DEVELOPMENT OF A QUEUEING MODEL FOR EFFECTIVE CREW SIZE IN MAINTENANCE OPERATIONS

BY

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(B.Eng. Mechanical Engineering, F.U.T.A, 1994)

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 M.ENG. (PRODUCTION ENGINEERING)

FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, NIGERIA

SEPTEMBER, 1998

ABSTRACT

This thesis describes the use of heuristics and cost models based on the queueing theory to determine effective crew size for maintenance operations. The model was applied to mechanical maintenance workshop, Federal University of Technology, Akure, due to the fact that it has characteristics of external maintenance system. A computer software in "QBASIC" was developed to solve the model. The results obtained from this approach showed that, the use of heuristics generated effective crew size of one (a seven-man crew), while that of maintenance cost model was two, given a difference of 50%. Also by using deterministic cost model 1.5 secs. was used to process the results, while the time used to process the results in stochastic cost model depends on maximum simulation time MCT , but for heuristic it was just 0.5 second. The results revealed the advantage of using heuristic over complex equations of maintenance cost models. Therefore, to achieve higher response rate, the jobshop should operate on two crews. Although, management can decide to operate on one crew (as prescribed by heuristic) if other maintenance strategic decisions are in her favour than any other jobshops in the environment.

Finally, the results generated by both deterministic and stochastic cost models showed that both are equally likely to describe the maintenance jobshop under study.

DEDICATION

Dedicated to:

The Owner of the heavens and earth and whatever it contain.

My parents – Mr. & Mrs. Abdkareem and well wisher.

CERTIFICATION

We certify that this thesis was the work of KAREEM, Buliaminu in the Department of Mechanical Engineering, School of Post Graduate Studies, Federal University of Technology, Akure, Ondo State, Nigeria.

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ACKNOWLEDGEMENT

I thank Almighty Allah, the Cherisher, the Sustainer of the whole universe and whatever it contains for making this work a reality.

"Whoever unthankful to people, unthankful to God" (Dawood). My profound thanks go to my Supervisor Engr. Dr. A. A. Aderoba (Reader/Associate Professor of Production Engineering) for his invaluable advice, thorough supervision and for, taking pains to read through and correct this thesis.

I owe a special debt of gratitude to the entire staff of the Department of Mechanical Engineering, Federal University of Technology, Akure. Among them are Dr. O. P. Fapetu (Coordinator of Mechanical Engineering Department), Engr. Dr. C. O. Adegoke, Engr. Ogunleye, Engr. T. I. Mohammed, Engr. E. I. Bello, Engr. S. A. Adejuyigbe, Engr. K. O. Lawal for their support and useful suggestions.

I also acknowledge the assistance rendered by the management and staff of works department and bursary departments, Federal University of Technology, Akure, in obtaining necessary data/information used in this study.

NOMENCLATURE

C_1	Cost of using a crew size per day
C_2	Cost of waiting of job per day
λ	Rate of reporting maintenance job
μ	Rate of departure of job
Ls	Number of jobs in the system
Lq	Number of jobs in the queue
Ps	Degree of utilization of service facilities (Utilization factor)
P_{ZERO}	Probability of no customer (job) in the system
S	Number of maintenance crew size
TC	Average total maintenance cost per day
Ws	Waiting time of job in the system
Wq	Waiting time of job in the queue
Wq*	Acceptable response rate
T_n	Repair time for the nth failure
V(t)	Maintenance backlog at time t
W(t)	Repair backlog at time t
δ	Time between failure
θ	Threshold value
S_T	Service time
A_T	Arrival time
$\overline{S_T}$	Mean service time
O_i, f_n	Observed frequency of service time and arrival time distributions respectively.
n_i, T_n	Expected (theoretical) frequency of both service time and arrival time distributions respectively.
X^2	Chi - square

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1.0 INTRODUCTION

1.1 STRATEGIC DECISIONS IN MAINTENANCE JOBSHOPS

There are many definitions attributed to maintenance in literatures, but the one from British Standard Institution (1974) defined maintenance generally as the set of "actions" carried out to retain facilities in use, (preventive maintenance), or restore them back to "acceptable" condition, (corrective maintenance) [5]. A centre where these maintenance actions or activities are carried out on public facilities is known as a "maintenance jobshop".

The maintenance jobshop is open to every customer in the environment who wishes to repair or maintain their facilities without restriction. A maintenance engineer who has established or has intention of establishing a maintenance jobshop for public use must put into consideration other competitors. Therefore, management must ensure that maintenance activities are monitored, evaluated and reviewed from time to time, so that problem areas are identified and appropriate solutions are applied so that the essence of establishing such a maintenance jobshop will not be in jeopardy.

In view of this, a model can be developed to diagnose the problem areas in order to improve the effectiveness of the system. There are myriad of problems associated with maintenance jobshop. These problems depend on how effective maintenance management is. Effective maintenance management requires a great deal of data, a huge volume of paper work and records etc; if these are properly simulated, it can lead to the simplification and streamlining of maintenance activities [10].

The strategic decisions of maintenance management which can generate minor and major problems are given below [1].

i. Service demand forecast;

ii. Crew size determination;

iii. Tools and Equipment planning;

iv. Spare parts planning;

v. Maintenance operation planning;

vi Evaluation techniques adopted by the management.

These problem areas need to be diagnosed for effective operations of the maintenance jobshop. Figure 1.1 shows the interrelationships between these strategic decisions.

Problems of lack of effective maintenance are evidenced both in developed and developing worlds. But concerted efforts put up in solving these problems in the former is better than the latter. A United Kingdom Government Report published in 1970 (Department of Industry's Report in Maintenance Engineering HMSO, London, 1970) showed that British Manufacturing Industry wasted colossal sums of money each year because of ineffective and badly organised maintenance [17].

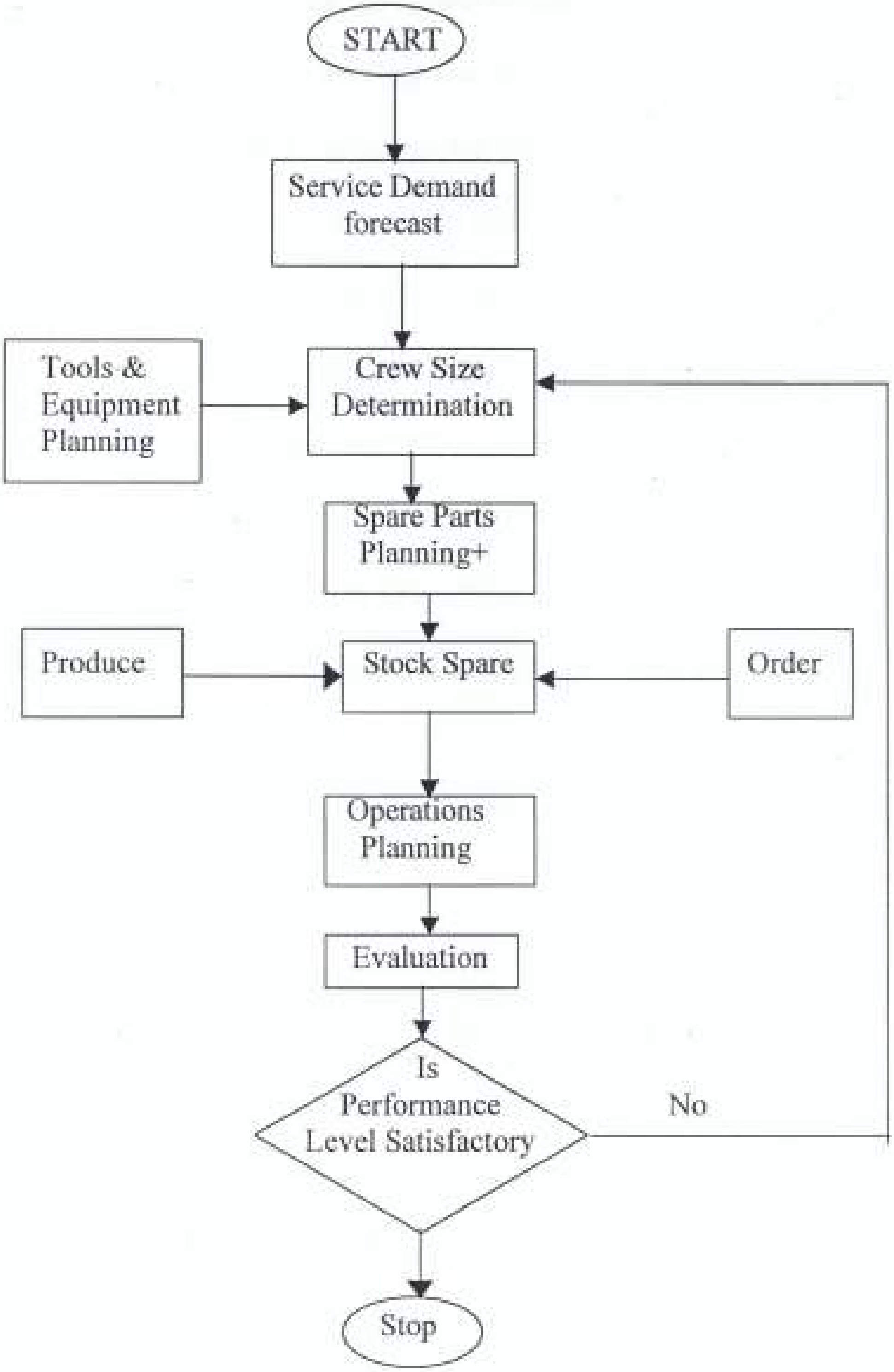


Fig. 1.1 Inter-relationships Between Strategic Decisions

Source: Aderoba and Lawal [1].

Also, in developing countries, slow pace of maintenance improvement has caused a lot of havoc to industrial development which have direct adverse effect on our economy. Everyday, new machinery are imported as a result of lack of proper maintenance for old machinery. When such items are no longer available abroad (due to technological development or otherwise), it signifies the end to industries here still depending on such items.

What is an effective maintenance crew? An effective maintenance crew consists of a team of technical personnel fully competent to inspect, diagnose, maintain, test, and certify a maintenance requisition. Determination of crew size in a maintenance system which will generate a higher response rate (that is, a lower waiting time) is known as "effective crew size determination". For the purpose of this study, "model for crew size determination in maintenance operations" will be developed.

1.2 SIGNIFICANCE OF CREW SIZE DETERMINATION

Crew size for maintenance operations must be determined for effective utilization of maintenance machinery and to achieve higher response rate. If maintenance crew is underestimated the following problems may arise:

i. Waiting time for the repairs and maintenance will be higher. Customers will be running away from the system (reneging).

ii. Maintenance jobs will be higher – queue will be too long.

iii. Loss in maintenance output.

iv. Excess overtime – Maintenance crew will be overworked/overused.

v. Frequent emergency maintenance work in the jobshop.

vi. Problem of inventory control of spare parts.

1.3 IMPORTANCE OF THE STUDY

The study shows that negligence on the part of management to install a well organised maintenance system will affect the maintenance organisational objective of increasing customer's patronage. It helps also to determine the effective crew size that will cope with teaming customers reporting one repair job or other.

In summary, effective crew size determination will enable the maintenance management to monitor how well the maintenance jobshop is using resources allocated to the system.

1.4 OBJECTIVE OF STUDY

The main aim of this study is to develop a model for determining the effective crew size for a maintenance jobshop.

The study is carried out using Queueing model. Queueing model is a versatile operations research tool for solving a myriad of maintenance problems. The results obtained using heuristic and one obtained using the complex form of queueing model are compared to determine how efficient the heuristic is. Time of the computation (using computer) are also compared to show how easy the practitioner can apply the heuristic to maintenance crew size determination.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 REVIEW OF CURRENT WORKS IN MAINTENANCE PLANNING

Determination of organisational performance has been receiving considerable attention of some researchers over the last couple of decades [22]. The maintenance workshop performance is a function of the following criteria [15]:

i. Efficiency, a measure of "how right" things are working;

ii. Effectiveness, a measure of actual output against planned output, i.e. are you accomplishing the "right" things;

iii. Productivity, the ratio of output to input;

iv. Profitability, the ratio of sales revenue to the cost incurred;

v. Quality, conformity to specification;

vi. Quality of work life, a measure of effective responsiveness of human beings to work in and living in an organisational system;

vii. Innovation, defined as the development and use of method of technology.

Effectiveness of various strategic decisions (Section 1.1) in many maintenance organisations is being viewed as an important factor that deserves evaluation.

Effectiveness of crew size in maintenance operations had been receiving attention in the past years. Raymond in Higgins and Marrow [10] developed an approach that is particularly well adapted to the study and improvement of maintenance performance. The objective of this approach is to minimise the operation time with a reasonable number of operators. The tool used for this purpose was "the multiple-activity process chart". Raymond broke the operation time into three:

(i) Make ready time;

(ii) Do time; and

(iii) Put away time.

The operation time in the system can be reduced by introduction of another helper to the operator. This will increase machine utilization and operator effectiveness. He gave the following definitions:

(i) Machine utilization $= \frac{\text{Machine time}}{\text{Total operation time}}$

(ii) Operation effectiveness $= \frac{\text{Man-time}}{\text{Total operation time}}$

The consequence of introducing another operator was the reduction in waiting time of the customers.

Also in Lindley [14], Lester described behaviours of the maintenance group (crew) which may have influence on the response rate of the customers.

