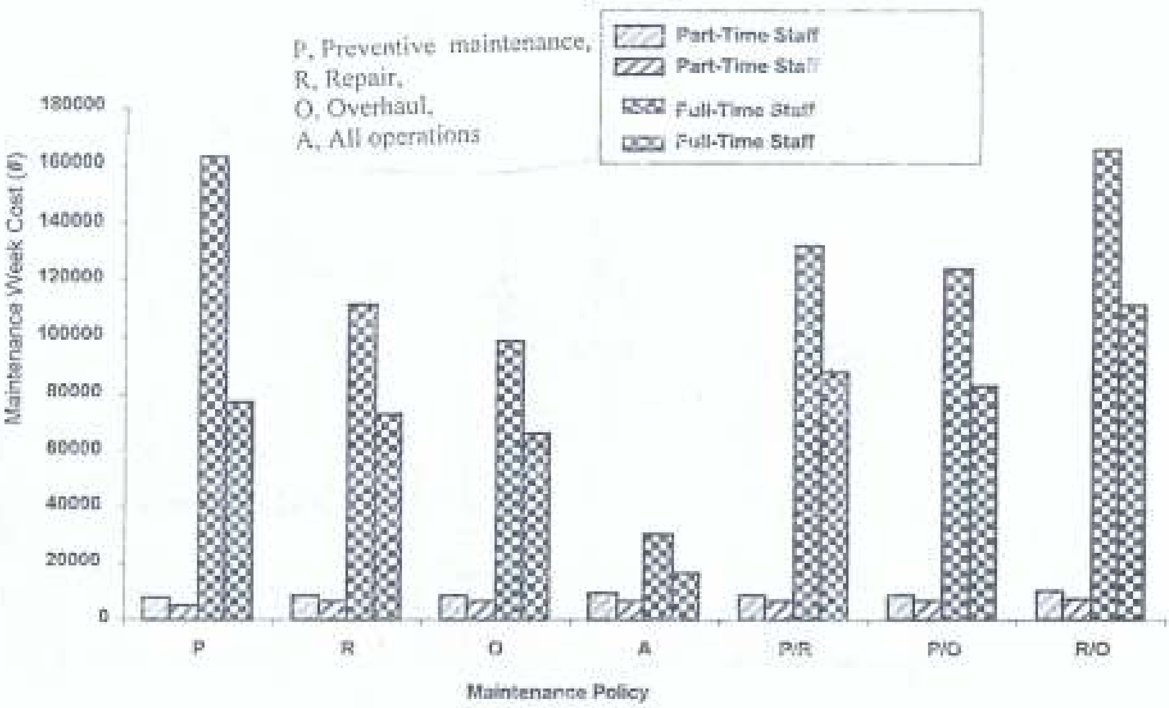


Fig. 5.7: Maintenance Week Cost for Part-Time and Full-Time Staff Engagement (Crew size 7 and 5*, Osogbo

5.8 Sensitivity Analysis

The sensitivity analysis is necessary to investigate the level at which the model can work well. This was done by varying service demand rate, λ, from 1 to n for various maintenance policy. The results obtained are shown in Table 5.38. The results showed that a reasonable number of maintenance crew was obtained only when the value of service demand rate, λ is less than service rate, μ. In the reverse case, reasonable number of crew can be gotten only under very low response rate (very high acteptable waiting time) of customers that in normal situation sounds impossible. Therefore, for continuing application of the model there is need for sensitivity analysis. The model recommends the effective service rates, μ_{max} for various service demands, λ. Using the Adekar factor, $\bar{\gamma}$, the results of the analysis are shown in Tables 5.39-5.43.When the results of the various service demands are plotted against their corresponding values of recommended service rate, μ_{max} the Charts in Figures 5.8 –5.12 are obtained. These Charts assist to select the appropriate service rates for various service demands (instantaneous demands) of a given maintenance policy.

Table 5.38: Model Sensitivity Analysis

Mtce policy	Gang Size / Service Demand, λ	Akure	Osogbo	Ibadan	Ajaokuta	Lagos
P	λ=1	1	1	1	1	1
	λ=2	1	1	1	1	1
	λ=3	1	1	1	4	1
	λ=4	1	2	2	>>22	2
	λ=5	3	>>9	>>8		>>9
	λ=6	>19				
R	λ=1	1	1	1	1	1
	λ=2	1	1	1	1	1
	λ=3	1	3	2	>>4	4
	λ=4	3	>>16	>>13		>32
	λ=5	>17				
O	λ=1	1	1	1	1	1
	λ=2	1	1	1	2	1
	λ=3	>>4	>>4	>>3	>>10	>>3
A	λ=1	1	1	1	1	1
	λ=2	1	1	1	1	1
	λ=3	1	2	2	>>5	2
	λ=4	>>5	>>9	>>7		>>10
P/R	λ=1	1	1	1	1	1
	λ=2	1	1	1	1	1
	λ=3	1	1	1	5	1
	λ=4	2	>>6	>>5	>42	>>7
	λ=5	>>8				
P/O	λ=1	1	1	1	1	1
	λ=2	1	1	1	1	1
	λ=3	1	1	1	>>6	2
	λ=4	>>6	>>7	>>6		>>7
R/O	λ=1	1	1	1	1	1
	λ=2	1	1	1	1	1
	λ=3	1	1	1	2	1
	λ=4	1	1	1	>>14	1
	λ=5	>>5	>>5	>>4		>>4

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.39: Recommended Service Rate for various Service Demands (Akure)

Maintenance Policy	Service Demand λ	Service rate μ	$\gamma = \lambda^*/\mu$	Recommended $\mu_{max} = \lambda/\gamma$
P	1	5.45		1.09
	2	5.45		2.18
	3	5.45		3.27
	4	5.45		4.36
	5*	5.45	0.92	5.46
	6	5.45		6.54
R	1	4.29		1.07
	2	4.29		2.15
	3	4.29		3.22
	4*	4.29	0.93	4.29
	5	4.29		5.36
O	1	3.00		1.5
	2*	3.00	0.67	3.0
	3	3.00		4.5
A	1	4.00		1.33
	2	4.00		2.67
	3*	4.00	0.75	4.00
	4	4.00		5.33
P/R	1	4.80		1.20
	2	4.80		2.40
	3	4.80		3.60
	4*	4.80	0.83	4.80
	5	4.80		6.00
P/O	1	3.87		1.29
	2	3.87		2.58
	3*	3.87	0.78	3.87
	4	3.87		5.16
R/O	1	5.00		1.25
	2	5.00		2.50
	3	5.00		3.75
	4*	5.00	0.80	5.00
	5	5.00		6.25

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.40: Recommended Service Rate for various Service Demands (Osogbo)

Maintenance Policy	Service Demand λ	Service rate μ	$\gamma = \lambda^*/\mu$	Recommended $\mu_{max} = \lambda/\gamma$
P	1	5.00		1.25
	2	5.00		2.50
	3	5.00		3.75
	4*	5.00	0.80	5.00
	5	5.00		6.25
R	1	3.33		1.11
	2	3.33		2.22
	3*	3.33	0.90	3.33
	4	3.33		4.44
O	1	3.00		1.50
	2*	3.00	0.67	3.00
	3	3.00		4.50
A	1	3.60		1.20
	2	3.60		2.40
	3*	3.60	0.83	3.60
	4	3.60		4.80
P/R	1	4.00		1.33
	2	4.00		2.67
	3*	4.00	0.75	4.00
	4	4.00		5.33
P/O	1	3.75		1.25
	2	3.75		2.50
	3*	3.75	0.80	3.75
	4	3.75		5.00
R/O	1	5.00		1.25
	2	5.00		2.50
	3	5.00		3.75
	4*	5.00	0.80	5.00
	5	5.00		6.25

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.41: Recommended Service Rate for various Service Demands (Ibadan, Noble Tech. Ltd)

Maintenance Policy	Service Demand λ	Service rate μ	$\gamma = \lambda^*/\mu$	Recommended $\mu_{min} = \lambda/\gamma$
P	1	4.62		1.16
	2	4.62		2.31
	3	4.62		3.47
	4*	4.62	0.87	4.62
	5	4.62		5.77
R	1	3.33		1.11
	2	3.33		2.22
	3*	3.33	0.90	3.33
	4	3.33		4.44
O	1	3.00		1.5
	2*	3.00	0.67	3.0
	3	3.00		4.5
A	1	3.53		1.18
	2	3.53		2.35
	3*	3.53	0.85	3.53
	4	3.53		4.71
P/R	1	3.87		1.29
	2	3.87		2.58
	3*	3.87	0.78	3.87
	4	3.87		5.16
P/O	1	3.64		1.21
	2	3.64		2.23
	3*	3.64	0.82	3.64
	4	3.64		4.85
R/O	1	5.00		1.25
	2	5.00		2.50
	3	5.00		3.75
	4*	5.00	0.80	5.00
	5	5.00		6.25

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

Table 5.42: Recommended Service Rate for various Service Demands (Ajaokuta, ASCL)

Maintenance Policy	Service Demand λ	Service rate μ	$\gamma = \lambda^*/\mu$	Recommended $\mu_{new} = \lambda/\gamma$
P	1	3.33		1.11
	2	3.33		2.22
	3*	3.33	0.90	3.33
	4	3.33		4.44
R	1	3.00		1.50
	2*	3.00	0.67	3.00
	3	3.00		4.50
O	1	2.40		1.20
	2*	2.40	0.83	2.40
	3	2.40		3.60
A	1	2.86		1.43
	2*	2.86	0.70	2.86
	3	2.86		4.2
P/R	1	3.16		1.05
	2	3.16		2.11
	3*	3.16	0.95	3.16
	4	3.16		4.21
P/O	1	2.79		1.39
	2*	2.79	0.72	2.79
	3	2.79		4.18
R/O	1	3.33		1.11
	2	3.33		2.22
	3*	3.33	0.90	3.33
	4	3.33		4.44

Table 5.43: Recommended Service Rate for various Service Demands (Lagos)

Maintenance Policy	Service Demand λ	Service rate μ	$\gamma = \lambda^*/\mu$	Recommended $\mu_{new} = \lambda/\gamma$
P	1	5.0		1.25
	2	5.0		2.50
	3	5.0		3.75
	4*	5.0	0.80	5.00
	5	5.0		6.25
R	1	3.16		1.05
	2	3.16		2.11
	3*	3.16	0.95	3.16
	4	3.16		4.21
O	1	2.86		1.43
	2*	2.86	0.70	2.86
	3	2.86		4.29
A	1	3.46		1.15
	2	3.46		2.30
	3*	3.46	0.87	3.46
	4	3.46		4.60
P/R	1	3.87		1.29
	2	3.87		2.58
	3*	3.87	0.78	3.87
	4	3.87		5.16
P/O	1	3.64		1.21
	2	3.64		2.43
	3*	3.64	0.82	3.64
	4	3.64		4.85
R/O	1	5.00		1.25
	2	5.00		2.50
	3	5.00		3.75
	4*	5.00	0.80	5.00
	5	5.00		6.25

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

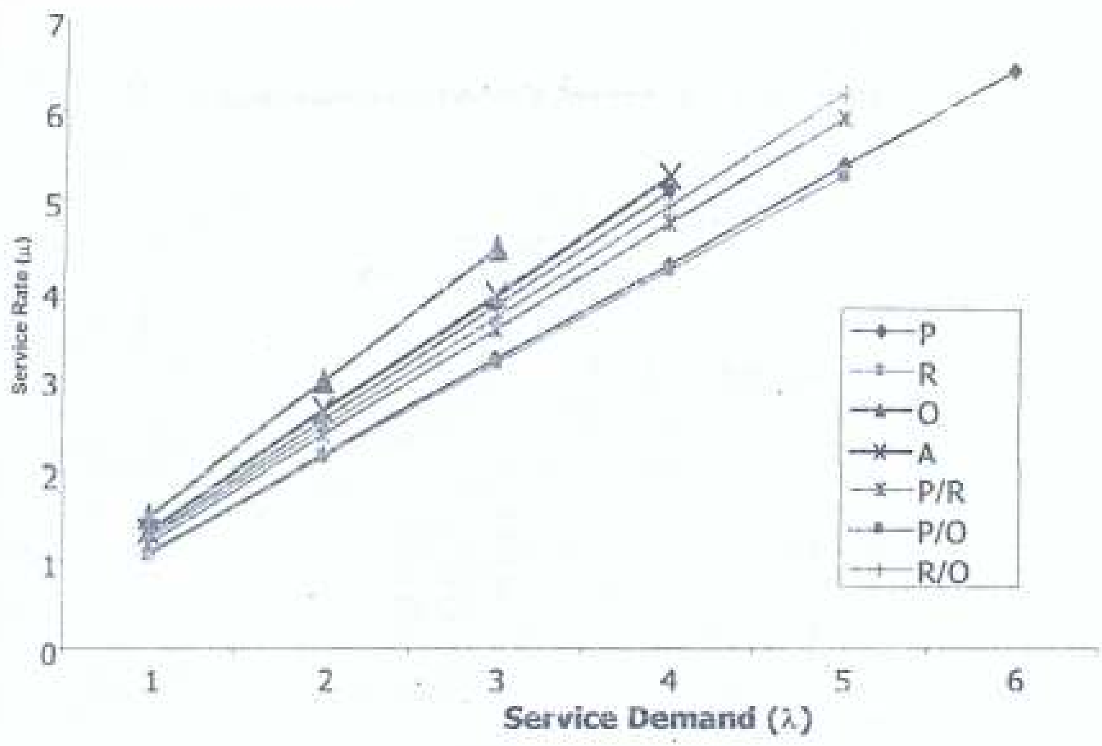


Fig. 5.8: Recommended Service Rate for various Service Demands (Akure)

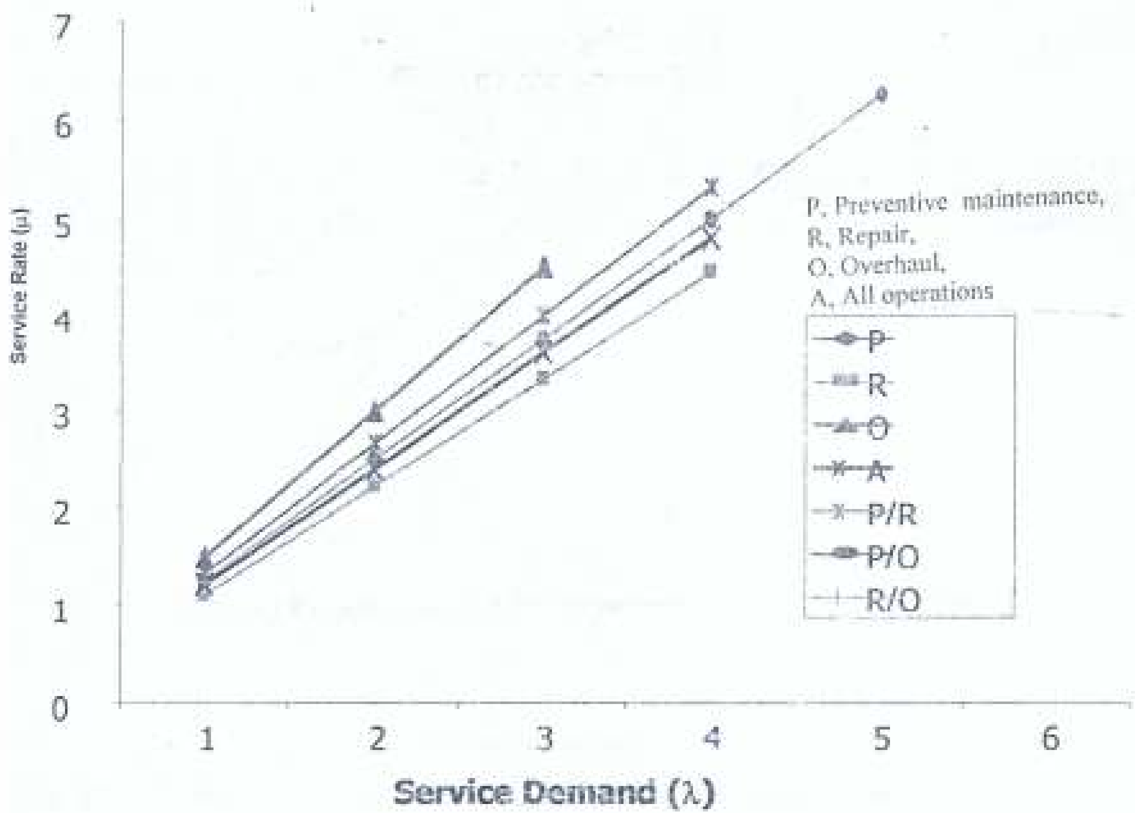


Fig. 5.9: Recommended Service Rate for various Service Demands (Osogbo)

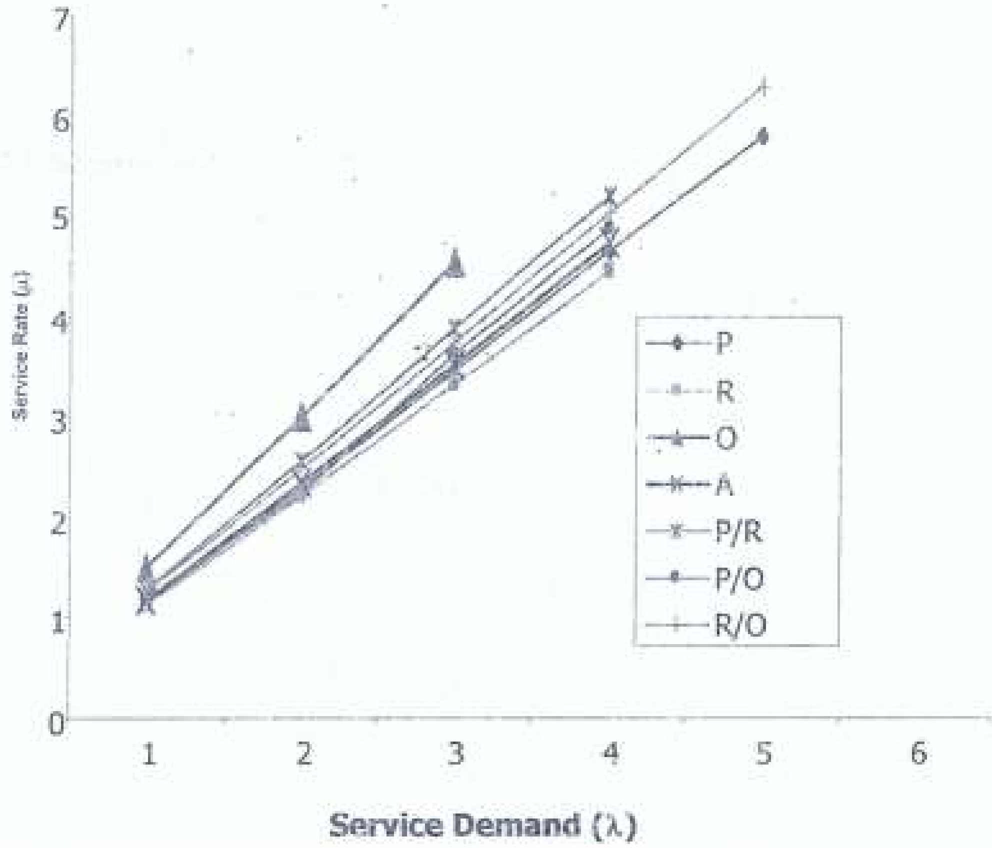


Fig. 5.10: Recommended Service Rate for various Service Demands (Ibadan)

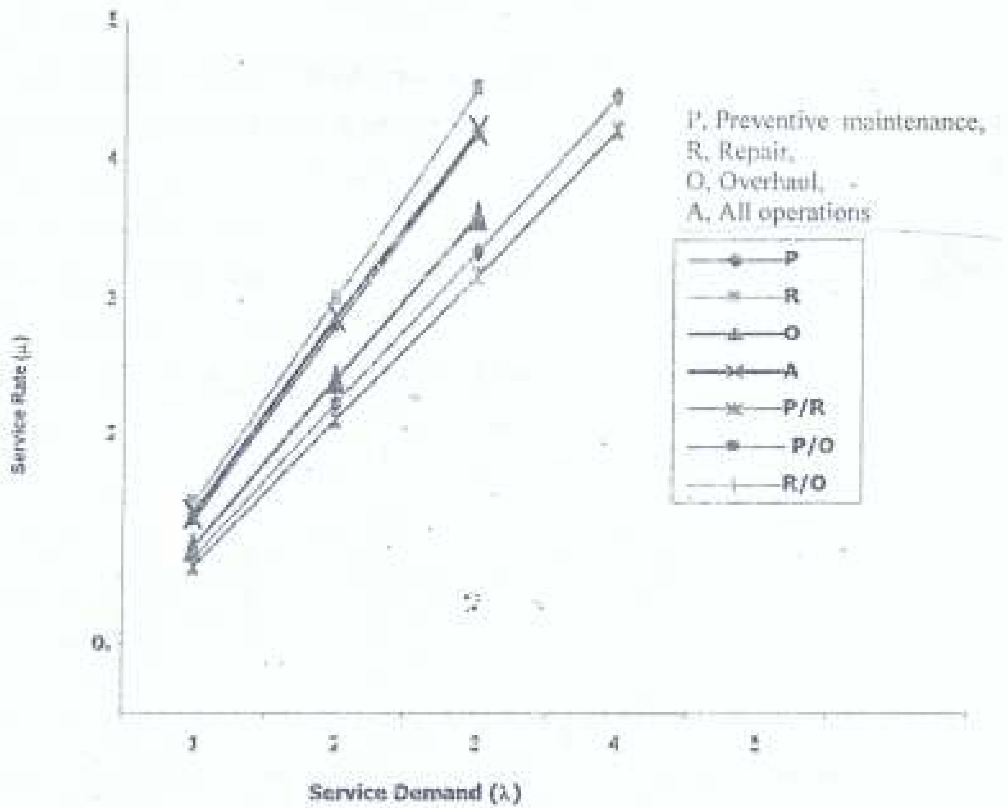


Fig. 5.11: Recommended Service Rate for various Service Demands (Ajaokuta)

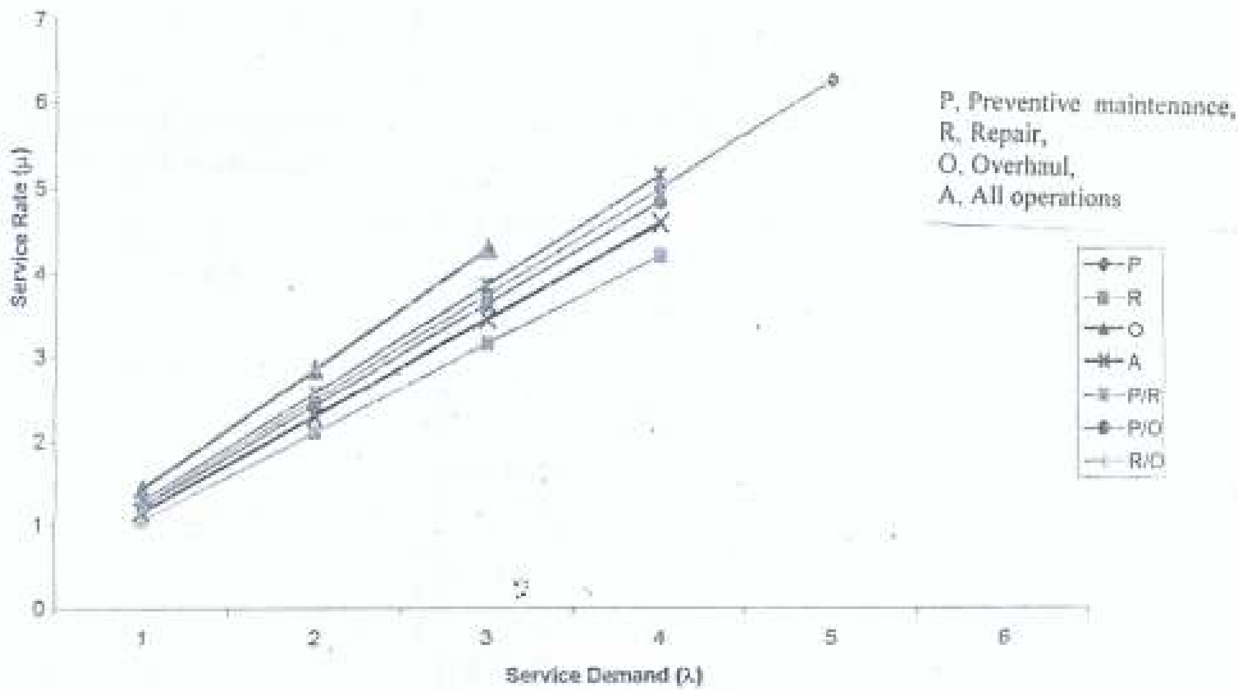


Fig. 5.12: Recommended Service Rate for various Service Demands (Lagos)

The results obtained from maintenance jobshops operating in Akure was used to test for the efficacy and workability of the sensitivity analysis. The results (Table 5.44) show that the analysis is acceptable and efficient under the earlier assumption that the crews are equally efficient. In the same vain, the rate at which the crew is increased using the analysis is totally lesser than the level of reduction in service rate. Even, there is no reduction in number of crew at all in O, P/O, and R/O maintenance policies.

Table 5.44 Test of Sensitivity Analysis (Akure)

Maintenance policy	Optimal from the model			Hypothesis analysis results			% Reduction in service rate	% Increase in crews
	λ	μ	Optimal crew S (r =0.7)	γ	$\mu_{new}=\lambda/\gamma$	Optimal crew S_h (r =0.7)	$(\mu-\mu_{new})/\mu$	$(S_h-S)/S_h$
P	1.08	5.45	1	0.92	1.17	4	78.5%	75%
R	1.08	4.29	1	0.93	1.16	2	73.0%	50%
O	1.08	3.00	1	0.67	1.61	1	46.3%	0%
A	1.08	4.00	1	0.73	1.44	2	64.0%	50%
P/R	1.08	4.80	1	0.83	1.30	2	72.9%	50%
P/O	1.08	3.87	1	0.78	1.39	1	64.1%	0%
R/O	1.08	5.00	1	0.80	1.35	1	73.0%	0%

P, Preventive maintenance,
R, Repair,
O, Overhaul,
A, All operations

5.10 Limitations of the Model

The model has the following limitations:

(i) The model cannot account for the state of the defective machines before being brought to the maintenance jobshop.

(ii) Also, it cannot account for the state of defective machine parts until the machine is brought to the maintenance jobshop.

5.11 Areas of General Application

The model is flexible and versatile. It may be applied to other sectors of economy, such as:

(i) Manufacturing

(ii) Agro-machinery

(iii) Aeronautics

(iv) Marines

(v) Food processing

(vi) Oil and Gas

(vii) Refineries etc.

The rate at which these sectors are producing using appropriate machinery determines service rate while the rate at which customers demands for products or services determines demand rate. However, the rate of producing for customers' satisfaction depends on the availability of machinery in use. The availability of machinery in use depends on effectiveness of maintenance on such machinery. Maintenance effectiveness can be achieved only when the optimised strategic decisions are well implemented.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations could be drawn from this research on maintenance planning:

6.1 Conclusions

This study shows that there is need for integration of strategic decisions often witnessed in maintenance job-shops, since single decision optimization in literatures failed to give expected wholly solution to maintenance problems, especially in developing countries. The formulated integrated model solved the problems of maintenance calls, maintenance crew, maintenance tools/equipment, spare part inventory, communication, job scheduling and maintenance costing in a single run for various maintenance policies. Benefit-Cost Ratio (BCR) analysis served as indicator as to what type of maintenance policy and maintenance crew would benefit the centre in the following year. Besides, the developed computer software-CAMSOP-2003 quickened the implementation of the model. The CAMSOP-2003 runs on Pentium-1, 32.0MB RAM microprocessor based computer system took about 3 minutes to complete a single run. Manual computation could be very tiresome and as well cumbersome. A single run could take several hours for a resilient mathematician to compute. Finally, the model has prescribed the best maintenance policy for the year 2004 through effective cost estimation.

However, the following conclusions could also be drawn from the study:

(i) The lowest service demand witnessed in maintenance centres in Osogbo may be attributed to inability of such centres to meet the response rate or acceptable waiting time of customers. Therefore, the developed software – CAMSOP – 2003 could be useful in prompt planning for the strategic decisions mentioned earlier in such centres and other similar centres based on existing response rate of customers.

(ii) Excessive use of manpower (crew size) witnessed in maintenance centres in Akure, Osogbo, and Ibadan would not have been known if a framework provided by this study is not in existence. This study successively prescribed the actual size of maintenance crew required for maintenance activities at a time based on level of service demand and response rate of customers. This development favourably influences the size of tools and equipment as well as communication rating.

(iii) The methodology provided in this study for spare parts management in maintenance centres, if well utilized, will safeguard excessive procurement of spare parts that would add to the operation cost. Installation of the developed software in maintenance centres in Akure, Osogbo, Ibadan, Ajaokuta and Lagos has prescribed the actual time of ordering and number to order at a time to maintain optimal inventory management.

(iv) Inclusion of maintenance scheduling based on full time and part time staff engagement has highly benefited the maintenance centre operations by allowing the better choice out of the two alternatives.

(v) Besides, consideration of various maintenance policies with their stochastic nature makes the system robust. This widens the scope of choices and allows the model to give a realistic result.

(vi) The study accounting for various cost elements in maintenance system would be of immense help to maintenance practitioners as to how to effectively cost maintenance activities. With this shortage could be prevented thereby enhancing sustainability of the centre.

6.2 Recommendations

The integrated model could be useful in maintenance planning both in the developing and developed countries of the world. All operations maintenance policy is recommended for developing countries that are characterised by low capital outlay. Besides, the following recommendations could also be made:

(i) Effectiveness of this model lies on genuineness of the input data. Therefore, data should be reviewed from time to time to reflect changes in the state of the art. This would enhance continuing reliability of the model's results.

(ii) Effectiveness or diagnostic ability of maintenance staff changes from time to time. As a result of this, it is recommended that user of the software should take adequate records of activities of maintenance personnel in his centre and justify it with the optimal results prescribed by the model. This would help to determine the reliability for the next operation.

(iii) Part time staff is recommended when there is high supply of labour but few demand while, full time staff is recommended when there is few supply but high demand. At the equilibrium point it is worthwhile to retain your staff based on their competency. The latter depict the peculiarity of developing countries.

REFERENCES

Aderoba A.A. (2000). Manpower Planning for New Jobshops. Nigerian Journal of Engineering Management. Vol. 1,No. 4, pp.1-4

Aderoba A.A. (2001). A generalized Cost-Estimation Model for Job- shops, Nigerian Journal of Engineering management. Vol. 2, No. 1, pp. 22-27.

Aderoba A.A. (1995). Tools of Engineering Management, Vol. I: Engineering Project Management. Besade Publication, Ondo.

Aderoba A.A. (2004). Tools of Engineering Management, Vol. II: Engineering works Management. Besade Publication, Ondo.

Aderoba A.A. and Banerjee J. (1993). Improving Work Performance in the Public Sector: A Need for Research: *in Kareem B. (1993)*, B. Eng. Thesis in the Department of Mechanical Engineering, FUTA.

Aderoba A.A. and Lawal K.O. (1997). "Development of Commercial Industrial Maintenance Centres in Nigeria". Proceedings of the 1997 International Engineering Conference, pp. 96-103

Aderoba A.A. (1997). A Sequential Model for Concurrent Expansion in Machinery and Building using reinvested earning, Integrated Manufacturing Systems, Vol. 8, No. 4, pp. 223-230.

Akanbi O.G. Oluleye A.E. and Onanuga M.A. (2001). Inventory Model for Deteriorating In terms with Inflationary factors. Nigeria Journal of Engineering Management, Vol. 2, No 1., pp. 28-34.

Alhamdan A.M. (2003). Evaluation of Potential DSS Tool for BDF HQ Manpower and Operational Equipment Resource Planninng, http://www.stormingmedia.us/12/123714.html

Andrew C.P., John V.C. and Lawrence R.P.R.(1996). Management for Engineers. John Wiley & Sons inc., New York.

Azadivar F. and Shu V. (1999): Maintenance Policy Selection for JIT Production Systems. International Journal of Production Research Vol. 37. No. 6, 3725-3738.

Bello E.I., Akinola A.O. and Ogunleye M.A. (2000). Interchangeability of Motor Parts for Vehicle Maintenance. Nigerian Journal of Engineering Management. Vol.1, No. 3, pp. 51-58.

Bourn J. (1989). Report of National Audit Office, NAO on Manpower Planning in the Civil Service, http://www.boperis.ac.uk/bop1984/ref784.html

Brimson J.A. (1991). Activities Accounting: An Activity Based Costing Approach. New York. John Wiley and Sons.

Buzacott A.A. (1975). Economics Order Quantity with Inflation. Operations Research Quarterly, Vol. 26 No. 31, pp. 553-558.

Charles-Owaba O.E. (2002). Gantt Charting Multiple Machines Preventive Maintenance Activities. Nigerian Journal of Engineering Research and Development, Vol. 1, No 60-67.

Coder G.G. (1957). Maintenance Techniques and Outlook, British Productivity Council, London.

Cohen S. S. (1985). Operational Research. Edward Arnold. London.

Cooper R. (1990). 'Cost Classification in Unit-based, and Activity-based Manufacturing Cost System'. Journal of Cost Management. Vol. 4, No. 3 pp. 4-14.

Diparkar D. (1999): Growth Versus Welfare in a Model of Non-rival Infrastructure. Journal of Development Economics. Vol. 58, No. 2, pp. 359-385.

Fapetu O.P. and Kareem B. (2003). An Effective Manpower Planning Approach for Maintenance Departments: A Case Study of a Cocoa Processing Industry, Ondo. Global Journal of Pure and Applied Sciences. Vol.2, No 1&2 pp 59-67.

Felix, K.R. (1999). Productiveness and Welfare Implication of Public Infrastructure. A Dynamic of Two-Sector General Equilibrium Analysis'. Journal of Productivity Analysis. Vol. 11, No. 2, pp. 387-404.

Hamlin J.L. (1979). Production Appraisal for Maintenance Centres. Industrial Engineering Vol. 11, No. 9.

Idris M.O. and Aderoba A.A. (2000). An Integrated Investment Model for New Jobshops, Nigerian Journal of Engineering Management. Vol. 1, No. 2, pp. 38-45.

Ikhwan M.A.H. and Burney F.A. (1994). Maintenance in Saudi Industry. International Journal of Operations & Production Management. Vol. 14, No. 7, pp. 101-114.

Ikpo I.J. (2000). Optimal Economic Criteria for the Maintenance of Repairable Building Components. Nigerian Journal of Engineering Management. Vol. 1, No. 4, pp. 16-22.

Inegbenebor A.O. and Adeniji F.A. (2002): Impact of Maintenance on the Production of Some Companies in the North-Eastern States of Nigeria. Nigeria Journal of Industrial and Systems Studies. Vol. 1, No. 1, pp. 19-27.

IHUPDS-International Horizons Unlimited Project Development Services (2004). Economics and Manpower Evaluation, http://www.medhorizons.com/economics.html

John A.W., Marvin H.A. and Kenneth E.C. (1989). Principles of Engineering Economic Analysis. John Wiley & Sons, Inc. U.S.A.

Kareem B. and Aderoba A.A. (2000). Development of a Queuing Model for Effective Crew Size Determination in Maintenance Operations, Nigeria Journal of Engineering Management, Vol.1, No.1, pp. 1-5.

Kareem B. and Aderoba A.A. (2003). Assessment of Constraints Affecting Maintenance Job-shop Operations in Nigeria. Nigerian Journal of Engineering Management. Vol 4, No. 2,pp 29-32.

Kenne J.P. and Gharbi A. (1999). Experimental Design in Production and Maintenance Single Product Manufacturing System. International Journal of Production Research, Vol. 37, No. 3, pp. 621-637.

Knight C.E. (1988). Operating Policies by which Management should be Guided, *in Lindley R.H. (1988)*, Maintenance Engineering Handbook, McGraw-Hill Inc. U.S A.

Lawal K.O. and Adeyemo S.B. (2002): Maintenance Performance Appraisal in a Local Production Organization. Nigeria Journal of Industrial and Systems Studies, Vol. 1, No.1, pp. 65-75.

Lawal K.O. and Lawal S.M. (2001). A Survey of the Use of Forecasting Techniques in Nigerian Manufacturing Industries. Nigerian Journal of Engineering Management. Vol.2, No.4, pp.27-34.

Lawal K.O. and Lawal S.M. (2002): An Evaluation of Sales Force Performance in a local Bottling Plant Using Forecasting Model. Nigerian Journal of Engineering Management. Vol.3, No. 1 pp 50-61.

Lawal Y.O. (2000). Maintenance Culture: The Nigerian Situation, Nigeria Journal of Engineering Management, Vol. 1, No. 4, pp. 38-43.

Lester R.B. (1988). Human Factors in Maintenance, *in Lindley R.H. (1988)*, Maintenance Engineering Handbook, McGraw-Hill Inc. U.S A.

MacMillian J., Freeman B., Tatum B.C. and Gary A. (1998). Evaluation of a Software User Coach for Manpower Planning, http://www.stormingmedia.us/06/0610/A061053.html

Michael A.T. (1996). Lagrangian Relaxation: Application to Manpower Planning, http://mat.gsia.cmu.edu/mstc/relax/node9.html

Martin J.C. (1988). Maintenance Stores and Inventory Control, *in Lindley R.H. (1988)*, Maintenance Engineering Handbook, McGraw-Hill Inc. U.S A.

Matsui M., Yang G. and Miga T. (1999). Optimal Control of a Job-shop Production System with Order-Selection and Switch-Over. International Journal of Production Research. Vol. 37, No. 1, pp. 73-90

Mwewa W.I. (1999). 'The Development of Apprentices in the Construction Industry: A Botswana Case Study. Botswana Journal of Technology. Vol. 8, No. 1, pp 53-61.

Nwachukwu J.C. (2000). Introduction to Maintenance and Reliability, Ambik Press, Benin City.

O' Donovan R., Uzsoy R. and McKay K.N. (1999). Predictable Scheduling of a Single Machine with Breakdowns and Sensitive jobs. International Journal of Production Research, Vol.37, No. 18, 4217-4233.

OMR-Office of Resource Management (1992). Resource Planning, Evaluation, and Management, http://www.fda.gov/ora/hfc40.html.

Offiong A. (2001). Determination of Optimal Replacement Period for a Group of Machines. Nigerian journal of Engineering Management Vol.2 No.4 pp. 74-79.

Offiong A. (2002). Heuristic Procedure for the Determination of Group Maintenance Scheduling Frequencies. Nigerian Journal of Industrial and Systems Studies. Vol. 1, No. 1, pp. 50-64.

Offiong A. and Okokon F. (2003): Maintenance Management of Identical Farm Tractor in Cross River Farm Mechanization Services Limited, Nigeria- A Case Study, Nigerian Journal of Engineering Management, Vol. 4, No.1, pp. 7-15.

Olorunniwo F.O. (1986). Overview of Productivity Schemes, NIIE Short Course, University of Ibadan.

Olorunniwo F.O. (1989). Identity Maintenance Productivity Improvement Measures Using NGT Pre-conference Workshop at 2nd Asia-Pacific Conference (ASPACON) on Automotive Technology and Management, Pan-Pacific Hotel, Singapore.

Priel V.Z. (1974). Systematic Maintenance Organization, MacDonald and Evans Ltd, London.

Ray W. (1979). Production and Operation Management: Principles and Techniques. Holt, Rinechart and Winston Ltd. East Sussex BN 213 UN.

Raymond R.I. (1988). Work Simplification in Maintenance, *in Lindley R.H. (1988)*, Maintenance Engineering Handbook, McGraw-Hill, Inc. U.S.A.

Richard G.C. (1976). Manpower Planning with Uncertain Requirement. The Journal of the Operations Research Society of America, Vol. 24, No. 2 pp. 382-399.

Richard I.L., David S.R., Joel P.S. and Everette S.G. (1987). Quantitative Approaches to Management. McGraw-Hill, Inc., Singapore.

SPMC -Service Providers of Manpower Consultants (2003).
http://www.indianyellowpages.com/india/service_provider/m/man-power_consultants.htm

Shaw L. (1976). Busy Period Control of Queues Based on Waiting Times at Arrivals. The Journal of Operation Research Society of America. Vol. 24, No.3, pp. 543-548.

Sodiki J.I. (2001). Planning for Scheduled Maintenance Work in Nigerian Industries. Nigerian Journal of Engineering Management. Vol. 2, No3, pp. 5-8.

Stephen P.M. (2001). Using Social Network Analysis to Virtualize Project. Project Management Journal. Vol. 32 No. 4 pp. 32-38.

Swanson L. (1999). The Impact of New Production Technologies on the Maintenance Function: An Empirical Study. International Journal of Production Research. Vol. 37, No. 14, pp. 849-869.

Taha H.A. (1987). Operations Research: An Introduction. Macmillan, Inc. U.S.A.

Taha H.A. (1988). Simulation Modelling and Simnet. Prentice-Hall Inc. U.S.A.

Takacs L. (1976). On the Busy Period of Single-Server Queues with Poisson Input and General Service Time. The Journal of the Operations Research Society of America, Vol. 24, No. 3. pp. 564-571.

APPENDIX I - ALGORITHM DEVELOPMENT

Algorithm for the integrated model formulated for optimising maintenance strategic decisions is presented here.

1. Input various values (past data), λ_{ti}, G_i, t, n_i, N_i, t_o, t_m, t_p, q_o, q_m, q_p, P, , C_m, C_u, C_n, C_b, P, R, C, B, λ_n, and λ_{on} .
2. Compute previous values of θ_t from the previous λ_{ti}, G_i, t, n_i, N_i, obtained through response to questionnaire.
3. Forecast for the expected θ_t using naive model, exponential smoothing, moving average and regression model.
4. Calculate errors, e_t for each model in (3)
5. Calculate MSEs' for each model in (3)
6. Compare MSEs'with naive model MSL_n, and choose MSE such that MSE*<<<MSL_n.
7. With the model having MSE*, forecast for the next θ_t expected, θ_{t+1}
8. Calculate service demand rate λ_t corresponds to the next expected θ_{t+1} at present G_{it}, n_i, N_i, for various existing centres at period, t.

8' If there is increase or decrease, ω in the existing maintenance centre in the following period then $\lambda_t = N_i \lambda_t/(N_i \pm \omega)$

9. Categorise repair works that patronised the centre according to maintenance policy.
10. Obtain average time of repair of each category through response to questionnaire.
11. Using Set Theory, obtain the possible maintenance policies in the centre.
12. Using β–probability distribution, calculate the expected time of complete the repair of various order of reporting jobs.
13. If there is an increase or decrease in the current crew size (P) in the following period, t goto 13' then goto 14, else go directly to 14

13' $\mu_{m\pm\gamma} = \mu_m \pm \gamma\mu_m /P = \mu_m \{1\pm \gamma/P \}$

14. Input time of simulation, t_{sim} .
15. Set the initial conditions: clock = 0, a_t = 0, nq = 0, twt = 0, tnq = 0, tidt = 0, tna = 1, mql=0
16. Generate the time of the next departure s_t = clock – (1/ μ_m) Log (F (S_t)), 0< F (S_t)< 1
17. Generate the time of the next arrival, a_t = clock – (1/λ_t) Log (F(A_t)), 0<(F(A_t)<1
18. If next event is an arrival that is ($s_t \geq a_t$) goto 17 else goto 27
19. Update the total waiting time of all arrivals, twt = twt + nq (a_t – clock)
20. Update the clock to the time of the next event (arrival), clock = a_t
21. If next event is both an arrival and a departure (that is $s_t = a_t$) goto 22 else goto 23
22. If the current clock time greater than the simulation time, goto 35 else return to 16
23. Increase the number in queue by 1, nq = nq +1
24. If the current number in the queue (nq) greater than the maximum queue length (mql) to date, set mql = nq and goto 25 else go directly to 25
25. Increase the total number of jobs which enter the queue (tnq) by 1, tnq = tnq + 1
26. If the current clock time greater than maximum simulation time goto 36 otherwise return to 17
27. If queue is empty (nq = 0) goto 28 else goto 32
28. Update the clock to the time of next event (departure), clock = s_t
29. Update the total idle time of the maintenance crew, tidt = tidt + (a_t – clock)
30. Update the clock to the time of the next event (arrival), clock = a_t
31. Increase number of arrivals (tna) by 1, tna = tna + 1
32. Update total waiting time of all arrivals, twt = twt + nq (s_t – clock)
33. Update the clock to the time of the next event (departure), clock = s_t
34. Decrease the number in queue (nq) by 1 and generate the time of next departure, nq = nq – 1 and s_t = clock – (1/μ_m) Log (F(s_t)), 0< F(s_t) < 1
35. If the current clock greater than maximum simulation time, goto 36 else return to 18
36. Calculate the following statistics

    Respond rate for each maintenance policy, W*q_m

Average time in queue for each maintenance policy, Wq_{nt} = twt/tna
Engaged time of maintenance crew, etm = clock – tidt
Degree of utilization of maintenance facilities λ_{nt}/μ_{nt}
Optimum crew number, S_{nt} = Integer $[Wq_{nt} / W^*q_{nt}] + 1$

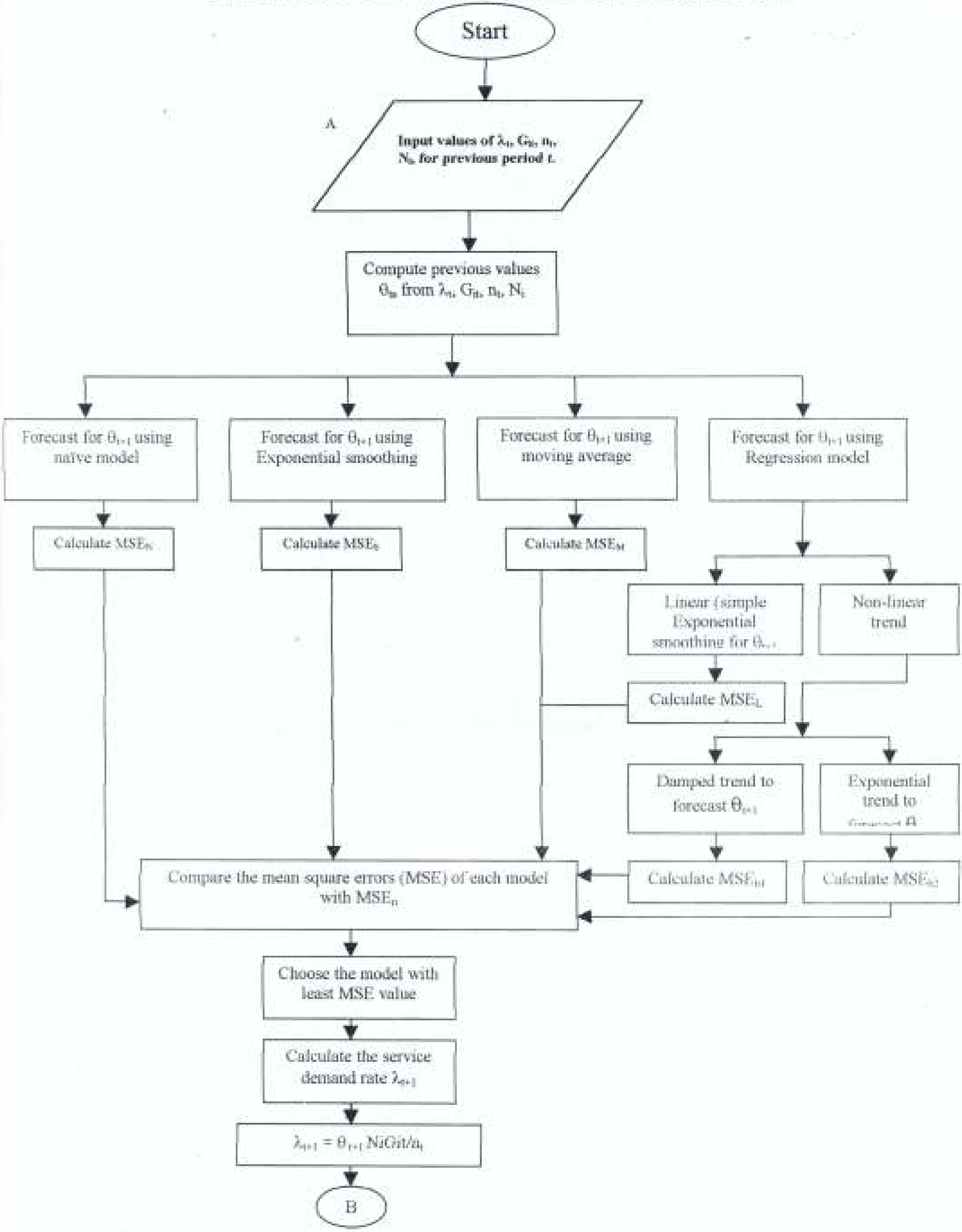
37. Calculate the optimum number of set off maintenance tools/equipments for each policy, n, $Q_{nt} = S_{nt}\,\psi_n$, ψ_n is a set of tools used for a maintenance policy n
38. If there is decrease or increase, (ξ) in the current tools/ equipments in the following period then $Q_{nt} = S_{nt}(\psi_n \pm \xi)$ else go directly to 39
39. Input the used rate λ_u and receipt rate λ_r for A-class spare part
39' If there is increase or decrease in service rate then $\lambda_{ut} = \lambda_{ut}(1\pm(\gamma/P))$ else go directly to 40
40. Set initial conditions: $t_r = 0$, ns = 0, tns = 0, tst = 0, tost = 0, tnr = 1, mns = 0
41. Generate the time of the next use, t_u = clock – $(1/\lambda_{ut})$ Log $F(t_u)$, $0< F(t_u) < 1$
42. Generate the time of the next receipt, t_r = clock $-(1/\lambda_{rt})$ Log $F(t_r)$, $0< F(t_r) < 1$
43. If next event is receipt ($t_u \geq t_r$) goto 42 else goto 52
44. Update the total stock time (tst) of all receipt, tst = tst + ns (t_r – clock)
45. Update the clock to the time of the next event (receipt), clock = t_r
46. If next event is both a receipt and a use ($t_u = t_r$), goto 47 else goto 48
47. If the current clock time greater than the simulation time, goto 60 else, return to 41
48. Increase the number in stock by 1, ns = ns + 1,
49. If the current number in stock (ns) greater than the maximum stock capacity (mns) to date, set mns = ns and goto 50 else go directly to 50
50. Increase the total of receipts which enter which enter the store tns by 1, tns = tns + 1
51. If the current clock time greater than maximum simulation time goto 61 otherwise return to 42
52. If store is empty (ns = 0) goto 53 else goto 57
53. Update the clock to the time of next event (use), clock = t_u
54. Update the total out of stock time tost = tost + (t_r –clock)
55. Update the time of the next event (receipt), clock = t_r
56. Increase number of receipts (tns) by 1
57. Update total stock time of all receipts, tst = tst + ns (t_u - clock)
58. Update the time to the time of the next event (use), clock = t_u
59. Decrease the number in store (ns) by 1 and generate the time of next use (t_u), ns = ns – 1 and t_u = clock – $1/(1/\lambda_{ut})$ Log $F(t_u)$, $0< F(t_u) < 1$
60. If the current clock greater than maximum simulation time, goto 61 else return to 43
61. Calculate the following quantities

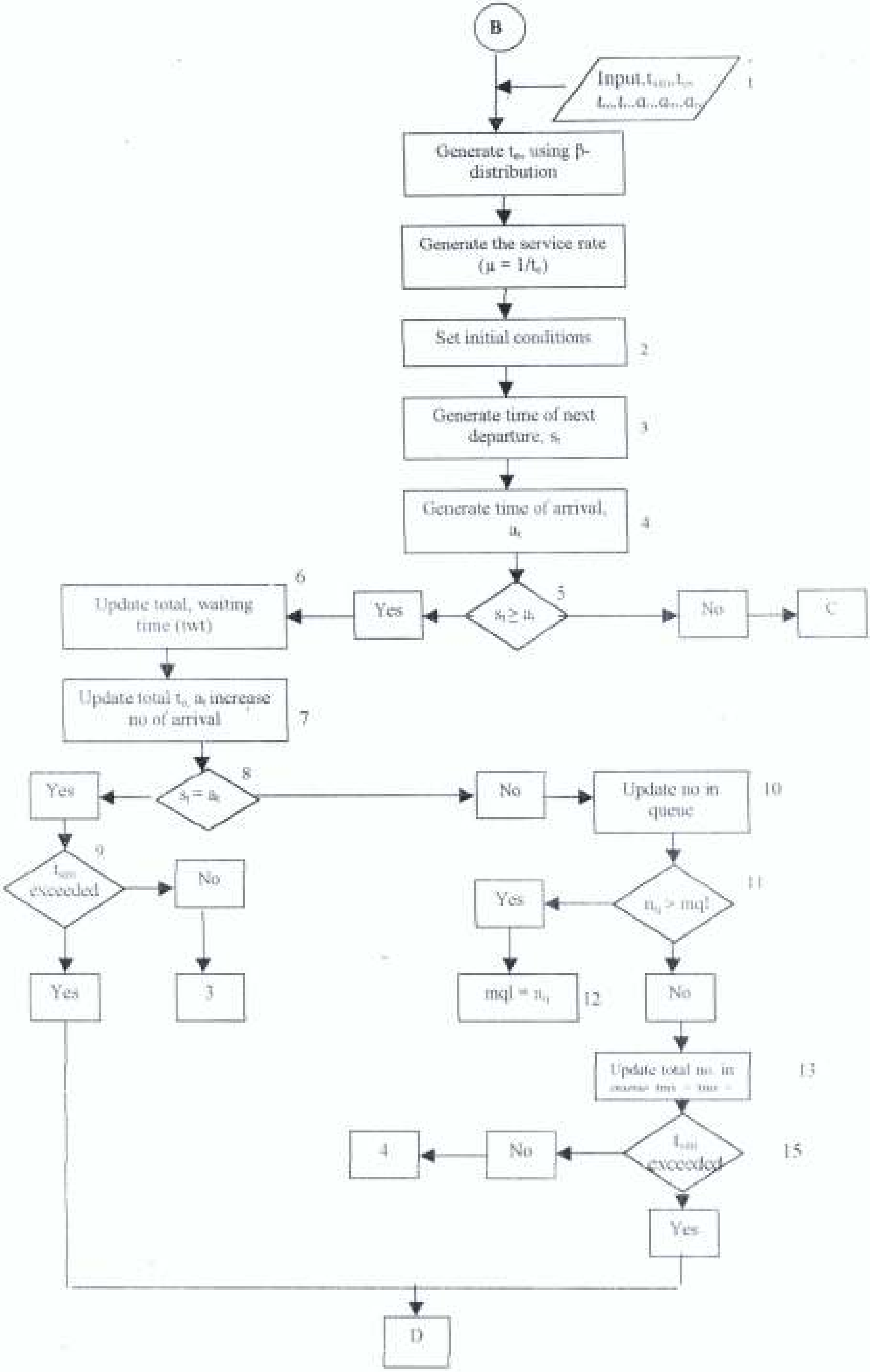
    Total stock time, tst
    Total out of stock time
    Total number of spare part entered the stock, tns
    Maximum stock capacity, mns
    Average number of spare part used, Y = (tns – mns)/tst

62. Input ordering cost per unit, p, unit cost, R and carrying cost, C (in %)
63. Optimum number of spare part to order at a time S_{nt} Nu = Int. $\{S_{nt}\,[2pY/CR]^{1/2}\}+1$
63' Optimum number of order, No = Int.$[Y/ S_{nt}\,Nu] + 1$
64. Optimum time of order, t_{nt} = tst/No
65. Obtain the optimum engage time (etm*), etm* = clock – tidt, if tidt $\geq$ tost, then etm* =clock – tost, if tidt $\leq$ tost
66. Input communication level of individual personnel, P
67. Obtain total level of interaction of individual, $\sum P_{ij}$
68. Obtain total level of interaction of the maintenance crew, $\sum\sum P_{ij}$
69. Obtain the total interaction $N_p = P\,(P - 1)$
70. Obtain the proportion of interaction of each personnel, $I_p = [\sum P_{ij} / \sum\sum P_{ij}]\, N_p$
71. Obtain total weighted interaction of the crew, $I_{pw} = \sum I_p$
72. If there is decrease or increase in personnel, γ goto 73 otherwise return to 71
73. $I_{pw} = \sum I_{p\pm\gamma} = (P\pm\gamma)\,[(P\pm\gamma) - 1]$
74. Obtain the cost of maintenance crew a = $S_{nt}\,C_m$ etm, $C_m = C_m(1\pm\gamma/P)$

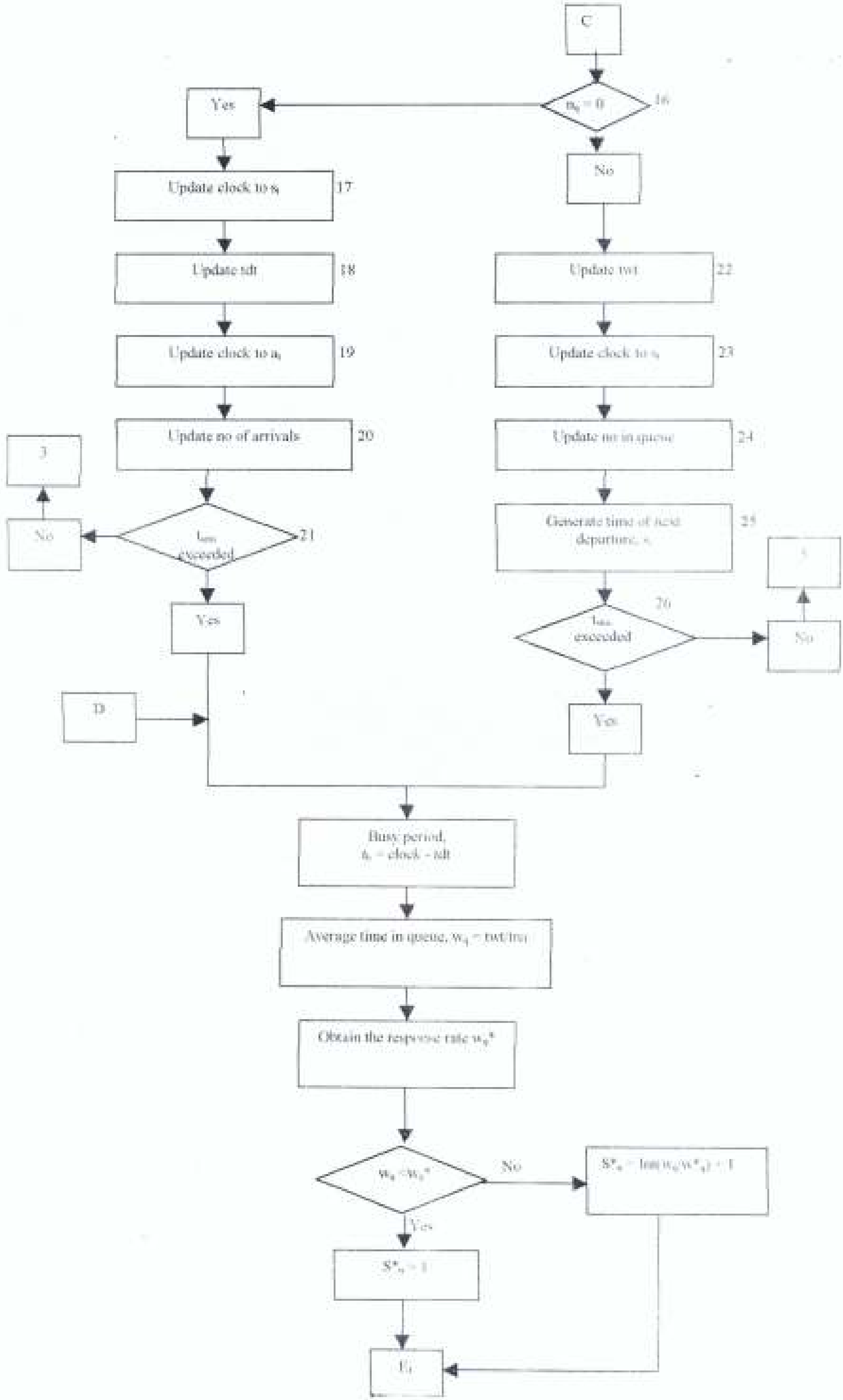
75. Obtain the tools/equipment cost(maintenance cost inclusive), $b = S_{nt} C_e \, etm$
76. Obtain cost of inventory, $c = (pY/S_{nt} N_u) + S_{nt} N_u \, CR/2$
77. Obtain cost of utility, $d = S_{nt} C_u \, etm$, $C_u = C_w + C_e + C_t$
78. Obtain cost of building, $e = S_{nt} C_b d_s$, d_s = % depreciation
79. Input inflation rate, s and interest rate, i
80. Obtain total cost of maintenance (contract staff)($tmt_a = (a + b + c + d + e)/(1/(1+i)(1+s))$
81. Obtain performance index, $P_e = W^* q_{nt}/tmt_a$
82. Calculate the cost of maintenance using traditional method (full-time staff by replacing etm by clock tmt_b
    $(a' + b' + c' + d' + e') \, 1/(1+i)(1+s)$
83. If available cost to maintenance in the following year is x% then $tmt_v = tmt_b.x$
84. Obtain performance index $P_{eb} = W^* q_{nt}/tmt_v$
85. Obtain the budget surplus/shortage, $B_s = tmt_v - tmt_a$
86. If $P_e \geq P_{eb}$ accept the strategic decisions and go directly to 87, otherwise review the strategic decision, go
    13'
87. Obtain the Benefit-Cost Ratio for full-time and contract staff, $BCR = \partial X_{i \text{ or } j} / \partial A_{n(i \text{ or } j)}$
88. Select the best alternative and goto
89. Stop

APPENDIX II: FLOW-CHART DEVELOPMENT

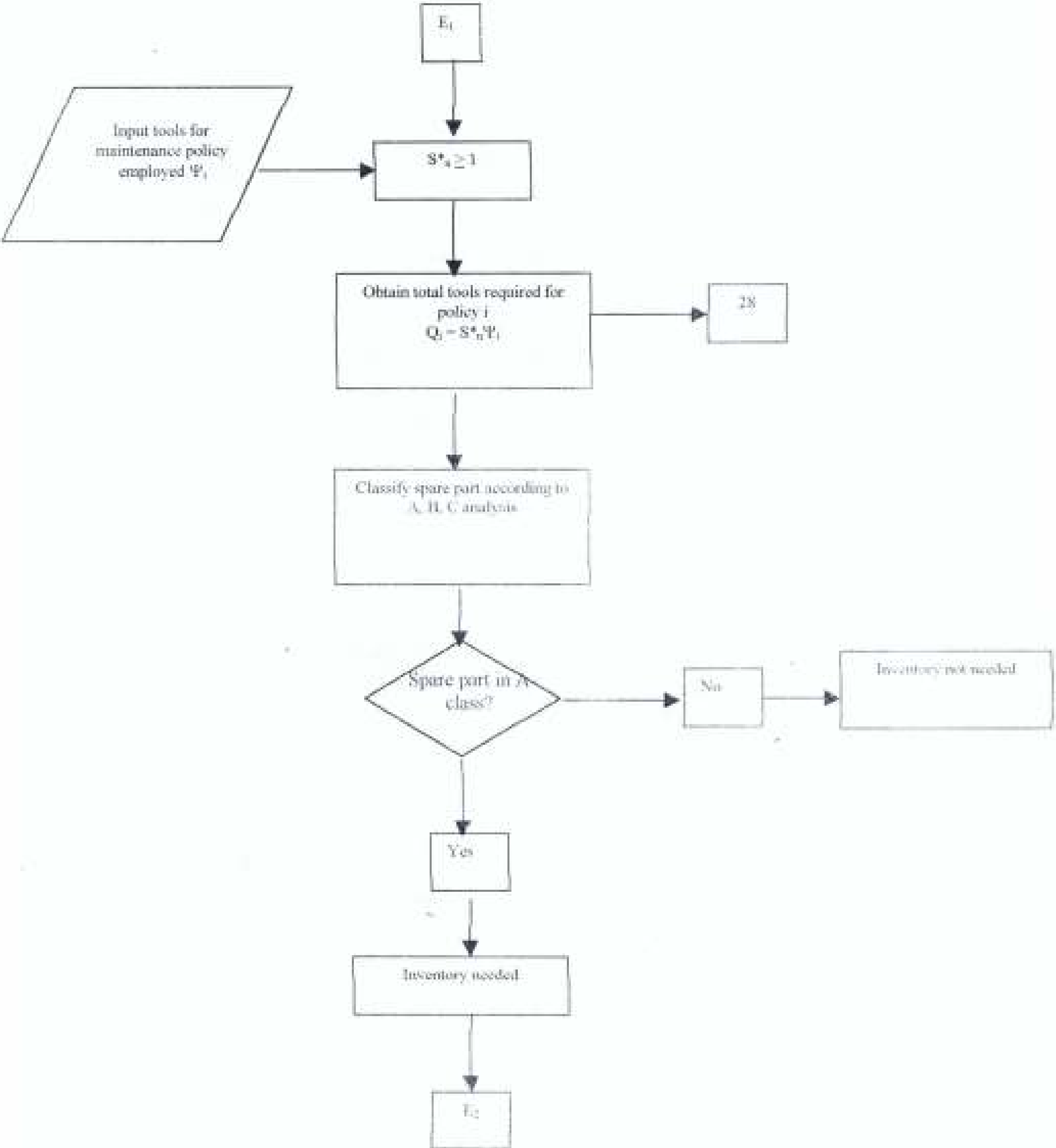


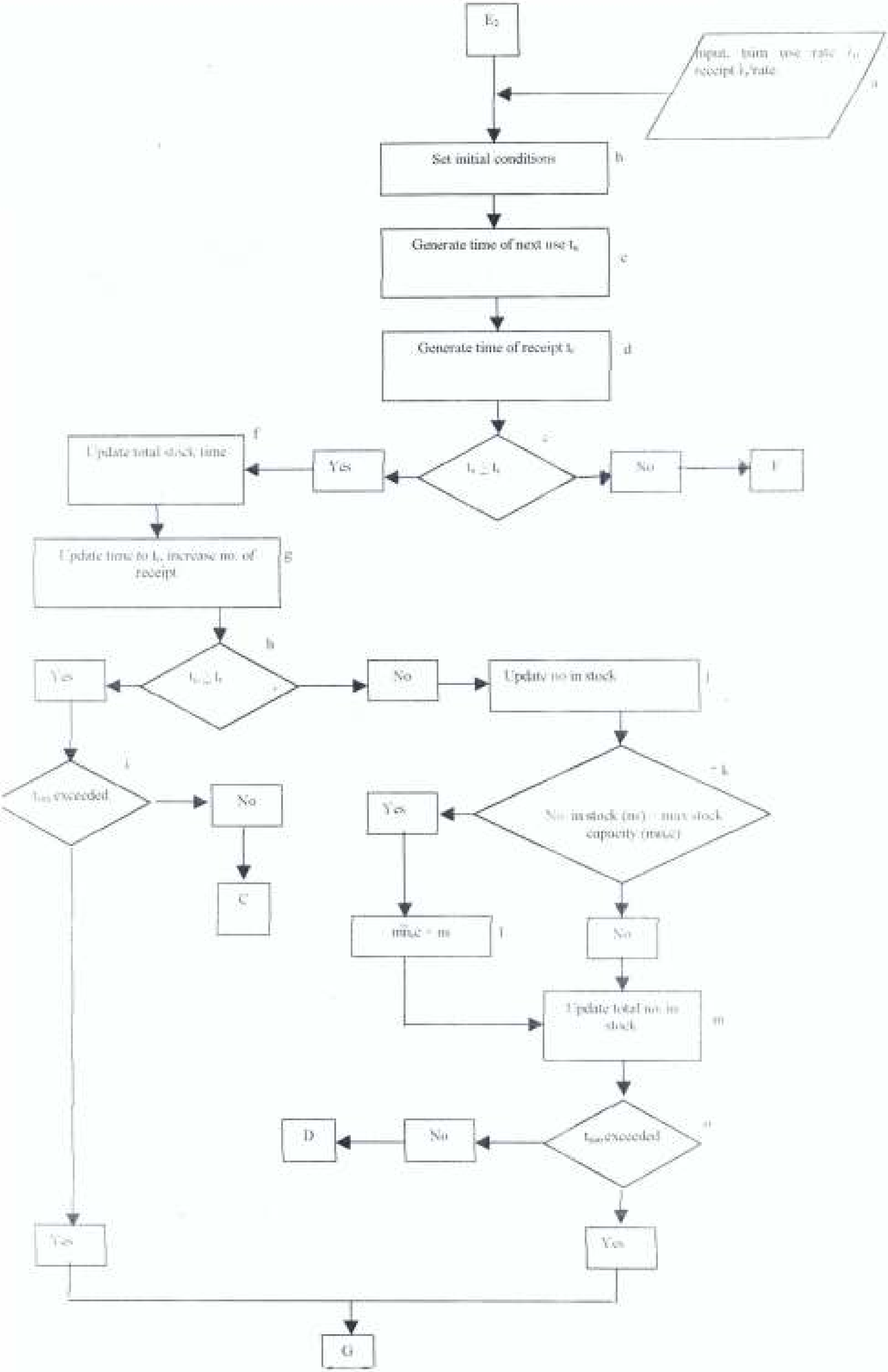


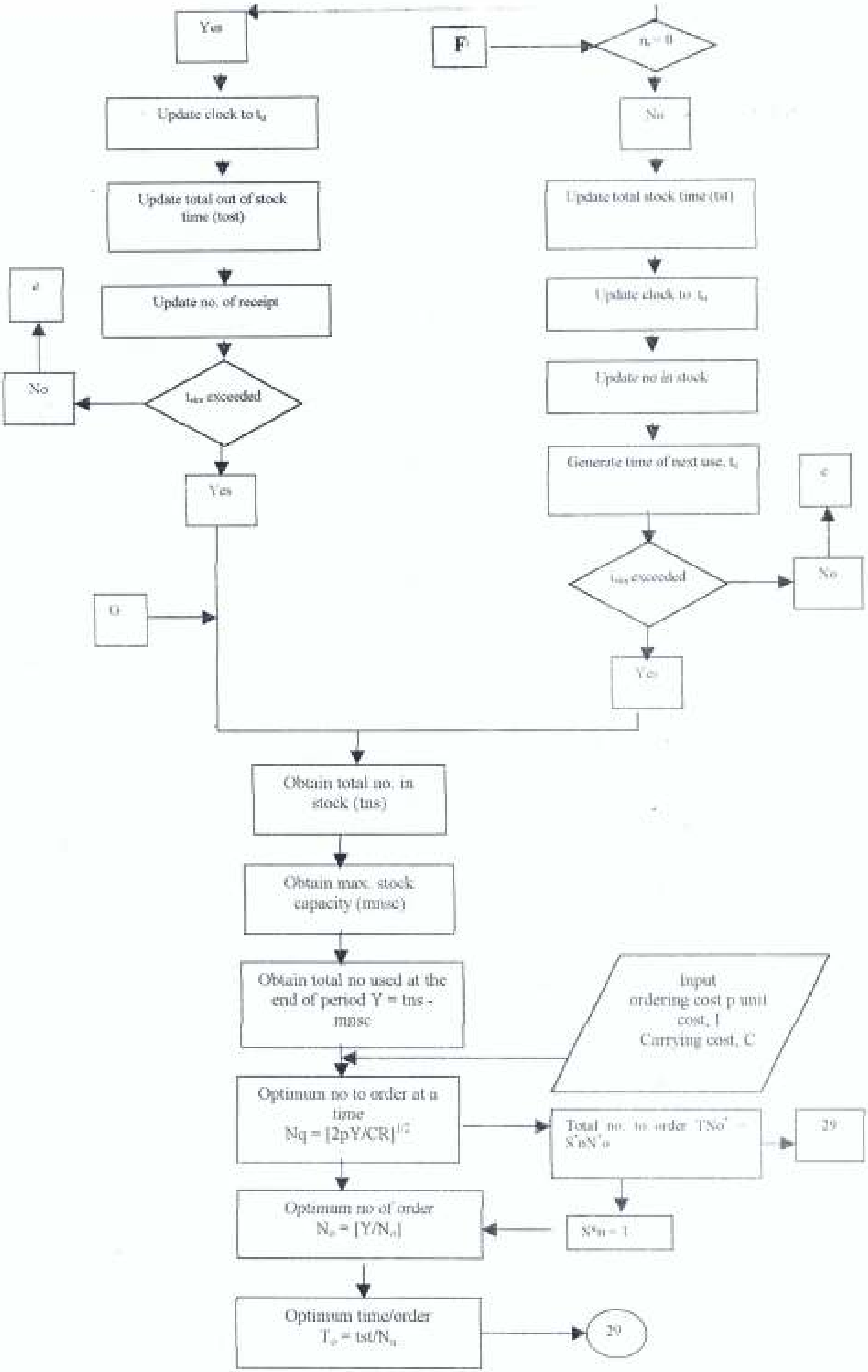
B
Input,
1
Generate t_e, using β-distribution
Generate the service rate ($\mu = 1/t_e$)
Set initial conditions
2
Generate time of next departure, s_i
3
Generate time of arrival, a_i
4
$s_i \geq a_i$
5
Yes
No
C
Update total, waiting time (twt)
6
Update total t_0, a_i increase no of arrival
7
$s_i = a_i$
8
Yes
No
Update no in queue
10
9
exceeded
No
Yes
3
11
Yes
No
12
Update total no. in
13
4
No
exceeded
15
Yes
D