These are:

i Some members of the group may be too lazy, hence, longer repair time;

ii There will be influence of an individual in the group. This is known as "group dynamics";

iii One of the members of the group may not be competent enough to perform the job thus leading to delays in maintenance activities;

iv Group effectiveness takes precedence over an individual.

He also described the behaviours of the maintenance management that may influence the effectiveness of the maintenance group. These are:

i. Keeping in mind the relationship of individual to its work group;

ii. Individuals should not be embarrassed or expected to perform contrary to the group's norms;

iii. Management should respect their collective power to be able to achieve high response rate;

iv. Management should work with them to solve a problem instead of trying to force them to change a direction that seems to satisfy their collective needs;

v. They should acknowledge the presence of influential leaders in every group. This may be done by virtue of age, experience know-how etc. If all the above points are achieved, the group will work effectively, hence leading to reduction in waiting time of the customers.

However, queueing model which is a modern industrial engineering quantitative tool could be used to diagnose the problems of the maintenance operations.

Takacs [25] developed a queueing model on the busy period of single-server queue with Poisson input and general service time. In his model, he determined the following probabilities:

i. The length of a busy period ($\leq x$)

ii. The maximum queue size during the busy period in the maintenance jobshop ($\leq k$).

iii. The maximum virtual waiting time during the busy period ($\leq y$).

He gave the following mathematical methods for determining the probabilities.

For initial conditions:

$P(x, k/i)$ = $P[\theta \leq x \text{ and } \Sigma(t) \leq k \text{ for } 0 \leq k \leq \theta/\Sigma [o] = i]$

for $x \geq 0$ and $0 \leq i \leq k$ 2.1

and

$G(x, y/c)$ = $P[\theta \leq x \text{ and } y(t) \leq y \text{ for } 0 \leq t \leq \theta_O/y(o) = c]$

for $x \geq 0$ and $0 \leq c \leq y$ 2.2

$P(x, k/i)$ = Probability that the initial busy period has a length $\leq x$ and the maximum queue size during the initial busy period is $\leq k$, given that the initial queue size is i; and $G(x, y/c)$, the probability that the initial busy period has length $\leq x$ and the maximum virtual waiting time during the initial busy period is $\leq y$, given that the initial occupation time of the server is c.

$\Sigma(t)$ = the queue size at time t, number of customer in the system at time t.

$y(t)$ = the virtual waiting time at time t, that is, the time that a customer has to wait if he arrives at time t,

λ^{-1} = arrival time

μ^{-1} = service time,

λ and μ are independent.

$\Sigma[o] = 0$, $y(o) = 0$, then $\theta_0 \equiv 0$ for initial conditions.

If $\theta_0 = 0$, then $\Sigma(o) = i$, $i \geq 0$

$y(o) = c$, $c \geq o$

Then the probabilities for any other busy period:

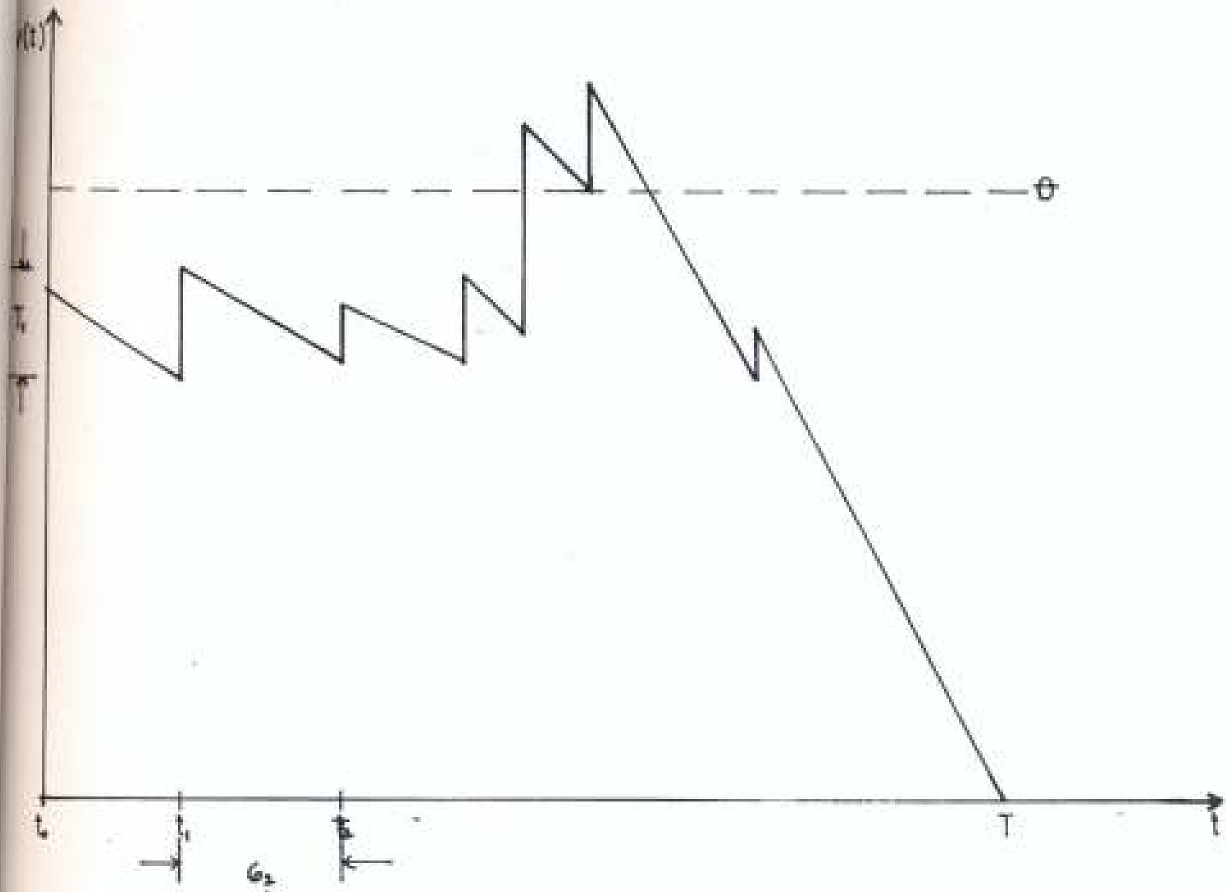
$$P(x, k) = p(x, k/i) \qquad \text{.......................................2.3}$$

i.e. the probability that the length of any busy period other than the initial one is ≤ x and the maximum virtual waiting time during busy period is ≤ y, is given by:

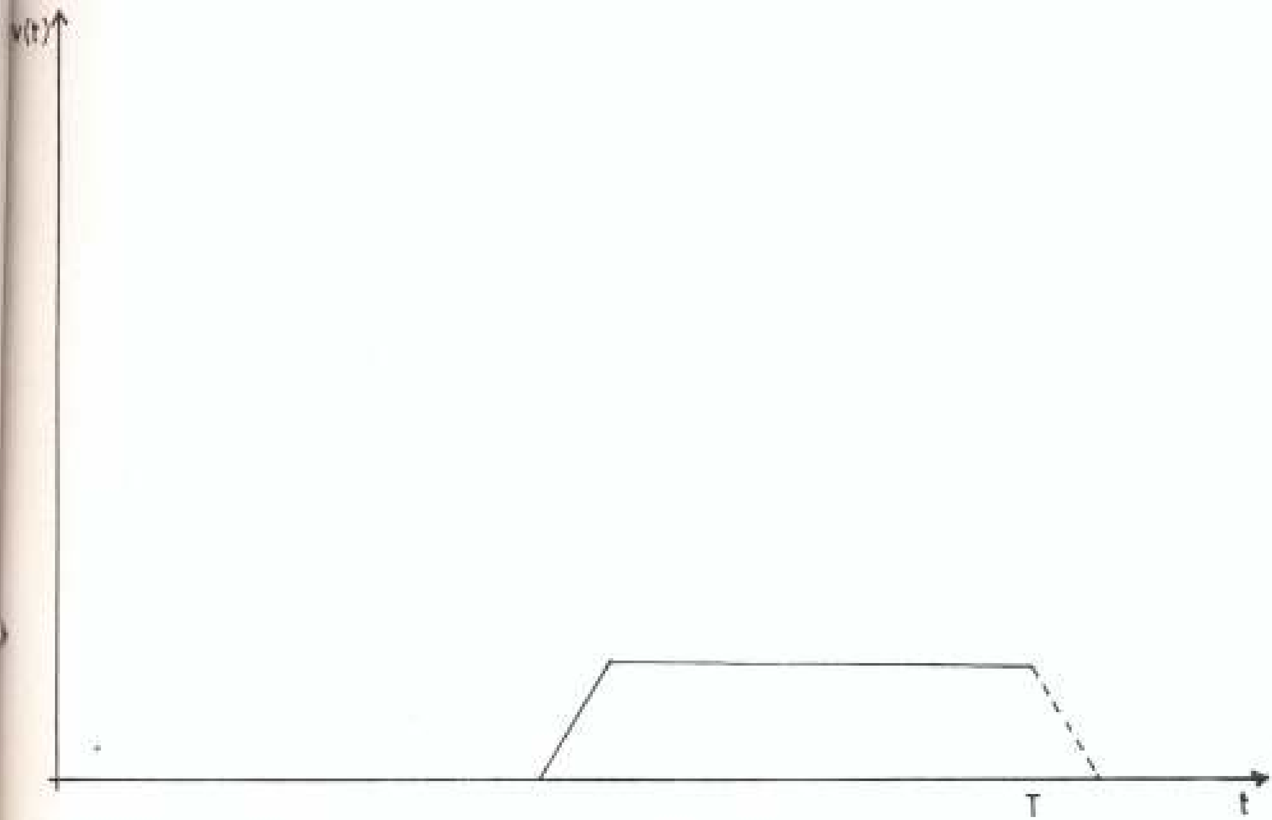
$$G(x,y) = \int_o^y G(x, y/c)\, dH(c) \qquad \text{.................................2.4}$$

H (c) = distribution function of the service time and is independent of the arrival time.

Also Shaw [21] developed a model on busy period control of queues based on waiting times at arrivals. In his work, he assumed that manpower can be shifted between repair and maintenance assignments in order to reduce the waiting time of the customers in the queues which will result to higher response rate. In the simplest case, he considered one repairman and one maintenance man with the latter assignable to help the former when the repair backlog (customer waiting time) becomes substantial. The objective is to minimise the mean time to complete all repairs, subject to a penalty for the time the maintenance man is shifted away from his main duties. He represented the results of his model by Figure 2.1 shown below.



(a) Repair backlog



(b) Maintenance backlog
SOURSE : SHAW (16)

Fig 2.1 TYPICAL BACKLOG WITH DYNAMIC ASSIGNMENT

δ	=	time between failure
T_n	=	repair time for the nth failure
$W(t)$	=	the repair backlog at time t
λ	=	rate at which failure occur (Poisson process)
μ	=	rate at which repairs are carried out (independently and identically distributed)
$v(t)$	=	maintenance backlog that is due for repair work
θ	=	threshold value

The maintenance man shift is made at the first failure time, t_i when the backlog is sufficiently big, i.e. the first time that $w(t_i) = w_i > \theta$ (threshold value). If $w(t_i) < \theta$ at some future failure time, the maintenance man is shifted back. Several shifts in both directions are possible during one repair episode (repair busy period). This model assumed that the necessary repair time can be diagnosed immediately when a failure occurs.

The w(t) curve falls with a steeper slope when both men are repairing. A small θ results, in a corresponding small repair duration T. Inversely, the maintenance backlog v(t) will be large. The idea is to choose θ to minimise the maintenance and repair time to reduce maintenance cost. Assumption made in the model was that one man is as productive as two men and they cooperate in serving a single remaining customer.

Furthermore, Richard [19] developed a queue model on manpower planning with uncertainty requirement. The demand for effective manpower is determined by the state of a finite Markov chain. According to him there are delays in training of effective manpower which is an input to the training process; thus it is not always available to meet demand. He presents an operational method for calculating optimal accession policies. This calculation can in turn be used to find the equilibrium operating rules for measuring the impact of alternate assumptions, continuation rates, manpower utilization policies, demand levels, and transition probabilities in the demand process. The model formulation of the flow of manpower, demand and supply of effective manpower, control objective, the optimal accession policy and cost performance trade-offs were given in the works of Richard [19]

Moreover, Priel [17] has written authoritatively on maintenance organisation particularly on maintenance ratios. The ratios are useful for effective maintenance planning. Out of these ratios those associated with maintenance manpower planning are given below:

i. Manpower efficiency $= \dfrac{\text{total man-hour allowed}}{\text{Total man-hour worked on same job}}$;

ii. Incentive coverage $= \dfrac{\text{Man-hour on bonus}}{\text{Total direct hours available}}$;

iii. Craft utilization $= \dfrac{\text{total craft hours clocked}}{\text{total craft hours clocked}}$;

vi. Work done turnover $= \dfrac{\text{number of jobs completed}}{\text{total number of jobs handled}}$;

v. Cost maintenance hours $= \dfrac{\text{total maintenance cost}}{\text{total direct maintenance hours}}$.

Olorunniwo [16] also gave the maintenance performance measure concerning manpower similar to the one given above. The performance concerning planning and scheduling is also given as:

i. Actual backlog (crew-week) = $\frac{\text{hours of maintenance on open order}}{\text{weekly maintenance Crew hours}}$;

ii. Completion delays (job-weeks) = $\frac{\text{job-weeks of delays}}{\text{number of jobs handled}}$;

iii. Overtime ratio = $\frac{\text{total overtime hours}}{\text{total maintenance hours}}$;

iv. Maintenance productivity ratio = $\frac{\text{total maintenance direct}}{\text{total direct production hours}}$

v. $\left(\begin{array}{l}\text{number of equipment per}\\ \text{maintenance man}\end{array}\right) = \left(\begin{array}{l}\text{equipment}\\ \text{availability}\end{array}\right)$

The model developed in literatures are either stochastic or deterministic. A deterministic model has the following defects:

i. It does not represent the system as a whole;

ii. Cannot account for time change effect in the effective measurement;

iii. All the "cause and effect' relationships among different components of the model are not accounted for at all times [24]

While stochastic models discussed in literatures solved the problems associated with deterministic model, the disadvantages of stochastic models are:

i. they have complex mathematical relationships which can be solved effectively only by the use of computer system;

ii. As a result of (i), they cannot be used easily by any layman for effective maintenance evaluation of a jobshop.

Most of the models developed in literatures are applicable only to internal maintenance system in which maintenance department is part of the production system. A model which can be applied to an external maintenance system is discussed in this thesis. The model which can be used to solve the problem of crew size in maintenance operations has the following advantages over those discussed in literatures:

i. The model is versatile and practical;

ii. The computer software has been developed for the model to achieve rapid solution;

iii. It can be used to access the maintenance crew size effectiveness of any maintenance jobshop;

iv. It can cope with down to earth problem of effective maintenance in the developed and developing countries;

v. It imitates the behaviour of the real system as closely as possible;

vi. it has more applicability on external maintenance jobshop.

2.2 QUEQUEING MODEL FOR CREW SIZE DETERMINATION IN MAINTENANCE JOBSHOPS

The queueing model is one of versatile operations research tools for determining and measuring the level of effectiveness of maintenance jobshops. Many studies on maintenance planning have modelled the maintenance problem as a single queueing system [1]. For maintenance jobshops, the objectives of this study is are to:

i. Know how long a customer waited before being served - that is, the cost of delaying service;

ii. Know the effect of crew size on the maintenance jobshop performance;

iii. Know the percentage of time the service facility (crew size) is not used (idle time) - that is, the degree of utilization of maintenance crew;

iv. Minimise the cost of maintenance crew subject to a satisfactory response rate. The response rate can be defined in terms of the average waiting time for a maintenance job.

For a single queue with Poisson arrival of jobs and exponential service times with a First-in First-out (FIFO) service discipline, the following expressions and equations hold for a one-gang crew [1]

i. Mean arrival rate of jobs = λ per unit time

ii. Mean service rate of jobs = μ per unit time

iii. Utilization factor = $P = \lambda / \mu$

iv. The probability of n jobs being in the system $P(n) = P^n (1-P)$

v. The average number of jobs in queue $Lq = \lambda^2 / \mu (\mu - \lambda) = \lambda Wq$

vi. The average waiting time for a job in the queue $Wq = P / (\mu - \lambda)$

vii. The average number of jobs in the system (number in the queue + number being served) = $L = \lambda W = Lq + \lambda / \mu$

viii. The average time in the system (job waiting time + service time) $Ws = Wq + 1/\mu$.

The queueing model can also take the form of multi-channel model leading to a complex equations which can be solved easily using appropriate computer software [13]. Under the same conditions for the single-channel model given above, the following equations can be written for multi-channel queueing model in parallel [20].

P_o = probability that all channels are idle.

Appendix 5 [20] shows different values of P_o corresponding to various ratios of $\lambda/k\mu$:

Where,

k = S = number of channels.

$$P_s = \frac{1}{S!}\left(\frac{\lambda}{\mu}\right)^s \left(\frac{S\mu}{S\mu - \lambda}\right) P_o \quad \text{.................. .... 2.5}$$

Where,

Ps = Probability that all channels are simultaneously busy (utilisation factor).

$$Ls = \left(\frac{\lambda\mu\,(\lambda/\mu)^s\,Po}{(S-1)!\,(S\mu - \lambda)^2}\right) + \lambda/\mu \quad \text{................................ 2.6}$$

Ls = mean number of jobs in the system .

$Lq = Ls - \lambda/\mu$ 2.7

Lq = mean number of jobs in the queue

$Ws = Ls/\lambda$ 2.8

Ws = mean time of waiting of jobs in the system

$Wq = Lq/\lambda$ 2.9

Wq = mean time of waiting of jobs in queue

μ = service rate per channel

W_q = mean time of waiting of jobs in queue

μ = service rate per channel

λ = Arrival rate of jobs.

In summary, the following options are possible for effective layout of the maintenance jobshop operations:

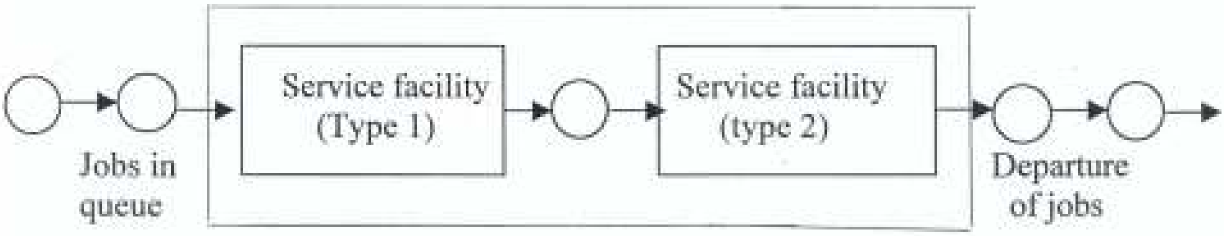
(i) Single channel

(ii) Single channel in series

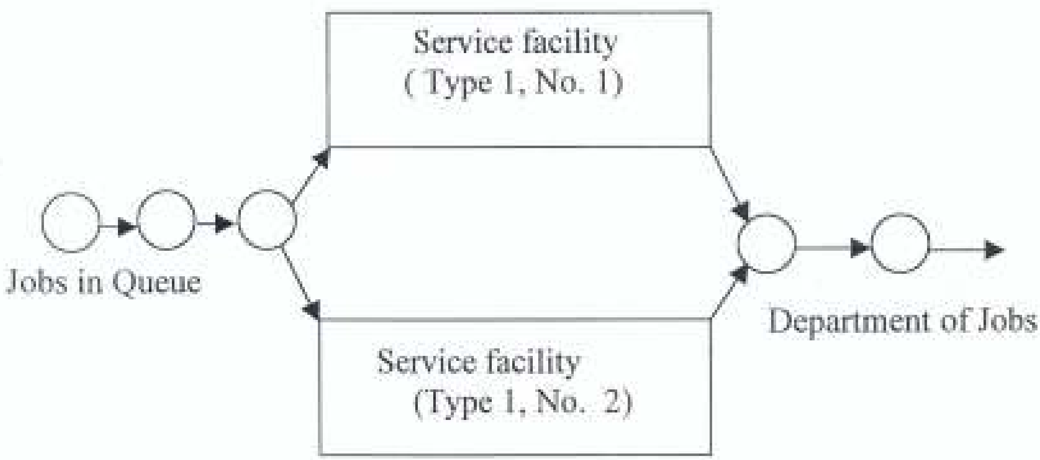
(iii) Multi-channel in parallel.

These options are shown in Figure 2.2.

a. **Single Channel**



b. **Single Channel, in Series**



c. **Double Channel, in parallel**

Fig 2.2 Physical Layouts of the Maintenance Jobshop

CHAPTER THREE

3.0 MODEL FORMULATION

3.1 QUEUEING MODEL FORMULATION

Model for crew size determination in maintenance jobshop is formulated from queueing theory. The jobs reported for maintenance are on the waiting-line (Queue), waiting for service while the maintenance crew(s) is/are to render service(s).

If the number of maintenance crew is increased there will be increase in labour cost. This in turn will result in achievement of a higher response rate (i.e. a lower waiting time in the queue). The increase in crew size can lead to the use of complex equations applicable for multi-channel queues which can not be solved easily by maintenance practitioners [13]. It can be solved by resorting to simulation or judgmental decision.

For a comprehensive solution, the single channel equation can be effectively applied for crew size determination by the application of the heuristics stated below.

3.2 MODEL DEVELOPMENT

3.2.1 DETERMINATION OF THE ARRIVAL RATE (λ) AND SERVICE RATE (μ) FOR A SINGLE-CHANNEL QUEUE

In determining λ and μ the following should be noted:

i. Kendal M/M/1/∞/FIFO queueing model notation should be used. This notation means infinite queue, infinite source, single server (a maintenance crew) model with first-in first-out queue discipline [8].

No room for LIFO (Last-in first-out), random selection (serving randomly), priority selection (given some customers precedence over others). Priority selection may be preemptive (interrupting the service of a given customer by another customer of higher priority) and non preemptive (service rendered to a customer cannot be interrupted unless the level of priority of the next customers is considered).

ii. λ occurs completely at random at a certain average rate i.e. Poisson distribution.

iii. μ also follows an exponential distribution but at a constant average rate.

iv. The chi-square goodness of fit test can also be used to test whether the parameters are in random distribution.

v. $\lambda < \mu$ to prevent the queue from building up, otherwise queueing model is not valid. (Stochastic cost model developed in section 4.2.6 solves this problem).

Note: λ = LAMBDA = Average Arrival rate of the jobs

μ = MU = Average service rate.

3.2.2. RESPONSE RATE Wq* ACCEPTABLE

Response rate Wq* acceptable to the potential customers can be established by calculating the average of the acceptable response rates for the various maintenance activities. This can be achieved by conducting questionnaires and interviews among the maintenance jobshop customers. Actually, for minor repairs, the customers would like to get their jobs within a day but for major repairs not later than a week.

3.2.3 EXPECTED WAITING TIME FOR A JOB Wq

This can be known from the analysis of the data collected when studying a maintenance system. It gives the actual waiting time in the queue before being served.

The average waiting time of a job Wq can be calculated from mathematical relation.

$$Wq = P/(\mu - \lambda)$$

Where, P = degree of utilization of service facilities or utilization factor

$= \lambda/\mu$.

The expected waiting time (Wq) should be reasonable enough to prevent:

i. reneging – leaving of the customers in the queue as a result of high waiting time;

ii. balking – unwillingness of customers to make their jobs join the queue because of too many jobs on the queue waiting for maintenance;

iii. jockeying – jumping the queue in order to reduce waiting time of the jobs.

3.2.4 COMPARING Wq* AND Wq

Computed waiting time in queue Wq is compared with acceptable response rate Wq* of the customers:

i. if $Wq \leq Wq^*$, operating with a single maintenance crew (gang) is acceptable;

ii. if $Wq > Wq^*$, the number of the maintenance crew that would work effectively under such condition can be obtained by finding the value of Wq/Wq^* to the nearest higher integer.

Fig. 3.1 shows the flow pattern for maintenance crew size determination using heuristics.

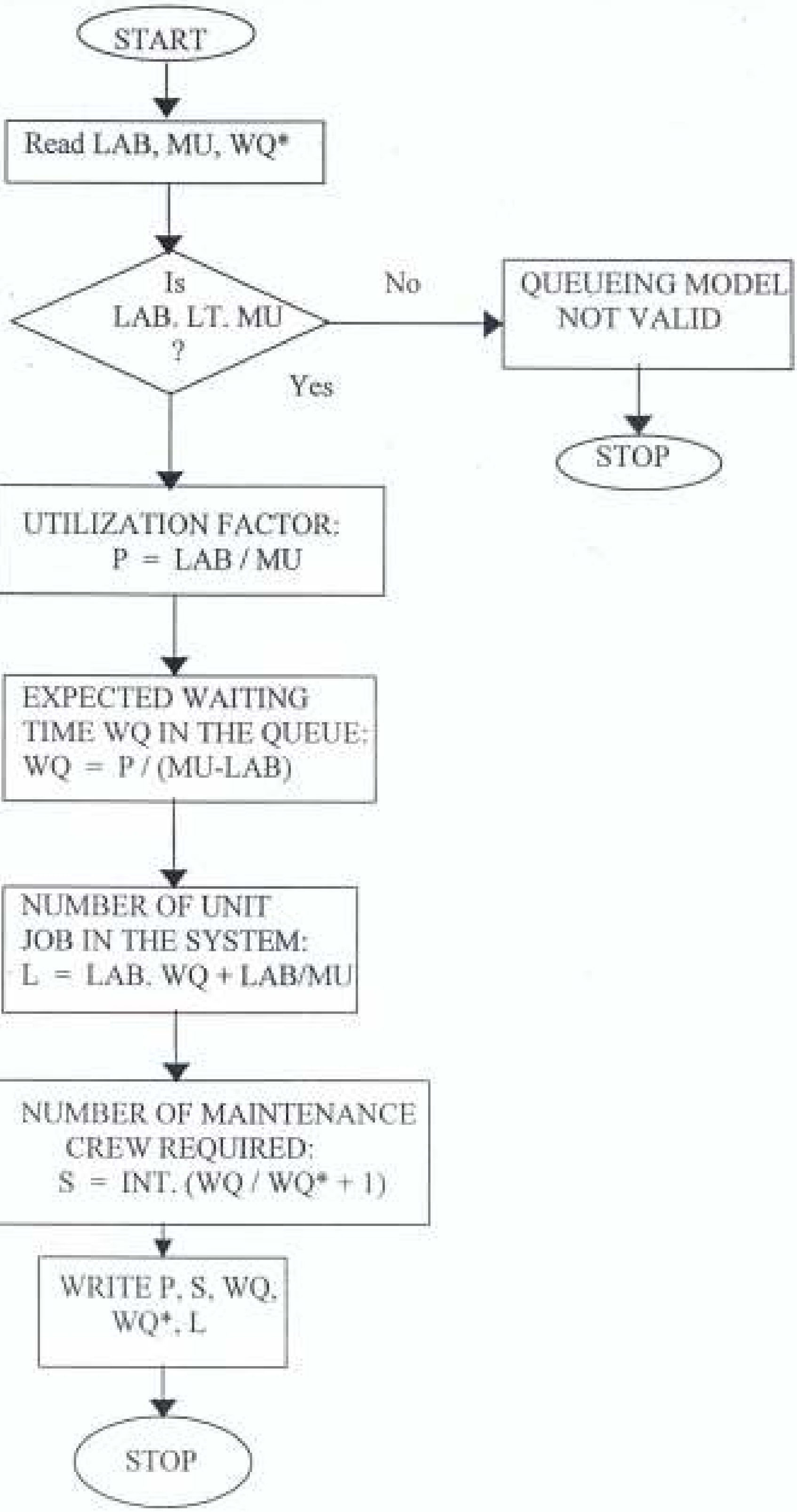


FIG. 3.1: FLOW CHART FOR MAINTENANCE CREW SIZE DETERMINATION USING HEURISTICS

3.2.5 MINIMISATION OF TOTAL COST OF MAINTENANCE (SINGLE CHANNEL)

Total maintenance cost is the sum of the cost of using maintenance crew(s) and the cost of waiting of job(s) in the queue [23].