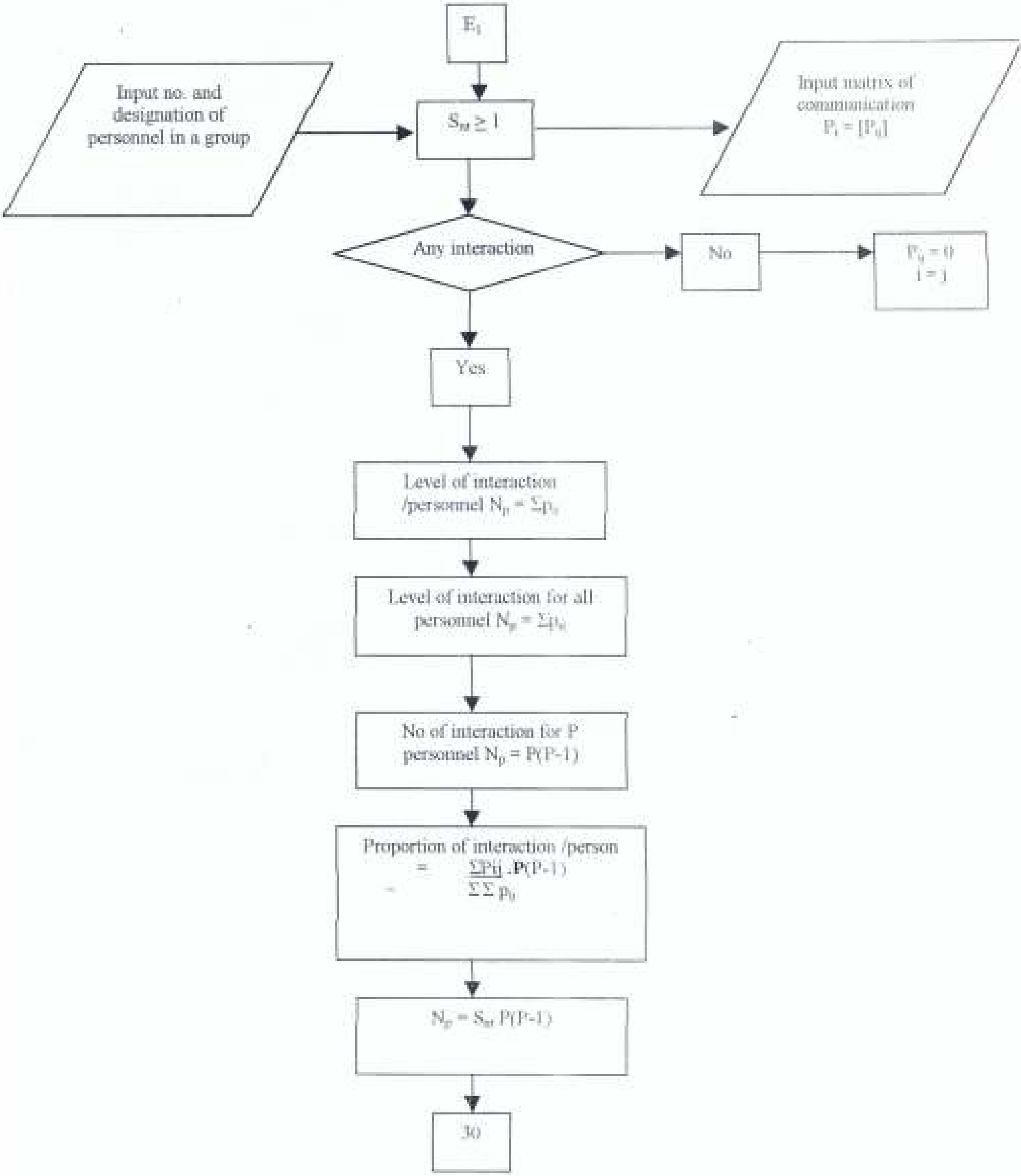


C
n₀ = 0
16
Yes
No
Update clock to s
17
Update tdt
18
Update clock to a
19
Update no of arrivals
20
3
No
exceeded
21
Yes
D
Update twt
22
Update clock to s
23
Update no in queue
24
Generate time of next departure, s
25
26
exceeded
No
Yes
Busy period,
= clock - tdt
Average time in queue, = twt/tm
Obtain the response rate
No
Yes
E

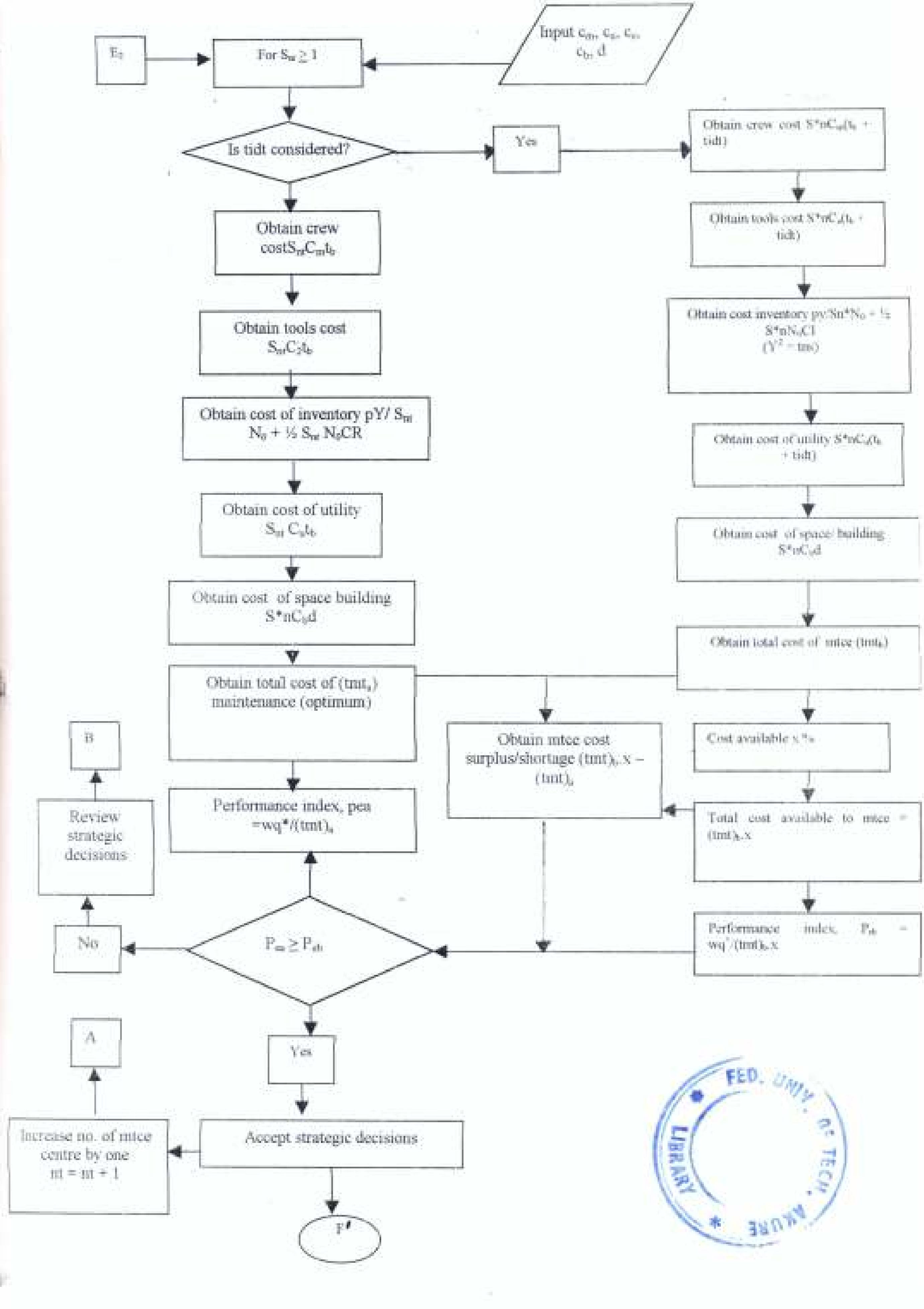

E_1
Input tools for maintenance policy employed Ψ_i
$S^*_n \geq 1$
Obtain total tools required for policy i
$Q_i = S^*_n \Psi_i$
28
Classify spare part according to A, B, C analysis
Spare part in A class?
No
Inventory not needed
Yes
Inventory needed
E_2


E2
Set initial conditions
Generate time of next use
Generate time of receipt
Update total stock time
Yes
No
F
Update time to t, increase no. of receipt
Yes
No
Update no in stock
exceeded
No
C
Yes
No in stock (ns) > max stock capacity (maxc)
maxc = ns
No
Update total no. in stock
D
No
exceeded
Yes
Yes
G

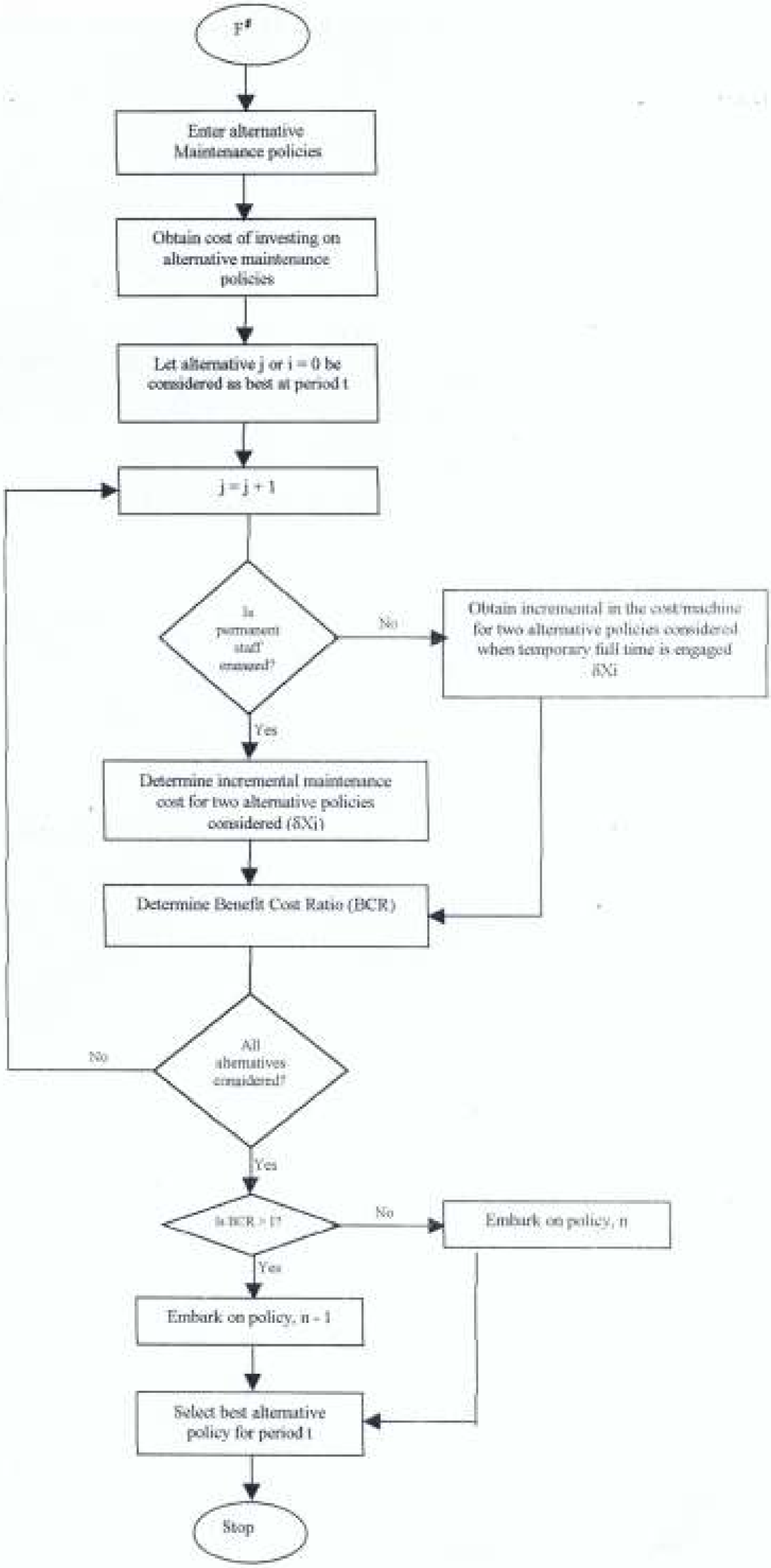

Yes
F
No
Update clock to t_d
Update total out of stock time (tost)
Update total stock time (tst)
Update clock to t_d
Update no. of receipt
Update no in stock
No
t_{stn} exceeded
Generate time of next use, t_d
Yes
t_{stn} exceeded
No
G
Yes
Obtain total no. in stock (tns)
Obtain max. stock capacity (mnsc)
Obtain total no used at the end of period Y = tns - mnsc
Input
ordering cost p unit
cost, I
Carrying cost, C
Optimum no to order at a time
$Nq = [2pY/CR]^{1/2}$
Optimum no of order
$N_o = [Y/N_q]$
Optimum time/order
$T_o = tst/N_o$
29
29



E_1
Input no. and designation of personnel in a group
$S_M \geq 1$
Input matrix of communication $P_i = [P_{ij}]$
Any interaction
No
$P_{ij} = 0$ $i = j$
Yes
Level of interaction /personnel $N_p = \Sigma p_{ij}$
Level of interaction for all personnel $N_p = \Sigma p_{ij}$
No of interaction for P personnel $N_p = P(P-1)$
Proportion of interaction /person $= \frac{\Sigma P_{ij} \cdot P(P-1)}{\Sigma\Sigma p_{ij}}$
$N_p = S_M P(P-1)$
30



Input
For $S_m \geq 1$
Is tidt considered?
Yes
Obtain crew cost $S_m C_m t_b$
Obtain tools cost $S_m C_2 t_b$
Obtain cost of inventory pY/ S_m N_0 + ½ S_m N_2CR
Obtain cost of utility S_m $C_u t_b$
Obtain cost of space building S*nC$_b$d
Obtain total cost of (tmt_s) maintenance (optimum)
Performance index, pea =wq*/(tmt)$_s$
Obtain crew cost
Obtain tools cost
Obtain cost inventory
Obtain cost of utility
Obtain cost of space/ building S*nC$_b$d
Obtain total cost of mtce
Cost available
Total cost available to mtce
Performance index
Obtain mtce cost surplus/shortage
$P_{ea} \geq P_{eb}$
No
B
Review strategic decisions
Yes
A
Accept strategic decisions
Increase no. of mtce centre by one m = m + 1


Enter alternative Maintenance policies
Obtain cost of investing on alternative maintenance policies
Let alternative j or i = 0 be considered as best at period t
j = j + 1
Is permanent staff engaged?
No
Obtain incremental in the cost/machine for two alternative policies considered when temporary full time is engaged δXi
Yes
Determine incremental maintenance cost for two alternative policies considered (δXi)
Determine Benefit Cost Ratio (BCR)
All alternatives considered?
No
Yes
Is BCR > 1?
No
Embark on policy, n
Yes
Embark on policy, n - 1
Select best alternative policy for period t
Stop

plash - 1

APPENDIX III: CODING OF THE SOFTWARE

```
Priva e Sub Form_Click()
Unload Me
frmmdi.Show
End Sub

Private Sub Timer1_Timer()
'frmmdi.Show
'Unload Me
'End Sub

Randomize
Dim colo
colo = Int((15 * Rnd) + 1)
If colo = 7 Then Exit Sub
lblcam.ForeColor = QBColor(colo)

End Sub

Private Sub Form_KeyPress(KeyAscii As Integer)
Unload Me
frmmdi.Show
End Sub

Private Sub Timer2_Timer()
'lblday.Left = lblday.Left + 100
'lblday.Refresh
'If lblday.Left >= Me.Width Then
 ' lblday.Left = -Me.Width
  'lblday.Refresh
'End If


lblday.Left = lblday.Left - 50
lblday.Refresh
If lblday.Left <= -Me.Width Then
  lblday.Left = Me.Width
  lblday.Refresh
End If


End Sub
```

```
Private Sub MDIForm_Load()
pctback.Height = 9000
'pctback.Width = frmmdi.Width
pctback.BackColor = Me.BackColor
lbltitle.Top = (Me.Height - lbltitle.Height) / 2
lbltitle.Left = (Screen.Width - lbltitle.Width) / 2

End Sub

Private Sub MDIForm_MouseMove(Button As Integer, Shift As Integer, X As Single, Y As
Single)
For intctr = Forms.Count - 1 To 0
frmmdi.pctback.Visible = True
Next intctr
End Sub

Private Sub mnudatacity_Click()
frmtown.Show
End Sub

Private Sub mnudatacomm_Click()
frmcomm.Show
End Sub

Private Sub mnudataconstant_Click()
frmalphas.Show
End Sub

Private Sub mnudatacost_Click()
frmoplanning.Show

End Sub

Private Sub mnudatacrew_Click()
frmpercrew.Show
End Sub

Private Sub mnudatadata_Click()
frmmse.Show
End Sub

Private Sub mnudatadiscounted_Click()
frmdiscount.Show
End Sub

Private Sub mnudatapart_Click()
frmpart.Show
End Sub

Private Sub mnudatapolicy_Click()
frmmaintdat.Show
End Sub

Private Sub mnudatapreg_Click()
frmpersreg.Show
End Sub

Private Sub mnudatashops_Click()
frmshop.Show
End Sub

Private Sub mnudataspear_Click()
frmparts.Show
End Sub

Private Sub mnudatatools_Click()
frmtooldata.Show
End Sub
```



```
Private Sub mnufileexit_Click()
```

```
End Sub

Private Sub mnuoperation3_Click()
frmthree.Show

End Sub

Private Sub mnuoperationlr_Click()
frmlreg.Show
End Sub

Private Sub mnuoperationmaint_Click()
frmmaintenance.Show

End Sub

Private Sub mnuoperationnfm_Click()
frmmsetab.Show
End Sub

Private Sub mnuoperationpers_Click()
frmpersdata.Show
End Sub

Private Sub mnuoperationses_Click()
frmses1.Show
End Sub

Private Sub mnuoperationtown_Click()
frmtownsel.Show
End Sub

Private Sub mnureportcost_Click()
'frmoplanning.Show

End Sub

Private Sub mnureportpers_Click()
frmcomchart.Show



End Sub
Private Sub mnuwizardmaster_Click()
frmwiz.Show
End Sub

Private Sub mnuwizardspear_Click()
frmspartsrep.Show
End Sub

Private Sub mnuwizardtools_Click()
frmtools.Show
End Sub



Private Sub pctback_GotFocus()
For intctr = 1 To Forms.Count - 1
frmmdi.pctback.Visible = True
Next intctr
End Sub

Private Sub pctback_LostFocus()
Call foreach_array
End Sub
```

```
Sub main()
Dim frmmyforms As Form
For Each frmmyforms In Forms
frmmdi.pctback.Visible = True
Next frmmyforms
End Sub
Sub foreach_array()
'Dim frmmyforms As Form
'For Each frmmyforms In Forms
'frmmdi.pctback.Visible = False
'Next frmmyforms

For intctr = 1 To Forms.Count - 1
frmmdi.pctback.Visible = False
Next intctr



End Sub
Public Sub addc()
'Data1.DatabaseName = App.Path & "/casting1.mdb"
Dim mdata As String
mdata = App.Path & "/casting1.mdb"
Data1.DatabaseName = mdata



End Sub
```

```
Private Sub cmbtype_Click()
frmmdi.Caption = "MAINTENANCE STRATEGIC DECISIONS OPTIMIZATION" + " (" & cmbtype
& ")"

End Sub

Private Sub Form_Load()
Me.Height = 3150
Me.Width = 6945
End Sub
```

frmtown - 1

```
Private Sub cmbadd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select name from town")

If cmbtown.Text = "" Then
MsgBox "Please Enter the City's Name", vbInformation
cmbtown.SetFocus
Exit Sub
End If

With myrs
  .FindFirst "name='" & Trim(cmbtown) & "'"
    If .NoMatch Then
        .AddNew
        Else
        result = MsgBox("This City is in existence,Overwrite?", vbQuestion)


        MsgBox "Registration Fails ....", vbExclamation
        Exit Sub
        End If


        myrs!Name = Trim(cmbtown.Text)
        .Update

End With



End Sub




Private Sub cmdexit_Click()
Unload Me
End Sub

Private Sub Form_Load()
Me.Height = 2520
Me.Width = 4800


Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from town")

    With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbtown.AddItem (!Name)
    cmbtown.ItemData(cmbtown.NewIndex) = !no
    .MoveNext
    Next I
    End With

End Sub
```

```
Private Sub cmdclose_Click()
Unload Me

End Sub

Private Sub cmdnaive_Click()
'frmmsetab.lbltown.Caption = cmbtown.Text
frmmsetab.Show

End Sub

Private Sub cmdok_Click()
Me.Hide
End Sub

Private Sub cmdreg_Click()
'frmlreg.lbltown.Caption = cmbtown.Text
frmlreg.Show

End Sub

Private Sub cmdsimple_Click()
'frmses1.lbltown.Caption = cmbtown.Text
frmses1.Show
End Sub

Private Sub cmdthree_Click()
'frmthree.txttown.Text = cmbtown.Text
frmthree.Show

End Sub

Private Sub cmdwiz_Click()
'frmwiz.lbltown.Caption = cmbtown.Text
frmwiz.Show
End Sub

Private Sub Form_Load()
Me.Height = 5235
Me.Width = 5550

Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from town")

    With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    cmbtown.Text = !Name
    For I = 0 To .RecordCount - 1
    cmbtown.AddItem (!Name)
    cmbtown.ItemData(cmbtown.NewIndex) = !no
    .MoveNext
    Next I
    End With

End Sub
```

```
frmtooldata - 1

Private Sub cmbtools_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from " & cmbtype.Text & " where town='" & cmb
town & "'and name='" & cmbtools & "'")
    With myrs
  lblno.Caption = myrs!no
    txtcost.Text = myrs!cost
    End With


End Sub

Private Sub cmbtype_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from " & cmbtype.Text & " where town='" & cmb
town & "'")
    cmbtools.Clear
    txtcost.Text = ""
    With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbtools.AddItem (!Name)
    cmbtools.ItemData(cmbtools.NewIndex) = !no
    .MoveNext
    Next I
    End With



End Sub

Private Sub cmdadd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
If cmbtype.Text = "" Then
MsgBox "Select the Maintenance type", vbCritical
cmbtype.SetFocus
Exit Sub
End If

Set myrs = mydb.OpenRecordset("select name,town,cost from " & cmbtype.Text & " where
town='" & cmbtown & "'")

If cmbtools.Text = "" Then
MsgBox "Please Enter the Tool's Name", vbInformation
cmbtools.SetFocus
Exit Sub
End If

With myrs
  .FindFirst "name='" & Trim(cmbtools) & "'"
    If .NoMatch Then
        .AddNew
        Else
        result = MsgBox("This Tool is in existence,Overwrite?", vbQuestion)


        MsgBox "Registration Fails ....", vbExclamation
        Exit Sub
        End If


        myrs!Name = Trim(cmbtools.Text)
        myrs!town = cmbtown.Text
        myrs!cost = txtcost.Text
        .Update

End With

End Sub
```

```
Private Sub cmdexit_Click()
Unload Me

End Sub

Private Sub cmdupdate_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
If cmbtype.Text = "" Then
MsgBox "Select the Maintenance type", vbCritical
cmbtype.SetFocus
Exit Sub
End If

If cmbtools.Text = "" Then
MsgBox "Please Enter the Tool's Name", vbInformation
cmbtools.SetFocus
Exit Sub
End If

Set myru = mydb.OpenRecordset("select * from " & cmbtype.Text & " where town='" & cmb
town & "'")

If cmbtools.Text = "" Then
MsgBox "Please Enter the Tool's Name", vbInformation
cmbtools.SetFocus
Exit Sub
End If

With myru
          .Edit
          myru!Name = Trim(cmbtools.Text)
          myru!cost = txtcost.Text
        .Update

End With



End Sub

Private Sub Form_Load()
Me.Height = 3240
Me.Width = 9180

Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from town")

    With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    cmbtown.Text = !Name
    For I = 0 To .RecordCount - 1
    cmbtown.AddItem (!Name)
    cmbtown.ItemData(cmbtown.NewIndex) = !no
    .MoveNext
    Next I
    End With
End Sub
```

frmpersreg - 1

```
Private Sub cmbadd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from post")

If cmbpers.Text = "" Then
MsgBox "Please Enter the Personnel", vbInformation
cmbpers.SetFocus
Exit Sub
End If

With myrs
'  .FindFirst "position='" & Trim(cmbpers) & "'"
 '    If .NoMatch Then
          .AddNew
  '        Else
   '       result = MsgBox("This Personnel is in existence,Overwrite?", vbQuestion


    '     MsgBox "Registration Fails ....", vbExclamation
     '    Exit Sub
      '   End If


        myrs!Position = Trim(cmbpers.Text)
        myrs!town = Trim(cmbtown.Text)
        .Update

End With
cmbpers.Text = ""


End Sub

Private Sub cmbtown_Change()
cmbpers.Clear
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from post where town='" & cmbtown & "'")

 With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbpers.AddItem (!Position)
    cmbpers.ItemData(cmbpers.NewIndex) = !no
    .MoveNext
    Next I
    End With

End Sub

Private Sub cmbtown_Click()
cmbpers.Clear
 Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from post where town='" & cmbtown & "'")

 With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbpers.AddItem (!Position)
    cmbpers.ItemData(cmbpers.NewIndex) = !no
    .MoveNext
    Next I
    End With
End Sub

Private Sub cmdexit_Click()
Unload Me
End Sub

Private Sub Form_Load()
Me.Height = 3600
Me.Width = 6525
```

```
Me.Top = 200

Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrx = mydb.OpenRecordset("select * from town")

    With myrx
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbtown.AddItem (!Name)
    cmbtown.ItemData(cmbtown.NewIndex) = !no
    .MoveNext
    Next I
    End With



End Sub
```

```
Private Sub cmdclose_Click()
Unload Me

End Sub

Private Sub Form_Load()
Me.Height = 7750
Me.Width = 9210
Me.Top = 100
Me.Left = 100
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select sum(ilevel) as level1 from interaction where to
wn='" & frmtownsel.cmbtown.Text & "'")
'Set myrc = mydb.OpenRecordset("select count(position1)as pno,sum(ilevel) as level1 f
rom interaction group by position1")
Set myrt = mydb.OpenRecordset("select * from srate where town='" & frmtownsel.cmbtown
.Text & "'")

    With myrt
      n = !alpha
      p = !pe
        k = ((p + n) * ((p + n) - 1))
      lbln.Caption = k
     ' L = lblcrew.Caption
      'lbltotal.Caption = (k * L)

        End With


With myrs
lblint.Caption = myrs!level1

End With
ayo = "select position1,sum(ilevel) as level1,((level1*'" & lbln & "')/'" & lblint &
"as level2 from interaction where town='" & frmtownsel.cmbtown.Text & "' group by position1

Adodc1.RecordSource = ayo

Adodc1.Refresh


End Sub
```

```
Private Sub cmdclose_Click()
Unload Me

End Sub

Private Sub Form_Load()
Me.Height = 7750
Me.Width = 9210
Me.Top = 100
Me.Left = 100
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select sum(ilevel) as level1 from interaction where to
wn='" & frmtownsel.cmbtown.Text & "'")
'Set myrc = mydb.OpenRecordset("select count(position1)as pno,sum(ilevel) as level1 f
rom interaction group by position1")
Set myrt = mydb.OpenRecordset("select * from srate where town='" & frmtownsel.cmbtown
.Text & "'")

    With myrt
      n = !alpha
      p = !pe
        k = ((p + n) * ((p + n) - 1))
      lbln.Caption = k
     ' L = lblcrew.Caption
      'lbltotal.Caption = (k * L)

        End With


With myrs
lblint.Caption = myrs!level1

End With
ayo = "select position1,sum(ilevel) as level1,((level1*'" & lbln & "')/'" & lblint &
"')as level2 from interaction where town='" & frmtownsel.cmbtown.Text & "' group by position1

Adodc1.RecordSource = ayo

Adodc1.Refresh


End Sub
```

```
frmalphas = 1

Private Sub cmbtown_Click()
cmdref_Click
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from alph")
  With myrs
        .FindFirst "town ='" & cmbtown.Text & "'"
        If .NoMatch = True Then
        cmdref_Click
        cmdsave.Visible = True
        cmdupd.Visible = False
        Else
        cmdupd.Visible = True
        cmdsave.Visible = False
        txtalpha1.Text = myrs!alpha1
        txtalpha2.Text = myrs!alpha2
        txtalpha3.Text = myrs!alpha3
        End If
End With
End Sub

Private Sub cmdclose_Click()
Unload Me
End Sub

Private Sub cmdref_Click()
        txtalpha1.Text = ""
        txtalpha2.Text = ""
        txtalpha3.Text = ""
End Sub

Private Sub cmdsave_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("alph", 2)
    If IsNumeric(txtalpha1.Text) = False Then
    MsgBox "Please Enter Numeric value Only", vbInformation
    txtalpha1.SetFocus
    Exit Sub
    End If
    If IsNumeric(txtalpha2.Text) = False Then
    MsgBox "Please Enter Numeric value Only", vbInformation
    txtalpha2.SetFocus
    Exit Sub
    End If
    If IsNumeric(txtalpha3.Text) = False Then
    MsgBox "Please Enter Numeric value Only", vbInformation
    txtalpha3.SetFocus
    Exit Sub
    End If

    With myrs
       .AddNew

        myrs!alpha1 = txtalpha1.Text
        myrs!alpha2 = txtalpha2.Text
        myrs!alpha3 = txtalpha3.Text
        myrs!town = cmbtown.Text

        .Update

End With

End Sub

Private Sub cmdupd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
If cmbtown.Text = "" Then
MsgBox "Select the City", vbCritical
cmbtown.SetFocus
Exit Sub
End If

Set myrs = mydb.OpenRecordset("select * from alph where town='" & cmbtown.Text & "'")
```

```
frmalphas = 2

        With myrs

                .Edit

                myrs!alpha1 = txtalpha1.Text
                myrs!alpha2 = txtalpha2.Text
                myrs!alpha3 = txtalpha3.Text

                .Update

        End With

        End Sub

        Private Sub Form_Load()
        Me.Height = 3020
        Me.Width = 5000

        Set mydb = OpenDatabase(App.Path & "/casting1")
        'Set myrs = mydb.OpenRecordset("select * from alph")
        Set myrp = mydb.OpenRecordset("select * from town")


            With myrp
            If Not .EOF Then .MoveLast
            If Not .BOF Then .MoveFirst
            'cmbtown.Text = !Name
            For I = 0 To .RecordCount - 1
            cmbtown.AddItem (!Name)
            cmbtown.ItemData(cmbtown.NewIndex) = !no
            .MoveNext
            Next I
            End With


        End Sub
```

```
Private Sub cmbno_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from datax where t=" & cmbno.Text & " and tow
n='" & cmbtown & "'")

        With myrs
          txtfail.Text = myrs!frate
          txtequip.Text = myrs!equip
          txtage.Text = myrs!age
         txtcentres.Text = myrs!centre
          txtyear.Text = myrs!ryear
          lblx.Caption = myrs!xt
End With



End Sub

Private Sub cmbtown_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select distinct t from datax where town='" & cmbtown &
"'")


    With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
  cmbno.Clear
    For I = 0 To .RecordCount - 1
    cmbno.AddItem (!t)
    'cmbno.ItemData(cmbno.NewIndex) = !n
    .MoveNext
    Next I
    End With
cmdref_Click

End Sub

Private Sub cmdclose_Click()
Unload Me

End Sub

Private Sub cmddelete_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
mydb.Execute "DELETE * FROM " _
        & "datax WHERE t =" & cmbno & " and town='" & cmbtown & "';"




mydb.Close
cmdref_Click
End Sub

Private Sub cmdref_Click()


        cmbno.Text = ""
        txtfail.Text = ""
        txtequip.Text = ""
        txtage.Text = ""
       txtcentres.Text = ""
        txtyear.Text = ""
        lblx.Caption = ""


'Set mydb = OpenDatabase(App.Path & "/casting1")
'Set myrs = mydb.OpenRecordset("select t,n from datax")

'
 '   With myrs
  '  If Not .EOF Then .MoveLast
```

```
            ' If Not .BOF Then .MoveFirst
            '
            ' For I = 0 To .RecordCount - 1
             'cmbno.AddItem (!t)
             'cmbno.ItemData(cmbno.NewIndex) = !n
             '.MoveNext
             'Next I
             'End With

        End Sub

        Private Sub cmdsave_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from datax where town='" & cmbtown & "'")
            If IsNumeric(txtage.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtage.SetFocus
            Exit Sub
            End If
            If IsNumeric(txtfail.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtfail.SetFocus
            Exit Sub
            End If
            If IsNumeric(txtyear.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtyear.SetFocus
            Exit Sub
            End If

            With myrs
              .FindFirst "t=" & Trim(cmbno) & ""
            If .NoMatch Then
                .AddNew
                Else
                MsgBox "This Serial Number is in existence", vbInformation
                cmbno.Text = ""

                Exit Sub
                End If

                myrs!t = cmbno.Text
                myrs!town = cmbtown.Text
                myrs!frate = txtfail.Text
                myrs!equip = txtequip.Text
                myrs!age = txtage.Text
                myrs!centre = txtcentres.Text
                myrs!ryear = txtyear.Text
                myrs!xt = lblx.Caption
                .Update

        End With

         cmdref_Click

        End Sub

        Private Sub cmdupd_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from datax where t=" & cmbno.Text & " and tow
n='" & cmbtown & "'")
            If IsNumeric(txtage.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtage.SetFocus
            Exit Sub
            End If
            If IsNumeric(txtfail.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtfail.SetFocus
            Exit Sub
            End If
            If IsNumeric(txtyear.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtyear.SetFocus
```

```
frmuse = 3
        Exit Sub
        End If

        With myrs
            .Edit

            myrs!frate = txtfail.Text
            myrs!equip = txtequip.Text
            myrs!age = txtage.Text
            myrs!centre = txtcentres.Text
            myrs!ryear = txtyear.Text
            myrs!xt = lblx.Caption
            .Update

    End With

    End Sub

    Private Sub Form_Load()
    Me.Height = 5010
    Me.Width = 12000

    Me.Top = Screen.Height / 9
    Set mydb = OpenDatabase(App.Path & "/casting1")
         Set myrt = mydb.OpenRecordset("select * from town")

        With myrt
        If Not .EOF Then .MoveLast
        If Not .BOF Then .MoveFirst
        For I = 0 To .RecordCount - 1
        cmbtown.AddItem (!Name)
        cmbtown.ItemData(cmbtown.NewIndex) = !no
        .MoveNext
        Next I
        End With



    End Sub

    Private Sub txtage_Change()
    On Error GoTo err:
    a = Val(txtfail.Text)
    b = Val(txtequip.Text)
    c = Val(txtage.Text)
    d = Val(txtcentres.Text)
    e = (a * d) / (b * c)
    lblx.Caption = Format(e, "fixed")
err:
    End Sub

    Private Sub txtcentres_Change()
    On Error GoTo err:
    a = Val(txtfail.Text)
    b = Val(txtequip.Text)
    c = Val(txtage.Text)
    d = Val(txtcentres.Text)
    e = (a * d) / (b * c)
    lblx.Caption = Format(e, "fixed")
err:
    End Sub

    Private Sub txtequip_Change()
    On Error GoTo err:
    a = Val(txtfail.Text)
    b = Val(txtequip.Text)
    c = Val(txtage.Text)
    d = Val(txtcentres.Text)
    e = (a * d) / (b * c)
    lblx.Caption = Format(e, "fixed")
err:
    End Sub
```

```
        Private Sub txtfail_Change()
        On Error GoTo err:
        a = Val(txtfail.Text)
        b = Val(txtequip.Text)
        c = Val(txtage.Text)
        d = Val(txtcentres.Text)
        e = (a * d) / (b * c)
        lblx.Caption = Format(e, "fixed")
err:
        End Sub
```

```
        Dim mydb As Database
        Dim myrs As Recordset

        Private Sub cmdexe_Click()
        Dim col6 As Integer


        DBGrid1.Col = 4
        DBGrid1.Row = 0
        DBGrid1.Text = ""
        DBGrid1.Col = 3
        DBGrid1.Row = 0
        DBGrid1.Text = ""





        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myra = mydb.OpenRecordset("select sum((xt-nft)^2)as rep from datax where town='"
& frmtownsel.cmbtown & "'")
        myrb = mydb.OpenRecordset("select count(datax.n)as period from datax where town='" &
frmtownsel.cmbtown & "'")
        Set myrt = mydb.OpenRecordset("select * from srate")
        Set myrc = mydb.OpenRecordset("select sum(centre)as cent from datax where town='" & f
rmtownsel.cmbtown & "'")

                With myra
                lbltotal.Caption = myra!rep - col6
                End With
                With myrb
                lblno.Caption = !period
                End With
                mse = lbltotal.Caption / lblno.Caption
                lblmse.Caption = Format(mse, "0.000000")
        cmdexe.Enabled = False
        d = lblxt

        g = Val(lblequip.Caption)
        e = Val(lblage.Caption)
        f = Val(lblcentre.Caption)
        h = d * (e * g) / f
        With myrc
            l = myrc!cent
        With myrt
                k = myrt!pe
                m = (l * h) / (l + k)


        lblnext = Format(m, "fixed")
        End With
        End With


        End Sub

        Sub showfields()
        lblt1.Caption = myrs!t
        lblxt.Caption = myrs!xt
        lblequip.Caption = myrs!equip
        lblage.Caption = myrs!age
        lblcentre.Caption = myrs!centre

        End Sub

        Private Sub cmdnext_Click()
        On Error GoTo sol
        lblft.Caption = lblxt

        myrs.MoveNext
        Call showfields
```



```
sol:
        cmdsave_Click
```

```
End Sub

Private Sub cmdpolicy_Click()
frmmaintenance.txtlt.Text = lblnext.Caption
frmmaintenance.lblcaption.Caption = "Naive Model"
Unload Me
frmmaintenance.Show

End Sub

Private Sub cmdsave_Click()
Dim mdata As String
mdata = App.Path & "/casting1.mdb"
Data1.DatabaseName = mdata
Adodc1.RecordSource = "select t,nft from datax where town='" & frmtownsel.cmbtown & "
'"

Set mydt = OpenDatabase(App.Path & "/casting1")
Set myrb = mydt.OpenRecordset("select t,nft from datax where t=" & lblt1 & " and town
='" & frmtownsel.cmbtown & "'")
        With myrb
        .Edit
        myrb!nft = lblft.Caption
        .Update
        End With
Data1.RecordSource = "select ryear,t,xt,nft,(xt-nft)as et,(et^2)as sqerror from datax
 where town='" & frmtownsel.cmbtown & "'"
Adodc1.RecordSource = "select t,nft from datax where town='" & frmtownsel.cmbtown & "
'"
Data1.Refresh
DBGrid1.ReBind
DBGrid1.Refresh
Adodc1.Refresh
MSChart1.Refresh

myrb.Close
mydt.Close
End Sub


Private Sub Form_Load()
Dim mdata As String
mdata = App.Path & "/casting1.mdb"
Data1.DatabaseName = mdata


Me.Width = 12000
Me.Height = 8500
Me.Left = 70
Me.Top = 70





Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
 & "'")

myrs.MoveFirst
Call showfields




Data1.RecordSource = "select t,xt,nft,(xt-nft)as et,abs(xt-nft)as abset,abs(et/xt)as
absperc,(et^2)as sqerror from datax where town='" & frmtownsel.cmbtown & "'"

Timer1.Interval = 100


End Sub
```

```
Private Sub Timer1_Timer()
Timer1.Interval = 0

Set mydb = OpenDatabase(App.Path & "/casting1")

Set myrn = mydb.OpenRecordset("select count(n)as sn from datax where town='" & frmtow
nsel.cmbtown & "'")
With myrn
For I = 1 To myrn!sn - 1
cmdnext_Click
Next I
End With
cmdexe_Click


End Sub
```

```
Private Sub cmbtown_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from cost")

        With myrs
       .FindFirst "town ='" & cmbtown.Text & "'"
        If .NoMatch = True Then
        cmdref_Click
        cmdadd.Visible = True
        cmdsave.Visible = False
        Else
        cmdsave.Visible = True
        cmdadd.Visible = False

        txtelect.Text = !elcost
        txtwater.Text = !wtcost
        txtcrew.Text = !cscost
        txtbuild.Text = !bdcost
        End If
        End With

End Sub

Private Sub cmdadd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from cost")

        With myrs
        .AddNew
        !town = cmbtown.Text
        !elcost = txtelect.Text
        !wtcost = txtwater.Text
        !cscost = txtcrew.Text
        !bdcost = txtbuild.Text
        .Update
        End With
End Sub

Private Sub cmdclose_Click()
Unload Me

End Sub

Private Sub cmdref_Click()
        txtelect.Text = ""
        txtwater.Text = ""
        txtcrew.Text = ""
        txtbuild.Text = ""
End Sub

Private Sub cmdsave_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from cost where town='" & cmbtown & "'")

        With myrs
        .Edit
        !elcost = txtelect.Text
        !wtcost = txtwater.Text
        !cscost = txtcrew.Text
        !bdcost = txtbuild.Text
        .Update
        End With

End Sub

Private Sub Form_Load()
Me.Height = 4000
Me.Width = 8070
Me.Top = 200
Me.Left = 200

Set mydb = OpenDatabase(App.Path & "/casting1")
```

```
        Set myrt = mydb.OpenRecordset("select * from town")

       With myrt
       If Not .EOF Then .MoveLast
       If Not .BOF Then .MoveFirst
       For I = 0 To .RecordCount - 1
       cmbtown.AddItem (!Name)
       cmbtown.ItemData(cmbtown.NewIndex) = !no
       .MoveNext
       Next I
       End With


   End Sub
```

```
Private Sub cmbadd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from spear")

If cmbpart.Text = "" Then
MsgBox "Please Enter the Spear Part's Name", vbInformation
cmbpart.SetFocus
Exit Sub
End If

With myrs
 ' .FindFirst "part='" & Trim(cmbpart) & "'"
  '  If .NoMatch Then
       .AddNew
   '    Else
    '   result = MsgBox("This Part is in existence,Overwrite?", vbQuestion)


     '  MsgBox "Registration Fails ....", vbExclamation
      ' Exit Sub
       ' End If

       myrs!town = cmbtown.Text
       myrs!part = Trim(cmbpart.Text)
       .Update

End With



End Sub


Private Sub cmbtown_Change()

cmbpart.Clear

Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from spear where town='" & cmbtown & "'")

    With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbpart.AddItem (!part)
    cmbpart.ItemData(cmbpart.NewIndex) = !no
    .MoveNext
    Next I
    End With

End Sub

Private Sub cmbtown_Click()
cmbpart.Clear

Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from spear where town='" & cmbtown & "'")

    With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbpart.AddItem (!part)
    cmbpart.ItemData(cmbpart.NewIndex) = !no
    .MoveNext
    Next I
    End With

End Sub

Private Sub cmddelete_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
mydb.Execute "DELETE * FROM "
         & "spear WHERE part ='" & cmbpart & "' and town='" & cmbtown & "';"
```

```
mydb.Close
End Sub

Private Sub cmdexit_Click()
Unload Me
End Sub

Private Sub Form_Load()
Me.Height = 2900
Me.Width = 6435
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrx = mydb.OpenRecordset("select * from town")

    With myrx
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbtown.AddItem (!Name)
    cmbtown.ItemData(cmbtown.NewIndex) = !no
    .MoveNext
    Next I
    End With


End Sub
```

```
frmthree = 1

        Dim mydb As Database
        Dim myrs As Recordset



        Private Sub cmdmse_Click()
        Set mydt = OpenDatabase(App.Path & "/casting1")
        Set myrm = mydb.OpenRecordset("select count(n)as sn,sum((xt-tma)^2)as sslet from data
x where tma <> 0 and town='" & frmtownsel.cmbtown & "'")
        Set myrn = mydb.OpenRecordset("select count(n)as sn from datax where town='" & frmtow
nsel.cmbtown & "'")

                With myrm
                lmse = myrm!sslet

                    End With
                    With myrn
                    lmn = myrn!sn
                    End With
                       lmsr = lmse / lmn
                    lblmse.Caption = Format(lmsr, "0.000000")

        End Sub
        Sub isiax()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrt = mydb.OpenRecordset("select * from srate")
        Set myrc = mydb.OpenRecordset("select sum(centre)as cent from datax where town='" & f
rmtownsel.cmbtown & "'")

        On Error GoTo sol
        lbl3 = lbl2.Caption
        lbl2 = lbl1.Caption
        lbl1.Caption = lblxt.Caption

        myrs.MoveNext

        Call showfields
sol:
        If lbl3 <> "" Then
        a = Val(lbl3.Caption)
        b = Val(lbl2.Caption)
        c = Val(lbl1.Caption)
        d = (a + b + c) / 3
        g = Val(lblequip.Caption)
        e = Val(lblage.Caption)
        f = Val(lblcentre.Caption)
        h = d * (e * g) / f
        With myrc
            l = myrc!cent
        With myrt
                k = myrt!pe
                m = (l * h) / (1 + k)


        lblft1 = Format(m, "fixed")
        End With
        End With

        End If

        End Sub


        Private Sub cmdnext_Click()

        On Error GoTo sol
        lbl3 = lbl2.Caption
        lbl2 = lbl1.Caption
        lbl1.Caption = lblxt.Caption

        myrs.MoveNext

        Call showfields
sol:
```

```
If lbl3 <> "" Then
a = Val(lbl3.Caption)
b = Val(lbl2.Caption)
c = Val(lbl1.Caption)
d = (a + b + c) / 3

lblft1 = Format(d, "fixed")
End If

If lbl3 <> "" Then

cmdsave_Click
End If

End Sub

Private Sub cmdpolicy_Click()
frmmaintenance.txtlt.Text = lblft1.Caption
frmmaintenance.lblcaption = "Three Moving Average"
frmmaintenance.Show
Unload Me

End Sub

Private Sub cmdsave_Click()
Dim mdata As String
mdata = App.Path & "/casting1.mdb"
Data1.DatabaseName = mdata

Set mydt = OpenDatabase(App.Path & "/casting1")
Set myrb = mydt.OpenRecordset("select t,tma from datax where t=" & lblt1 & " and town
='" & frmtownsel.cmbtown & "'")
        With myrb
        .Edit
        myrb!tma = Val(lblft1.Caption)
        .Update
        End With

ayo = "select ryear,t,xt,tma,(xt-tma)as slet from datax where town='" & frmtownsel.cm
btown & "'"
Data1.RecordSource = ayo
Adodc1.RecordSource = "select t,tma from datax where town='" & frmtownsel.cmbtown & "
'"
Data1.Refresh
DBGrid1.ReBind
DBGrid1.Refresh
Adodc1.Refresh
MSChart1.Refresh

myrb.Close
mydt.Close

End Sub


Private Sub Form_Load()
Dim mdata As String
mdata = App.Path & "/casting1.mdb"
Data1.DatabaseName = mdata
Adodc1.RecordSource = "select t,tma from datax where town='" & frmtownsel.cmbtown & "
'"
Me.Width = 12000
Me.Height = 6210
Me.Top = 60
Me.Left = 60

Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
& "'")

myrs.MoveFirst
Call showfields
Set myrn = mydb.OpenRecordset("select count(n)as sn from datax where town='" & frmtow
```

```
nsel.cmbtown & "'")
        With myrn
        For I = 1 To myrn!sn - 1
        cmdnext_Click
        Next I
        For k = 1 To 1
        Call isiak
        Next k

        End With
        cmdmse_Click

        End Sub



        Sub showfields()
        lbltl.Caption = myrs!t
        lblxt.Caption = myrs!xt
        lblequip.Caption = myrs!equip
        lblage.Caption = myrs!age
        lblcentre.Caption = myrs!centre

        End Sub
```

```
        Dim mydb As Database
        Dim myrs As Recordset

        Private Sub cmdmse_Click()
        Set mydt = OpenDatabase(App.Path & "/casting1")
        Set myrm = mydb.OpenRecordset("select count(n)as sn,sum((xt-seft)^2)as sslet from dat
ax where town='" & frmtownsel.cmbtown & "'")
                With myrm
                lmse = myrm!sslet / myrm!sn
                    lblmse.Caption = Format(lmse, "0.000000")

                    End With

        End Sub

        Private Sub cmdnext_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrt = mydb.OpenRecordset("select * from srate")
        Set myrc = mydb.OpenRecordset("select sum(centre)as cent from datax where town='" & f
rmtownsel.cmbtown & "'")

        On Error GoTo sol
        d = lblft1.Caption
        g = Val(lblequip.Caption)
        e = Val(lblage.Caption)
        f = Val(lblcentre.Caption)
        h = d * (e * g) / f
        With myrc
            l = myrc!cent
        With myrt
                k = myrt!pe
                m = (l * h) / (l + k)


        lblfte.Caption = Format(m, "fixed")
        End With
        End With

        myrs.MoveNext
        Call isiak
        cmdsave_Click

sol:
        End Sub

        Private Sub cmdpolicy_Click()
        frmmaintenance.txtlt.Text = lblfte.Caption
        frmmaintenance.lblcaption.Caption = "Simple Exponential Smoothing"
        Unload Me
        frmmaintenance.Show


        End Sub

        Private Sub cmdsave_Click()
        Dim mdata As String
        mdata = App.Path & "/casting1.mdb"
        Data1.DatabaseName = mdata
        Adodc1.RecordSource = "select t,seft from datax where town='" & frmtownsel.cmbtown &
"'"
        Set mydt = OpenDatabase(App.Path & "/casting1")
        Set myrb = mydt.OpenRecordset("select t,seft from datax where t=" & lblt1 & " and tow
n='" & frmtownsel.cmbtown & "'")
                With myrb
                .Edit
                myrb!seft = lblft1.Caption
                .Update
                End With

        ayo = "select ryear,t,n,xt,seft,(xt-seft)as et,(seft+ ('" & txtal & "' * et))as ft1 f
rom datax where town='" & frmtownsel.cmbtown & "'"
        Data1.RecordSource = ayo
        Adodc1.RecordSource = "select t,seft from datax where town='" & frmtownsel.cmbtown &
"'"
```

```
Data1.Refresh
DBGrid1.ReBind
DBGrid1.Refresh
Adodc1.Refresh
MSChart1.Refresh

myrb.Close
mydt.Close
End Sub

Private Sub Form_Load()
Dim mdata As String
mdata = App.Path & "/casting1.mdb"
Data1.DatabaseName = mdata

Me.Width = 12000
Me.Height = 9000
Me.Top = 60
Me.Left = 60
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
& "'")

myrs.MoveFirst
Call showfields
Timer1.Interval = 100

End Sub



Sub showfields()
lblt1.Caption = myrs!t
lblxt.Caption = myrs!xt
lblft.Caption = myrs!seft
lblequip.Caption = myrs!equip
lblage.Caption = myrs!age
lblcentre.Caption = myrs!centre

et = Val(lblxt - lblft)
lblet.Caption = Format(et, "fixed")
a1 = Val(txta1.Text)
so = Val(lblft.Caption) + (a1 * Val(lblet.Caption))
lblft1.Caption = Format(so, "0.000000")

'a2 = Val(txta2.Text)
't = Val(lblt.Caption)
'tt = Val(t + (a2 * lblet))
'lbltt.Caption = Format(tt, "fixed")
'ft = so + tt
'lblft1.Caption = Format(ft, "fixed")



End Sub
Sub isiak()
lblt1.Caption = myrs!t
lblxt.Caption = myrs!xt
lblft.Caption = lblft1
lblequip.Caption = myrs!equip
lblage.Caption = myrs!age
lblcentre.Caption = myrs!centre

Call tunde
End Sub
Sub tunde()
et = Val(lblxt - lblft)
lblet.Caption = Format(et, "0.000000")
a1 = Val(txta1.Text)
s1 = Val(lblft.Caption)
t = Val(lblet.Caption)
so = s1 + (a1 * t)
lblft1.Caption = Format(so, "0.000000")
End Sub
```

```
Private Sub Timer1_Timer()
Timer1.Interval = 0

Set mydb = OpenDatabase(App.Path & "/casting1")

Set myrn = mydb.OpenRecordset("select count(n)as sn from datax where town='" & frmtow
nsel.cmbtown & "'")
With myrn
For I = 1 To myrn!sn
cmdnext_Click
Next I
End With
cmdmse_Click


End Sub

Private Sub txta1_Change()
a1 = Val(txta1.Text)
so = Val(lblft + (a1 * lblet))
lblso.Caption = so
ft = Val(so + lbltt)
lblft1.Caption = Format(ft, "fixed")
End Sub

Private Sub txtf1_Change()
a1 = Val(txtf1.Text)
so = Val(lblft + (a1 * lblet))
lblso.Caption = so
End Sub
```

frmses1 - 1

```
Private Sub cmdnext_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
& "'")
            If IsNumeric(txtft.Text) = False Then
    MsgBox "Please Enter Numeric data Only", vbInformation
    txtft.SetFocus
    Exit Sub
    End If
    If IsNumeric(txtalpha.Text) = False Then
    MsgBox "Please Enter Numeric data Only", vbInformation
    txtalpha.SetFocus
    Exit Sub
    End If

            With myrs

            .Edit
            !seft = txtft.Text
            .Update
            End With

frmses.txtfl.Text = txtft.Text
frmses.txtal.Text = txtalpha.Text
'frmses.frmtownsel.cmbtown.Caption = frmtownsel.cmbtown.Caption
frmses.Show
Unload Me

End Sub

Private Sub Form_Load()
Me.Height = 2000
Me.Width = 5295
Me.Top = 100
Me.Left = 100
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrp = mydb.OpenRecordset("select * from alph where town='" & frmtownsel.cmbtown
& "'")
Set isiak = mydb.OpenRecordset("select xt from datax where town='" & frmtownsel.cmbto
wn & "'")

        With myrp
        txtalpha.Text = !alpha1
        End With

        With isiak
        txtft.Text = !xt
        End With

End Sub

Private Sub Timer1_Timer()
cmdnext_Click

End Sub
```

```
        Dim mydb As Database
        Dim myrs As Recordset

        Private Sub cmdmse_Click()
        Set mydt = OpenDatabase(App.Path & "/casting1")
        Set myrm = mydb.OpenRecordset("select count(n)as sn,sum((xt-slft)^2)as sslet from dat
ax where town='" & frmtownsel.cmbtown & "'")
                With myrm
                lmse = myrm!sslet / myrm!sn
                    lblmse.Caption = Format(lmse, "0.000000")

                    End With

        End Sub

        Private Sub cmdnext_Click()
        On Error GoTo sol
        lblfte.Caption = lblft1
        lblttt.Caption = lbltt
        myrs.MoveNext
        Call isiak
sol:
        cmdsave_Click

        End Sub

        Private Sub cmdpolicy_Click()
        frmmaintenance.txtlt.Text = lblnext.Caption
        frmmaintenance.lblcaption = "Exponential Smoothing Linear Trend"
        frmmaintenance.Show
        Unload Me

        End Sub

        Private Sub cmdsave_Click()

        Dim mdata As String
        mdata = App.Path & "/casting1.mdb"
        Data1.DatabaseName = mdata
        Adodc1.RecordSource = "select t,slft from datax where town='" & frmtownsel.cmbtown &
"'"
        Set mydt = OpenDatabase(App.Path & "/casting1")
        Set myrb = mydt.OpenRecordset("select t,slft from datax where t=" & lblt1 & " and tow
n='" & frmtownsel.cmbtown & "'")
                With myrb
                .Edit
                myrb!slft = lblfte.Caption
                .Update
                End With

        ayo = "select ryear,t,xt,slft,(xt-slft)as slet,(slft+ ('" & txta1 & "' * slet))as st,
(t+ ('" & txta2 & "' * slet))as tt,(st + tt)as ftn  from datax where town='" & frmtownsel.cmb
town & "'"
        Data1.RecordSource = ayo
        Adodc1.RecordSource = "select t,slft from datax where town='" & frmtownsel.cmbtown &
"'"
        Data1.Refresh
        DBGrid1.ReBind
        DBGrid1.Refresh
        Adodc1.Refresh
        MSChart1.Refresh

        myrb.Close
        mydt.Close
        End Sub

        Private Sub Form_Load()
        Dim mdata As String
        mdata = App.Path & "/casting1.mdb"
        Data1.DatabaseName = mdata

        Me.Width = 12000
        Me.Height = 7400
        Me.Top = 60
```

```
'frmslt - 2

        Me.Left = 60

        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
 & "'")

        myrs.MoveFirst

        Timer1.Interval = 70
        Timer2.Interval = 30
        End Sub
        Sub isiak()
        lblt1.Caption = myrs!t
        lblxt.Caption = myrs!xt
        lblequip.Caption = myrs!equip
        lblage.Caption = myrs!age
        lblcentre.Caption = myrs!centre


        lblft.Caption = lblft1.Caption
        et = Val(lblxt - lblft)
        lblet.Caption = Format(et, "fixed")
        a1 = Val(txta1.Text)
        so = Val(lblft + (a1 * lblet))
        lblso.Caption = Format(so, "fixed")

        a2 = Val(txta2.Text)
        t = Val(lblttt.Caption)
        tt = Val(t + (a2 * lblet))
        lbltt.Caption = Format(tt, "fixed")
        ft = so + tt
        lblft1.Caption = Format(ft, "fixed")



        End Sub


        Sub showfields()
        lblt1.Caption = myrs!t
        lblxt.Caption = myrs!xt
        lblft.Caption = myrs!slft
        et = Val(lblxt - lblft)
        lblet.Caption = Format(et, "fixed")
        a1 = Val(txta1.Text)
        so = Val(lblft + (a1 * lblet))
        lblso.Caption = Format(so, "fixed")

        a2 = Val(txta2.Text)
        t = Val(lblt.Caption)
        tt = Val(t + (a2 * lblet))
        lbltt.Caption = Format(tt, "fixed")
        ft = so + tt
        lblft1.Caption = Format(ft, "fixed")



        End Sub


        Private Sub Timer1_Timer()
        Timer1.Interval = 0

        Set mydb = OpenDatabase(App.Path & "/casting1")

        Set myrn = mydb.OpenRecordset("select count(n)as sn from datax where town='" & frmtow
nsel.cmbtown & "'")
        Set myrt = mydb.OpenRecordset("select * from srate")
        Set myrc = mydb.OpenRecordset("select sum(centre)as cent from datax where town='" & f
rmtownsel.cmbtown & "'")

        With myrn
        For I = 1 To myrn!sn - 1
        cmdnext_Click
```

```
frmslt = 3

        Next I
        End With
        cmdmse_Click
         d = lblft1.Caption
            g = Val(lblequip.Caption)
        e = Val(lblage.Caption)
        f = Val(lblcentre.Caption)
        h = d * (e * g) / f
        With myrc
             l = myrc!cent
        With myrt
                k = myrt!pe
                m = (l * h) / (l + k)

        lblnext.Caption = Format(m, "fixed")
        End With
        End With


        End Sub

        Private Sub Timer2_Timer()
        Timer2.Interval = 0
        Call showfields
        End Sub
```

frmsnt - 1

```
        Dim mydb As Database
        Dim myrs As Recordset

        Private Sub cmdmse_Click()
        Set mydt = OpenDatabase(App.Path & "/casting1")
        Set myrm = mydb.OpenRecordset("select count(n)as sn,sum((xt-snt)^2)as sslet from data
x where town='" & frmtownsel.cmbtown & "'")
                With myrm
                lmse = myrm!sslet / myrm!sn
                    lblmse.Caption = Format(lmse, "0.000000")

                    End With

        End Sub

        Private Sub cmdnext_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrt = mydb.OpenRecordset("select * from srate")
        Set myrc = mydb.OpenRecordset("select sum(centre)as cent from datax where town='" & f
rmtownsel.cmbtown & "'")

        On Error GoTo sol
        lblfte.Caption = lblft1
        lblttt.Caption = lbltt
        myrs.MoveNext
        Call isiak
        g = Val(lblequip.Caption)
        e = Val(lblage.Caption)
        f = Val(lblcentre.Caption)
        d = lblft1
        h = d * (e * g) / f
        With myrc
            l = myrc!cent
        With myrt
                k = myrt!pe
                m = (l * h) ./ (l + k)


        lblnext.Caption = Format(m, "fixed")
        End With
        End With

sol:
        cmdsave_Click
        End Sub

        Private Sub cmdpolicy_Click()
        frmmaintenance.txtlt.Text = lblnext.Caption
        frmmaintenance.lblcaption = "Smoothing a Non Linear Trend"
        frmmaintenance.Show
        Unload Me

        End Sub

        Private Sub cmdsave_Click()
        Dim mdata As String
        mdata = App.Path & "/casting1.mdb"
        Data1.DatabaseName = mdata
        Adodc1.RecordSource = "select t,snt from datax where town='" & frmtownsel.cmbtown & "
'"

        Set mydt = OpenDatabase(App.Path & "/casting1")
        Set myrb = mydt.OpenRecordset("select t,snt from datax where t=" & lblt1 & " and town
='" & frmtownsel.cmbtown & "'")
                With myrb
                .Edit
                myrb!snt = lblfte.Caption
                .Update
                End With

        ayo = "select ryear,t,xt,snt,(xt-snt)as slet,(snt+ ('" & txta1 & "' * slet))as st,(t+
 ('" & txta2 & "' * slet))as tt,(st + tt)as ftn  from datax where town='" & frmtownsel.cmbtow
n & "'"
        Data1.RecordSource = ayo
```

```
        Adodc1.RecordSource = "select t,snt from datax where town='" & frmtownsel.cmbtown & "
'"
        Data1.Refresh
        DBGrid1.ReBind
        DBGrid1.Refresh
        Adodc1.Refresh
        MSChart1.Refresh

        myrb.Close
        mydt.Close
        End Sub

        Private Sub Form_Load()
        Dim mdata As String
        mdata = App.Path & "/casting1.mdb"
        Data1.DatabaseName = mdata


        Me.Height = 7000
        Me.Width = 12000
        Me.Left = 50
        Me.Top = 50

        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
& "'")

        myrs.MoveFirst
        Timer1.Interval = 70
        Timer2.Interval = 30

        End Sub



        Sub showfields()
        lblt1.Caption = myrs!t
        lblxt.Caption = myrs!xt
        lblft.Caption = myrs!snt
        lblequip.Caption = myrs!equip
        lblage.Caption = myrs!age
        lblcentre.Caption = myrs!centre

        et = Val(lblxt - lblft)
        lblet.Caption = Format(et, "fixed")
        a1 = Val(txta1.Text)
        so = Val(lblft + (a1 * lblet))
        lblso.Caption = Format(so, "fixed")

        a2 = Val(txta2.Text)
        t = Val(lblt.Caption)
        zt = Val(txtzeta.Text)
        tt = t * zt + a2 * lblet
        lbltt.Caption = Format(tt, "fixed")
        ft = so + (zt * tt)
        lblft1.Caption = Format(ft, "fixed")



        End Sub
        Sub isiak()
        lblt1.Caption = myrs!t
        lblxt.Caption = myrs!xt
        lblequip.Caption = myrs!equip
        lblage.Caption = myrs!age
        lblcentre.Caption = myrs!centre

        lblft.Caption = lblfte.Caption
        et = Val(lblxt - lblft)
        lblet.Caption = Format(et, "fixed")
        a1 = Val(txta1.Text)
        so = Val(lblft + (a1 * lblet))
        lblso.Caption = Format(so, "fixed")
```

```
        a2 = Val(txta2.Text)
        t = Val(lbltttt.Caption)
        zt = Val(txtzeta.Text)
        tt = zt * t + a2 * lblet
        lbltt.Caption = Format(tt, "fixed")
        ft = so + (zt * tt)
        lblft1.Caption = Format(ft, "fixed")


        End Sub


        Private Sub Timer1_Timer()
        Timer1.Interval = 0

        Set mydb = OpenDatabase(App.Path & "/casting1")

        Set myrn = mydb.OpenRecordset("select count(n)as sn from datax where town='" & frmtow
nsel.cmbtown & "'")
        With myrn
        For I = 1 To myrn!sn - 1
        cmdnext_Click
        Next I
        End With
        cmdmse_Click

        End Sub

        Private Sub Timer2_Timer()
        Timer2.Interval = 0

        Call showfields

        End Sub
```

```
frmwiz = 1

        Private Sub cmdclose_Click()
        Unload frmlreg
        Unload frmthree
        Unload frmmsetab

        Unload frmses
        Unload frmforecast
        Unload frmslt
        Unload frmsnt
        Unload Me

        End Sub

        Private Sub cmdexe_Click()

        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
 & "'")
                    If IsNumeric(txtft.Text) = False Then
            MsgBox "Please Enter Numeric data Only", vbInformation
            txtft.SetFocus
            Exit Sub
            End If
            If IsNumeric(txtalpha.Text) = False Then
            MsgBox "Please Enter Numeric data Only", vbInformation
            txtalpha.SetFocus
            Exit Sub
            End If


                    With myrs

                    .Edit
                    !seft = txtft.Text
                    .Update
                    End With

        frmses.txtf1.Text = txtft.Text
        frmses.txtal.Text = txtalpha.Text
        frmses.Hide
        'frmses.cmbtown.Text = frmtownsel.cmbtown.Text
        'frmlreg.frmtownsel.cmbtown.Caption = frmtownsel.cmbtown.Caption
        frmlreg.txta.Text = txta.Text
        frmlreg.txtb.Text = txtb.Text
        frmlreg.txtzeta = txtzeta.Text
        lbl3mse.Caption = frmthree.lblmse.Caption
        lblnaive.Caption = frmmsetab.lblmse.Caption

        frmlreg.cmdfore.Value = True
        frmforecast.Hide
        frmlreg.cmdslt.Value = True
        frmslt.Hide
        frmlreg.cmdsnlt.Value = True
        frmsnt.Hide

        Timer1.Interval = 30000
        Timer2.Interval = 31000
        cmdexe.Visible = False
        lblnote.Visible = True


        End Sub


        Private Sub cmdnext_Click()
        tmse = Val(frmthree.lblmse.Caption)
        naive = Val(frmmsetab.lblmse.Caption)
        fore = Val(frmforecast.lblmse.Caption)
        slt = Val(frmslt.lblmse.Caption)
        snt = Val(frmsnt.lblmse.Caption)
        ses = Val(frmses.lblmse.Caption)
```

```
        If tmse < naive And tmse < fore And tmse < slt And tmse < snt And tmse < ses Then
        lblans.Caption = tmse
        frmthree.cmdpolicy.Value = True
        ElseIf naive < tmse And naive < fore And naive < slt And naive < snt And naive < ses
Then
        lblans.Caption = naive
        frmmsetab.cmdpolicy.Value = True
        ElseIf fore < tmse And fore < naive And fore < slt And fore < snt And fore < ses Then
        lblans.Caption = fore
        frmforecast.cmdpolicy.Value = True
        ElseIf slt < tmse And slt < naive And slt < fore And slt < snt And slt < ses Then
        lblans.Caption = slt
        frmslt.cmdpolicy.Value = True
        ElseIf snt < tmse And snt < naive And snt < slt And snt < fore And snt < ses Then
        lblans.Caption = snt
        frmsnt.cmdpolicy.Value = True
        ElseIf ses < tmse And ses < naive And ses < slt And ses < snt And ses < fore Then
        lblans.Caption = ses
        frmses.cmdpolicy.Value = True
        End If
        lblnote.Caption = "Done, Thank U!"
        End Sub

        Private Sub Form_Load()
        Me.Width = 6500
        Me.Height = 5500
        Me.Left = Screen.Width * 0.2
        Me.Top = Screen.Height * 0.1
        'frmlreg.frmtownsel.cmbtown.Caption = frmtownsel.cmbtown.Caption
        frmmdi.mnuoperationses.Checked = True
        frmses.Hide


        Timer3.Interval = 70
        frmmdi.mnuoperationlr.Checked = True
        frmlreg.Hide
        'frmthree.frmtownsel.cmbtown.Caption = frmtownsel.cmbtown.Caption
        frmmdi.mnuoperation3.Checked = True
        frmthree.Hide
        'frmmsetab.frmtownsel.cmbtown.Caption = frmtownsel.cmbtown.Caption
        frmmdi.mnuoperationnfm.Checked = True
        frmmsetab.Hide
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrp = mydb.OpenRecordset("select * from alph where town='" & frmtownsel.cmbtown
& "'")
        Set isiak = mydb.OpenRecordset("select xt from datax where town='" & frmtownsel.cmbto
wn & "'")

                With myrp
                txtalpha.Text = !alpha1
                txta.Text = !alpha1
                txtb.Text = !alpha2
                txtzeta.Text = !alpha3
                End With

                With isiak
                txtft.Text = !xt
                End With


        End Sub

        Private Sub Timer1_Timer()
        Timer1.Interval = 0

        lblses.Caption = frmses.lblmse.Caption
        'frmlreg.cmdtest.Value = True

        lblslt.Caption = frmslt.lblmse.Caption


        End Sub
```

```
Private Sub Timer2_Timer()
Timer2.Interval = 0
lbllrf.Caption = frmforecast.lblmse.Caption
lblslt.Caption = frmslt.lblmse.Caption
lblsnt.Caption = frmsnt.lblmse.Caption
cmdnext.Visible = True
lblnote.Caption = "Ready, Click Next to Proceed"

End Sub

Private Sub Timer3_Timer()
Timer3.Interval = 0
frmses.txtfl.Text = txtft.Text
frmses.txtal.Text = txtalpha.Text
frmses.Hide

End Sub
```