Total maintenance cost is expressed as

$$TC(S) = SC_1 + C_2L(S) \qquad \text{.................................. 3.1}$$

at a given S = Number of maintenance crew

C_1 = Average cost of using a maintenance crew per unit time

C_2 = Average cost of waiting of a job in the system per unit time

$L(S)$ = expected number of jobs in the system at a given S.

Since S is discrete, differentiation is not applicable in this case. To minimise the total cost, computation based on the minimum value of the given function can be used [23]. Once there will be only one job for service at any time, single channel system can still be applied for additional crew(s) [20].

From the expected number of jobs in the system for a single channel queue

$$L = \lambda/(\mu - \lambda) \qquad \text{...................................... 3.2}$$

If the number of the crew is increased by one then the service rate in the system is doubled (under the assumption that both are working at the same rate).

Therefore, $S = 1, \mu_1 = \mu$

$S = 2, \mu_2 = 2\mu$

For single channel in series, similarly,

$$L(1) = \frac{\lambda}{\mu - \lambda} \qquad (S = 1)$$

$$L(2) = \frac{\lambda}{2\mu - \lambda} \qquad (S = 2)$$

$$L(3) = \frac{\lambda}{3\mu - \lambda} \qquad (S = 3)$$

$$L(n) = \frac{\lambda}{n\mu - \lambda} \qquad (S = n)$$

Therefore, total cost of waiting of job in the system is given by:

$$C_2L(n) = C_2 (\lambda/n\mu - \lambda) \qquad (S = n) \qquad \text{.................. } 3.3$$

Total cost of using crew size is given by:

$$C_1 \times n = nC_1 \qquad (S = n) \qquad \text{.................... } 3.4$$

Total maintenance cost TC(S)

$$TC(S) = SC_1 + C_2 L(S) \qquad (S = 1, 2, ...n)$$

$$TC(S) = SC_1 + C_2 L(S) \qquad (S = 1, 2, ...)$$

and

$$L(S) = \frac{\lambda}{S\mu - \lambda} \qquad (S = 1, 2, ...n)$$

Therefore, combining equations 3.1 and 3.2

$$TC(S) = SC_1 + C_2 (\lambda/S\mu - \lambda) \qquad (S = 1, 2, ...n) \text{ .... } 3.5$$

The minimum total maintenance cost can be known graphically (see Fig. 3.3) by tracing the optimum number of crew size to the total cost curve [23]. This gives the minimum cost that will generate higher response rate. Cost of using maintenance crew (C_1) consists of crew salary/bonuses/allowances and cost of tools and building. Cost of waiting of a job (C_2) can be obtained from the cost of hiring such an item or cost generated by using such an item in a unit time of waiting [24]. Flow chart for the calculation of total maintenance cost is given in Figure 3.2 while the maintenance costs curve is in Figure 3.3.

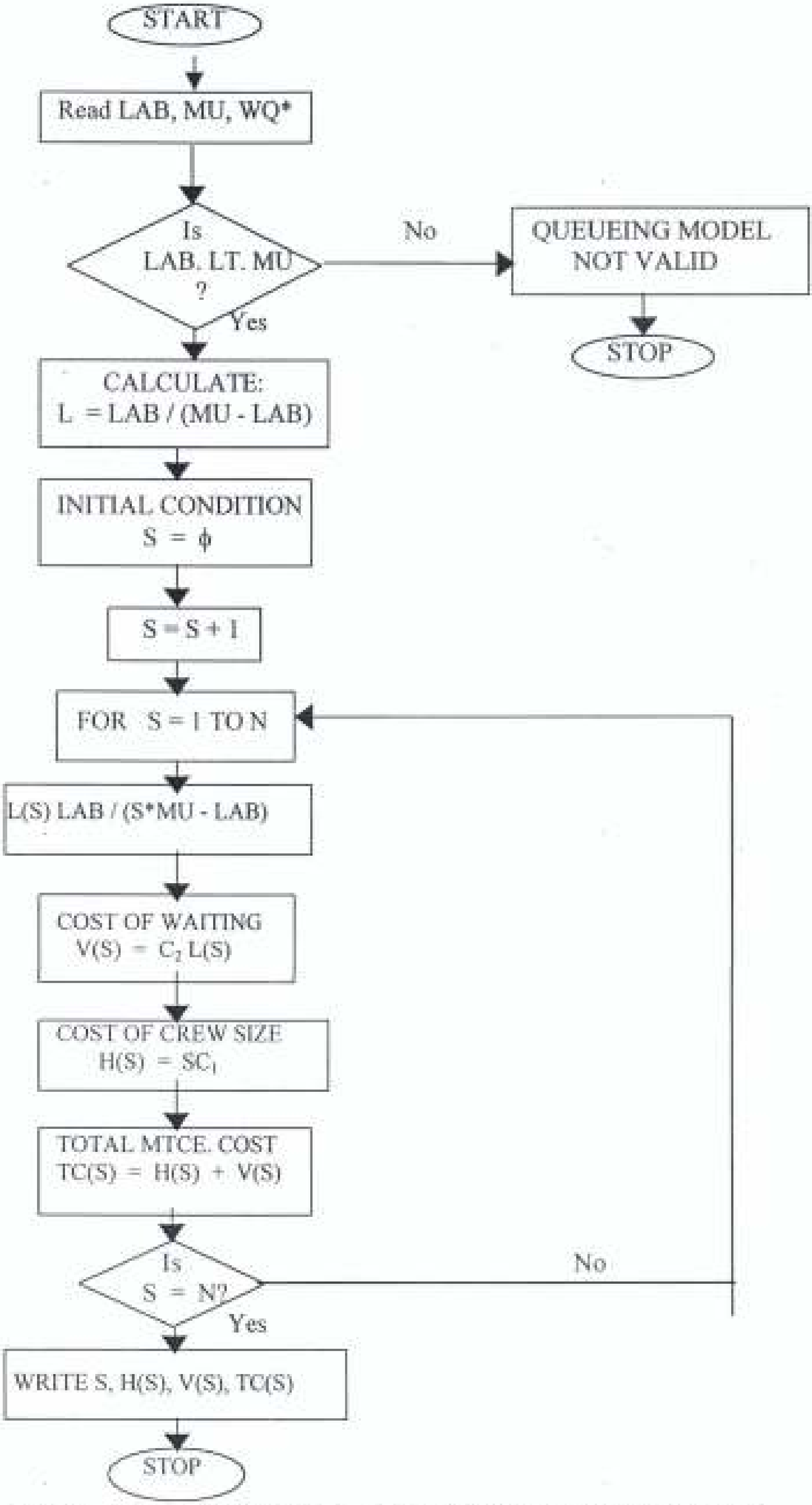


FIG. 3.2: FLOW CHART FOR MAINTENANCE CREW SIZE DETERMINATION USING COST MODEL (IN SERIES) (DETERMINISTIC APPROACH)

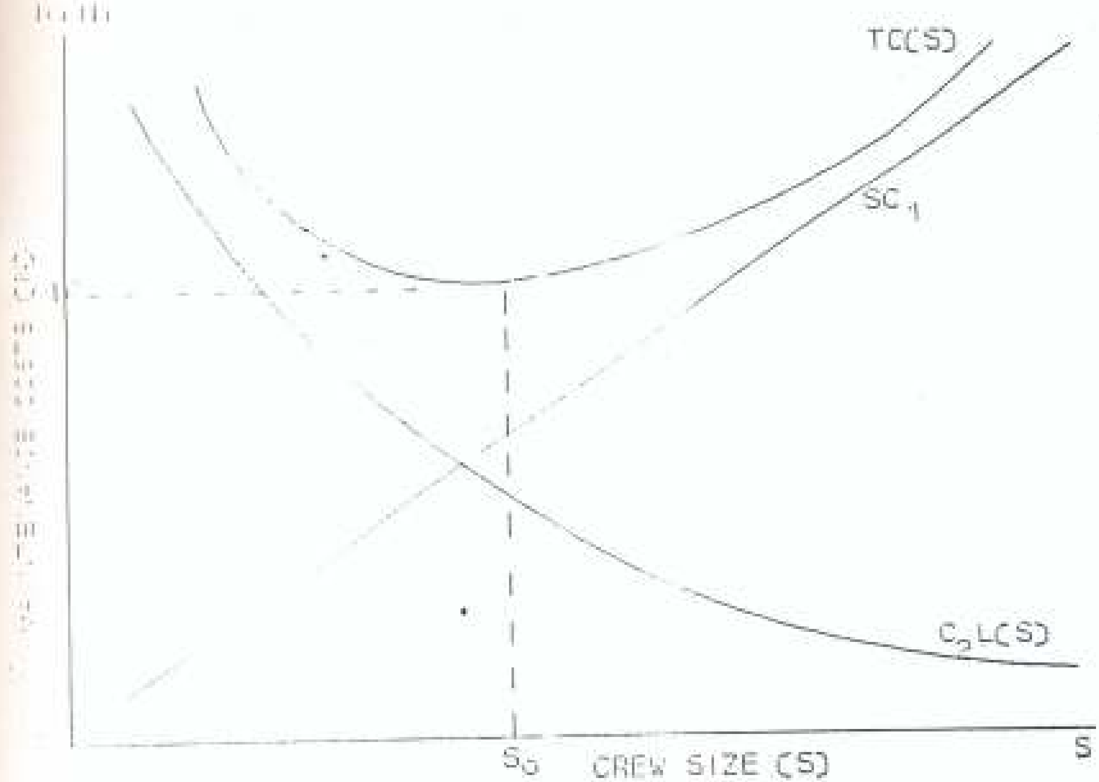


Fig. 3.3. Typical Maintenance Cost Curve.

Adapted from [23]

SC_1	=	Cost of using crew size (s)
$C_2L(S)$	=	Cost of waiting at a given crew size
TC(S)	=	Total maintenance cost at a given crew size
TCo	=	Minimum total maintenance cost
So	=	Effective crew size corresponds to minimum cost.

3.2.6 MULTI-CHANNEL COST MODEL

Multi-channel cost model can also be used for the basis of comparison to be able to determine cost effective layout of the system if the optimum crew size (from 3.2.5) is greater than one.

Minimum maintenance cost for the multi-channel system can be computed by substituting the optimum crew size obtained from single-channel cost model to the multi-channel cost model. The multi-channel cost model for minimum maintenance cost is given as [23]:

$$TC(So) = SoC_1 + C_2 L(So) \quad \ldots\ldots\ldots 3.6$$

So = optimum crew size from single-channel

TC(So) = minimum maintenance cost

SoC_1 = total cost of using optimum crew size

$L(So) C_2$ = total cost of waiting incurred when optimum crew size is used.

The last paragraph of section 2.2 presents multi-channel equations relating the above quantities.

3.3 POISSON DISTRIBUTION

The following statistical methods are applicable for assessing whether a given distribution is Poisson or not [4, 8, 23].

i. If arrivals/departures appear to occur randomly there is a good chance that the process may be Poisson distribution.

ii. Gathering the data on number of arrival of customers, by recording the number of customers arriving during appropriate equal time intervals (e.g. hourly, daily, weekly). Then, compute the mean and variance. If the distribution is Poisson.

MEAN ≈ VARIANCE

Mathematically,

$$\bar{n} = \sum_{n=o}^{n} nf_n / N \approx S_n^2 \approx \sum_{n=o}^{n} n^2 f_n - N\bar{n}^2 / N - 1 \qquad \ldots\ldots\ldots\ldots 3.7$$

Where,

$\bar{n}$	=	mean of the distribution
S_n^2	=	variance of the distribution
n	=	number of the chosen equal time interval
f_n	=	number of arrival during the chosen equal time interval
N	=	sum of the number of arrivals during the chosen equal time interval

(iii) Kolmogorov smirnov test can also be used to test the hypothesis that the sample follows some hypothesised distribution

The test technique is given below [8]

(a) Let S (x) be the empirical cumulative distribution function constructed from the sample of N observation(s).