frmparts - 1

```
Private Sub cmbpart_Click()
cmdrefresh_Click

Set mydb = OpenDatabase(App.Path & "/casting1")

If cmbtype.Text = "Preventive" Then
Set myrt = mydb.OpenRecordset("select * from preventived where town='" & cmbtown.Text
 & "' and part='" & cmbpart & "'")
ElseIf cmbtype = "Repair" Then
Set myrt = mydb.OpenRecordset("select * from repaired where town='" & cmbtown.Text &
"' and part='" & cmbpart & "'")
ElseIf cmbtype.Text = "Overhauling" Then
Set myrt = mydb.OpenRecordset("select * from overhaulingd where town='" & cmbtown.Tex
t & "' and part='" & cmbpart & "'")
End If
    On Error GoTo err
    With myrt
        'txtu.Text = myrt!u
        txtp.Text = myrt!p
        txtr.Text = myrt!r
        txtc.Text = myrt!c
        txty.Text = myrt!Y
        txtx.Text = myrt!X
        dtpdate.Value = myrt!tdate
    End With

err:
End Sub



Private Sub cmbtown_Change()
cmbtype_Click
End Sub

Private Sub cmbtown_Click()
cmbtype_Click
End Sub

Private Sub cmbtype_Change()
cmbpart.Clear
Set mydb = OpenDatabase(App.Path & "/casting1")

Set myrp = mydb.OpenRecordset("select * from spear where town='" & cmbtown & "'")
 With myrp
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst

    For p = 0 To .RecordCount - 1
    cmbpart.AddItem (!part)
    cmbpart.ItemData(cmbpart.NewIndex) = !no
    .MoveNext
    Next p
    End With


End Sub

Private Sub cmbtype_Click()
cmbpart.Clear
Set mydb = OpenDatabase(App.Path & "/casting1")

Set myrp = mydb.OpenRecordset("select * from spear where town='" & cmbtown & "'")
 With myrp
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst

    For p = 0 To .RecordCount - 1
    cmbpart.AddItem (!part)
    cmbpart.ItemData(cmbpart.NewIndex) = !no
    .MoveNext
    Next p
    End With
```

```
End Sub

Private Sub cmdadd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
If cmbtown.Text = "" Then
MsgBox "Select the Town", vbCritical
cmbtown.SetFocus
Exit Sub
End If
If cmbpart.Text = "" Then
MsgBox "Enter the Spare Part", vbCritical
cmbpart.SetFocus
Exit Sub
End If


If cmbtype.Text = "" Then
MsgBox "Please Enter select the maintenance type", vbInformation
cmbtype.SetFocus
Exit Sub
End If
'If IsNumeric(txtu.Text) = False Then
'MsgBox "Enter Numeric Value for U", vbCritical
'txtu.SetFocus
'Exit Sub
'End If
If IsNumeric(txtp.Text) = False Then
MsgBox "Enter Numeric Value for P", vbCritical
txtp.SetFocus
Exit Sub
End If
If IsNumeric(txtr.Text) = False Then
MsgBox "Enter Numeric Value for R", vbCritical
txtr.SetFocus
Exit Sub
End If
If IsNumeric(txtc.Text) = False Then
MsgBox "Enter Numeric Value for C", vbCritical
txtc.SetFocus
Exit Sub
End If
If IsNumeric(txty.Text) = False Then
MsgBox "Enter Numeric Value for y", vbCritical
txty.SetFocus
Exit Sub
End If
If IsNumeric(txtx.Text) = False Then
MsgBox "Enter Numeric Value for x", vbCritical
txtx.SetFocus
Exit Sub
End If


If cmbtype.Text = "Preventive" Then
Set myrt = mydb.OpenRecordset("select * from preventived")
ElseIf cmbtype = "Repair" Then
Set myrt = mydb.OpenRecordset("select * from repaired")
ElseIf cmbtype.Text = "Overhauling" Then
Set myrt = mydb.OpenRecordset("select * from overhaulingd")
End If
With myrt
        .AddNew
        myrt!town = cmbtown.Text
        myrt!part = cmbpart.Text
        'myrt!u = txtu.Text
        myrt!p = txtp.Text
        myrt!r = txtr.Text
        myrt!c = txtc.Text
        myrt!Y = txty.Text
        myrt!X = txtx.Text
        myrt!tdate = dtpdate.Value
        .Update
        End With
```

```
        cmdrefresh_Click

End Sub

Private Sub cmdexit_Click()
Unload Me

End Sub

Private Sub cmdrefresh_Click()
'txtu.Text = ""
txtp.Text = ""
txtr.Text = ""
txtc.Text = ""
txty.Text = ""
txtx.Text = ""
'cmbtown.Text = ""

End Sub

Private Sub cmdupd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
If cmbtown.Text = "" Then
MsgBox "Select the City", vbCritical
cmbtown.SetFocus
Exit Sub
End If
If cmbpart.Text = "" Then
MsgBox "Enter the Spear Part", vbCritical
cmbpart.SetFocus
Exit Sub
End If


If cmbtype.Text = "" Then
MsgBox "Please Enter select the maintenance type", vbInformation
cmbtype.SetFocus
Exit Sub
End If
'If IsNumeric(txtu.Text) = False Then
'MsgBox "Enter Numeric Value for U", vbCritical
'txtu.SetFocus
'Exit Sub
'End If
If IsNumeric(txtp.Text) = False Then
MsgBox "Enter Numeric Value for P", vbCritical
txtp.SetFocus
Exit Sub
End If
If IsNumeric(txtr.Text) = False Then
MsgBox "Enter Numeric Value for R", vbCritical
txtr.SetFocus
Exit Sub
End If
If IsNumeric(txtc.Text) = False Then
MsgBox "Enter Numeric Value for C", vbCritical
txtc.SetFocus
Exit Sub
End If
If IsNumeric(txty.Text) = False Then
MsgBox "Enter Numeric Value for y", vbCritical
txty.SetFocus
Exit Sub
End If
If IsNumeric(txtx.Text) = False Then
MsgBox "Enter Numeric Value for x", vbCritical
txtx.SetFocus
Exit Sub
End If


If cmbtype.Text = "Preventive" Then
```

```
        Set myrt = mydb.OpenRecordset("select * from preventived where town='" & cmbtown.Text
 & "' and part='" & cmbpart.Text & "'")
        ElseIf cmbtype = "Repair" Then
        Set myrt = mydb.OpenRecordset("select * from repaired where town='" & cmbtown.Text &
"' and part='" & cmbpart.Text & "'")
        ElseIf cmbtype.Text = "Overhauling" Then
        Set myrt = mydb.OpenRecordset("select * from overhaulingd where town='" & cmbtown.Tex
t & "' and part='" & cmbpart.Text & "'")
        End If
        With myrt
                .Edit

                'myrt!u = txtu.Text
                myrt!p = txtp.Text
                myrt!r = txtr.Text
                myrt!c = txtc.Text
                myrt!Y = txty.Text
                myrt!X = txtx.Text
                myrt!tdate = dtpdate.Value
                .Update
                End With


        End Sub

        Private Sub Form_Load()
        Me.Width = 11000
        Me.Height = 4240
        Me.Top = 300
        Me.Left = 300


        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from town")


            With myrs
            If Not .EOF Then .MoveLast
            If Not .BOF Then .MoveFirst
            cmbtown.Text = !Name
            For I = 0 To .RecordCount - 1
            cmbtown.AddItem (!Name)
            cmbtown.ItemData(cmbtown.NewIndex) = !no
            .MoveNext
            Next I
            End With
            dtpdate.Value = Now



        End Sub
```

```
Private Sub cmbtown_Change()

Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrt = mydb.OpenRecordset("select * from srate where town='" & cmbtown & "'")
    With myrt
    txtalph.Text = !alpha
    txtpers.Text = !pe
    End With

End Sub

Private Sub cmbtown_Click()
 txtalph.Text = ""
    txtpers.Text = ""
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrt = mydb.OpenRecordset("select * from srate where town='" & cmbtown & "'")
On Error GoTo err
    With myrt
    txtalph.Text = !alpha
    txtpers.Text = !pe
    End With
err:
End Sub

Private Sub cmdadd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrt = mydb.OpenRecordset("select * from srate where town='" & cmbtown & "'")
    With myrt
    If Val(txtalph) + Val(txtpers) < 0 Then
    MsgBox "Decrease value must less than Personnel value", vbCritical
    txtalph.Text = ""
    txtalph.SetFocus

    Else
    .AddNew
    !alpha = txtalph.Text
    !pe = txtpers.Text
    !town = cmbtown.Text
    .Update
    End If
    End With


End Sub

Private Sub cmdclose_Click()
Unload Me

End Sub

Private Sub cmdsave_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrt = mydb.OpenRecordset("select * from srate where town='" & cmbtown & "'")
    With myrt
    If Val(txtalph) + Val(txtpers) < 0 Then
    MsgBox "Decrease value must less than Personnel value", vbCritical
    txtalph.Text = ""
    txtalph.SetFocus

    Else
    .Edit
    !alpha = txtalph.Text
    !pe = txtpers.Text
    .Update
    End If
    End With

End Sub

Private Sub Form_Load()
Me.Height = 2775
Me.Width = 6615
Set mydb = OpenDatabase(App.Path & "/casting1")
```

```
Set myrx = mydb.OpenRecordset("select * from town")

    With myrx
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbtown.AddItem (!Name)
    cmbtown.ItemData(cmbtown.NewIndex) = !no
    .MoveNext
    Next I
    End With

End Sub
```

frmpersdata - 1

```
        Private Sub cmbpers1_Change()
        txtrating.Text = ""
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from interaction where town='" & cmbtown & "'
 and position1='" & cmbpers1 & "'and position2='" & cmbpers2 & "'")
         On Error GoTo err
            With myrs
        txtrating.Text = !ilevel

            End With
err:
        End Sub

        Private Sub cmbpers1_Click()
        txtrating.Text = ""
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from interaction where town='" & cmbtown & "'
 and position1='" & cmbpers1 & "'and position2='" & cmbpers2 & "'")
         On Error GoTo err
            With myrs
        txtrating.Text = !ilevel

            End With
err:
        End Sub

        Private Sub cmbpers2_Change()
        txtrating.Text = ""
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from interaction where town='" & cmbtown & "'
 and position1='" & cmbpers1 & "'and position2='" & cmbpers2 & "'")
         On Error GoTo err
            With myrs
        txtrating.Text = !ilevel

            End With
err:
        End Sub

        Private Sub cmbpers2_Click()
        txtrating.Text = ""
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from interaction where town='" & cmbtown & "'
 and position1='" & cmbpers1 & "'and position2='" & cmbpers2 & "'")
         On Error GoTo err
            With myrs
        txtrating.Text = !ilevel

            End With
err:
        End Sub

        Private Sub cmbtown_Change()
        cmbpers1.Clear
        cmbpers2.Clear
        txtrating.Text = ""
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from post where town='" & cmbtown & "'")

            With myrs
            If Not .EOF Then .MoveLast
            If Not .BOF Then .MoveFirst
            cmbpers1.Text = !Position
            cmbpers2.Text = !Position
            For I = 0 To .RecordCount - 1
            cmbpers1.AddItem (!Position)
            cmbpers2.AddItem (!Position)

            cmbpers1.ItemData(cmbpers1.NewIndex) = !no
            cmbpers2.ItemData(cmbpers2.NewIndex) = !no
            .MoveNext
            Next I

            End With
```

```
        End Sub

        Private Sub cmbtown_Click()
        cmbpers1.Clear
        cmbpers2.Clear
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from post where town='" & cmbtown & "'")

            With myrs
            If Not .EOF Then .MoveLast
            If Not .BOF Then .MoveFirst
            cmbpers1.Text = !Position
            cmbpers2.Text = !Position
            For I = 0 To .RecordCount - 1
            cmbpers1.AddItem (!Position)
            cmbpers2.AddItem (!Position)

            cmbpers1.ItemData(cmbpers1.NewIndex) = !no
            cmbpers2.ItemData(cmbpers2.NewIndex) = !no
            .MoveNext
            Next I

            End With

        End Sub

        Private Sub cmdclose_Click()
        Unload Me
        End Sub

        Private Sub cmdok_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select position1,position2,ilevel,town from interactio
n")

        If cmbpers1.Text = "" Then
        MsgBox "Please select the personel", vbInformation
        cmbpers1.SetFocus
        Exit Sub
        End If

        If cmbpers2.Text = "" Then
        MsgBox "Please select the personel", vbInformation
        cmbpers2.SetFocus
        Exit Sub
        End If

        If IsNumeric(txtrating.Text) = False Then
        MsgBox "Please Enter Numeric value", vbInformation
        txtrating.SetFocus
        Exit Sub
        End If

        With myrs
        .AddNew
                myrs!position1 = cmbpers1.Text
                myrs!position2 = cmbpers2.Text
                myrs!ilevel = txtrating.Text
                myrs!town = cmbtown.Text

         .Update

        End With
        txtrating.Text = ""
        End Sub

        Private Sub Form_Load()
        Me.Height = 3600
        Me.Width = 6855
        Me.Top = 100
        Me.Left = 200

        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrx = mydb.OpenRecordset("select * from town")
```

```
        With myrx
        If Not .EOF Then .MoveLast
        If Not .BOF Then .MoveFirst
        For I = 0 To .RecordCount - 1
        cmbtown.AddItem (!Name)
        cmbtown.ItemData(cmbtown.NewIndex) = !no
        .MoveNext
        Next I
        End With



    End Sub
```

```
Private Sub cmbcom_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select name,cost from comm where town='" & cmbtown & "
' and name='" & cmbcom.Text & "'")
            With myrs
            txtcost.Text = myrs!cost
            cmbcom.Text = myrs!Name
            End With

End Sub

Private Sub cmbtown_Change()
cmdref_Click
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from comm where town='" & cmbtown & "'")

    With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbcom.AddItem (!Name)
    cmbcom.ItemData(cmbcom.NewIndex) = !no
    .MoveNext
    Next I
    End With




End Sub

Private Sub cmbtown_Click()
cmdref_Click
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from comm where town='" & cmbtown & "'")

    With myrs
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbcom.AddItem (!Name)
    cmbcom.ItemData(cmbcom.NewIndex) = !no
    .MoveNext
    Next I
    End With




End Sub

Private Sub cmdadd_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select name,cost,town from comm where town='" & cmbtow
n & "'")
'Set myrx = mydb.OpenRecordset("select name,cost,town from comm where town='" & cmbto
wn & "'")

If cmbcom.Text = "" Then
MsgBox "Please Enter the Communication Means", vbInformation
cmbcom.SetFocus
Exit Sub
End If

With myrs
 ' .FindFirst "name='" & Trim(cmbcom) & "'"
  '  If .NoMatch Then
        .AddNew
   '     Else
   '     result = MsgBox("This Communication means is in existence,Overwrite?", vbQue
```

```
            '   MsgBox "Registration Fails ....", vbExclamation
             '  Exit Sub
              ' End If


            myrs!Name = Trim(cmbcom.Text)
            myrs!cost = Trim(txtcost.Text)
            myrs!town = Trim(cmbtown.Text)
            .Update

      End With
      cmdref_Click
      End Sub

      Private Sub cmdexit_Click()
      Unload Me
      End Sub

      Private Sub cmdref_Click()
      cmbcom.Clear

      cmbcom.Text = ""
      txtcost.Text = ""




      End Sub

      Private Sub cmdupdate_Click()
      Set mydb = OpenDatabase(App.Path & "/casting1")
      Set myrs = mydb.OpenRecordset("select name,cost from comm where name='" & cmbcom.Text
 & "'")
              With myrs
              .Edit
              myrs!cost = txtcost.Text

              .Update
              End With

      End Sub

      Private Sub Form_Load()
      Me.Height = 4600
      Me.Width = 7000
      Me.Left = 200
      Me.Top = 200

      Set mydb = OpenDatabase(App.Path & "/casting1")
      Set myrx = mydb.OpenRecordset("select * from town")

         With myrx
         If Not .EOF Then .MoveLast
         If Not .BOF Then .MoveFirst
         For I = 0 To .RecordCount - 1
         cmbtown.AddItem (!Name)
         cmbtown.ItemData(cmbtown.NewIndex) = !no
         .MoveNext
         Next I
         End With



      Set mydb = OpenDatabase(App.Path & "/casting1")
      Set myrs = mydb.OpenRecordset("select * from comm")

         With myrs
         If Not .EOF Then .MoveLast
         If Not .BOF Then .MoveFirst
         For I = 0 To .RecordCount - 1
         cmbcom.AddItem (!Name)
```

```
        cmbcom.ItemData(cmbcom.NewIndex) = !no
        .MoveNext
        Next I
        End With

    End Sub
```

```
Private Sub cmbtown_Change()
txtinf.Text = ""
txtint.Text = ""
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrt = mydb.OpenRecordset("select * from discounted where town='" & cmbtown & "'"
)
 On Error GoTo err
    With myrt
    txtinf.Text = !inf
    txtint.Text = myrt!Int
    End With
err:
End Sub

Private Sub cmbtown_Click()
txtinf.Text = ""
txtint.Text = ""
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrt = mydb.OpenRecordset("select * from discounted where town='" & cmbtown & "'"
)
  On Error GoTo err
    With myrt
    txtinf.Text = !inf
    txtint.Text = myrt!Int
    End With
err:
End Sub

Private Sub cmdadd_Click()

Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrt = mydb.OpenRecordset("select * from discounted")
    With myrt
    .AddNew
    !inf = txtinf.Text
    !Int = txtint.Text
    !town = cmbtown.Text
    .Update

    End With

End Sub

Private Sub cmdclose_Click()
Unload Me

End Sub

Private Sub cmdsave_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrt = mydb.OpenRecordset("select * from discounted where town='" & cmbtown & "'"
)
    With myrt
    .Edit
    !inf = txtinf.Text
    !Int = txtint.Text
    .Update

    End With

End Sub

Private Sub Form_Load()
Me.Height = 2775
Me.Width = 6615

Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrx = mydb.OpenRecordset("select * from town")

    With myrx
    If Not .EOF Then .MoveLast
    If Not .BOF Then .MoveFirst
    For I = 0 To .RecordCount - 1
    cmbtown.AddItem (!Name)
```

```
        cmbtown.ItemData(cmbtown.NewIndex) = !no
        .MoveNext
        Next I
        End With



    End Sub
```

frmforecast - 1

```
Private Sub cmdpolicy_Click()
frmmaintenance.txtlt.Text = Val(lblnext.Caption)
frmmaintenance.lblcaption.Caption = "Linear Regression Forecast"
frmmaintenance.Show
Me.Hide

End Sub

Private Sub Form_Load()
Me.Height = 9000
Me.Width = 12000
Me.Top = 50
Me.Left = 50
Dim mdata As String
mdata = App.Path & "/casting1.mdb"
Data1.DatabaseName = mdata

End Sub
```

```
        Dim mydb As Database
        Dim myrp As Recordset


        Private Sub cmdfore_Click()

        Set mydb = OpenDatabase(App.Path & "/casting1")

        'Set myrs = mydb.OpenRecordset("select n,('" & lbla & "'+('" & lblb & "' * n))as ft,(
xt-ft)as et,(et^2)as ets,sum(ets)as fin from datax group by '" & lbla & "','" & lblb & "',n,x
t,ft")
        Set myrn = mydb.OpenRecordset("select sum((xt-('" & lbla & "'+('" & lblb & "' * t))^
2)as fn1 from datax where town='" & frmtownsel.cmbtown & "'")

        Set myrx = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
 & "'")
        Set myrt = mydb.OpenRecordset("select * from srate")
        Set myrc = mydb.OpenRecordset("select sum(centre)as cent from datax where town='" & f
rmtownsel.cmbtown & "'")


        With myrn
        mse = !fn1 / lbln.Caption
        frmforecast.lblmse = Format(mse, "0.000000")
        frmforecast.lbln.Caption = lbln.Caption

        End With
        With myrx
        If Not .EOF Then .MoveLast
        t = myrx!t

        a = lbla.Caption
        b = lblb.Caption
        d = a + (b * !t)

        g = Val(lblequip.Caption)
        e = Val(lblage.Caption)
        f = Val(lblcentre.Caption)
        h = d * (e * g) / f

        With myrc
            l = myrc!cent
        With myrt
                k = myrt!pe
                m = (l * h) / (l + k)
        frmforecast.lblnext.Caption = Format(m, "fixed")
        End With
        End With

        End With

        ayo = "select ryear,t,xt,('" & lbla & "'+('" & lblb & "' * t))as ft,(xt-ft)as et from
 datax where town='" & frmtownsel.cmbtown & "'"
        ayo1 = "select t,('" & lbla & "'+('" & lblb & "' * t))as ft from datax where town='"
 & frmtownsel.cmbtown & "'"

        'frmforecast.frmtownsel.cmbtown.Caption = frmtownsel.cmbtown.Caption
        frmforecast.Data1.RecordSource = ayo
        frmforecast.Data1.Refresh
        frmforecast.Adodc1.RecordSource = "select t,ft from datax where town='" & frmtownsel.
cmbtown & "'"

        frmforecast.Adodc1.Refresh
        frmforecast.Adodc1.RecordSource = ayo1
        frmforecast.Adodc1.Refresh

        frmforecast.MSChart1.Refresh
        frmforecast.Show
        End Sub

        Private Sub cmdslt_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
 & "'")
```

```
        If IsNumeric(txta.Text) = False Then
    MsgBox "Please Enter Numeric data Only", vbInformation
    txta.SetFocus
    Exit Sub
    End If
        If IsNumeric(txtb.Text) = False Then
    MsgBox "Please Enter Numeric data Only", vbInformation
    txtb.SetFocus
    Exit Sub
    End If

        With myrs
        .Edit
        myrs!slft = Val(lbla.Caption) + Val(lblb.Caption)
        .Update
        End With
frmslt.txta1.Text = txta.Text
frmslt.txta2.Text = txtb.Text
'frmslt.frmtownsel.cmbtown.Caption = frmtownsel.cmbtown.Caption
frmslt.lbls.Caption = lbla.Caption
frmslt.lblt.Caption = lblb.Caption
frmslt.lblf.Caption = Val(lbla.Caption) + Val(lblb.Caption)
'frmslt.lbltt.Caption = lblb.Caption
frmslt.lblft1.Caption = Val(frmslt.lblso.Caption) + Val(lblb.Caption)

frmslt.Show
End Sub

Private Sub cmdsnlt_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
& "'")
        If IsNumeric(txta.Text) = False Then
    MsgBox "Please Enter Numeric data Only", vbInformation
    txta.SetFocus
    Exit Sub
    End If
        If IsNumeric(txtb.Text) = False Then
    MsgBox "Please Enter Numeric data Only", vbInformation
    txtb.SetFocus
    Exit Sub
    End If
        If IsNumeric(txtzeta.Text) = False Then
    MsgBox "Please Enter Numeric data Only", vbInformation
    txtzeta.SetFocus
    Exit Sub
    End If
        With myrs
        .Edit
        myrs!snt = Val(lbla.Caption) + (Val(lblb.Caption) * Val(txtzeta.Text))
        .Update
        End With
frmsnt.txta1.Text = txta.Text
frmsnt.txta2.Text = txtb.Text
frmsnt.txtzeta.Text = txtzeta.Text
'frmsnt.frmtownsel.cmbtown.Caption = frmtownsel.cmbtown.Caption
frmsnt.lbls.Caption = lbla.Caption
frmsnt.lblt.Caption = lblb.Caption
frmsnt.lblf.Caption = Val(lbla.Caption) + (Val(lblb.Caption) * Val(txtzeta.Text))
frmsnt.lbltt.Caption = lblb.Caption
frmsnt.lblft1.Caption = Val(frmsnt.lblso.Caption) + Val(lblb.Caption) * Val(txtzeta.T
ext)

frmsnt.Show
End Sub

Private Sub cmdtest_Click()


Set mydb = OpenDatabase(App.Path & "/casting1")
'1st phase
'Set myrs = mydb.OpenRecordset("select t,('" & lbla & "'+('" & lblb & "' * n))as ft,(
xt-ft)as et,(et^2)as ets,sum(ets)as fin from datax group by '" & lbla & "','" & lblb & "',n,x
t,ft")
```

```
        Set myrn = mydb.OpenRecordset("select sum((xt-('" & lbla & "'+('" & lblb & "' * t)))^
2)as fnl from datax where town='" & frmtownsel.cmbtown & "'")

        Set myrx = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
& "'")



        With myrn
        mse = !fnl / lbln.Caption
        frmforecast.lblmse = Format(mse, "0.000000")
        frmforecast.lbln.Caption = lbln.Caption

        End With
        With myrx
        If Not .EOF Then .MoveLast
        t = !t
        a = lbla.Caption
        b = lblb.Caption
        frmforecast.lblnext.Caption = a + (b * !t)

        End With

        ayo = "select ryear,t,xt,('" & lbla & "'+('" & lblb & "' * t))as ft,(xt-ft)as et from
datax where town='" & frmtownsel.cmbtown & "'"
        frmforecast.Data1.RecordSource = ayo
        frmforecast.Data1.Refresh
        frmforecast.Hide



        'the second phase
        Set myrs = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
& "'")

                With myrs
                .Edit
                myrs!slft = Val(lbla.Caption) + Val(lblb.Caption)
                .Update
                End With
        frmslt.txta1.Text = txta.Text
        frmslt.txta2.Text = txtb.Text

        frmslt.lbls.Caption = lbla.Caption
        frmslt.lblt.Caption = lblb.Caption
        frmslt.lblf.Caption = Val(lbla.Caption) + Val(lblb.Caption)
        'frmslt.lbltt.Caption = lblb.Caption
        frmslt.lblft1.Caption = Val(frmslt.lblso.Caption) + Val(lblb.Caption)

        frmslt.Hide

        '3rd phase former myrs change to myrk

        Set myrk = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
& "'")

                With myrk
                .Edit
                myrk!snt = Val(lbla.Caption) + (Val(lblb.Caption) * Val(txtzeta.Text))
                .Update
                End With
        frmsnt.txta1.Text = txta.Text
        frmsnt.txta2.Text = txtb.Text
        frmsnt.txtzeta.Text = txtzeta.Text

        frmsnt.lbls.Caption = lbla.Caption
        frmsnt.lblt.Caption = lblb.Caption
        frmsnt.lblf.Caption = Val(lbla.Caption) + (Val(lblb.Caption) * Val(txtzeta.Text))
        frmsnt.lbltt.Caption = lblb.Caption
        frmsnt.lblft1.Caption = Val(frmsnt.lblso.Caption) + Val(lblb.Caption) * Val(txtzeta.T
ext)

        frmsnt.Hide
```

```
End Sub


Private Sub Form_Load()
Dim mdata As String
mdata = App.Path & "/casting1.mdb"
Data1.DatabaseName = mdata


Me.Height = 9000
Me.Width = 12000
Me.Top = 50
Me.Left = 50


Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrp = mydb.OpenRecordset("select * from datax where town='" & frmtownsel.cmbtown
 & "'")
Set myalph = mydb.OpenRecordset("select * from alph where town='" & frmtownsel.cmbtow
n & "'")
myrp.MoveLast
Call showfields

Set myrs = mydb.OpenRecordset("select count(n)as no,sum(t)as st,sum(t^2)as stt,sum(xt
)as sx,sum(n*xt)as stx from datax where town='" & frmtownsel.cmbtown & "'")


With myrs

lblt.Caption = !st
lblx.Caption = !sx
lbltx.Caption = !stx
lbltt.Caption = !stt
nn = !no
lbln.Caption = nn
pt = !st / !no
px = !sx / !no
b = (!stx - (!no * pt * px)) / (!stt - !no * (pt ^ 2))
a = (px - (b * pt))
lbla = Format(a, "fixed")
lblb = Format(b, "fixed")
End With


With myalph
    txta.Text = myalph!alpha1
    txtb.Text = myalph!alpha2
    txtzeta.Text = myalph!alpha3
End With

tayo = "select ryear,t,xt,(t * xt)as X,(t^2)as TT from datax where town='" & frmtowns
el.cmbtown & "'"
Data1.RecordSource = tayo
Data1.Refresh
DBGrid1.ReBind

End Sub

Sub showfields()
lblequip.Caption = myrp!equip
lblage.Caption = myrp!age
lblcentre.Caption = myrp!centre

End Sub
```

```
Private Sub cmbtown_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")

Set myrp = mydb.OpenRecordset("select * from ttime")
        With myrp
        .FindFirst "town ='" & cmbtown.Text & "'"
        If .NoMatch = True Then
        cmdref_Click
        cmdadd.Visible = True
           cmdupd.Visible = False
        Else
        cmdupd.Visible = True
           cmdadd.Visible = False
           txtto.Text = myrp!pto
           txttm.Text = !ptm
           txttp.Text = !ptp
           txtwp1.Text = !pop
           txtwp2.Text = !plik
           txtwp3.Text = !ppes

            txttor.Text = !rto
           txttmr.Text = !rtm
           txttpr.Text = !rtp
           txtwr1.Text = !rop
           txtwr2.Text = !rlik
           txtwr3.Text = !rpes

            txttoo.Text = !oto
           txttmo.Text = !otm
           txttpo.Text = !otp
           txtwo1.Text = !oop
           txtwo2.Text = !olik
           txtwo3.Text = !opes
           End If
           End With

End Sub

Private Sub cmdadd_Click()
    Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrs = mydb.OpenRecordset("select * from ttime")
        If cmbtown.Text = "" Then
        MsgBox "select the town please", vbInformation
        cmbtown.SetFocus
        Exit Sub
        End If



        With myrs
            .AddNew
            !town = cmbtown.Text
         !pto = txtto.Text
           !ptm = txttm.Text
           !ptp = txttp.Text
           !pop = txtwp1.Text
           !plik = txtwp2.Text

           !ppes = txtwp3.Text

            !rto = txttor.Text
           !rtm = txttmr.Text
           !rtp = txttpr.Text
           !rop = txtwr1.Text
           !rlik = txtwr2.Text
           !rpes = txtwr3.Text

            !oto = txttoo.Text
           !otm = txttmo.Text
            !otp = txttpo.Text
           !oop = txtwo1.Text
           !olik = txtwo2.Text
```

```
            !opes = txtwo3.Text
            .Update
            End With

    End Sub

    Private Sub cmdclose_Click()
    Unload Me
    End Sub

    Private Sub cmdref_Click()
             txtto.Text = ""
            txttm.Text = ""
            txttp.Text = ""
            txtwp1.Text = ""
            txtwp2.Text = ""
            txtwp3.Text = ""

             txttor.Text = ""
            txttmr.Text = ""
            txttpr.Text = ""
            txtwr1.Text = ""
            txtwr2.Text = ""
            txtwr3.Text = ""

             txttoo.Text = ""
            txttmo.Text = ""
            txttpo.Text = ""
            txtwo1.Text = ""
            txtwo2.Text = ""
            txtwo3.Text = ""
    End Sub

    Private Sub cmdupd_Click()
    Set mydb = OpenDatabase(App.Path & "/casting1")
    Set myrs = mydb.OpenRecordset("select * from ttime where town='" & cmbtown.Text & "'"

          With myrs
             .Edit

           !pto = txtto.Text
             !ptm = txttm.Text
             !ptp = txttp.Text
             !pop = txtwp1.Text
             !plik = txtwp2.Text

             !ppes = txtwp3.Text

              !rto = txttor.Text
             !rtm = txttmr.Text
             !rtp = txttpr.Text
             !rop = txtwr1.Text
             !rlik = txtwr2.Text
             !rpes = txtwr3.Text

              !oto = txttoo.Text
             !otm = txttmo.Text
              !otp = txttpo.Text
             !oop = txtwo1.Text
             !olik = txtwo2.Text
             !opes = txtwo3.Text
             .Update
             End With

     End Sub



     Private Sub Form_Load()
     Me.Width = 12000
     Me.Height = 7000

     Set mydb = OpenDatabase(App.Path & "/casting1")
```

```
    Set myrt = mydb.OpenRecordset("select * from town")

   With myrt
   If Not .EOF Then .MoveLast
   If Not .BOF Then .MoveFirst
   For I = 0 To .RecordCount - 1
   cmbtown.AddItem (!Name)
   cmbtown.ItemData(cmbtown.NewIndex) = !no
   .MoveNext
   Next I
   End With


End Sub
```

```
Private Sub cmdcml_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myrt = mydb.OpenRecordset("select * from srate where town='" & frmtownsel.cmbtown
.Text & "'")

    With myrt
      n = !alpha
      p = !pe
        k = ((p + n) * ((p + n) - 1))
     ' lbln.Caption = k
      l = lblcl.Caption
      j = (k * l)



frmcomchart.lblcrew.Caption = lblcl.Caption
frmcomchart.lbltotal.Caption = j
End With
frmcomchart.Show

End Sub

Private Sub cmdexe_Click()
Set mydb = OpenDatabase(App.Path & "/casting1")
Set myalp = mydb.OpenRecordset("select * from srate where town='" & frmtownsel.cmbtow
n.Text & "'")



lam = Val(txtlt.Text)
mu = Val(lblmtl.Caption)
mct = Val(txtmct.Text)
rf = txtrf.Text
If rf > 1 Or rf <= 0 Then
MsgBox "Review your Reliability Factor", vbInformation
txtrf.Text = ""
txtrf.SetFocus
Exit Sub
End If

clock = 0!
at = 0!
nq = 0!
tnjeq = 0!
twt = 0!
tidt = 0!
tna = 1
mql = 0
3       ix = Rnd((1))
st = clock + (-1 / mu) * Log(ix)
4       ix = Rnd((1))
at = clock + (-1 / lam) * Log(ix)
5       If st >= at Then GoTo 6 Else GoTo 16

6       twt = twt + nq * (at - clock)
7       clock = at
tna = tna + 1
8       If st = at Then GoTo 9 Else GoTo 10
16      If (nq = 0) Then GoTo 17 Else GoTo 22
17      clock = st
18      tidt = tidt + (at - clock)
19      clock = at
20      tna = tna + 1
9       If clock > mct Then GoTo 15 Else GoTo 3
22      twt = twt + nq * (st - clock)
23      clock = st
24      nq = nq - 1
25      ix = Rnd((1))
st = clock + (-1 / mu) * Log(ix)
26      If clock > mct Then GoTo 15 Else GoTo 5
10      nq = nq + 1
11      If nq > mql Then GoTo 12 Else GoTo 13
12      mql = nq
```

```
13          tnjeq = tnjeq + 1
14          If clock > mct Then GoTo 15 Else GoTo 4
15          tisf = clock - tidt
            tis = tisf + twt
            atis = tis / tna
            atisf = tisf / tna
            atiq = twt / tna
            ateq = twt / tnjeq
            potb = tisf / clock

        lblawt1.Caption = Format(atiq, "0.0000")
        nn = Val(lblta.Caption)

        cno = Int(((atiq / nn) / rf) + 1)
        lblc1.Caption = cno
        With myalp
                all = myalp!alpha
                pp = myalp!pe

                cs = ((pp + all) * cno)
        lblcsize.Caption = cs

        lbluf1.Caption = Format(potb, "0.0000")
        lbltit.Caption = Format(tidt, "fixed")
        lbltet.Caption = Format(tisf, "fixed")
        lbltwt.Caption = Format(twt, "fixed")
        lbltnj.Caption = Format(tnjeq, "fixed")
        lblmjq.Caption = Format(mql, "fixed")
        lblclv.Caption = Format(clock, "fixed")
        End With

        End Sub


        Private Sub cmdref_Click()
                txtto.Text = ""
                txttm.Text = ""
                txttp.Text = ""
                txtwp1.Text = ""
                txtwp2.Text = ""
                txtwp3.Text = ""

                lblawt1.Caption = ""
        lblc1.Caption = ""

        lbluf1.Caption = ""
        lbltit.Caption = ""
        lbltet.Caption = ""
        lbltwt.Caption = ""
        lbltnj.Caption = ""
        lblmjq.Caption = ""
        lblclv.Caption = ""

        End Sub

        Private Sub cmdtc1_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")

        Set myrt = mydb.OpenRecordset("select * from srate where town='" & frmtownsel.cmbtown
.Text & "'")

            With myrt
              n = !alpha
              p = !pe
                k = ((p + n) * ((p + n) - 1))
             ' lbln.Caption = k
              l = lblc1.Caption
              j = (k * l)

        frmtools.txtint.Text = j
        End With
        frmtools.txtcrew.Text = lblc1.Caption
        frmtools.txtrr.Text = lblta.Caption
        frmtools.txtcv.Text = lblclv.Caption
```

```
        df = Val(txtmct.Text) / 52
        frmtools.lbldf.Caption = df
        frmtools.Hide

        frmspartsrep.txttisf.Text = lbltet.Caption

        frmspartsrep.txtlt.Text = lblcl.Caption
        frmspartsrep.txtmct.Text = txtmct.Text
        frmspartsrep.Show
        End Sub

        Private Sub Form_Load()
        Me.Width = 12000
        Me.Height = 8000


        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myry = mydb.OpenRecordset("select max(ryear)as ayo from datax where town='" & frm
townsel.cmbtown.Text & "'")
                 With myry
                 Y = myry!ayo
                 Me.Caption = "MAINTENANCE POLICY FORECAST FOR '" & frmtownsel.cmbtown.Text &
"' FOR THE YEAR" & " " & Y + 1
                 End With
        End Sub



        Private Sub optall_Click()
        cmdref_Click

         If IsNumeric(txtlt.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtlt.SetFocus
            optpr.Value = False
            Exit Sub


            End If
        cmdref_Click
        Frame2.Caption = "All Operations"
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from ttime where town='" & frmtownsel.cmbtown
.Text & "'")
        Set myrt = mydb.OpenRecordset("select * from srate where town='" & frmtownsel.cmbtown
.Text & "'")
               With myrs
               a = myrs!pto
               b = myrs!ptm
               c = myrs!ptp
               d = myrs!oto
               e = myrs!otm
               f = myrs!otp
               g = myrs!pop
               h = myrs!plik
               j = myrs!ppes
               k = myrs!oop
               l = myrs!olik
               m = myrs!opes

               n = myrs!rto
               o = myrs!rtm
               p = myrs!rtp
               q = myrs!rop
               r = myrs!rlik
               s = myrs!rpes


               I = txtlt.Text


                 an = (a + 4 * b + c) / 6
                 bn = (d + 4 * e + f) / 6
                 cn = (n + 4 * o + p) / 6
```

```
            dn = (an + bn + cn) / 3

                    lbltel.Caption = Format(dn, "0.0000")
                na = 1 / dn
                With myrt
                alph = myrt!alpha
                p = myrt!pe
                ma = na * (1 + (alph / p))

                lblmt1.Caption = Format(ma, "fixed")
                pa = Format(I / ma, "0.0000")
                'lbluf1.Caption = pa
                wa = Format(pa / (ma - ((1 / 27) * I)), "0.0000")
                'lblawt1.Caption = wa

                ta = (g + 4 * h + j) / 6
                tb = (k + 4 * l + m) / 6
                tc = (q + 4 * r + s) / 6

                awp = ta
                awr = tb
                awo = tc
                awpr = (awp + awr + awo) / 3
                    lblta.Caption = Format(awpr, "0.0000")


        End With

        End With
        Timer1.Interval = 500
        End Sub

        Private Sub optover_Click()
        cmdref_Click

        Frame2.Caption = "Overhauling Only"
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from ttime where town='" & frmtownsel.cmbtown
.Text & "'")
        Set myrt = mydb.OpenRecordset("select* from srate where town='" & frmtownsel.cmbtown.
Text & "'")
              With myrs
                txtto.Text = myrs!oto
                txttm.Text = myrs!otm
                txttp.Text = myrs!otp
                txtwp1.Text = myrs!oop
                txtwp2.Text = myrs!olik
                txtwp3.Text = myrs!opes
        End With
                      a = (Val(txtto) + 4 * Val(txttm) + Val(txttp)) / 6

                lbltel.Caption = Format(a, "0.0000")
                na = 1 / a
                With myrt
                alph = myrt!alpha
                p = myrt!pe
                ma = na * (1 + (alph / p))
             End With
                lblmt1.Caption = Format(ma, "fixed")

                pa = Format(I / ma, "0.0000")
                'lbluf1.Caption = pa
                wa = Format(pa / (ma - ((1 / 27) * I)), "0.0000")
                'lblawt1.Caption = wa
                ta = (Val(txtwp1) + 4 * Val(txtwp2) + Val(txtwp3)) / 6
                lblta.Caption = Format(ta, "0.0000")
                awp = ta
                If wa <= awp Then
                'lblc1.Caption = 1
        Else
                'lblc1.Caption = Round((wa / awp), "0000000000")
        End If
        Timer1.Interval = 500
```

```
        End Sub

        Private Sub optpo_Click()
        cmdref_Click

         If IsNumeric(txtlt.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtlt.SetFocus
            optpr.Value = False
            Exit Sub
            End If
        cmdref_Click
        Frame2.Caption = "Preventive and Overhauling Only"
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from ttime where town='" & frmtownsel.cmbtown
.Text & "'")
        Set myrt = mydb.OpenRecordset("select * from srate where town='" & frmtownsel.cmbtown
.Text & "'")
              With myrs
              a = myrs!pto
              b = myrs!ptm
              c = myrs!ptp
              d = myrs!oto
              e = myrs!otm
              f = myrs!otp
              g = myrs!pop
              h = myrs!plik
              j = myrs!ppes
              k = myrs!oop
              l = myrs!olik
              m = myrs!opes


              I = txtlt.Text


                an = (a + 4 * b + c) / 6
                bn = (d + 4 * e + f) / 6
            dn = (an + bn) / 2

                    lblte1.Caption = Format(dn, "0.0000")
                na = 1 / dn
                With myrt
                alph = myrt!alpha
                p = myrt!pe
                ma = na * (1 + (alph / p))

                lblmt1.Caption = Format(ma, "fixed")

                pa = Format(I / ma, "0.0000")
                'lbluf1.Caption = pa
                wa = Format(pa / (ma - ((1 / 27) * I)), "0.0000")
                'lblawt1.Caption = wa

                ta = (g + 4 * h + j) / 6
                tb = (k + 4 * l + m) / 6

                awp = ta
                awr = tb

                awpr = (awp + awr) / 2

                   lblta.Caption = Format(awpr, "0.0000")
                awp = ta
                If wa <= awp Then
                'lblcl.Caption = 1
        Else
                'lblcl.Caption = Round((wa / awp), "0000000000")
        End If


        End With
        End With
```

```
        Timer1.Interval = 500
        End Sub

        Private Sub optpr_Click()
        cmdref_Click

         If IsNumeric(txtlt.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtlt.SetFocus
            optpr.Value = False
            Exit Sub
            End If
        cmdref_Click
        Frame2.Caption = "Preventive and Repair Only"
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from ttime where town='" & frmtownsel.cmbtown
.Text & "'")
        Set myrt = mydb.OpenRecordset("select* from srate where town='" & frmtownsel.cmbtown.
Text & "'")
            With myrs
            a = myrs!pto
            b = myrs!ptm
            c = myrs!ptp
            d = myrs!rto
            e = myrs!rtm
            f = myrs!rtp
            g = myrs!pop
            h = myrs!plik
            j = myrs!ppes
            k = myrs!rop
            l = myrs!rlik
            m = myrs!rpes


            I = txtlt.Text


              an = (a + 4 * b + c) / 6
              bn = (d + 4 * e + f) / 6
           dn = (an + bn) / 2

                  lbltel.Caption = Format(dn, "0.0000")
              na = 1 / dn
              With myrt
              alph = myrt!alpha
              p = myrt!pe
              ma = na * (1 + (alph / p))

              lblmt1.Caption = Format(ma, "fixed")


              pa = Format(I / ma, "0.0000")
              'lbluf1.Caption = pa
              wa = Format(pa / (ma - ((1 / 27) * I)), "0.0000")
              'lblawt1.Caption = wa

              ta = (g + 4 * h + j) / 6
              tb = (k + 4 * l + m) / 6

              awp = ta
              awr = tb

              awpr = (awp + awr) / 2
               lblta.Caption = Format(awpr, "0.0000")

              awp = ta
              If wa <= awp Then
              'lblc1.Caption = 1
        Else
              'lblc1.Caption = Round((wa / awp), "0000000000")
        End If

           End With
```

```
        End With



        Timer1.Interval = 500
        End Sub

        Private Sub optpre_Click()
        cmdref_Click

        Frame2.Caption = "Preventive Only"
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from ttime where town='" & frmtownsel.cmbtown
.Text & "'")
        Set myalp = mydb.OpenRecordset("select * from srate where town='" & frmtownsel.cmbtow
n.Text & "'")
        Set myrt = mydb.OpenRecordset("select* from srate where town='" & frmtownsel.cmbtown.
Text & "'")
                With myrs
                  txtto.Text = myrs!pto
                  txttm.Text = myrs!ptm
                  txttp.Text = myrs!ptp
                  txtwp1.Text = myrs!pop
                  txtwp2.Text = myrs!plik
                  txtwp3.Text = myrs!ppes

        End With
        With myalp
                  al = myalp!alpha
                  p = myalp!pe

                  a = (Val(txtto) + 4 * Val(txttm) + Val(txttp)) / 6

                  lblte1.Caption = Format(a, "0.0000")
                  sr = Format(1 / a, "0.0000")
                  na = sr * (1 + (al / p))
                  cs = (p + al)

                  With myrt
                  alph = myrt!alpha
                  p = myrt!pe
                  ma = na * (1 + (alph / p))

                  lblmt1.Caption = Format(ma, "fixed")

                  pa = Format(1 / ma, "0.0000")
                  'lblufl.Caption = pa
                  wa = Format(pa / (ma - ((1 / 27) * 1)), "0.0000")
                  'lblawt1.Caption = wa
                  ta = (Val(txtwp1) + 4 * Val(txtwp2) + Val(txtwp3)) / 6
                  lblta.Caption = Format(ta, "0.0000")

                  awp = ta
                  If wa <= awp Then
                  'lblc1.Caption = 1
        Else
                  'lblc1.Caption = Round((wa / awp), "0000000000")
        End If
        End With
        End With
        Timer1.Interval = 500

        End Sub

        Private Sub optrep_Click()
        cmdref_Click

        Frame2.Caption = "Repair Only"
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from ttime where town='" & frmtownsel.cmbtown
.Text & "'")
        Set myrt = mydb.OpenRecordset("select* from srate where town='" & frmtownsel.cmbtown.
```

```
frmmaintenance = 8

Text & "'")
            With myrs
              txtto.Text = myrs!rto
              txttm.Text = myrs!rtm
              txttp.Text = myrs!rtp
              txtwp1.Text = myrs!rop
              txtwp2.Text = myrs!rlik
              txtwp3.Text = myrs!rpes
        End With
                    a = (Val(txtto) + 4 * Val(txttm) + Val(txttp)) / 6

              lblte1.Caption = Format(a, "0.0000")
              na = 1 / a

              With myrt
              alph = myrt!alpha
              p = myrt!pe
              ma = na * (1 + (alph / p))
        End With
              lblmt1.Caption = Format(ma, "fixed")
              pa = Format(I / ma, "0.0000")
              'lbluf1.Caption = pa
              wa = Format(pa / (ma - ((1 / 27) * I)), "0.0000")
              'lblawt1.Caption = wa
              ta = (Val(txtwp1) + 4 * Val(txtwp2) + Val(txtwp3)) / 6
                  lblta.Caption = Format(ta, "0.0000")
              awp = ta
              If wa <= awp Then
              'lblc1.Caption = 1
        Else
              'lblc1.Caption = Round((wa / awp), "0000000000")
        End If
        Timer1.Interval = 500
        End Sub

        Private Sub optro_Click()
        cmdref_Click

         If IsNumeric(txtlt.Text) = False Then
            MsgBox "Please Enter Numeric value Only", vbInformation
            txtlt.SetFocus
            optpr.Value = False
            Exit Sub
            End If
        cmdref_Click
        Frame2.Caption = "Repair and Overhauling Only"
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from ttime where town='" & frmtownsel.cmbtown
.Text & "'")
        Set myrt = mydb.OpenRecordset("select* from srate where town='" & frmtownsel.cmbtown.
Text & "'")
            With myrs
            a = myrs!rto
            b = myrs!rtm
            c = myrs!rtp
            d = myrs!oto
            e = myrs!otm
            f = myrs!otp
            g = myrs!rop
            h = myrs!rlik
            j = myrs!rpes
            k = myrs!oop
            l = myrs!olik
            m = myrs!opes


            I = txtlt.Text


              an = (a + 4 * b + c) / 6
              bn = (d + 4 * e + f) / 6
          dn = (an + bn) / 2

              lblte1.Caption = Format(dn, "0.0000")
```

```
            na = 1 / a

            With myrt
            alph = myrt!alpha
            p = myrt!pe
            ma = na * (1 + (alph / p))
      End With
            lblmt1.Caption = Format(ma, "fixed")
            pa = Format(I / ma, "0.0000")
            'lbluf1.Caption = pa
            wa = Format(pa / (ma - ((1 / 27) * I)), "0.0000")
            'lblawt1.Caption = wa

            ta = (g + 4 * h + j) / 6
            tb = (k + 4 * l + m) / 6

            awp = ta
            awr = tb

            awpr = (awp + awr) / 2
                lblta.Caption = Format(awpr, "0.0000")

            awp = ta
            If wa <= awp Then
            'lblc1.Caption = 1
      Else
            'lblc1.Caption = Round((wa / awp), "0000000000")
      End If


      End With

      Timer1.Interval = 500
      End Sub

      Private Sub Timer1_Timer()
      Timer1.Interval = 0
      cmdexe_Click
      End Sub
```

```
        Private Sub cmdcost_Click()
        frmtools.txtic.Text = lbltic.Caption
        frmtools.txttic.Text = lbltti.Caption
        frmtools.txttisf.Text = lbloet.Caption
        frmtools.txtefr.Text = txtefr.Text
        frmtools.txtemc.Text = txtemc.Text

        frmtools.Show
        Unload Me
        End Sub



        Private Sub cmdref_Click()
                lblurate.Caption = ""
                lblsrate.Caption = ""
                lbltit.Caption = ""
                lbltwt.Caption = ""
                lblmjq = ""
                lbltnj.Caption = ""
                lblused.Caption = ""
                lblclv.Caption = ""

                lbloc.Caption = ""
                lblcc.Caption = ""

                lbltic.Caption = ""
        End Sub



        Private Sub Form_Load()

        Me.Height = 6500
        Me.Width = 12000
        Me.Top = 100
        Me.Left = 0

        Set mydb = OpenDatabase(App.Path & "/casting1")
        'Set myrs = mydb.OpenRecordset("select * from town where town='" & frmtownsel.cmbtown
.Text & "'")
        Set myrp = mydb.OpenRecordset("select * from spear")

        Set myry = mydb.OpenRecordset("select max(ryear)as ayo from datax where town='" & frm
townsel.cmbtown.Text & "'")
                With myry
                Y = myry!ayo
                Me.Caption = "SPARE PART INVENTORY UNIT FOR  '" & frmtownsel.cmbtown.Text & "
' FOR THE YEAR" & " " & Y + 1
                End With

        On Error GoTo out
            'With myrs
            'If Not .EOF Then .MoveLast
            'If Not .BOF Then .MoveFirst
            cmbtown.Text = "" & frmtownsel.cmbtown.Text & ""
            'For I = 0 To .RecordCount - 1
            'cmbtown.AddItem (!Name)
            'cmbtown.ItemData(cmbtown.NewIndex) = !no
            '.MoveNext
            'Next I
            'End With


            With myrp
            If Not .EOF Then .MoveLast
            If Not .BOF Then .MoveFirst
            cmbpart.Text = !part
            For p = 0 To .RecordCount - 1
            cmbpart.AddItem (!part)
            cmbpart.ItemData(cmbpart.NewIndex) = !no
            .MoveNext
            Next p
            End With
```

```
out:
        End Sub
        Private Sub optall_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")

        Set myrs = mydb.OpenRecordset("select ((preventived.x+repaired.x+overhaulingd.x)/3)
 xx,((preventived.y+repaired.y+overhaulingd.y)/3)as yy,((preventived.p+repaired.p+overhauli
d.p)/3)as pp,((preventived.c+repaired.c+overhaulingd.c)/3)as cc,((preventived.r+repaired.r+
erhaulingd.r)/3)as rr from preventived,repaired,overhaulingd where preventived.town='" & cm
own.Text & "' and preventived.part='" & cmbpart.Text & "' and repaired.town='" & cmbtown.Te
 & "' and repaired.part='" & cmbpart.Text & "' and overhaulingd.town='" & cmbtown.Text & "'
nd overhaulingd.part='" & cmbpart.Text & "'")
                cmdref_Click
               ' On Error GoTo err
                With myrs
                a = myrs!xx
                b = myrs!yy
                p = myrs!pp
                c = myrs!cc
                m = myrs!rr
                 d = txtlt.Text
        lam = a
        mu = b
        mct = Val(txtmct.Text)

        clock = 0!
        at = 0!
        nq = 0!
        tnjeq = 0!
        twt = 0!
        tidt = 0!
        tna = 1
        mql = 0
3           ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
4           ix = Rnd((1))
        at = clock + (-1 / lam) * Log(ix)
5           If st >= at Then GoTo 6 Else GoTo 16

6           twt = twt + nq * (at - clock)
7           clock = at
        tna = tna + 1
8           If st = at Then GoTo 9 Else GoTo 10
16          If (nq = 0) Then GoTo 17 Else GoTo 22
17          clock = st
18          tidt = tidt + (at - clock)

19          clock = at
20          tna = tna + 1
9           If clock > mct Then GoTo 15 Else GoTo 3
22          twt = twt + nq * (st - clock)
23          clock = st
24          nq = nq - 1
25          ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
26          If clock > mct Then GoTo 15 Else GoTo 5
10          nq = nq + 1
11          If nq > mql Then GoTo 12 Else GoTo 13
12          mql = nq
13          tnjeq = tnjeq + 1


14          If clock > mct Then GoTo 15 Else GoTo 4
15          tisf = clock - tidt
            tis = tisf + twt
            atis = tis / tna
            atisf = tisf / tna
            atiq = twt / tna
            ateq = twt / tnjeq
            pctb = tisf / clock
            ff = mct / 52
```



```
            tost = tidt / ff
```

```
            tst = (clock - tidt) / ff
            mns = mql
        tns = tnjeq
        Y = ((tns - mns) * 52) / (tst * ff)
        Y4 = (clock * Y) / (tst * ff)


        Nut = ((2 * p * d * Y) / (c * m)) ^ (1 / 2)
        Nu = -1 * Int(-Nut)
        'tnu = d * Nu
        Nu4 = ((2 * p * d * Y4) / (c * m)) ^ (1 / 2)
        'tNu4 = d * Nu4

        no = (d * (-1 * Int(-Y))) / Nu
        no4 = (d * (-1 * Int(-Y4))) / Nu4
        otp = tst / no
        g = txttisf.Text
        tisp = g / ff
        tisq = Val(txttisf.Text)
        lblet.Caption = Format(tisp, "fixed")

        lblono.Caption = Nu
        'INu4=int(Nu4)+1

        lblotpo.Caption = Format(otp, "fixed")
        lblnpp.Caption = no
        If tisp <= tisq Then
            egt = tisp
            lbloet.Caption = Format(egt, "fixed")
            ElseIf tisq < tisp Then
            egt = tisq
            lbloet.Caption = Format(egt, "fixed")
        End If


                lblurate.Caption = Format(a, "fixed")
                lblsrate.Caption = Format(b, "fixed")
                lbltit.Caption = Format(tost, "fixed")
                lbltwt.Caption = Format(tst, "fixed")
                lblmjq = Format(mns, "fixed")
                lbltnj.Caption = Format(tns, "fixed")
                lblused.Caption = (-1 * Int(-Y))
                lblclv.Caption = Format(clock, "fixed")
                t = (p * d * Y) / Nu
                s = (Nu * c * m) / 2
                t4 = (p * d * Y4) / Nu4
                s4 = (Nu4 * c * m) / 2
                lbltti.Caption = Format((t4 + s4), "fixed")
                lbloc.Caption = Format(t, "fixed")
                lblcc.Caption = Format(s, "fixed")
                lbltic.Caption = Format((t + s), "fixed")
                lbltoc.Caption = Format(t4, "fixed")
                lbltcc.Caption = Format(s4, "fixed")
                End With
err:


        End Sub

        Private Sub optover_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from overhaulingd where town='" & cmbtown.Tex
t & "' and part='" & cmbpart.Text & "'")
         cmdref_Click
         On Error GoTo err
                With myrs
                a = myrs!X
                b = myrs!Y
                p = myrs!p
                c = myrs!c
                m = myrs!r
         d = txtlt.Text
        lam = a
```

```
        mu = b
        mct = Val(txtmct.Text)

        clock = 0!
        at = 0!
        nq = 0!
        tnjeq = 0!
        twt = 0!
        tidt = 0!
        tna = 1
        mql = 0
3           ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
4           ix = Rnd((1))
        at = clock + (-1 / lam) * Log(ix)
5           If st >= at Then GoTo 6 Else GoTo 16

6           twt = twt + nq * (at - clock)
7           clock = at
        tna = tna + 1
8           If st = at Then GoTo 9 Else GoTo 10
16          If (nq = 0) Then GoTo 17 Else GoTo 22
17          clock = st
18          tidt = tidt + (at - clock)

19          clock = at
20          tna = tna + 1
9           If clock > mct Then GoTo 15 Else GoTo 3
22          twt = twt + nq * (st - clock)
23          clock = st
24          nq = nq - 1
25          ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
26          If clock > mct Then GoTo 15 Else GoTo 5
10          nq = nq + 1
11          If nq > mql Then GoTo 12 Else GoTo 13
12          mql = nq
13          tnjeq = tnjeq + 1


14          If clock > mct Then GoTo 15 Else GoTo 4
15          tisf = clock - tidt
            tis = tisf + twt
            atis = tis / tna
            atisf = tisf / tna
            atiq = twt / tna
            ateq = twt / tnjeq
            potb = tisf / clock
            ff = mct / 52

            tost = tidt / ff
            tst = (clock - tidt) / ff
            mns = mql
        tns = tnjeq
        Y = ((tns - mns) * 52) / (tst * ff)
        Y4 = (clock * Y) / tst


        Nut = ((2 * p * d * Y) / (c * m)) ^ (1 / 2)
        Nu = -1 * Int(-Nut)
        'tnu = d * Nu
        Nu4 = ((2 * p * d * Y4) / (c * m)) ^ (1 / 2)
        'tNu4 = d * Nu4

        no = (d * (-1 * Int(-Y))) / Nu
        no4 = (d * (-1 * Int(-Y4))) / Nu4
        otp = tst / no
        g = txttisf.Text
        tisp = g / ff
        tisq = Val(txttisf.Text)
        lblet.Caption = Format(tisp, "fixed")

        lblono.Caption = Nu
        'lNu4=int(Nu4)+1
```

```
        lblotpo.Caption = Format(otp, "fixed")
        lblnpp.Caption = no
        If tisp <= tisq Then
            egt = tisp
            lbloet.Caption = Format(egt, "fixed")
            ElseIf tisq < tisp Then
            egt = tisq
            lbloet.Caption = Format(egt, "fixed")
        End If


                lblurate.Caption = Format(a, "fixed")
                lblsrate.Caption = Format(b, "fixed")
                lbltit.Caption = Format(tost, "fixed")
                lbltwt.Caption = Format(tst, "fixed")
                lblmjq = Format(mns, "fixed")
                lbltnj.Caption = Format(tns, "fixed")
                lblused.Caption = (-1 * Int(-Y))
                lblclv.Caption = Format(clock, "fixed")
                t = (p * d * Y) / Nut
                s = (Nut * c * m) / 2
                t4 = (p * d * Y4) / Nu4
                s4 = (Nu4 * c * m) / 2
                lbltti.Caption = Format((t4 + s4), "fixed")
                lbloc.Caption = Format(t, "fixed")
                lblcc.Caption = Format(s, "fixed")
                lbltic.Caption = Format((t + s), "fixed")
                lbltoc.Caption = Format(t4, "fixed")
                lbltcc.Caption = Format(s4, "fixed")
                End With
err:
        End Sub

        Private Sub optpo_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select ((preventived.x+overhaulingd.x)/2)as xx,((preve
ntived.y+overhaulingd.y)/2)as yy,((preventived.p+overhaulingd.p)/2)as pp,((preventived.c+over
haulingd.c)/2)as cc,((preventived.r+overhaulingd.r)/2)as rr from preventived,overhaulingd whe
re preventived.town='" & cmbtown.Text & "' and preventived.part='" & cmbpart.Text & "' and ov
erhaulingd.town='" & cmbtown.Text & "' and overhaulingd.part='" & cmbpart.Text & "'")
               cmdref_Click
               On Error GoTo err
                With myrs
                a = myrs!xx
                b = myrs!yy
                p = myrs!pp
                c = myrs!cc
                m = myrs!rr
         d = txtlt.Text
        lam = a
        mu = b
        mct = Val(txtmct.Text)

        clock = 0!
        at = 0!
        nq = 0!
        tnjeq = 0!
        twt = 0!
        tidt = 0!
        tna = 1
        mql = 0
3           ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
4           ix = Rnd((1))
        at = clock + (-1 / lam) * Log(ix)
5           If st >= at Then GoTo 6 Else GoTo 16

6           twt = twt + nq * (at - clock)
7           clock = at
        tna = tna + 1
8           If st = at Then GoTo 9 Else GoTo 10
16          If (nq = 0) Then GoTo 17 Else GoTo 22
17          clock = st
```

```
18          tidt = tidt + (at - clock)

19          clock = at
20          tna = tna + 1
9           If clock > mct Then GoTo 15 Else GoTo 3
22          twt = twt + nq * (st - clock)
23          clock = st
24          nq = nq - 1
25          ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
26          If clock > mct Then GoTo 15 Else GoTo 5
10          nq = nq + 1
11          If nq > mql Then GoTo 12 Else GoTo 13
12          mql = nq
13          tnjeq = tnjeq + 1


14          If clock > mct Then GoTo 15 Else GoTo 4
15          tisf = clock - tidt
            tis = tisf + twt
            atis = tis / tna
            atisf = tisf / tna
            atiq = twt / tna
            ateq = twt / tnjeq
            potb = tisf / clock
            ff = mct / 52

            tost = tidt / ff
            tst = (clock - tidt) / ff
            mns = mql
        tns = tnjeq
        Y = ((tns - mns) * 52) / (tst * ff)
        Y4 = (clock * Y) / tst


        Nut = ((2 * p * d * Y) / (c * m)) ^ (1 / 2)
        Nu = -1 * Int(-Nut)
        'tnu = d * Nu
        Nu4 = ((2 * p * d * Y4) / (c * m)) ^ (1 / 2)
        'tNu4 = d * Nu4

        no = (d * (-1 * Int(-Y))) / Nu
        no4 = (d * (-1 * Int(-Y4))) / Nu4
        otp = tst / no
        g = txttisf.Text
        tisp = g / ff
        tisq = Val(txttisf.Text)
        lblet.Caption = Format(tisp, "fixed")

        lblono.Caption = Nu
        'INu4=int(Nu4)+1

        lblotpo.Caption = Format(otp, "fixed")
        lblnpp.Caption = no
        If tisp <= tisq Then
            egt = tisp
            lbloet.Caption = Format(egt, "fixed")
            ElseIf tisq < tisp Then
            egt = tisq
            lbloet.Caption = Format(egt, "fixed")
        End If


                lblurate.Caption = Format(a, "fixed")
                lblsrate.Caption = Format(b, "fixed")
                lbltit.Caption = Format(tost, "fixed")
                lbltwt.Caption = Format(tst, "fixed")
                lblmjq = Format(mns, "fixed")
                lbltnj.Caption = Format(tns, "fixed")
                lblused.Caption = (-1 * Int(-Y))
                lblclv.Caption = Format(clock, "fixed")
                t = (p * d * Y) / Nut
                s = (Nut * c * m) / 2
                t4 = (p * d * Y4) / Nu4
```

```
                s4 = (Nu4 * c * m) / 2
                lbltti.Caption = Format((t4 + s4), "fixed")
                lbloc.Caption = Format(t, "fixed")
                lblcc.Caption = Format(s, "fixed")
                lbltic.Caption = Format((t + s), "fixed")
                lbltoc.Caption = Format(t4, "fixed")
                lbltcc.Caption = Format(s4, "fixed")
                End With
err:

        End Sub

        Private Sub optpr_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select ((preventived.x+repaired.x)/2)as xx,((preventiv
ed.y+repaired.y)/2)as yy,((preventived.p+repaired.p)/2)as pp,((preventived.c+repaired.c)/2)as
 cc,((preventived.r+repaired.r)/2)as rr from preventived,repaired where preventived.town='" &
 cmbtown.Text & "' and preventived.part='" & cmbpart.Text & "' and repaired.town='" & cmbtown
.Text & "' and repaired.part='" & cmbpart.Text & "'")
             cmdref_Click
               On Error GoTo err
                With myrs
                a = myrs!xx
                b = myrs!yy
                p = myrs!pp
                c = myrs!cc
                m = myrs!rr
         d = txtlt.Text
        lam = a
        mu = b
        mct = Val(txtmct.Text)

        clock = 0!
        at = 0!
        nq = 0!
        tnjeq = 0!
        twt = 0!
        tidt = 0!
        tna = 1
        mql = 0
3           ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
4           ix = Rnd((1))
        at = clock + (-1 / lam) * Log(ix)
5           If st >= at Then GoTo 6 Else GoTo 16

6           twt = twt + nq * (at - clock)
7           clock = at
        tna = tna + 1
8           If st = at Then GoTo 9 Else GoTo 10
16          If (nq = 0) Then GoTo 17 Else GoTo 22
17          clock = st
18          tidt = tidt + (at - clock)

19          clock = at
20          tna = tna + 1
9           If clock > mct Then GoTo 15 Else GoTo 3
22          twt = twt + nq * (st - clock)
23          clock = st
24          nq = nq - 1
25          ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
26          If clock > mct Then GoTo 15 Else GoTo 5
10          nq = nq + 1
11          If nq > mql Then GoTo 12 Else GoTo 13
12          mql = nq
13          tnjeq = tnjeq + 1


14          If clock > mct Then GoTo 15 Else GoTo 4
15          tisf = clock - tidt
            tis = tisf + twt
            atis = tis / tna
            atisf = tisf / tna
```

```
            atiq = twt / tna
            ateq = twt / tnjeq
            potb = tisf / clock
            ff = mct / 52

            tost = tidt / ff
            tst = (clock - tidt) / ff
            mns = mql
        tns = tnjeq
        Y = ((tns - mns) * 52) / (tst * ff)
        Y4 = (clock * Y) / tst


        Nut = ((2 * p * d * Y) / (c * m)) ^ (1 / 2)
        Nu = -1 * Int(-Nut)
        'tnu = d * Nu
        Nu4 = ((2 * p * d * Y4) / (c * m)) ^ (1 / 2)
        'tNu4 = d * Nu4

        no = (d * (-1 * Int(-Y))) / Nu
        no4 = (d * (-1 * Int(-Y4))) / Nu4
        otp = tst / no
        g = txttisf.Text
        tisp = g / ff
        tisq = Val(txttisf.Text)
        lblet.Caption = Format(tisp, "fixed")

        lblono.Caption = Nu
        'INu4=int(Nu4)+1

        lblotpo.Caption = Format(otp, "fixed")
        lblnpp.Caption = no
        If tisp <= tisq Then
            egt = tisp
            lbloet.Caption = Format(egt, "fixed")
            ElseIf tisq < tisp Then
            egt = tisq
            lbloet.Caption = Format(egt, "fixed")
        End If


                lblurate.Caption = Format(a, "fixed")
                lblsrate.Caption = Format(b, "fixed")
                lbltit.Caption = Format(tost, "fixed")
                lbltwt.Caption = Format(tst, "fixed")
                lblmjq = Format(mns, "fixed")
                lbltnj.Caption = Format(tns, "fixed")
                lblused.Caption = (-1 * Int(-Y))
                lblclv.Caption = Format(clock, "fixed")
                t = (p * d * Y) / Nut
                s = (Nut * c * m) / 2
                t4 = (p * d * Y4) / Nu4
                s4 = (Nu4 * c * m) / 2
                lbltti.Caption = Format((t4 + s4), "fixed")
                lbloc.Caption = Format(t, "fixed")
                lblcc.Caption = Format(s, "fixed")
                lbltic.Caption = Format((t + s), "fixed")
                lbltoc.Caption = Format(t4, "fixed")
                lbltoc.Caption = Format(s4, "fixed")
                End With
err:
        End Sub

        Private Sub optpre_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from preventived where town='" & cmbtown.Text
 & "' and part='" & cmbpart.Text & "'")
              cmdref_Click
              On Error GoTo err
               With myrs
               a = myrs!X
               b = myrs!Y
               p = myrs!p
               c = myrs!c
```

```
            m = myrs!r
     d = txtlt.Text
    lam = a
    mu = b
    mct = Val(txtmct.Text)

    clock = 0!
    at = 0!
    nq = 0!
    tnjeq = 0!
    twt = 0!
    tidt = 0!
    tna = 1
    mql = 0
3       ix = Rnd((1))
    st = clock + (-1 / mu) * Log(ix)
4       ix = Rnd((1))
    at = clock + (-1 / lam) * Log(ix)
5       If st >= at Then GoTo 6 Else GoTo 16

6       twt = twt + nq * (at - clock)
7       clock = at
    tna = tna + 1
8       If st = at Then GoTo 9 Else GoTo 10
16      If (nq = 0) Then GoTo 17 Else GoTo 22
17      clock = st
18      tidt = tidt + (at - clock)

19      clock = at
20      tna = tna + 1
9       If clock > mct Then GoTo 15 Else GoTo 3
22      twt = twt + nq * (st - clock)
23      clock = st
24      nq = nq - 1
25      ix = Rnd((1))
    st = clock + (-1 / mu) * Log(ix)
26      If clock > mct Then GoTo 15 Else GoTo 5
10      nq = nq + 1 '
11      If nq > mql Then GoTo 12 Else GoTo 13
12      mql = nq
13      tnjeq = tnjeq + 1


14      If clock > mct Then GoTo 15 Else GoTo 4
15      tisf = clock - tidt
        tis = tisf + twt
        atis = tis / tna
        atisf = tisf / tna
        atiq = twt / tna
        ateq = twt / tnjeq
        potb = tisf / clock
        ff = mct / 52

        tost = tidt / ff
        tst = (clock - tidt) / ff
        mns = mql
    tns = tnjeq
    Y = ((tns - mns) * 52) / (tst * ff)
    Y4 = (clock * Y) / tst


    Nut = ((2 * p * d * Y) / (c * m)) ^ (1 / 2)
    Nu = -1 * Int(-Nut)
    'tnu = d * Nu
    Nu4 = ((2 * p * d * Y4) / (c * m)) ^ (1 / 2)
    'tNu4 = d * Nu4

    no = (d * (-1 * Int(-Y))) / Nu
    no4 = (d * (-1 * Int(-Y4))) / Nu4
    otp = tst / no
    g = txttisf.Text
    tisp = g / ff
    tisq = Val(txttisf.Text)
    lblet.Caption = Format(tisp, "fixed")
```

```
        lblono.Caption = Nu
        'INu4=int(Nu4)+1

        lblotpo.Caption = Format(otp, "fixed")
        lblnpp.Caption = no
        If tisp <= tisq Then
            egt = tisp
            lbloet.Caption = Format(egt, "fixed")
            ElseIf tisq < tisp Then
            egt = tisq
            lbloet.Caption = Format(egt, "fixed")
        End If


                lblurate.Caption = Format(a, "fixed")
                lblsrate.Caption = Format(b, "fixed")
                lbltit.Caption = Format(tost, "fixed")
                lbltwt.Caption = Format(tst, "fixed")
                lblmjq = Format(mns, "fixed")
                lbltnj.Caption = Format(tns, "fixed")
                lblused.Caption = (-1 * Int(-Y))
                lblclv.Caption = Format(clock, "fixed")
                t = (p * d * Y) / Nut
                s = (Nut * c * m) / 2
                t4 = (p * d * Y4) / Nu4
                s4 = (Nu4 * c * m) / 2
                lbltti.Caption = Format((t4 + s4), "fixed")
                lbloc.Caption = Format(t, "fixed")
                lblcc.Caption = Format(s, "fixed")
                lbltio.Caption = Format((t + s), "fixed")
                lbltoc.Caption = Format(t4, "fixed")
                lbltcc.Caption = Format(s4, "fixed")
                End With
err:
        End Sub

        Private Sub optrep_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from repaired where town='" & cmbtown.Text &
"' and part='" & cmbpart.Text & "'")
        cmdref_Click
               On Error GoTo err
                With myrs
                a = myrs!X
                b = myrs!Y
                p = myrs!p
                c = myrs!c
                m = myrs!r
         d = txtit.Text
        lam = a
        mu = b
        mct = Val(txtmct.Text)

        clock = 0!
        at = 0!
        nq = 0!
        tnjeq = 0!
        twt = 0!
        tidt = 0!
        tna = 1
        mql = 0
3           ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
4           ix = Rnd((1))
        at = clock + (-1 / lam) * Log(ix)
5           If st >= at Then GoTo 6 Else GoTo 16

6           twt = twt + nq * (at - clock)
7           clock = at
        tna = tna + 1
8           If st = at Then GoTo 9 Else GoTo 10
16          If (nq = 0) Then GoTo 17 Else GoTo 22
17          clock = st
```

```
18          tidt = tidt + (at - clock)

19          clock = at
20          tna = tna + 1
9           If clock > mct Then GoTo 15 Else GoTo 3
22          twt = twt + nq * (st - clock)
23          clock = st
24          nq = nq - 1
25          ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
26          If clock > mct Then GoTo 15 Else GoTo 5
10          nq = nq + 1
11          If nq > mql Then GoTo 12 Else GoTo 13
12          mql = nq
13          tnjeq = tnjeq + 1


14          If clock > mct Then GoTo 15 Else GoTo 4
15          tisf = clock - tidt
            tis = tisf + twt
            atis = tis / tna
            atisf = tisf / tna
            atiq = twt / tna
            ateq = twt / tnjeq
            potb = tisf / clock
            ff = mct / 52

            tost = tidt / ff
            tst = (clock - tidt) / ff
            mns = mql
        tns = tnjeq
        Y = ((tns - mns) * 52) / (tst * ff)
        Y4 = (clock * Y) / tst


        Nut = ((2 * p * d * Y) / (c * m)) ^ (1 / 2)
        Nu = -1 * Int(-Nut)
        'tnu = d * Nu
        Nu4 = ((2 * p * d * Y4) / (c * m)) ^ (1 / 2)
        'tNu4 = d * Nu4

        no = (d * (-1 * Int(-Y))) / Nu
        no4 = (d * (-1 * Int(-Y4))) / Nu4
        otp = tst / no
        g = txttisf.Text
        tisp = g / ff
        tisq = Val(txttisf.Text)
        lblet.Caption = Format(tisp, "fixed")

        lblono.Caption = Nu
        'INu4=int(Nu4)+1

        lblotpo.Caption = Format(otp, "fixed")
        lblnpp.Caption = no
        If tisp <= tisq Then
            egt = tisp
            lbloet.Caption = Format(egt, "fixed")
            ElseIf tisq < tisp Then
            egt = tisq
            lbloet.Caption = Format(egt, "fixed")
        End If


                lblurate.Caption = Format(a, "fixed")
                lblsrate.Caption = Format(b, "fixed")
                lbltit.Caption = Format(tost, "fixed")
                lbltwt.Caption = Format(tst, "fixed")
                lblmjq = Format(mns, "fixed")
                lbltnj.Caption = Format(tns, "fixed")
                lblused.Caption = (-1 * Int(-Y))
                lblclv.Caption = Format(clock, "fixed")
                t = (p * d * Y) / Nut
                s = (Nut * c * m) / 2
                t4 = (p * d * Y4) / Nu4
```

```
                s4 = (Nu4 * c * m) / 2
                lbltti.Caption = Format((t4 + s4), "fixed")
                lbloc.Caption = Format(t, "fixed")
                lblcc.Caption = Format(s, "fixed")
                lbltic.Caption = Format((t + s), "fixed")
                lbltoc.Caption = Format(t4, "fixed")
                lbltcc.Caption = Format(s4, "fixed")
                End With
err:
        End Sub

        Private Sub optro_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")

        Set myrs = mydb.OpenRecordset("select ((repaired.x+overhaulingd.x)/2)as xx,((repaired
.y+overhaulingd.y)/2)as yy,((repaired.p+overhaulingd.p)/2)as pp,((repaired.c+overhaulingd.c)/
2)as cc,((repaired.r+overhaulingd.r)/2)as rr from repaired,overhaulingd where repaired.town='
" & cmbtown.Text & "'and repaired.part='" & cmbpart.Text & "' and overhaulingd.town='" & cmbt
own.Text & "' and overhaulingd.part='" & cmbpart.Text & "'")

              cmdref_Click
                On Error GoTo err
                With myrs
                a = myrs!xx
                b = myrs!yy
                p = myrs!pp
                c = myrs!cc
                m = myrs!rr
         d = txtlt.Text
        lam = a
        mu = b
        mct = Val(txtmct.Text)

        clock = 0!
        at = 0!
        nq = 0!
        tnjeq = 0!
        twt = 0!
        tidt = 0!
        tna = 1
        mql = 0
3           ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
4           ix = Rnd((1))
        at = clock + (-1 / lam) * Log(ix)
5           If st >= at Then GoTo 6 Else GoTo 16

6           twt = twt + nq * (at - clock)
7           clock = at
        tna = tna + 1
8           If st = at Then GoTo 9 Else GoTo 10
16          If (nq = 0) Then GoTo 17 Else GoTo 22
17          clock = st
18          tidt = tidt + (at - clock)

19          clock = at
20          tna = tna + 1
9           If clock > mct Then GoTo 15 Else GoTo 3
22          twt = twt + nq * (st - clock)
23          clock = st
24          nq = nq - 1
25          ix = Rnd((1))
        st = clock + (-1 / mu) * Log(ix)
26          If clock > mct Then GoTo 15 Else GoTo 5
10          nq = nq + 1
11          If nq > mql Then GoTo 12 Else GoTo 13
12          mql = nq
13          tnjeq = tnjeq + 1


14          If clock > mct Then GoTo 15 Else GoTo 4
15          tisf = clock - tidt
            tis = tisf + twt
            atis = tis / tna
```

```
            atisf = tisf / tna
            atiq = twt / tna
            ateq = twt / tnjeq
            potb = tisf / clock
            ff = mct / 52

            tost = tidt / ff
            tst = (clock - tidt) / ff
            mns = mql
        tns = tnjeq
        Y = ((tns - mns) * 52) / (tst * ff)
        Y4 = (clock * Y) / tst


        Nut = ((2 * p * d * Y) / (c * m)) ^ (1 / 2)
        Nu = -1 * Int(-Nut)
        'tnu = d * Nu
        Nu4 = ((2 * p * d * Y4) / (c * m)) ^ (1 / 2)
        'tNu4 = d * Nu4

        no = (d * (-1 * Int(-Y))) / Nu
        no4 = (d * (-1 * Int(-Y4))) / Nu4
        otp = tst / no
        q = txttisf.Text
        tisp = q / ff
        tisq = Val(txttisf.Text)
        lblet.Caption = Format(tisp, "fixed")

        lblono.Caption = Nu
        'INu4=int(Nu4)+1

        lblotpo.Caption = Format(otp, "fixed")
        lblnpp.Caption = no
        If tisp <= tisq Then
            egt = tisp
            lbloet.Caption = Format(egt, "fixed")
            ElseIf tisq < tisp Then
            egt = tisq
            lbloet.Caption = Format(egt, "fixed")
        End If


                lblurate.Caption = Format(a, "fixed")
                lblsrate.Caption = Format(b, "fixed")
                lbltit.Caption = Format(tost, "fixed")
                lbltwt.Caption = Format(tst, "fixed")
                lblmjq = Format(mns, "fixed")
                lbltnj.Caption = Format(tns, "fixed")
                lblused.Caption = (-1 * Int(-Y))
                lblclv.Caption = Format(clock, "fixed")
                t = (p * d * Y) / Nut
                s = (Nut * c * m) / 2
                t4 = (p * d * Y4) / Nu4
                s4 = (Nu4 * c * m) / 2
                lbltti.Caption = Format((t4 + s4), "fixed")
                lbloc.Caption = Format(t, "fixed")
                lblcc.Caption = Format(s, "fixed")
                lbltic.Caption = Format((t + s), "fixed")
                lbltoc.Caption = Format(t4, "fixed")
                lbltcc.Caption = Format(s4, "fixed")
                End With
err:
        End Sub
```

```
Private Sub cmdexecute_Click()
cp = Val(txtcp.Text)
cr = Val(txtcr.Text)
co = Val(txtco.Text)
ca = Val(txtca.Text)
cpr = Val(txtcpr.Text)
cpo = Val(txtcpo.Text)
cro = Val(txtcro.Text)

fp = Val(txtfp.Text)
fr = Val(txtfr.Text)
fo = Val(txtfo.Text)
fa = Val(txtfa.Text)
fpr = Val(txtfpr.Text)
fpo = Val(txtfpo.Text)
fro = Val(txtfro.Text)

ipr = Abs(cp - cr)
iro = Abs(cr - co)
ioa = Abs(co - ca)
iapr = Abs(ca - cpr)
iprpo = Abs(cpr - cpo)
iporo = Abs(cpo - cro)

jpr = Abs(fp - fr)
jro = Abs(fr - fo)
joa = Abs(fo - fa)
japr = Abs(fa - fpr)
jprpo = Abs(fpr - fpo)
jporo = Abs(fpo - fro)

txtipr.Text = ipr
txtiro.Text = iro
txtioa.Text = ioa
txtiapr.Text = iapr
txtiprpo.Text = iprpo
txtiporo.Text = iporo

txtjpr.Text = jpr
txtjro.Text = jro
txtjoa.Text = joa
txtjapr.Text = japr
txtjprpo.Text = jprpo
txtjporo.Text = jporo


If jpr - ipr <= 0 Then
txtapr.Text = "NV"
Else
txtapr.Text = (jpr - ipr) / ipr
End If

If jro - iro <= 0 Then
txtaro.Text = "NV"
Else
txtaro.Text = (jro - iro) / iro
End If

If joa - ioa <= 0 Then
txtaoa.Text = "NV"
Else
txtaoa.Text = (joa - ioa) / ioa
End If



If japr - iapr <= 0 Then
txtaapr.Text = "NV"
Else
txtaapr.Text = (japr - iapr) / iapr
End If

If jprpo - iprpo <= 0 Then
txtaprpo.Text = "NV"
```

```
Else
txtaprpo.Text = (jprpo - iprpo) / iprpo
End If

If jporo - iporo <= 0 Then
txtaporo.Text = "NV"
Else
txtaporo.Text = (jporo - iporo) / iporo
End If


If ipr - jpr <= 0 Then
txtbpr.Text = "NV"
Else
txtbpr.Text = ipr - jpr / jpr
End If

If iro - jro <= 0 Then
txtbro.Text = "NV"
Else
txtbro.Text = (iro - jro) / jro

End If

If ioa - joa <= 0 Then
txtboa.Text = "NV"
Else
txtboa.Text = (ioa - joa) / joa
End If


If iapr - japr <= 0 Then
txtbapr.Text = "NV"
Else
txtbapr.Text = (iapr - japr) / japr
End If

If iprpo - jprpo <= 0 Then
txtbprpo.Text = "NV"
Else
txtbprpo.Text = (iprpo - jprpo) / jprpo
End If

If iporo - jporo <= 0 Then
txtbporo.Text = "NV"
Else
txtbporo.Text = (iporo - jporo) / jporo
End If


End Sub
```

```
frmtools = 1

        Private Sub cmbcom_Change()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select name,cost from comm where name='" & cmbcom & "'
")


        With myrs
          .FindFirst "name='" & Trim(cmbcom) & "'"
            If .NoMatch = False Then


                txtcom.Text = Format(myrs!cost, "fixed")
                Else
                txtcom.Text = ""
               End If
        End With

        End Sub

        Private Sub cmbcom_Click()
        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select name,cost from comm where name='" & cmbcom & "'
")


        With myrs
                  txtcom.Text = Format(myrs!cost, "fixed")

        End With
        End Sub


        Private Sub cmdexecute_Click()
        Dim mdata As String
        mdata = App.Path & "/casting1.mdb"
        Data1.DatabaseName = mdata


        Set mydb = OpenDatabase(App.Path & "/casting1")

        DBGrid1.Visible = True
        If optpre.Value = True Then
        pre = "select ('" & txtcrew & "')as quant,name,cost from preventive where town='" & f
rmtownsel.cmbtown.Text & "'"
        Data1.RecordSource = pre
        Data1.Refresh
        DBGrid1.ReBind
        Set myrs = mydb.OpenRecordset("select sum(cost)as price from preventive where town='"
 & frmtownsel.cmbtown.Text & "'")
         With myrs
                         txtt.Text = myrs!price
                         End With


        ElseIf optrep.Value = True Then
        rep = "select ('" & txtcrew & "')as quant,name,cost from repair where town='" & frmto
wnsel.cmbtown.Text & "'"
        Data1.RecordSource = rep
        Data1.Refresh
        DBGrid1.ReBind
        Set myrs = mydb.OpenRecordset("select sum(cost)as price from repair where town='" & f
rmtownsel.cmbtown.Text & "'")
         With myrs
                         txtt.Text = myrs!price
                         End With

        ElseIf optover.Value = True Then
        over = "select ('" & txtcrew & "')as quant,name,cost from overhauling where town='" &
 frmtownsel.cmbtown.Text & "'"
        Data1.RecordSource = over
        Data1.Refresh
        DBGrid1.ReBind
        Set myrs = mydb.OpenRecordset("select sum(cost)as price from overhauling where town='
" & frmtownsel.cmbtown.Text & "'")
```

```
        With myrs
                        txtt.Text = myrs!price
                        End With

        ElseIf optpr.Value = True Then
        par = "select ('" & txtcrew & "')as quant,name,cost from repair where town='" & frmto
wnsel.cmbtown.Text & "' union select ('" & txtcrew & "')as quant,name,cost from preventive wh
ere town='" & frmtownsel.cmbtown.Text & "'"
        Data1.RecordSource = par
        Data1.Refresh
        DBGrid1.ReBind
        '       Set myrs = mydb.OpenRecordset("select sum(cost)as price from repair where town
='" & frmtownsel.cmbtown.Text & "' union select sum(cost)as price from preventive where town=
'" & frmtownsel.cmbtown.Text & "'")
                Set myrs = mydb.OpenRecordset("select sum(cost)as price from repair where town
='" & frmtownsel.cmbtown.Text & "'")
        With myrs
                        txtt.Text = myrs!price
                        End With

        ElseIf optpo.Value = True Then
        pao = "select ('" & txtcrew & "')as quant,name,cost from overhauling where town='" &
frmtownsel.cmbtown.Text & "' union select ('" & txtcrew & "')as quant,name,cost from preventi
ve where town='" & frmtownsel.cmbtown.Text & "'"
        Data1.RecordSource = pao
        Data1.Refresh
        DBGrid1.ReBind
        'Set myrs = mydb.OpenRecordset("select sum(cost)as price from overhauling where town=
'" & frmtownsel.cmbtown.Text & "' union select sum(cost)as price from preventive where town='
" & frmtownsel.cmbtown.Text & "'")
        Set myrs = mydb.OpenRecordset("select sum(cost)as price from overhauling where town='
" & frmtownsel.cmbtown.Text & "'")
        With myrs
                        txtt.Text = myrs!price
                        End With

        ElseIf optro.Value = True Then
        rao = "select ('" & txtcrew & "')as quant,name,cost from overhauling where town='" &
frmtownsel.cmbtown.Text & "' union select ('" & txtcrew & "')as quant,name,cost from repair w
here town='" & frmtownsel.cmbtown.Text & "'"
        Data1.RecordSource = rao
        Data1.Refresh
        DBGrid1.ReBind
        'Set myrs = mydb.OpenRecordset("select sum(cost)as price from overhauling where town=
'" & frmtownsel.cmbtown.Text & "' union select sum(cost)as price from repair where town='" &
frmtownsel.cmbtown.Text & "'")
        Set myrs = mydb.OpenRecordset("select sum(cost)as price from overhauling where town='
" & frmtownsel.cmbtown.Text & "'")
        With myrs
                        txtt.Text = myrs!price
                        End With

        ElseIf optall.Value = True Then
        pro = "select ('" & txtcrew & "')as quant,name,cost from overhauling where town='" &
frmtownsel.cmbtown.Text & "' union select ('" & txtcrew & "')as quant,name,cost from repair w
here town='" & frmtownsel.cmbtown.Text & "' union select ('" & txtcrew & "')as quant,name,cos
t from preventive where town='" & frmtownsel.cmbtown.Text & "'"
        Data1.RecordSource = pro
        Data1.Refresh
        DBGrid1.ReBind
        'Set myrs = mydb.OpenRecordset("select sum(cost)as price from overhauling where town=
'" & frmtownsel.cmbtown.Text & "' union select sum(cost)as price from repair where town='" &
frmtownsel.cmbtown.Text & "' union select sum(cost)as price from preventive where town='" & f
rmtownsel.cmbtown.Text & "'")
        Set myrs = mydb.OpenRecordset("select sum(cost)as price from overhauling where town='
" & frmtownsel.cmbtown.Text & "'")
        With myrs
                        txtt.Text = myrs!price
                        End With


        End If
```

```
frmtools = 3

        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrx = mydb.OpenRecordset("select * from cost where town='" & frmtownsel.cmbtown.
Text & "'")
        Set myry = mydb.OpenRecordset("select * from discounted")
        Set myrt = mydb.OpenRecordset("select * from srate")

            With myrt
              nf = myrt!alpha
              pf = myrt!pe

        With myrx
                a = myrx!elcost
                b = myrx!wtcost
                c = myrx!bdcost
                npf = myrx!cscost
                d = npf * (1 + (nf / pf))
                e = txtcrew.Text
                f = txttisf.Text
                g = myrx!cmcost / 100
                h = txtint.Text
                I = txtcom.Text
                j1 = txtic.Text
                j2 = txttic.Text
                k = txtt.Text
                l = txtrr.Text
                m = lbldf.Caption
                n = txtcv.Text
                td = !cmcost
                j = j1
                txtic.Text = j
                jj = j2
                v = cmbtba.Text
                w = cmbtime.Text
                'tb=building
                'tc=crew size cost
                'cc=comuni
                'ct=tools cost/hour
            With myry
                yinf = myry!inf
                yint = myry!Int


                tc = (e * d * f * 30)
                tb = g * c * e
                elect = (e * a * f * 30)
                water = (e * b * f * 30)
                cc = (e * h * I * f * w)
                ct = (e * f * k * 30)
                txtd.Text = Format(((td) / 100), "percent")
                txtc.Text = Format(tc, "fixed")
                txtb.Text = Format(tb, "fixed")
                txtelect.Text = Format(elect, "fixed")
                txtwater.Text = Format(water, "fixed")
                txtcc.Text = Format(cc, "fixed")
                txtct.Text = Format(ct, "fixed")
                ttc = (1 + (yint / 100)) * (1 + (yinf / 100)) * (j + cc + water + elect + tb
 + tc + ct)
                lbltc.Caption = Format(ttc, "fixed")
                rpi = (1 * 52) / (ttc)
                lblrpi.Caption = Format(rpi, "scientific")
                lblmhc.Caption = Format(ttc / f, "fixed")

                'traditional Begins here
                txttic.Text = Format(j2, "fixed")
                tttc = (e * d * n * 30) / m
                ttb = g * c * e
                telect = (e * a * n * 30) / m
                twater = (e * b * n * 30) / m
                ttcc = (e * h * I * n * w) / m
                ttct = (e * n * k * 30) / m
                txttd.Text = Format(((td) / 100), "percent")
                txttc.Text = Format(tttc, "fixed")
                txttb.Text = Format(ttb, "fixed")
                txttelect.Text = Format(telect, "fixed")
```

```
            txttwater.Text = Format(twater, "fixed")
            txtttcc.Text = Format(ttcc, "fixed")
            txttct.Text = Format(ttct, "fixed")
            ttc2 = (1 + (yint / 100)) * (1 + (yinf / 100)) * (jj + ttcc + twater + telect
 + ttb + tttc + ttct)

            ttc22 = (ttc2 * (v / 100))
            lblttc.Caption = Format(ttc22, "fixed")

            rpi2 = (1 * 52) / (ttc2)
            lbltrpi.Caption = Format(rpi2, "scientific")
            lblse.Caption = Format((ttc22 - ttc), "fixed")
            lblmhct.Caption = Format(ttc22 / f, "fixed")

            If (ttc22 - ttc) >= 1 Then
            lblcomment.Caption = "Accept the Strategic Decisions"
            Else
            lblcomment.Caption = "Review the Strategic Decisions"
            End If


        End With
        End With
        End With

        cmdinsert_Click
    End Sub

    Private Sub cmdinsert_Click()
    'Load frmresult
    frmresult.Hide
    If optpre.Value = True Then
    frmresult.txtcp.Text = lbltc.Caption
    frmresult.txtfp.Text = lblttc.Caption
    ElseIf optrep.Value = True Then
    frmresult.txtcr.Text = lbltc.Caption
    frmresult.txtfr.Text = lblttc.Caption
    ElseIf optover.Value = True Then
    frmresult.txtco.Text = lbltc.Caption
    frmresult.txtfo.Text = lblttc.Caption
    ElseIf optpr.Value = True Then
    frmresult.txtcpr.Text = lbltc.Caption
    frmresult.txtfpr.Text = lblttc.Caption
    ElseIf optall.Value = True Then
    frmresult.txtca.Text = lbltc.Caption
    frmresult.txtfa.Text = lblttc.Caption
    ElseIf optpo.Value = True Then
    frmresult.txtcpo.Text = lbltc.Caption
    frmresult.txtfpo.Text = lblttc.Caption
    ElseIf optro.Value = True Then
    frmresult.txtcro.Text = lbltc.Caption
    frmresult.txtfro.Text = lblttc.Caption
    End If

    End Sub

    Private Sub cmdrep_Click()
    frmresult.Show
    End Sub

    Private Sub cmdatand_Click()
    d = Val(txtcrew.Text)



      f = txttisf.Text
      v = cmbtba.Text
    tc = lbltc.Caption
    mc = txtemc.Text
    fr = txtefr.Text
    fr = txtefr.Text
    ttc = lblttc.Caption

    oet = Val(txttisf.Text) / 52
```

```
        ttc = lblttc.Caption
        a = (tc + (mc * d * (Exp(-fr * oet) + fr * oet * Exp(-fr * oet))))
        lbltc.Caption = Format(a, "fixed")
        b = (ttc + (mc * d * (Exp(-fr * 1) + fr * 1 * Exp(-fr * 1))))
        lblttc.Caption = Format(b, "fixed")

        ttc22 = (b * (v / 100))
                'lblttc.Caption = Format(ttc22, "fixed")
        'rpi2 = (1 * 52) / (ttc2)
                'lbltrpi.Caption = Format(rpi2, "scientific")
                lblse.Caption = Format((ttc22 - a), "fixed")
                lblmhct.Caption = Format(ttc22 / f, "fixed")


        End Sub



        Private Sub cmdwithout_Click()
        d = Val(txtcrew.Text)


                 f = txttisf.Text
          v = cmbtba.Text
        tc = lbltc.Caption
        mc = txtemc.Text
        fr = txtefr.Text
        ttc = lblttc.Caption
        oet = Val(txttisf.Text) / 52
        c = (tc + (mc * d * (Exp(-fr * oet))))
        lbltc.Caption = Format(c, "fixed")
        d = (ttc + (mc * d * (Exp(-fr * 1))))
        lblttc.Caption = Format(d, "fixed")
        ttc22 = (d * (v / 100))
                'lblttc.Caption = Format(ttc22, "fixed")
        'rpi2 = (1 * 52) / (ttc2)
                'lbltrpi.Caption = Format(rpi2, "scientific")
                lblse.Caption = Format((ttc22 - c), "fixed")
                lblmhct.Caption = Format(ttc22 / f, "fixed")


        End Sub



        Private Sub Form_Load()
        Dim mdata As String
        mdata = App.Path & "/casting1.mdb"
        Data1.DatabaseName = mdata


        Me.Height = 8000
        Me.Width = 11000
        Me.Top = 100
        Me.Left = 100

        Set mydb = OpenDatabase(App.Path & "/casting1")
        Set myrs = mydb.OpenRecordset("select * from comm")

                'txtint.Text = k

        Set myry = mydb.OpenRecordset("select max(ryear)as ayo from datax WHERE town='" & frm
townsel.cmbtown.Text & "'")
                With myry
                Y = myry!ayo
                Me.Caption = "Tools / Equipment Planning and Maintenance Costing Unit For '"
& frmtownsel.cmbtown.Text & "' FOR THE YEAR" & " " & Y + 1
                End With


        'With myrc
        'n = myrc!pno
        'txtint.Text = (n * (n - 1))
```

```
    'End With

       With myrs
       If Not .EOF Then .MoveLast
       If Not .BOF Then .MoveFirst
       cmbcom.Text = !Name
       For I = 0 To .RecordCount - 1
       cmbcom.AddItem (!Name)
       cmbcom.ItemData(cmbcom.NewIndex) = !no
       .MoveNext
       Next I
       End With
    cmbcom_Click
    End Sub

    Private Sub optall_Click()
     cmdexecute_Click
    End Sub

    Private Sub optover_Click()
        cmdexecute_Click

    End Sub

    Private Sub optpo_Click()
     cmdexecute_Click
    End Sub

    Private Sub optpr_Click()
     cmdexecute_Click
    End Sub

    Private Sub optpre_Click()
        cmdexecute_Click

    End Sub

    Private Sub optrep_Click()
        cmdexecute_Click

    End Sub

    Private Sub optro_Click()
     cmdexecute_Click
    End Sub
```