(b) Let F (x) be the theoretical cumulative function assuming that the null hypothesis is true.

(c) For each of the N sample point, compute F (x_n) – S (x_n).

(d) Let $D = Max_n \mid F(x_n) - S(x_n) \mid$.

Choosing some value of α and if the calculated value of D is greater than the tabulated critical value at that level of significant (α), reject the hypothesis.

iv. Chi-square test of goodness of fit method can also be used to test whether distribution is Poisson in nature. This test makes a comparison between the actual and expected number of observations for various values of the random variable [4, 8]. However, the first two methods (i and ii) may not achieve accurate result because of its crudeness and unreliability.

The last two methods (iii and iv) are the best to analyse the system.

In this thesis, chi-square test of goodness of fit is used to assess the distribution of arrivals of repair job in the maintenance jobshop. The technique used in this test is described in Section 3.3.1 below:

3.3.1 THE CHI-SQUARE GOODNESS-OF-FIT TEST TECHNIQUE

(i) Construct a frequency table of the observation values (f_n) of the number variable. The intervals with fewer than three to five observation tend to distort the test results.

(ii) Calculate the expected or theoretical frequencies (T_n) for each interval under the assumption that the hypothesised distribution is correct. The parameters of the hypothesised distribution are usually estimated from the sample data.

(iii) calculate the quantity $(f_n - T_n)^2 / T_n$ for each interval n = 1, 2,…n, where f_n is the actual frequency of observation in this interval, and T_n is the frequency of observations expected under the hypothesised distribution.

(iv) As a rule of thumb, each T_n is contained to satisfy this condition. Also, T_n for all n greater than 14 must be contained to yield a theoretical frequency of 12 – 42.

(v) Calculate the chi-square statistics using the formula

$$X^2 = \sum_{n=o}^{n} (f_n - T_n)^2 / T_n \qquad 3.8$$

Where,

f_n = the observed frequency of observations in the nth interval

T_n = the frequency of observation if the assumed distribution is correct.

The degrees of freedom (v) for this statistics is

$$v = C - k - 1$$

Where,

C = number of class interval

k = number of parameter estimated for the hypothesised distribution

(vi) Compare the X^2 - value with the critical value of the X^2 - distribution.

This is at a certain level of significant (α) and degree of freedom

$v = C - k - 1$.

(vii) For the distribution to be Poisson

$X^2 \leq X^2_{v,\alpha}$

X^2 = chi-square value

$X^2_{v,\alpha}$ = the critical value of the chi-square distribution with a significant level (α) and degree of freedom (v).

If $X^2 > X^2_{v,\alpha}$ the hypothesis can be rejected, that is, distribution is not Poisson.

CHAPTER FOUR

4.0 DATA COLLECTION, EVALUATION AND MODEL ANALYSIS

The model developed was tested using primary data collected from Federal University of Technology, Akure, Mechanical Maintenance Workshop. Primary data are obtained directly through personal interviews, telephone interviews and (mail)questionnaires from the system under study .

F.U.T.A. Mechanical Maintenance Workshop was used as a case study because it satisfied the following requirements:

(i) It possesses all necessary information and data needed.

(ii) Its operations are similar to that of the jobshop for commercial purposes, hence it has a characteristic of external maintenance centre.

(iii) It has maintenance crew that is capable of maintaining diagnosing, testing and maintaining etc. the repair works (both major and minor repair).

(iv) Data/information can be easily collected, after analysis, showing correct behaviour of the system.

F.U.T.A. Mechanical Maintenance Workshop was operating under seven-man maintenance crew which is capable of inspecting, diagnosing, maintaining, testing and certifying a maintenance requisition.

Their cadres are given below:

(i)	Workshop attendant	(1)	-	To make tools available.
(ii)	Craftsman	(1)	-	working on maintenance jobs.
(iii)	Senior Craftsmen	(2)	-	Working on maintenance jobs.
(iv)	Senior Foreman	(1)	-	Repairing/supervising and giving

technical advice.

(v) Assistant Technical officer (1) - Repairing and giving technical assistance in the process of maintenance.

(vi) Technical Officer (1) - Repairing, certifying, and giving technical advice.

4.1 DATA COLLECTION

The maintenance operational procedure and management information systems were thoroughly examined. These include maintenance crew size, salary/allowances/bonuses of the crew, job cards, log books, work orders, operation statistics, cost reports and hiring costs of the brands of the vehicles repaired.

The effective maintenance works assumed to be carried out for 6 hours in a day while the balance of two hours is used for resting, eating, talking with friends or co-staff, attending to the visitors etc. Also, it was assumed that there is no arrival of the jobs at weekends and after working hours.

4.1.1 DATA CLASSIFICATION

The maintenance procedure during a period of one year, January to December, 1996 was critically examined. Out of these months, the behaviour of the system in the months of July and August 1996 completely represented the system . This was due to the fact that arrival of jobs and maintenance activities were continuously regular during the period.

Cost related data were obtained from customers, Bursary department and Maintenance jobshop. This includes cost of waiting and crew size cost. Data related to service/maintenance time and arrival time were obtained from Maintenance jobshop.

4.1.1.1 **Arrival and Service Process**

Data related to arrival and service process were obtained from Maintenance jobshop management. The data collection from maintenance jobshop was on hourly basis and classified into columns presented in Table 4.1.

(i) ARRIVAL: the order and sequence of the arrival of the faulty vehicles for repair/maintenance.

(ii) ARRIVAL TIME (hours): the time (hours) of arrival of individual faulty vehicle.

(iii) INTER-ARRIVAL TIME (hours):The time (hours) between the successive arrival to the maintenance jobshop.

(iv) SERVICE TIME (hours): The time (hours) each reported vehicle was taken to return it back to acceptable condition.

In Table 4.1 the first arrival time was assumed to be zero which served as a reference point.

TABLE 4.1: ARRIVAL AND SERVICE PROCESS

ARRIVAL OF VEHICLE	ARRIVAL TIME (HOURS)	INTER-ARRIVAL TIME (HOURS)	SERVICE TIME (HOURS)
1	0	0	4
2	7	7	3
3	10	3	2
4	15	5	7
5	22	7	5
6	26	4	1
7	35	9	2
8	50	15	3
9	62	12	7
10	69	7	8
11	75	6	3
12	92	17	5
13	112	20	9
14	120	8	6
15	132	12	2
16	151	19	5
17	159	8	9
18	175	16	5
19	179	4	2
20	199	20	3
21	205	6	1
22	209	4	3
23	211	2	1
24	217	6	4
25	226	9	2
26	230	4	2
27	234	4	9
28	235	1	7
29	237	2	2
30	240	3	1
TOTAL = 30		$\Sigma AT=240$	$\Sigma ST=123$

DATA SOURCE: F.U.T.A MECHANICAL MAINTENANCE WORKSHOP

4.1.1.2 **Cost of Waiting for Service**

Time spent in the queue before rendering service was converted to monetary value by making use of the average cost of hiring such a vehicle in an hour. The effective time or useful time in a day is 6 hours. The remaining hours are used for fueling, eating, going to toilet, talking, police checking etc. Average amount realised per hour in using the vehicle for commercial purpose can also be used.

Waiting cost for different brands of vehicle were obtained from customers. The average of which are given in Table 4.2 below.

TABLE 4.2: COST OF WAITING FOR SERVICE

S/N	TYPES	BRANDS	AMOUNT REALISED PER DAY IN NAIRA (AVERAGE)	AVERAGE AMOUNT (IN NAIRA) REALISED PER HOUR
1.	Car	Peugeot, Toyota, Datsun	2,000.00	333.33
2.	Buses	Toyota, Faka, J.5, Liteace, Daihatsu	3,000.00	500.00
3.	Truck	Bedford, 911 etc.	5,000.00	833.33
4.	Pick-up	Peugeot, Daihatsu	2,000.00	333.33
	Average cost		3,000.00	500.00

DATA SOURCE: SURVEY

4.1.1.3 **Cost of Using Maintenance Crew Size**

Cost of using maintenance crew size was estimated from the salary/allowances of the maintenance crew as well as depreciation cost on building and equipment/tools which were used to carry out various maintenance activities. The information concerning salary/allowances were obtained from

Bursary department (Appendix 7). Table 4.3 shows the salary/allowances of the crew. (Seven-man).

TABLE 4.3 MONTHLY MAINTENANCE CREW SALARY/ALLOWANCES

ONE CREW SIZE	CADRE	BASIC SALARY =N=	ALLOWANCE (RENT, TRANSPORT etc.) =N=	TOTAL SALARY =N=	TAX =N=	NET SALARY =N= TOTAL – TAX
1.	Technical officer	1562.91	2399.90	3962.81	40	3922.81
2.	Senior Foreman	1268.83	2042.59	3311.42	40	3271.42
3.	Senior Craftsman (1)	0878.66	1509.40	2388.06	30	2358.06
4.	Senior craftsman (2)	0829.00	1449.80	2278.80	30	2248.80
5.	Craftsman	0806.14	1422.40	2228.56	30	2198.56
6.	Assistant Craftsman	0704.50	1300.40	2004.80	20	1984.80
7.	Workshop Attendant	0659.75	1246.70	1906.75	20	1886.45

DATA SOURCE: FUTA BURSARY DEPARTMENT

The cost of using a maintenance crew size is the sum of the salary/ allowance and the depreciation costs on building and tools being used for operation. Data and analysis of depreciation costs on building and equipment/ tools are discussed in section 4.2.4 (Analysis of cost of using maintenance crew size).

4.2 ANALYSIS OF THE DATA COLLECTED

4.2.1 ANALYSIS OF RANDOMNESS OF ARRIVAL OF JOBS

Randomness of arrivals were tested using chi-square goodness of fit method (Section 3.3). These arrivals (Table 4.1) must follow Poisson distribution pattern. The arrivals time pattern (Table 4.1) was tested to know whether it was in conformity with Poisson distribution.

In carrying out the chi-square test, a day (interval of 6 hours) was chosen, so that number of arrivals per day are presented in Tables 4.4 and 4.5. Histogram describing the arrival pattern is given in Figure 4.1.

n = number of arrivals per day

f_n = observed frequency result if Poisson distribution is assumed.

TABLE 4.4 SCHEDULE OF ARRIVALS (HOURLY)

TIME SCALE	ARRIVAL TIME	NUMBER PER DAY		TIME SCALE	ARRIVAL TIME	NO. PER DAY
0				156	151	1
6	0	0		162	159	1
	7			168	0	0
12	10	2		174	0	0
18	15	1			175	
24	22	1		180	179	2
30	26	1		186	0	0
36	35	1		192	0	0
42	0	0		198	0	0
48	0	0		204	199	1
54	50	1			205	
60	0	0		210	209	2
66	62	1		216	211	1
72	69	1		222	217	1
78	75	1		228	226	1
84	0	0			230	
90	0	0		234	234	2
96	92	1			235	
102	0	0			239	
108	0	0		240	240	3
114	112	1				
120	120	1				
126	0	0				
132	132	1				
138	0	0				
144	0	0				
150	0	0				

TABLE 4.5 SUMMARY OF THE DISTRIBUTION OF ARRIVALS PER DAY

n	0	1	2	3	4	≥ 5
f_n	17	18	4	1	0	0

Once the observed frequency (f_n) is known, the next is the expected / theoretical frequency T_n. To calculate the expected/theoretical frequency (T_n), the mean (rate of arrival, λ) of the distribution (Table 4.5) must be known.

$$\lambda = \text{mean} = \sum_{n=0}^{\infty} nf_n / \sum_{n=0}^{\infty} f_n \qquad \text{.......... 4.1}$$

(0 x 17 + 1 x 18 + 2 x 4 + 4 x 0) / 40

(0 + 18 + 8 + 3 + 0) / 40

= 29/40

λ = 0.725 Arrival/day

The next step is to compute the probability of the arrival at a given 'n' (P_n for a Poisson distribution with the mean (rate of report of repair job) 0.725 Arrival/day.

Recall the statistical formula for Poisson distribution:

$$P_n = \lambda^n \in^{-\lambda} / n! \qquad n = 0,1,2, ... \infty \qquad \text{.......... 4.2}$$

$$\lambda > o$$

$$= \quad 0.725$$

$$P_n = \frac{(0.725)^n \in^{-0.725}}{n!}$$

$$P_n = 0.725^n (0.4843)/n!$$

Probability P_n for various values of n are tabulated below (Table 4.6).

TABLE 4.6: PROBABILITY P_n FOR POISSON DISTRIBUTION OF ARRIVALS

n	0	1	2	3	4	≥ 5
P_n	0.4843	0.3511	0.21273	0.0308	0.0056	0

Next, is to calculate chi-square value for the arrival time distribution.