APPENDIX IV: COMPUTER SAMPLE OUTPUTS

APPENDIX IVa: TITTLE PHASE

You are Welcome to

Computer Aided Maintenance Strategic Decisions Planni

CAMSOP 2003

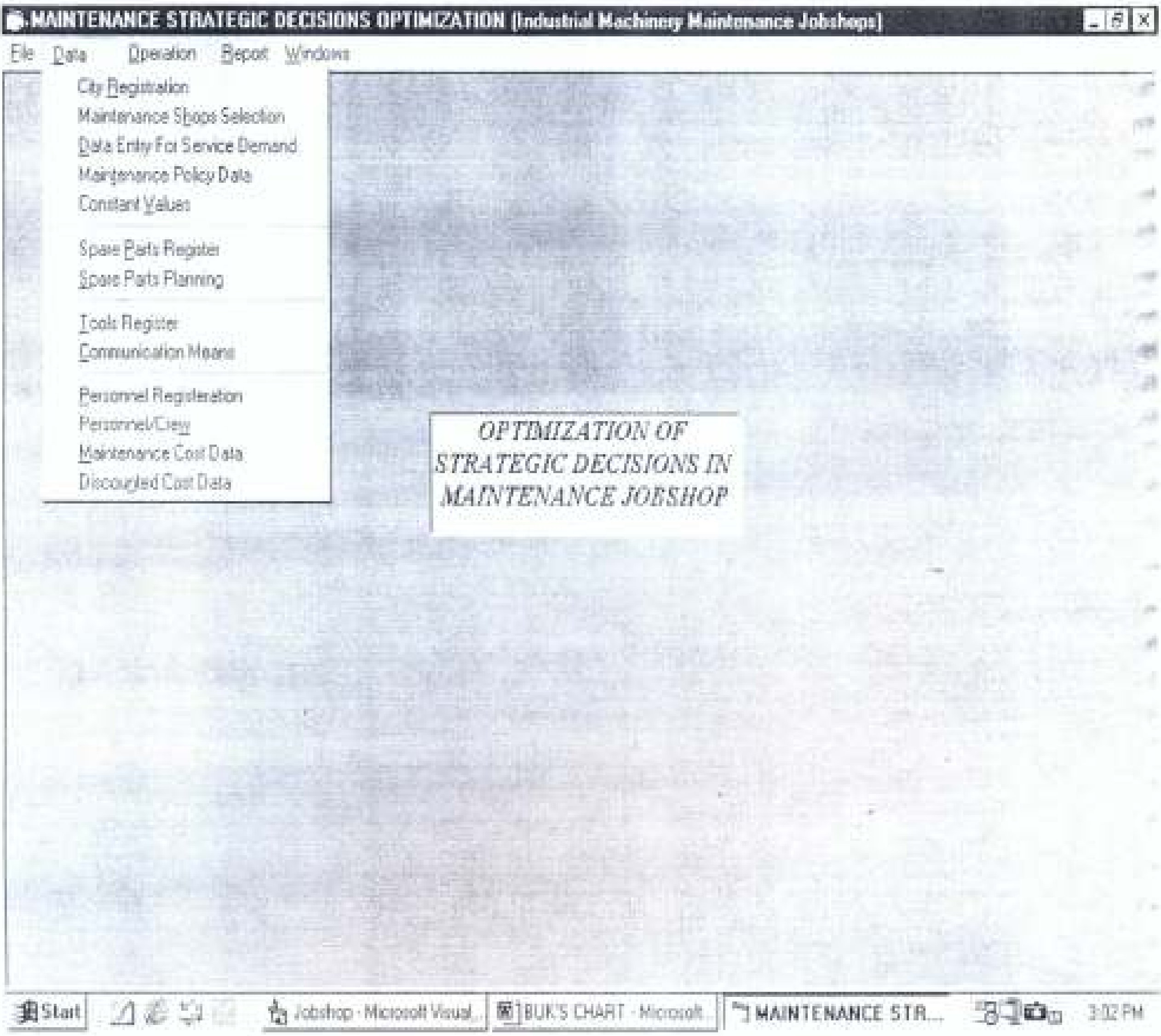
Developed by: *Engr. B. Kareem*

Supervised by: *Prof. A. A Aderoba*

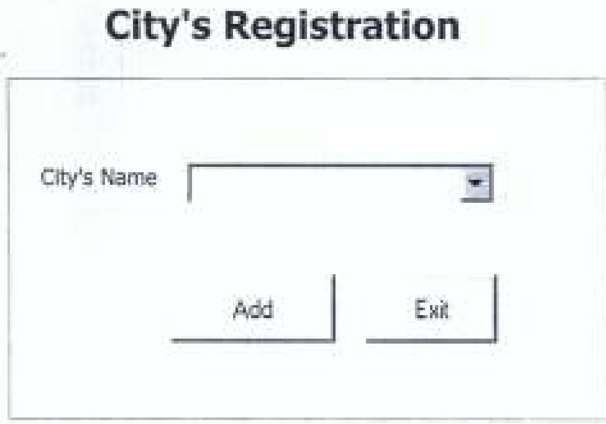
In Partial Fulfilment for the Award of a Ph.D. In Industrial Engineering

Department of Mechanical Engineering,
Federal University of Technology Akure

APPENKDIX IVb: DATA ENTRY PHASE



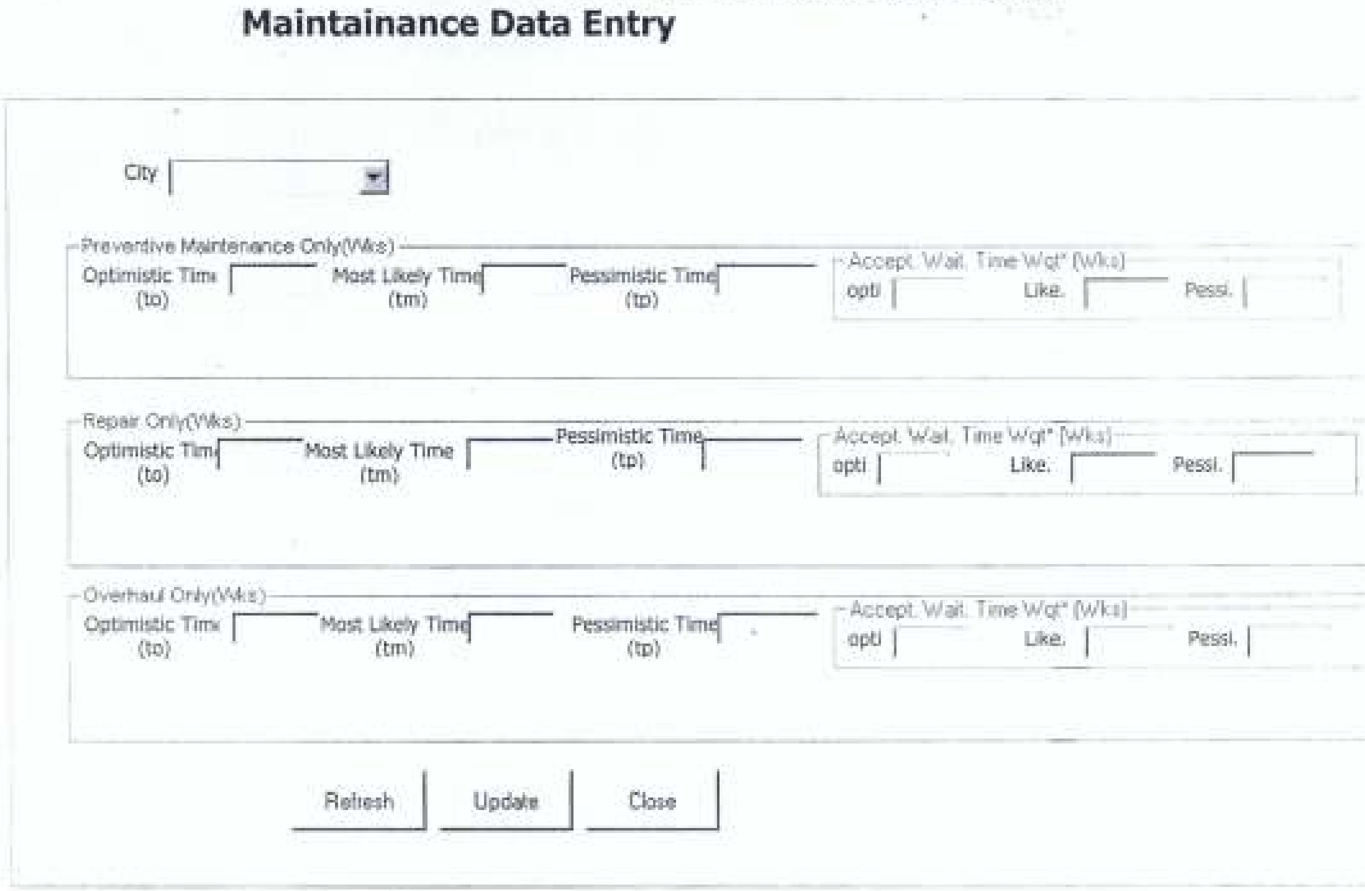
APPENDIX IVbi: CITY REGISTRATION



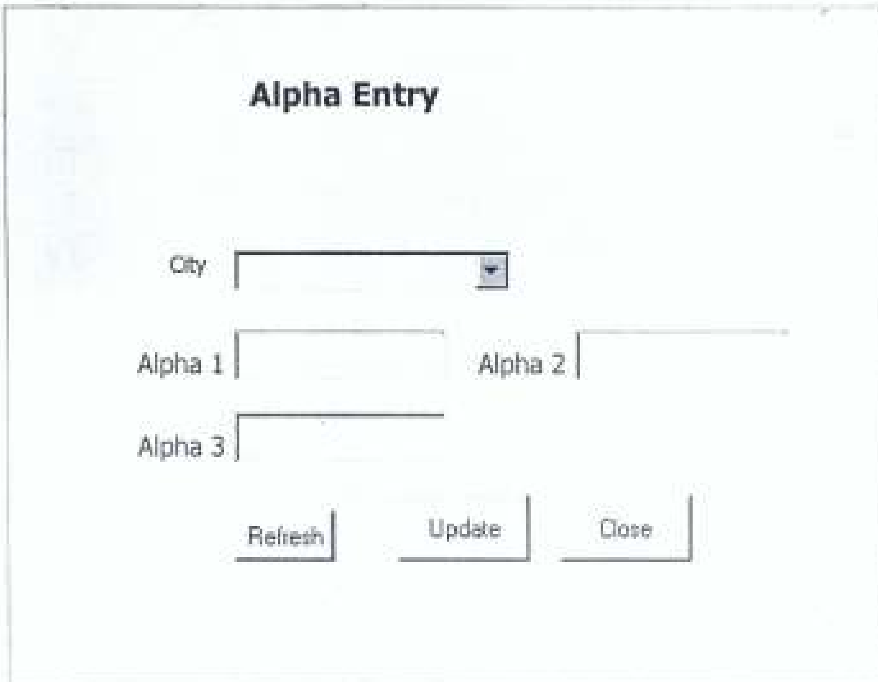
APPENDIX IVbii: MAINTENANCE JOBSHOP SELECTION

APPENDIX IVbiii: DATA ENTRY FOR SERVICE DEMAND

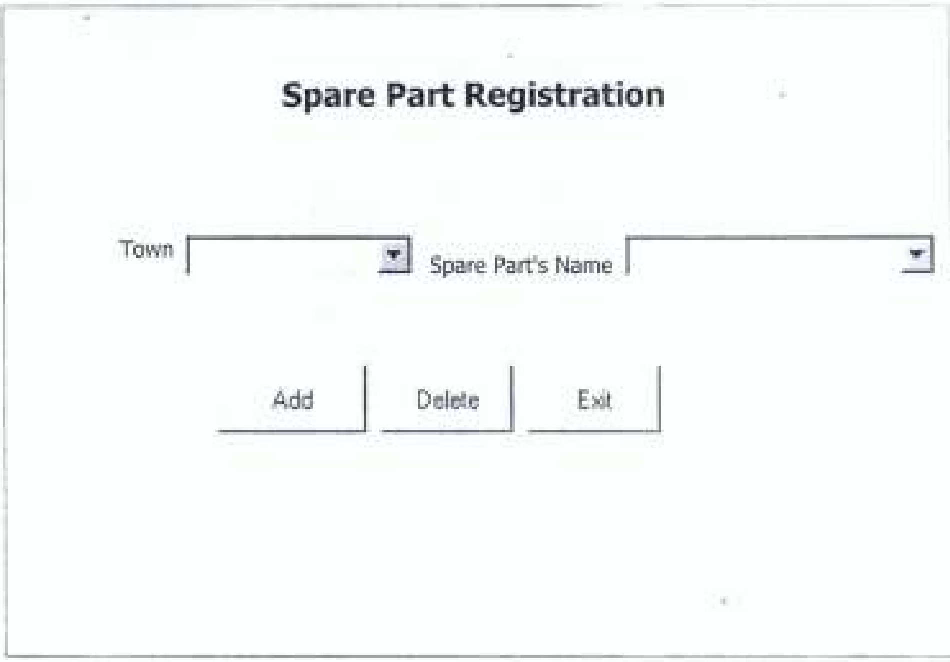
APPENDIX IVbiv: MAINTENANCE POLICY DATA



APPENDIX IVbv: CONSTANT VALUES DATA



APPENDIX IVbvi: SPARE PART REGISTRATION



APPENDIX IVbvi: SPARE PARTS REGISTRATION

Spare Parts Planning Entry

Town

Maintenance Type cmbtype

Spare Part Name Combo1

Annual Usage (U)

Ordering Cost (=N=)

Cost/Unit (R)

Carrying Cost (=N=

Use Rate (No/Wk)

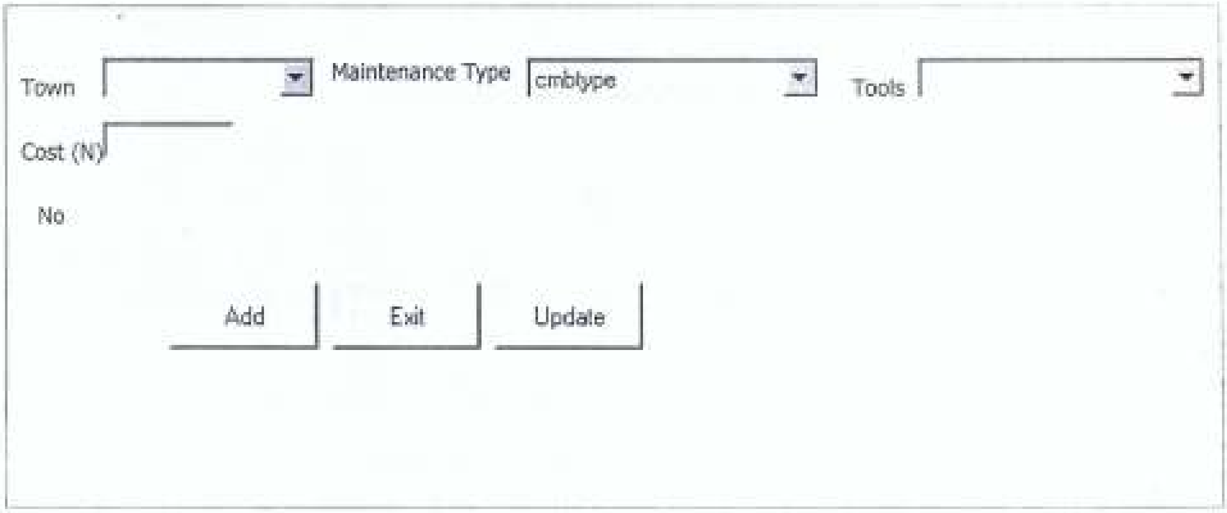
Supply Rate(No/Wk)