Total number of observations (Table 4.5) = 40

Therefore,

The expected/theoretical frequency (T_n)

T_n = $P_n (\Sigma f_n)$, from which

Σf_n = 40 (Table 4.5)

Therefore, T_n = $40 (P_n)$

The chi-square value is given by

$$X^2_{\text{-value}} = \frac{(f_n - T_n)^2}{T_n}$$

TABLE 4.7 THE CHI-SQUARE VALUE FOR THE ARRIVAL TIME DISTRIBUTION OF JOBS

N	P_n	f_n	T_n	$\frac{(f_n - T_n)^2}{T_n}$
0	0.4843	17	19.37	0.2899
1	0.3511	18	14.04	1.1169
2	0.1273	4 } 5	6.54	0.3626
3	0.0308	1		
4	0.0056	0		
Total	1	40	40	1.7694

In the above table (i.e. Table 4.7) as a rule of thumb, each T_n must be ≥ 5 and total observed frequency (f_n) to yield $T_n \geq 5$ must be between 3 and 11 [23]

From the above table, chi-square value is given by

$$= \sum (f_n - T_n)^2 / T_n$$

$$X^2_{\text{-value}} = 1.7694$$

This chi-square value must be compared with the critical value of the chi-square distribution obtained from the standard statistical tables (Section 3.3.1) using degree of freedom (v) and level of significance (α).

Degree of freedom v is given by

$$v = C - k - 1$$

where, C = number of class interval

k = number of parameters estimated.

Therefore, C = 3

k = 1 since only mean was estimated from the data.

Therefore,

$$v = 3 - 1 - 1 = 1$$

By using a significance level of 0.05 (i.e. $\alpha = 0.05$) and degree of freedom ($v = 1$).

From the statistical table (Appendix 6) [8]

$$X^2_{v,\alpha} = X^2_{1,(0.05)} = 3.841$$

By comparing the results

$$X^2_{\text{-value}} < X_{v,\alpha}$$

i.e. $1.7694 < 3.841$

This led to the conclusion that the hypothesis that the distribution came from a Poisson distribution with mean $\lambda = 0.725$ arrival per day into the maintenance jobshop for repair and maintenance can be accepted with a significance level (α) =0.05

Fig 4.1 (a, b) show the histogram of number of arrival per day based on the observed frequency (f_a) and the relative frequency curve of the distribution based on the (0,1) probability distribution. The curve shows that the distribution followed Poisson distribution [24]. Therefore, inter arrival time followed negative exponential distribution [4]. The histogram of the arrivals distribution and probability distribution function are shown in Figure 4.1.

Hence,

$$f(A_T) = \lambda \varepsilon^{-\lambda A_T}$$

Associated cumulative probability distribution function (CDF) is given by

$$F(t_a) = \int_{0}^{A_T} \lambda \varepsilon^{-\lambda A_T} \partial A_T$$

$$F(t_a) = 1 - \epsilon^{-\lambda A_T}$$

From which,

$$A_T = -1/\lambda \text{ LOG } [F(t_a)]$$

Where $F(t_a)$ is a random number in the range 0 and 1

i.e. $0 < F(t_a) < 1$.

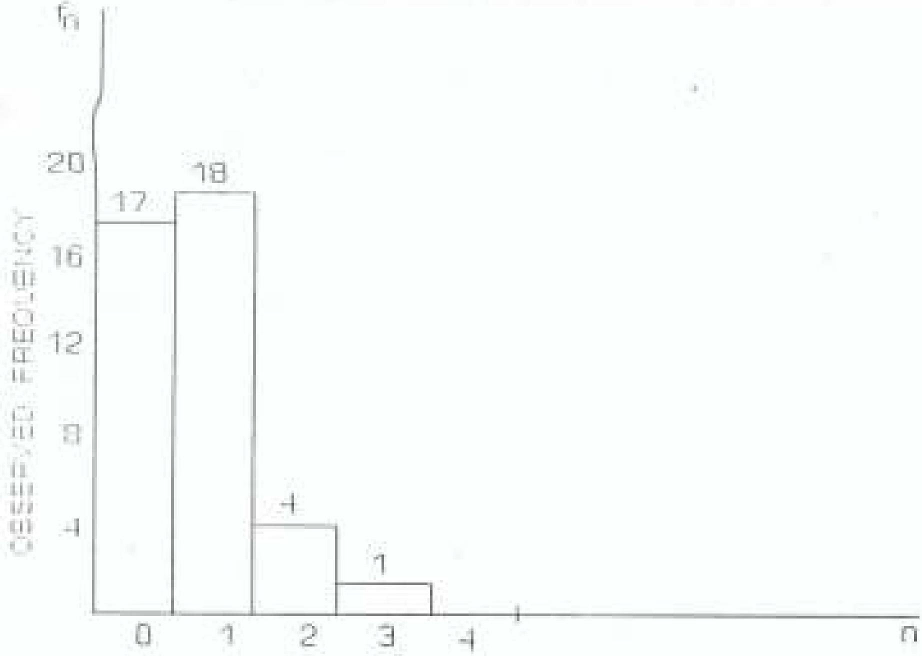
This concept is used in the stochastic cost model developed in section 4.2.6 for optimum crew size determination

Every computer system has a random number generator. For "QBASIC" computer language used in this project, the random numbers are generated by using command code "RND [(I)]"

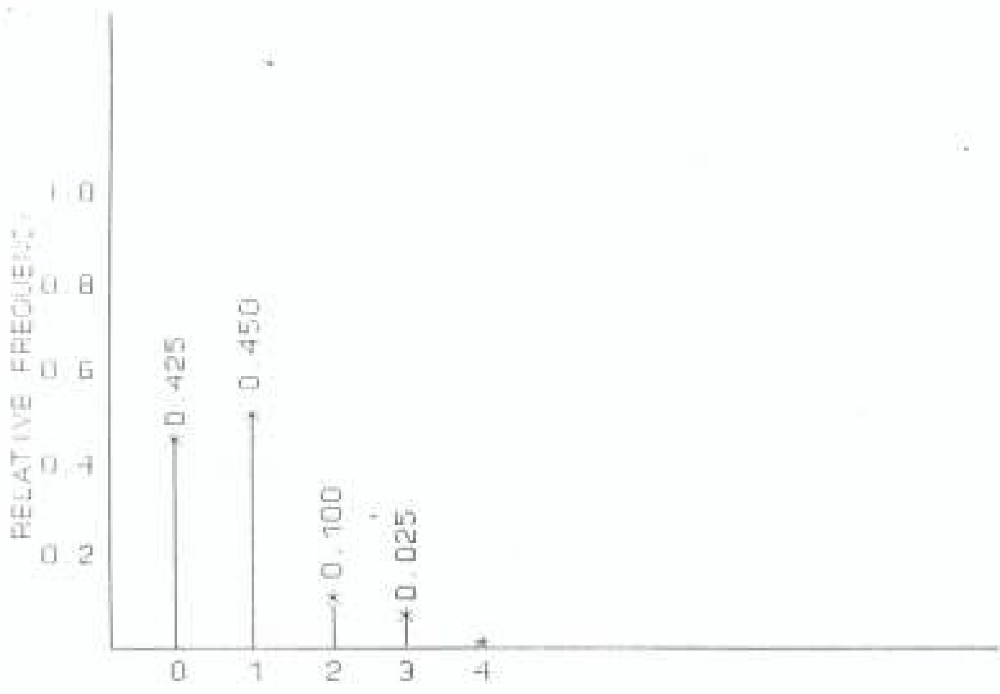
Where, I < O for the calling of the same random number

I = O for the calling of last random number

I > O for the calling of next random number.



a. Histogram Representation



a. Probability Distribution Function

Fig. 4.1 Histogram Representation and Probability Distribution Function of Number of Arrival/Day

4.2.2 SERVICE TIME DISTRIBUTION ANALYSIS

The service time of jobs (Table 4.1) can be put into frequency table using a time interval of 2 hours. The observed frequency O_i obtained are shown in Table 4.8 below.

TABLE 4.8: OBSERVED FREQUENCY OF SERVICE TIME

CELL NUMBER	CELL BOUNDARY	CLASS MIDPOINT	OBSERVATIONS	FREQUENCY (O_i)
1	0 – 2	1	1,2,1,2,2,2,2,1,2,2,1	11
2	2 – 4	3	4,3,3,3,3,3,4	7
3	4 – 6	5	5,5,5,5,6	5
4	6 –8	7	7,7,7,8	4
5	8 – 10	9	9,9,9	3
6	10 - ∞	-	-	-
			Total O_1	30

The histogram of the observed distribution and the probability density function curve are shown in Figure 4.2a and 4.2b respectively. These figures will be used to test whether the data observed follow certain hypothesised distribution [24].

The probability density curve for the service time distribution followed an exponential distribution as shown by the trend of the curve [24].

The exponential function is given by:

$f(x) = \mu e^{-\mu x}, x > 0$ 4.5

and its associated cumulative density/distribution function is thus given as

$$F(X) = \int_{o}^{X} f(x)\, \partial x$$

$$F(X) = 1 - e^{-\mu x}, X > 0 \quad \text{.......... 4.6}$$

Using chi-square goodness of fit test to test for null hypothesis (section 3.3), the mean value from the raw data is calculated using:

$$\overline{S_T} = (\Sigma S_T)/n \quad \text{.......... 4.7}$$

Where,

n = number of job

ΣS_T = summation of the service times

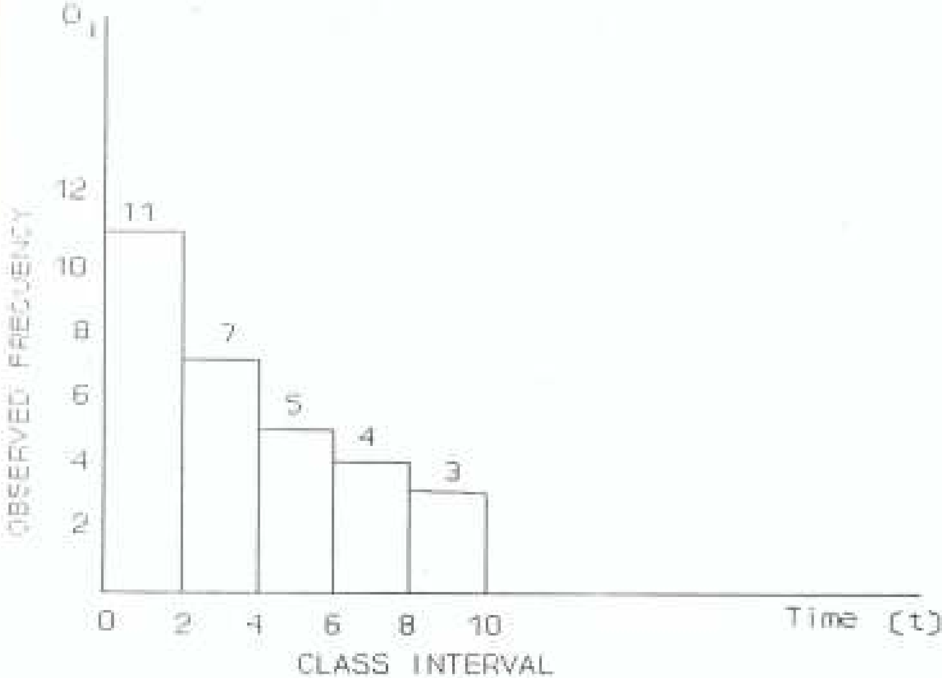
Therefore,

n = 30 jobs (Table 4.1)

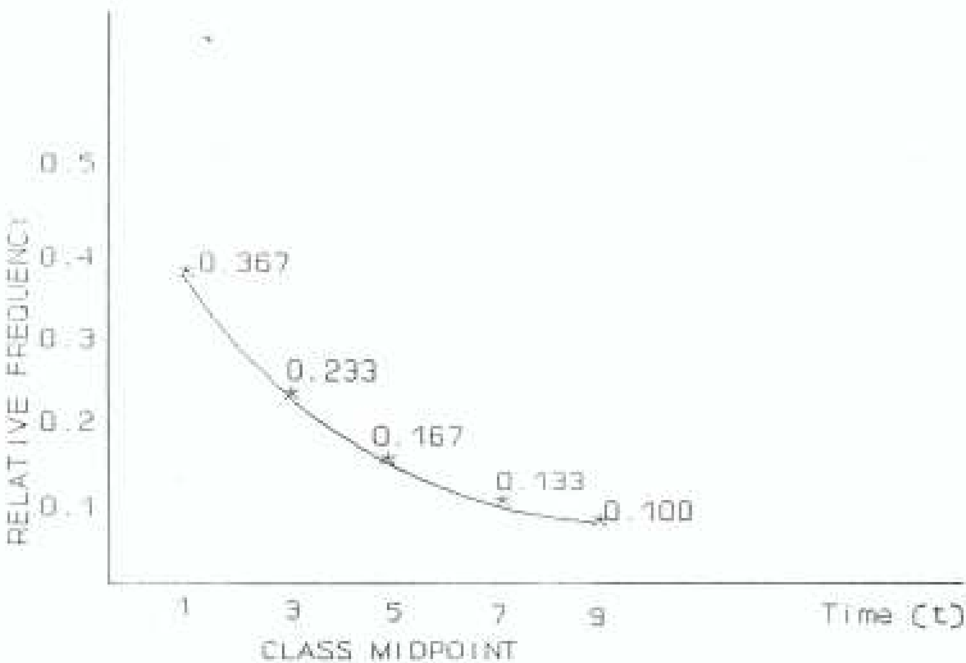
ΣS_T = 123 hours (Table 4.1)

$\overline{S_T}$ = 123/30 = 4.1 hours per unit job

= 4.1 hours per unit job



a. Histogram for Service Time Distribution



b. Probability Density Function for Service Time

.2 Histogram and Probability Density Curve for Service Time

Using equation 4.5 and 4.6 above, the hypothesised exponential density function is written as ($x = S_T$)

$$f(S_T) = \frac{1}{S_T} \epsilon^{-S_T/ \bar{S}T} \qquad S_T > 0$$

$$f(S_T) = \frac{1}{4.1} \epsilon^{-S_T/4.1}, \qquad S_T > 0$$

its associated CDF is given as ($x = S_t$)

$$F(S_t) = 1 - \epsilon^{-S_t/4.1}, \quad S_t > 0 \quad \ldots\ldots 4.8$$

The theoretical frequency (n_i) is then computed for the cell (a_{i-1}, a_i) as:

$$n_i = n P_i = n[F(a_i)] - F(a_{i-1})] \quad \ldots\ldots 4.9$$

$$n_i = n P_i = n [(1-\epsilon^{-ai/4.1}) - (1-\epsilon^{-ai-1/4.1})]$$

$$n_i = n P_i = n (\epsilon^{-ai-1/4.} - \epsilon^{-ai/4.1}) \quad \ldots\ldots 4.10$$

Table 4.9 shows chi-square test for service time.

TABLE 4.9 CHI-SQUARE TEST FOR SERVICE TIME DISTRBUTION

Cell Number	Cell Boundaries	Probability P_i	Observed frequency (O_i)	Theoretical frequency	$\frac{(O_i-n_i)^2}{n_i}$
1	(0.2)	0.3860	11	11.58	0.02905
2	(2.4)	0.2370	7	7.11	0.00170
3	(4.6)	0.1455	5	4.36	
4	(6.8)	0.0893	4	2.68	
			12	11.31	0.04210
5	(8,10)	0.0548	3	1.65	
6	(10,∞)	0.0872	0	2.62	
	Total	1	n = 30	n = 30	0.07285 X^2 value = 0.07285

As a rule of thumb, it is recommended that the expected frequency n_i in cell i contain no less than five (5) points [24]. This compression of cell results in a total of three (3) cells.

The mean $\overline{S}_T$ had been estimated from the observations.

Therefore, the degree of freedom (v) is given by the relation:

v = C - k - 1

C = number of cell (boundaries) = 3

k = number of estimated quantity = 1

Therefore, v = 3 – 1 – 1 = 1

v = 1, i.e. one degree of freedom

Using a significance level $\alpha = 0.05$, the critical value of chi-square from statistical tables (See Appendix 6) is given as

$$X^2_{1,(0.05)} = 3.841$$

$$X^2_{\text{-value}} < X^2_{1,(0.05)}$$

i.e. $0.07285 < 3.841$

Once $X^2_{\text{-value}}$ less than $X^2_{v,(\alpha)}$ value the hypothesis that the distribution comes from exponential distribution can be accepted with a significance level (α) = (0.05) with a mean services time of 4.1 hours. Therefore, the mean service rate (μ), is given as

$$\mu = 1/\overline{S}_T = 1/4.1$$

$$= 0.2439 \text{ job/hour}$$

$$= 0.2439 \text{ job} \times \frac{6 \text{ hours}}{1 \text{ Day}}$$

$\mu = 1.463$ jobs/day

Therefore, negative exponential distribution as discussed in Section 4.2.1 for arrival time also applies to the service time. Hence,

$$S_T = \frac{-1}{\mu} \text{LOG} \{F(S_t)\}$$

where $0 < F(S_t) < 1$

4.2.3 ANALYSIS OF COST OF WAITING OF JOBS

Cost of hiring or amount realised by making use of the job brought for maintenance was considered as the waiting cost of the job.

The average cost of waiting for service (C_2) can be obtained from Table 4.2. It contains the cost of hiring the facility per day.

The average cost of waiting per day (C_2)

$$C_2 = \frac{\text{Sum of hiring costs for all brands of job}}{\text{Total brand}}$$

$$C_2 = \frac{2{,}000 + 3{,}000 + 5{,}000 + 2{,}000}{4}$$

$$C_2 = \frac{\text{N12,000 per day}}{4}$$

$$C_2 = \text{N3,000.00 per day per job}$$

4.2.4 ANALYSIS OF COST OF MAINTENANCE CREW

The cost of maintenance crew size was obtained from Bursary/Registry departments. This is shown in Table 4.3. The maintenance jobshop consists of seven-man maintenance crew size. Table 4.10 shows the analysis of maintenance crew salary/allowance per month. Note that useful day in a month is 20 days.

ABLE 4.10: MAINTENANCE CREW SALARY/ALLOWANCE PER MONTH

No.	Cadre	Salary/Allowance per month =N=
1	Technical Officer	3922.81
2	Senior Foreman	3271.42
3	Senior Craftsman (1)	2358.06
4	Senior Craftsman (2)	2248.80
5	Craftsman	2198.56
6	Assistant Craftsman	1984.80
7	Workshop Attendant	1886.45
	Total	17870.90

DATA SOURCE: BURSARY DEPARTMENT (FUTA)

Cost of using a crew size consists of salaries/allowances, depreciation cost on tools/equipment and building.

The initial cost of tools and building for F.U.T.A. Mechanical workshop were estimated and the results are given in the Table 4.11 below.

TABLE 4.11: FIXED COST QUANTITIES OF THE JOBSHOP

Cost Items	Values =N=	Data Source
Tools and Equipment (tool box, tyre extractor, air pump, blower, gearguage etc)	150,000	Survey
Building and Infrastructural facilities	200,000	Survey

The cost of operating a crew size in maintenance jobshop per year are tabulated in table 4.12 below.

TABLE 4.12: COST OF OPERATING A CREW SIZE PER YEAR

Cost item	Value =N=	Data Source
Cost of crew (manpower)	17870.90 x 12 (Tab. 4.10) = 214450.80	FUTA Bursary Department
Depreciation on: (i) Tools and equipment at 10% (Tab. 4.11)	15,000.00	Aderoba [2]
(ii) Building and infrastructure at 5% (Tab. 4.11)	10,000.00	Aderoba [2]
Total	239450.80	

Cost of operating a maintenance crew size in a year (C_l)

C_l = =N=239450.80 per year

$$C_l = \frac{239450.80}{\text{year}} \times \frac{1\text{year}}{12\text{ months}} \times \frac{\text{month}}{20\text{ days}}$$

$$C_1 = \frac{239450.80}{12 \times 20 \text{ days}}$$

C_1 = =N=997.70 per day

4.2.5 ANALYSIS OF THE ACCEPTABLE RESPONSE RATE (Wq*)

The acceptable response rate (Wq*) gives the time limit the customers can tolerate waiting in the queue before being served. The response rate acceptable differs from job to job. It depends on the value of individual job. The higher the value of job, the lower the time the customer can tolerate to wait in the queue. Therefore, to achieve high response rate to the jobshop, waiting time of job should be kept to a minimum.

For the analysis of response rate, Wq*, average amount realised or cost of hiring per day of the job was used. The higher the amount realised per day, the lower the time the customer expected to wait. It follows the inverse law.

Mathematically,

$$Wq^* \propto \frac{1}{C\ wait} \qquad \text{.................................} 4.12$$

$$Wq^* = \frac{b}{C\ wait}$$

b = constant, which can be determined using the principle that the least valuable job would not like to wait for more than two (2) days (survey). The least waiting cost (Table 4.2) is =N=2000.00 per day. It gives acceptable response rate of 2 days. From equation (4.12) above, b = 2 x 2000.00 = =N=4000.00 in 2 days.

Applying b = 4000.00 Naira-day for the other values in table 4.2. The new table 4.13 can be constructed reflecting acceptable waiting time Wq* for different brands of vehicle reported for repairing and maintenance.

TABLE 4.13: ACCEPTABLE RESPONSE RATE (WAITING TIME) FOR BRANDS OF VEHICLE

No.	Types	Brands	Amount realised per day (average) in naira =N=	Acceptable waiting time Wq* for brands (day)
1	Car	Peugeot, Toyota, Datsun, Faka	2,000.00	2.00
2	Buses	J-5, Liteace, Daihatsu	3,000.00	1.33
3	Trucks	Bedford, 911	5,000.00	0.80
4	Pick-Up	Peugeot, Daihatsu	2,000.00	2.00
	Average		=N=3,000.00/pay	1.53 days

DATA SOURCE: SURVEY

The average acceptable response rate (acceptable waiting time) Wq* = 1.53 days.

In summary, the following quantities have been established on average level.

Arrival rate of jobs (LAMBDA = λ) = 0.725 job/day.

Service rate of jobs (MU = μ) = 1.463 jobs/day.

Cost of waiting of jobs (C_2 = H) = =N=3,000.00/job/day.

Maintenance crew size cost (C_1 = G) = =N=997.70/crew/day.

Acceptable response rate (Wq* = WQA) = 1.53 days.

4.2.6 STOCHASTIC COST MODEL FORMULATION

A Stochastic model is needed to solve the problems resulting from assumptions made in the development of deterministic model in Section 3.1. This includes;

(i) Arrival rate less than service rate;

(ii) Inter-arrival and inter-departure times followed negative exponential distribution;

The model was developed based on the following assumptions;

(i) The first job arrives at time zero;

(ii) FIFO queue discipline;

(iii) Infinite job requisition;

(iv) Infinite queue;

(v) Next-event-oriented model.

The symbols used in the model are;

AT	=	time of next arrival of repair job;
ST	=	time of next departure of finished job;
CLOCK	=	current clock time;
MCT	=	maximum time to run simulation;
NQ	=	current number of jobs in the queue;
TIDT	=	total idle time of maintenance facility;
TNJEQ	=	total number of jobs which enter the queue;
TWT	=	total waiting time of all jobs;
TISF	=	total time in service facility for all jobs;

TIS	=	total time for all the jobs in the system;
TNA	=	total number of jobs;
MQL	=	maximum queue length;
C1	=	average cost of using a maintenance crew;
C2	=	average cost of waiting per job;
L	=	total number of jobs per unit time;
TC	=	total maintenance cost;
S	=	crew size.

Steps to follow are given in the algorithm below:

4.2.6.1 ALGORITHM FOR THE STOCHASTIC MODEL DEVELOPMENT (SINGLE CHANNEL IN SERIES)

(i) Input MCT, λ μ, C1, C2.

(ii) Set the initial condition

CLOCK = 0, AT = 0 NQ = 0, TNJEQ = 0

TWT = O, TIDT = O, TNA = 1 MQL = 0

(iii) Generate the time of the next departure (ST);

(iv) Generate the time of the next arrival (AT);

(v) If next event is an arrival (ST$\geq$ AT) go to (iv) else go to (xiv);

(vi) Update the total waiting time of all arrivals.

TWT = TWT = NQ (AT – CLOCK);

(vii) Update the clock to the next event (arrival) CLOCK = AT.

(viii) If next event is both an arrival and a departure (ST = AT) go to (ix) else (x).

(ix) If the current clock time greater than the maximum simulation time, go to (xxii) else, return to (iii);

(x) Increase the number in queue by 1:

(xi) If the current number in the queue (NQ) greater than the longest queue length to date (MQL) set, MQL = NQ and go to (xii) else go directly to (xii);

(xii) Increase the total number of jobs which enter the queue (TNJEQ) by 1;

(xiii) If the current clock time greater than maximum simulation time, go to (xxiii); other wise return to (iv);

(xiv) If queue is empty (NQ = O) go to (xv), else, go to (xix);

(xv) Update the clock to the time of next event (departure) CLOCK = ST;

(xvi) Update the total idle time of the maintenance facility.

TIDT = TIDT + (AT – CLOCK);

(xvii) Update the clock to the time of next event (arrival). CLOCK = AT;

(xviii) Increase the number of arrivals by 1;

(xix) Update total waiting time of all arrivals TWT = TWT + NQ (ST – CLOCK)

(xx) Update the clock to the time of the next event (departure) CLOCK = ST;

(xxi) Decrease the number in queue by 1 and generate the time of the next departure;

(xxii) If the current clock greater than maximum simulation time, go to (xxiii) else return to (v);

(xxiii) Calculate the statistics.

TISF = CLOCK – TIDT

TIS = TISF + TWT

ATIS (Ws) = Average time in the system = TIS/TNA

ATIQ (Wq) = Average time in queue = TWT/TNA

ATJEQ = Average time for jobs that enter the queue

= TWT/TNJEQ

POTB = P = Utilization factor of maintenance facility.

(xxiv) Calculate average number of jobs for a unit time in the system

L = POTB/(1-POTB).

(xxv) Varying the crew size from 1 to N.

(xxvi) Calculate average number of jobs in the system L(S)= POTB/(S-POTB)

(xxvii)Calculate the waiting cost of jobs, Cwait = C2L (S);

(xxviii)Calculate the cost of using maintenance crew, Ccrew = C1S.