OK Update Refresh Exit

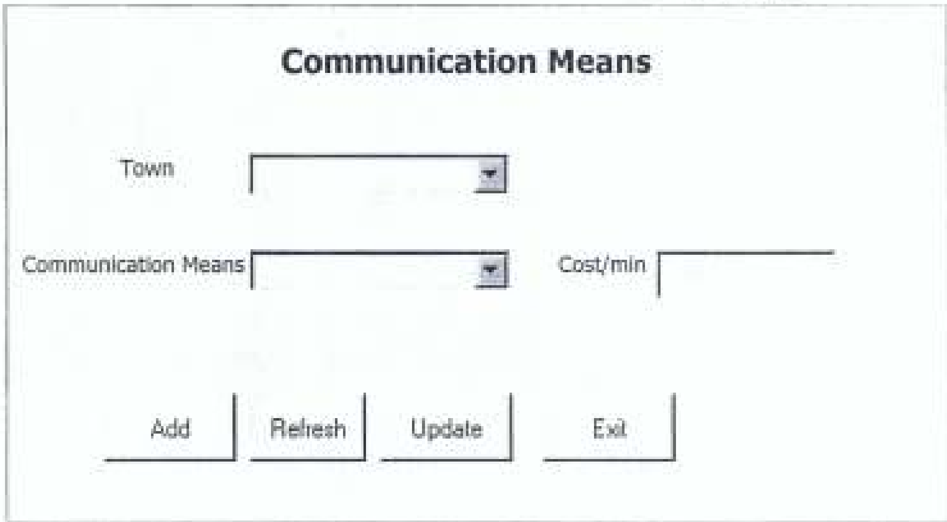
Date 2 / 2 /03

APPENDIX IVbviii: TOOLS REGISTRATION

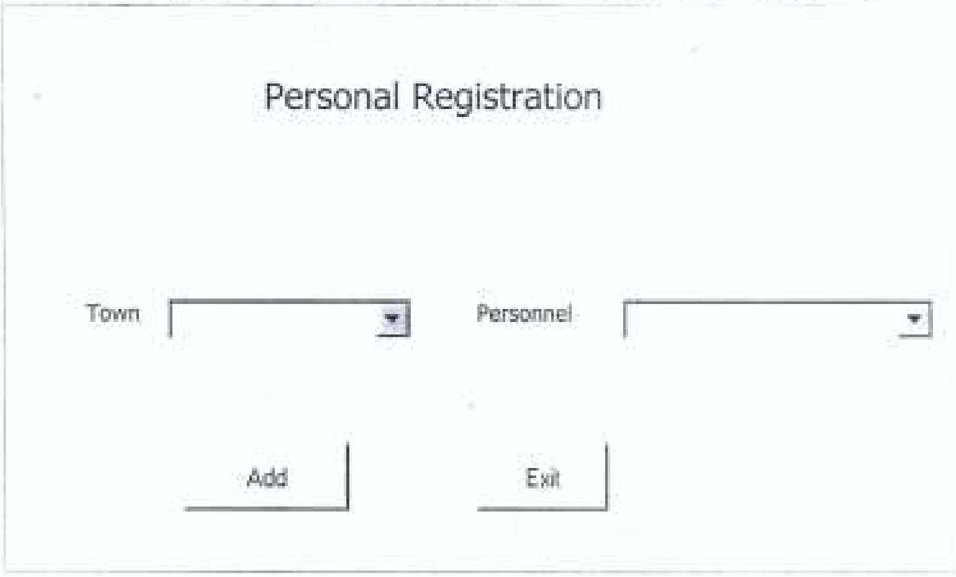
Tool Supplier Form



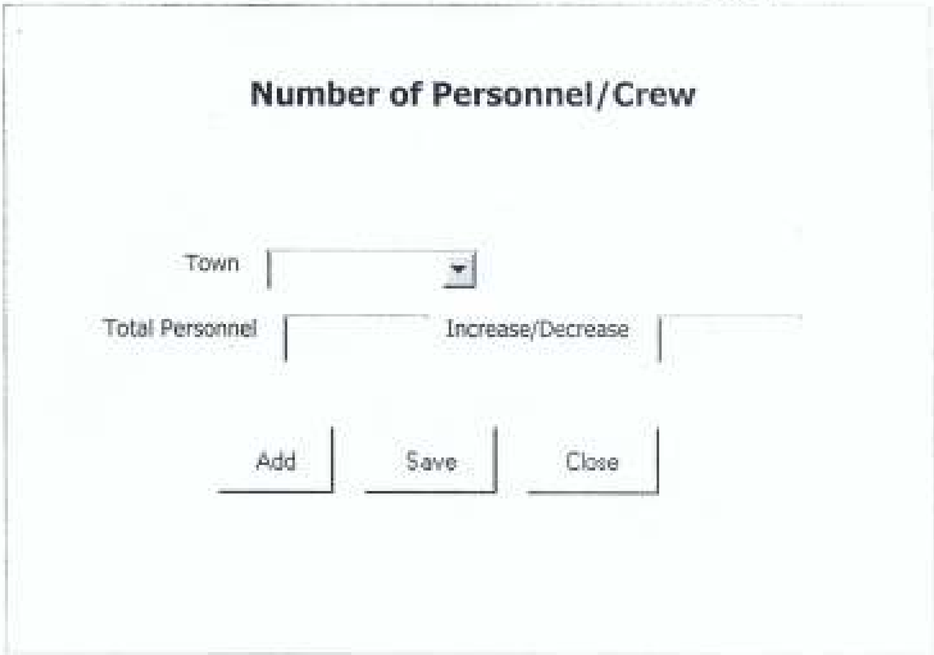
APPENDIX IVbix: COMMUNICATION MEANS



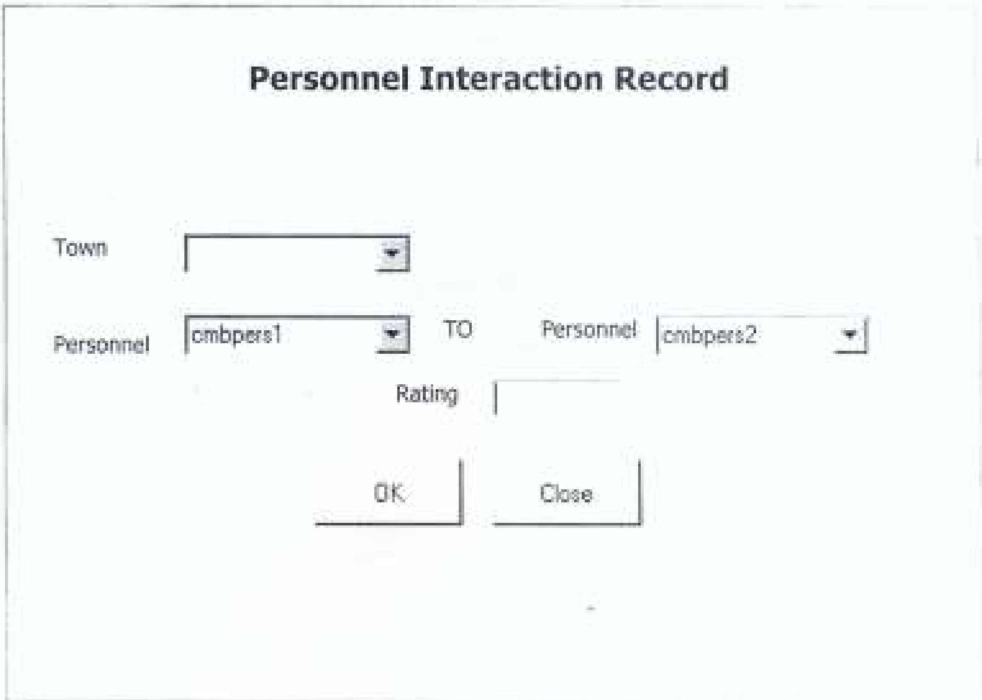
APPENDIX IVbx$_1$: PERSONNEL REGISTRATION



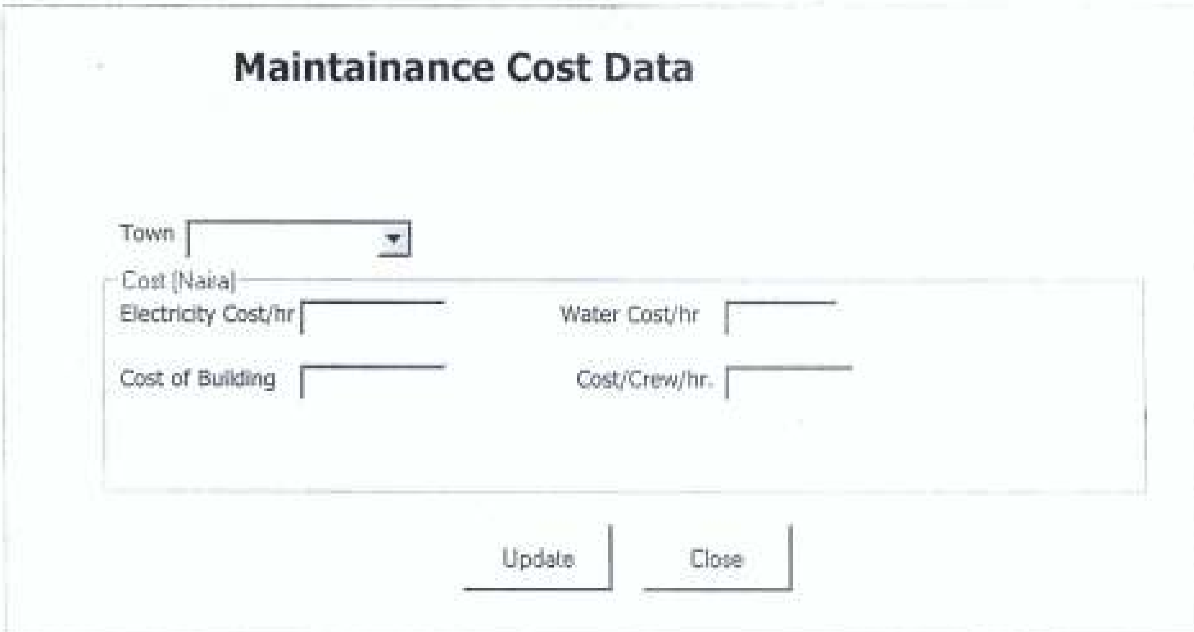
APPENDIX IVbx$_3$: PERSONNEL PER CREW



APPENDIX IVbxi: PERSONNEL INTERACTION RECORD

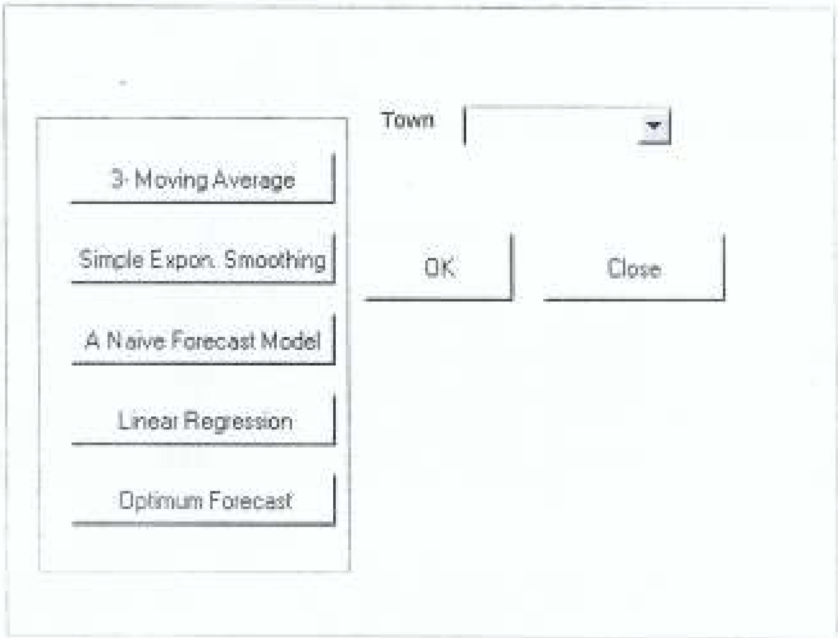


APPENDIX IVbxii: MAINTENANCE COST ENTRY



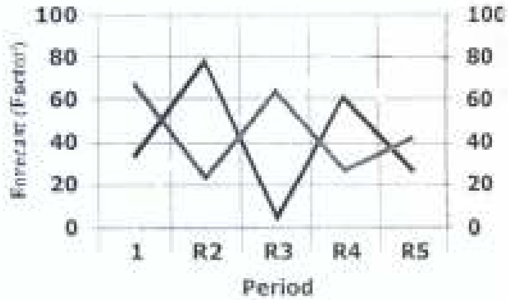
APPENDIX IVbxiii: DISCOUNTED COST DATA

APPENDIX IVc: FORECASTING



A Naive Forcasting Model

	Year	t	Data (xt)	Forecast (Ft)	Error (et)
*					



Next Forecast

MSE =

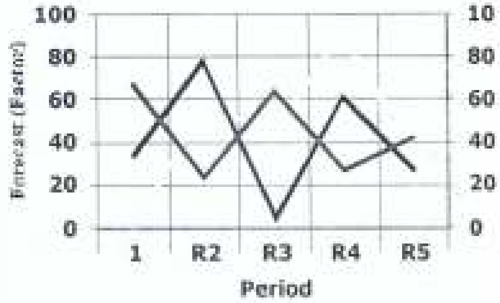
MSE

Maintenance Policy

APPENDIX IVcii: THREE-PERIOD MOVING AVERAGE

A Three-period moving Average

	Year	t	Data (xt)	Forecast (Ft)	Error (et)
*					



Next Forecast

MSE =

MSE

Maintenance Policy

Simple Exponential Smoothing

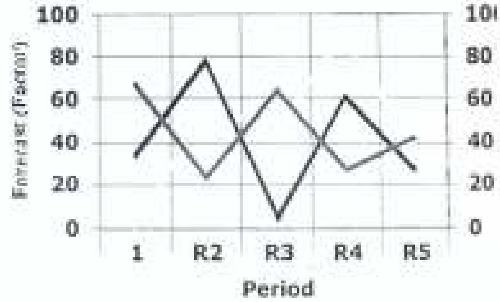
	Year	t	Data (xt)	Forecast (Ft)	Error (et)
*					

Next Forecast [ ]

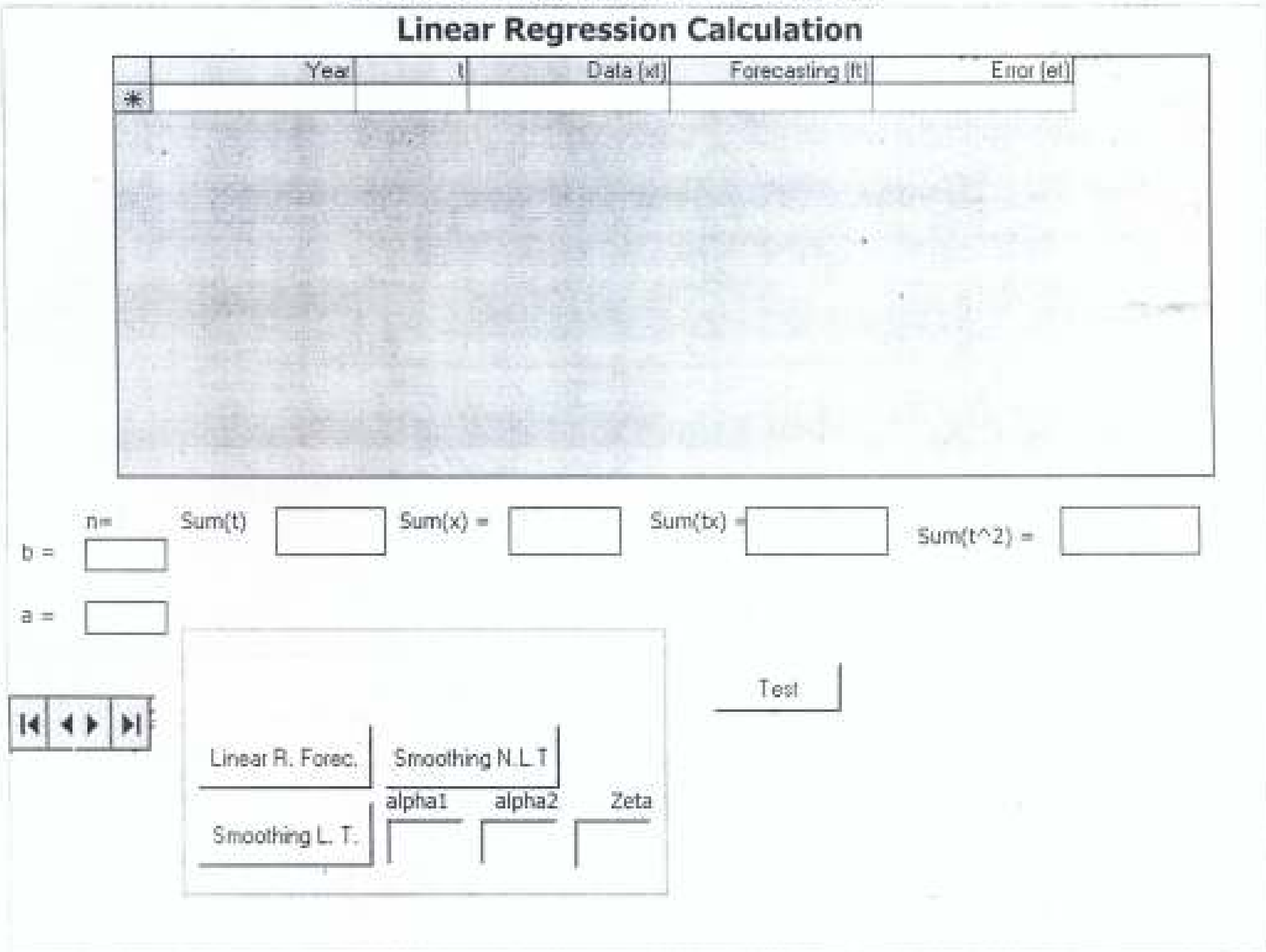
MSE = [ ]

MSE

Maintenance Policy

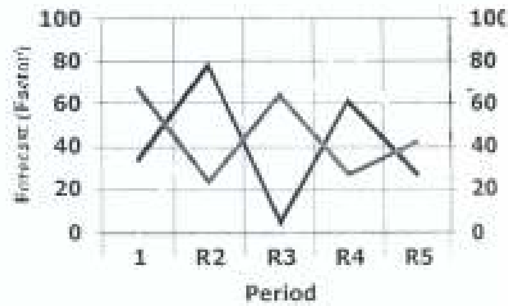


APPENDIX IVciv: LINEAR REGRESSION



Linear Regression Forecast

	Year	t	Data (xt)	Forecast (Ft)	Error (et)
*					



Next Forecast

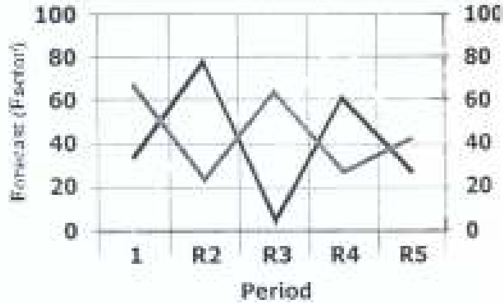
MSE =

MSE

Maintenance Policy

Exponential Smoothing Linear Trends

	Year	1	Data [xt]	Forecast [Ft]	Error [et]
*					



Next Forecast

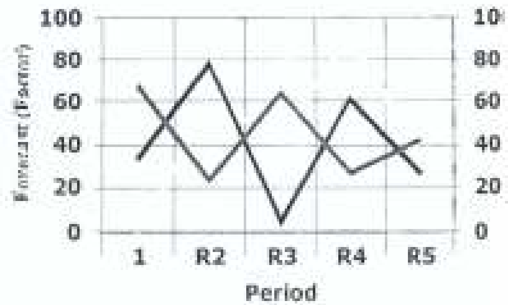
MSE =

MSE

Maintenance Policy

Smoothing A Nonlinear Trend

	Year	t	Data (xt)	Forecast (Ft)	Error (et)
*					



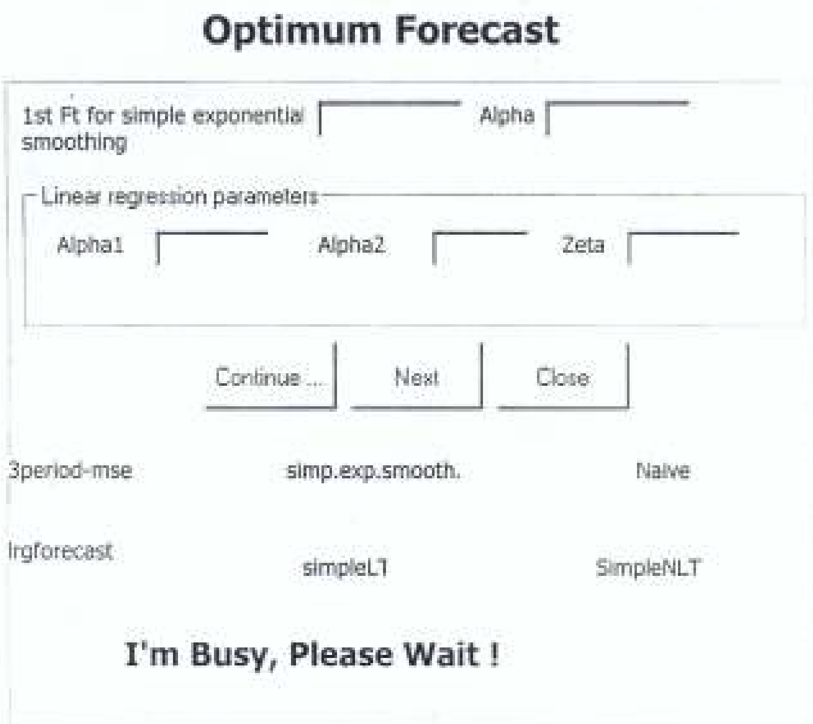
Next Forecast

MSE =

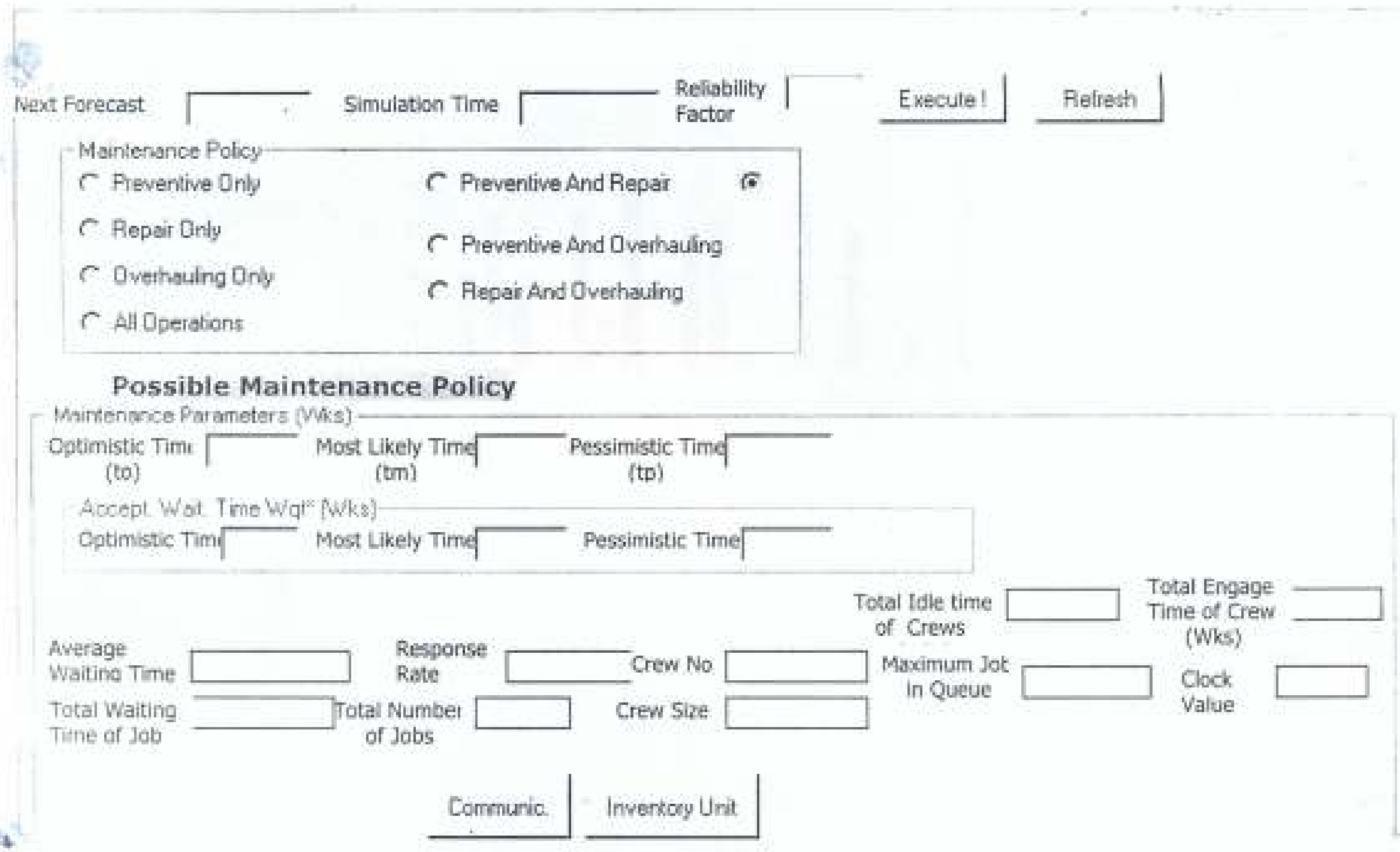
MSE

Maintenance Policy

APPENDIX IVcviii: OPTIMUM FORECAST



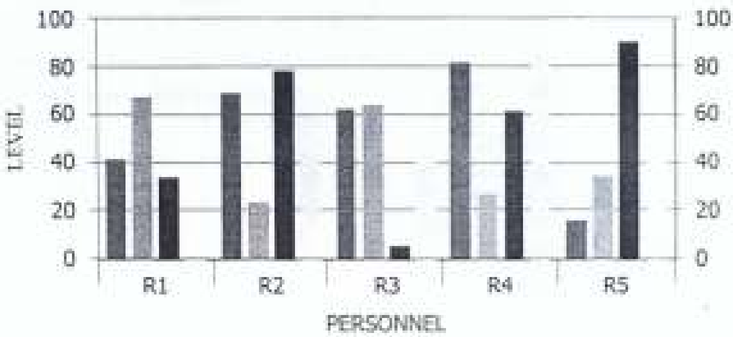
APPENDIX IVcix: MAINTENANCE POLICY UNIT



Crew No

APPENDIX IVcx: COMMUNICATION UNIT

Communication Level of Personels



Total Interaction=

Position	Level	Proportion

Total Level of Interaction

Close

APPENDIX IVcxi: SPARE PARTS INVENTORY UNIT

Spare Parts Inventory Planning Unit

Town | Crew No | Spare Part Name | Simulation Time

Maintenance Policy

- Preventive Only
- Preventive And Repair
- Repair Only
- Preventive And Overhauling
- Overhauling Only
- Repair And Overhauling
- All Operations

Equipment Maintenance data

Ave. Equipment Maintenance Cost/Year

Ave. Equipment Failure Rate(/Year)

Total Engage Time of Crew (Wk)

In Weeks or No/Week or =N=

Use Rate

Supply Rate

Engaged Time

Opt. Eng. Time

Total Out of Stock Time

Total Stock Time

Total No. of Spare Parts in Stock

Total No. Remain at the end of Period

Clock Value

Total No. Used/Period

Opt.

No. of Orders

Opt. Time/Order

Ordering Cost

Carying Cost

Total Inventory

Permanent/Fulltime

Ordering Cost

Carrying Cost

Total Inventory Cost

Total Cost

APPENDIX IVcxii: TOTAL COST UNIT

Tools / Equipment Planning and Maintainance Costing Unit(No equipment, no inventory failure

Crew No | Total Engage Time of Crew (Wk) | Interraction | Response Rate | Clock Value

Maintenance Policy

- Preventive Only
- Preventive And Repair
- Repair Only
- Preventive And Overhauling
- Overhauling Only
- Repair And Overhauling
- All Operations

Tools and Equipments maintenance

With one Standby | Without Standby | Report

Tools and Quantity Required

Quantity Required	Tool's Name	Cost/hr.
*		

Tools Cost/hr.

Divisional Factor

Contract/ Temporary Staff

Cost (Naira)

Electricity | Water | Communication Means | Cost/min. | Comm. Time (min.) 1 | Communication Cost

Other Cost (Naira)

Depreciation Cost of Building | at | Maintenance CrewCost (Naira) | Cost of Tools | Inventory Cost

Total Annual Maintenance Cost | Response-Cost Performance | Maintenance Wk. Cost

Permanent/ Full-time Staff

Cost (Naira)

Electricity | Water | Communication Cost

Other Cost (Naira)

Depreciation Cost of Building | at | Maintenance CrewCost (Naira) | Cost of Tools | Inventory Cost

Total Annual Maintenance Cost | %Budget Available 100 | Response Cost Performance Index | Maintenance Wk. Cost

Annual BudgetSuplus/Shortage

APPENDIX IVcxiii: BENEFIT- COST ANALYSIS UNIT

Maintainance Cost For Various Maintainance Policy

Maintenance policy cost per annum	Preventive (P)	Repair (R)	Overhauling(O)	All operation(A)	P and R	P and O	R and O
Contract staff (I)							
Full time staff (J)							

Execute

Benefit cost analysis of maintenance policies.

	P and R	R and O	O and A	A and P/R	P/R and P/O	P/O and R/O
Cost difference (I)						
Cost difference (J)						
Benefit cost ratio (I)						
Benefit cost ratio (J)						

APPENDIX V: DESIGN OF QUESTIONNAIRE

APPENDIX Va: PRODUCTION SHOP

(A) **INTRODUCTION**: This questionnaire is part of a research in Production/Industrial Engineering. The research topic is Optimisation of Strategic Decisions in Maintenance Job-shops. For this purpose, data are required (for the effective testing and analysis of the system) from the existing maintenance job-shops, as well as industrial plants. You are kindly requested to complete this questionnaire as quickly as possible. Your feedback/responses will be treated with strict confidentiality and under condition of anonymity.

Thank you so much for your cooperation.

(B) PREAMBLE QUESTIONS: Answer the following by filling or ticking the space provided.

(a) Name of the company/industry..

(b) Age of the plant ....

(c) Total number of industrial machines :

(i)Total number of production machines --

(ii)Total number of ancillary equipment --

(iii)Total number of material handling equipment --

(iv)Name of the external maintenance centre(s) patronized

(a)--

(b)--

(c)--

(d)--

(e)--

(v) State the area(s) of specialization of the centre(s) (Thick the applicable one(s)

(a) Preventive maintenance -------, repairs --------, overhauling --------,

(b) Preventive maintenance -------, repairs --------, overhauling --------,

(c) Preventive maintenance -------, repairs --------, overhauling --------,

(d) Preventive maintenance -------, repairs --------, overhauling --------,

(e) Preventive maintenance -------, repairs --------, overhauling --------,

(vi) Why are you patronizing the maintenance centre(s) in (iv)

(a) Management decision

(b) Proximity to the plant

(c) High quality of maintenance work

(d) Satisfying your response rate (i.e. acceptable waiting time to complete your job) .

(e) Good monitoring and control

(f) Others--

(vii) Why are you decided not to attend other available maintenance centre(s) in the environment?

(a) Their qualities have not been tasted before.

(b) Repair and maintenance over delayed (that is, not satisfying response rate)

(c) Improper repairing activities i.e maintenance crews are not competent

(d) Impose high charges on repairs i.e overcharging of maintenance activities.

(e) Job reporting procedure is too long.

(f) Insufficient basic repair and maintenance equipment.

(g) Lack of workspace.

(h) Inadequate security.

(i) Lack of basic spare parts.

(j) Poor documentation of repair work.

(k) Transportation problem

Others

(l) --

(m) --

(n) --

(viii) Comment on the maintenance facilities of the maintenance centre.

(a) Very good (b) good (c) average (d) poor (e) very poor.

(ix) The maintenance centre working environment and security.

(a) Very good (b) good (c) average (d) poor (e) very poor.

(x) Scheduling for the repair and overhaul of machinery.

(a) Very good (b) good (c) average (d) poor (e) very poor.

(xi) The procedure for collecting the repair jobs.

(a) Very good (b) good (c) average (d) poor (e) very poor.

(C) Thick and / or fill the appropriate space provided: concerning service demand.

Table 1.0 Service Demand

Year	Average No. of maintenance call per…..	No. of machines/ Equipment at the end of the year	Name of the machines/Equipment *(Attach extra sheets if applicable)	Nature of maintenance	Average time spent in maintenance centre	Expected completion time
1991				Preventive…. Repair……. Overhaul……		
1992				Preventive….		

				Repair...... Overhaul......		
1993				Preventive.... Repair...... Overhaul......		
1994				Preventive.... Repair...... Overhaul......		
1995				Preventive.... Repair...... Overhaul......		
1996				Preventive.... Repair...... Overhaul......		
1997				Preventive.... Repair...... Overhaul......		

1998				Preventive.... Repair...... Overhaul......		
1999				Preventive.... Repair...... Overhaul......		
2000				Preventive.... Repair...... Overhaul......		
2001				Preventive.... Repair...... Overhaul......		
2002				Preventive.... Repair...... Overhaul......		

2003				Preventive.... Repair....... Overhaul......		

APPENDIX Vb: MAINTENANCE JOBSHOP

(A) **INTRODUCTION**: This questionnaire is part of a research in production/industrial Engineering. The research topic is optimisation of strategic decision in maintenance job- shops. For this purpose data are required (for the effective testing and analysis of the system) from the existing maintenance job-shops, and industrial plants. You are kindly requested to complete this questionnaire as quickly as possible. Your feedback/responses will be treated with strict confidentiality, and under condition of anonymity.

Thank you so much for your cooperation.

(B) PREAMBLE QUESTIONS: Answer the following by filling or ticking the space provided.

(i) Name of the maintenance job-shop --

(ii) Location of the job-shop--

(iii) Age of the maintenance job-shop ....

(iv)State your major customers (industrial plants) patronizing your establishment and their address.

(a) --

(b) --

(c) --

(d) --

(e) --

(v)What are the major complaints of your customers.

(a) Repair and maintenance over delayed.

(b) Improper repairing activities.

(c) Impose high charges on repairs.

(d) Job reporting procedure is too long.

(e) Insufficient basic repair and maintenance equipment.

(f) Lack of workspace.

(g) Poor documentation of repair work.

(h) Lack of basic spare parts.

(i) Transportation problem.

(j) Insufficient infrastuctural facility.

Others --

(C) (i) Tick and/ or fill appropriately the spaces provided concerning operation of maintenance centre

Nature of maintenance	Name of machines/ equipment brought for service *(Attach sheet if required)	Tools / Equipment used *(Attach sheet if required).	Average time used for maintenance
Preventive			
Repair			
Overhaul			

(D) Fill the space below concerning maintenance spare parts inventory.

Nature of maintenance	Name of spare part(s) stock	Average No. used per	Average No. supplied per	Ordering cost per order	Holding cost per spare part	Cost of a unit spare part .
Preventive						
Repair						
Overhaul						

Note that: Ordering cost comprises

-Cost to request, process and issue the purchase order

-Cost to receive, inspect, identify and handle the incoming parts.

- Cost of receiving orders.

Inventory carrying or Holding cost includes:

-Interest rates

-Depreciation cost

-Insurance and taxes

-Cost of space, heat, or security etc.

(i) Tick the channel of supply for the class A spare part(s) in (D)

(a) Local vendors

- Local contractor.................

- Spare part shop......................

- Local manufacturing company.....................

(b) Foreign vendor

- Foreign contractors.................
- Foreign spare part manufacturer.....................

(ii) Why did you prefer:

Local spare parts:

(a) cheap (b) durable (c) available (d) centre policy

Foreign spare parts:

(a) cheap (b) durable (c) available (d) centre policy.

Both local and foreign spare parts:

(a) Using local spare when durability is required.

(b) Using foreign spare when durability is required.

(c) Using local spare when cost is lower.

(d) Using foreign spare when cost is lower.

(e) Using local spare because of its availability.

(f) Using foreign spare because of its availability.

(g) Using both foreign and local spare based on center's policy.

(E) (i) How many maintenance gangs are you operating presently?

(a) One (b) two (c) Three (d) Four (e) Five (f) More than Five

(ii)How many maintenance personnel constitute a crew (gang)?

(a) 2 – 4 (b) 4 – 6 (d) 6 – 8 (d) 8 – 10 (e) 10 – 12 (f) above 12

(iii) Tick and fill the space provided concerning maintenance personnel.

Maintenance Personnel (Cadre)	Qualifications (WASC, ND, HND, B.Sc etc).	Year of experience	Gross Salary per month	Level of Competence
i				Low....... Average...... High.......
ii				Low....... Average...... High.......
iii				Low....... Average...... High.......
iv				Low....... Average...... High.......
v				Low....... Average...... High.......
vi				Low....... Average...... High.......

vii				Low…… Average….. High……
vii				Low…… Average….. High……
ix				Low…… Average….. High……

(iv) Tick the means of communication of Maintenance Personnel

(a) NITEL (b) GSM (c) INTERNET (d) MEMO (e) PABX (f) Others……………

(v) Indicate the level of communication between Maintenance Personnel using the following notation:

Daily communication = 5

Every 2-days = 4

Every 3-days = 3

Every 4-days = 2

Weekly = 1

No communication = 0

	i	ii	iii	iv	v	vi	vii	viii	Ix
i									
ii									
iii									
iv									
v									
vi									
vii									
viii									
ix									