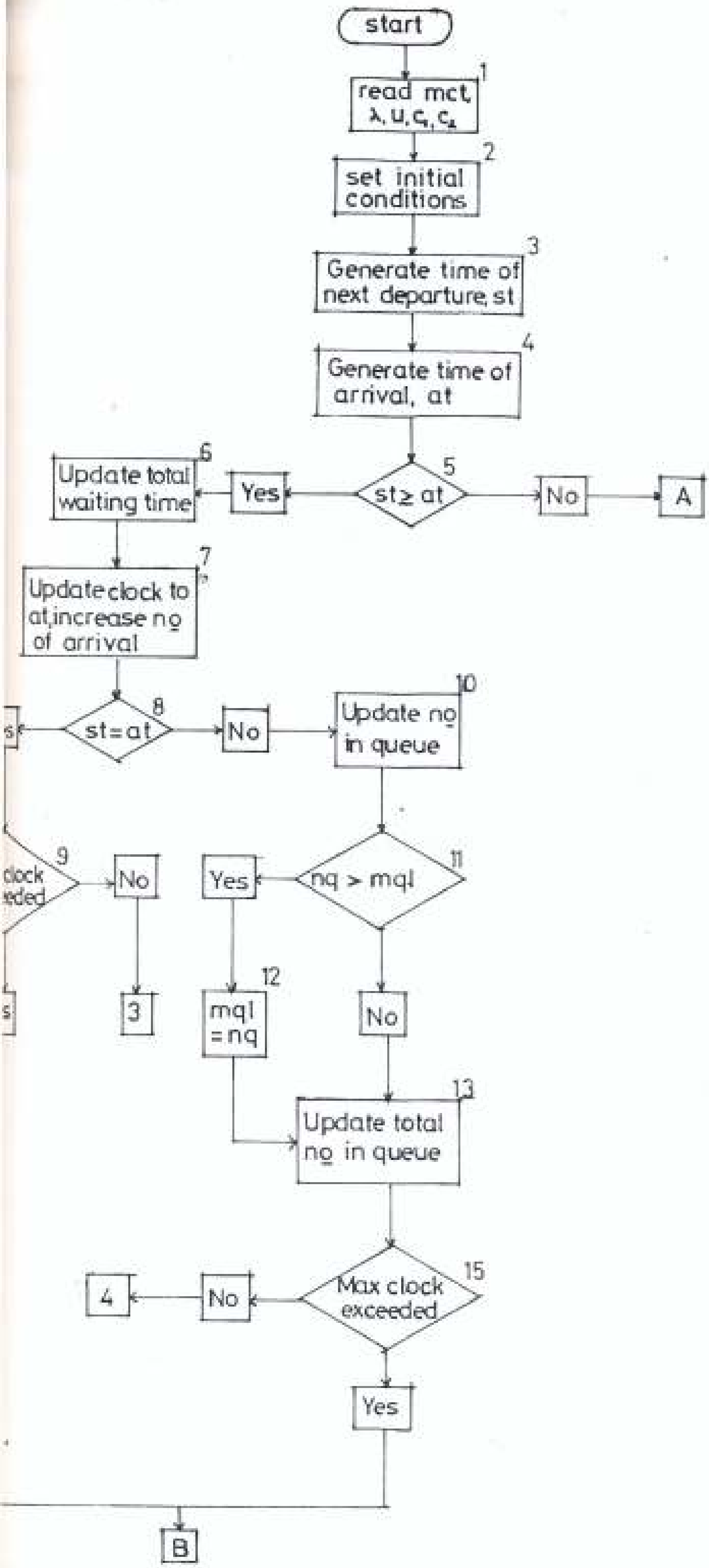
(xxix) Calculate the total maintenance cost TC(S) = C1S + C2L(S)

(xxx) Calculate the utilization factors POTB(S) = P(S) = TISF/(S*CLOCK);

(xxxi) Calculate waiting time in the queue WQ(S) = POTB *ATSF/(S-POTB)

(xxxii)Print results.

Flow chart for the algorithm designed above to simulate single channel queueing system with negative exponential input and service time distributions is given in Figure 4.3



Flow chart for Stochastic model for crew size determination (Single channel)

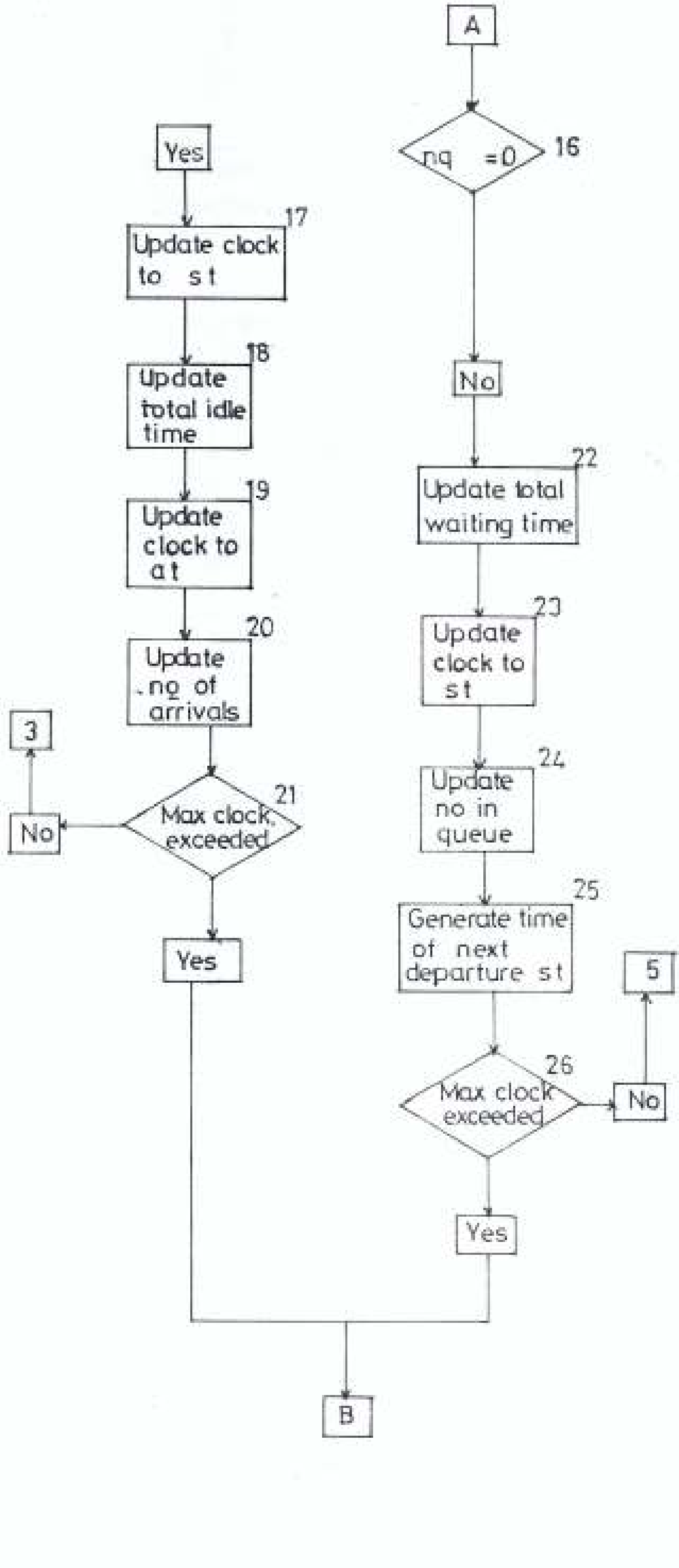
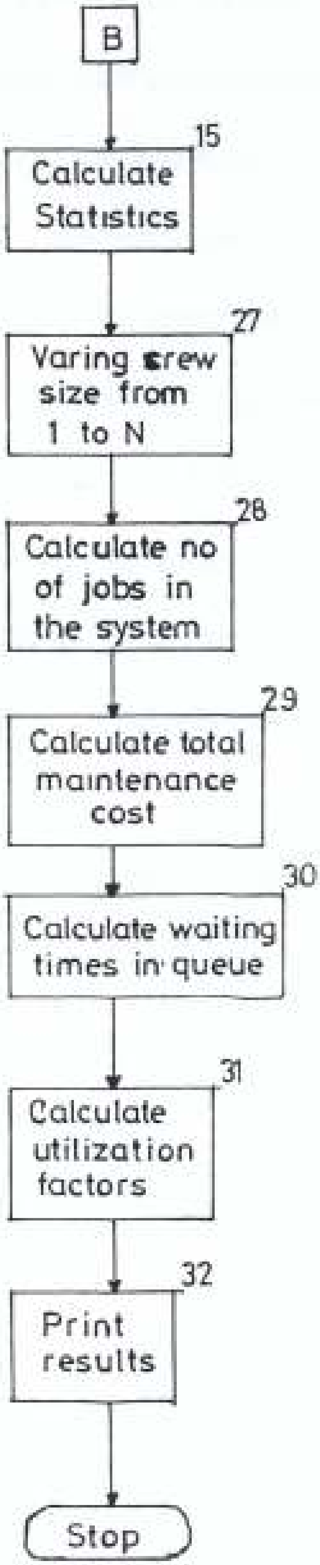


Fig 4·3 continues



ig 4.3 continues

4.3 FORMULATION OF OBJECTIVES

It was generally known that myriad of problems are associated with maintenance jobshops. Some of these problems were discussed in Section 1.1. The problems of effective maintenance revolve around lack of effective crew size to carry out maintenance activities. Therefore, a practical model is required to determine effective crew size for maintenance jobshops. The heuristics developed by Aderoba and Lawal (Section 3.2) and maintenance cost models (Section 3.2.5 and 4.2.6) based on queueing theory were used.

Below is the scope of the model used for this study:

i determination of the effective crew size based on the acceptable response rate using single channel;

ii. determination of the effective crew size based on the minimum maintenance cost using single-channel in series;

iii. determination of the maintenance cost for effective crew size obtained in (ii) using multi channel model in parallel.

From the above results, effective layout can be developed for the jobshop under study.

"QBASIC" computer software was used to develop the model (Appendices 1 and 3). The computer programming was carried out at the School of Engineering Data Processing Room and Computer Centre both in the Federal University of Technology, Akure (Appendix 8).

4.3.1 THE USE OF "QBASIC" SOFTWARE

"QBASIC" means Quick Beginners, All-purpose Symbolic Instruction Code [12]. "QBASIC" is very easy to handle and can be easily understood by any layman. Initially, "FORTRAN-77" (Formula Translator-77) computer software was used. Due to the fact that it consists of too many complex mathematical and scientific symbols, it was translated to "QBASIC" software which can be handled easily. The "QBASIC" computer software developed for the model is presented in (Appendices 1, and 3) of this thesis.

4.4 MODEL TESTING

The Model developed (in Section 3.2 and 4.2.6) was tested with the results generated from the analysis of the data obtained from the Mechanical maintenance jobshop under study.

4.4.1 THE INPUT VARIABLES FOR SINGLE CHANNEL MODEL

The following input variables were estimated from the analysis of the data (Section 4.2) on average basis for single-channel model.

- Arrival rate of jobs (LAMBDA =λ) = 0. 725 JOB/DAY (Section 4.2.1).
- Service rate of job (MU = μ) = 1.463 JOB/DAY (Section 4.2.2).
- Cost of waiting (H = C_2) = =N=3000.00 /JOB/DAY (Section 4.2.3)
- Cost of using maintenance crew (G = C_1) = =N= 997.70/crew/day (4.2.4).
- Acceptable response rate (WQA = WQ*) = 1. 53 day/job (4.2.5).

When these variables above were input into the "QBASIC" computer software developed for the model, the output/results for the single channel model in (Appendices 2 and 4) were generated. By using heuristic, So = 1 while So = 2 for both deterministic and stochastic cost models.

4.4.2 THE INPUT VARIABLES FOR MULTI-CHANNEL MODEL

In case of multi-channel model, all the input variables for the single-channel were used with the addition of variables P_{ZERO} (Section 2.2), and So (optimum or effective crew size). Multi-channel model equations depend on probability P_{ZERO}. P_{ZERO} means probability that no job in the system.

P_{ZERO} as obtained in Appendix 5 [20] corresponds to the factor $\lambda/k\mu$

From the above,

λ = 0. 725

μ = 1. 463

k = So = optimum crew size = 2

P_{ZERO} at $\lambda/So\mu$ = 0. 725/2x1.463

= 0. 2477

= 0. 25

From tables for P_{ZERO} (Appendix 5)

$\lambda/k\mu$ = 0. 24 corresponds to P_{ZERO} = 0. 61290

$\lambda/k\mu$ = 0. 26 corresponds to P_{ZERO} = 0. 58730

By interpolation

0. 2 ⇒ 0. 0256

0.1 ⇒ 0.01280

0.24 + 0.1 ⇒ 0.61290 - 0.01280

At $\lambda/k\mu$ = 0.25, P_{ZERO} = 0.60010

P_{ZERO} = 0.60010, So = 2

Table 4.14 below shows the values of P_{ZERO} by varying S from 1 to 10.

TABLE 4.14: THE VALUE OF P_{ZERO} BY VARYING CREW SIZE (S)

S	1	2	3	4	5	6	7	8	9	10
$\lambda/k\mu$	0.50	0.25	0.17	0.12	0.10	0.08	0.07	0.06	0.05	0.05
P_{ZERO}	0.5000	0.6001	0.6003	0.6188	0.6065	0.6188	0.6142	0.6188	0.6402	0.6096

SOURCE: APPENDIX 5.

After inputting these values into the software, the result at the last part of Appendix 2 were generated. The results obtained were compared and suggestions were proffered on the choice of effective crew size for continuous existence of the maintenance jobshop under study.

DISCUSSION OF RESULTS

Tables 5.1, 5.2, 5.3 and 5.4 show the results obtained for both deterministic and stochastic approaches under single channel in series by varying crew size (S). The results are plotted and are shown in Figures 5.1, 5.2, 5.3 and 5.4. In Figure 5.1, total maintenance cost of N3936.54, N2983.59 and N10133.42 are obtained when operating on crew size of one, two and ten respectively. These show that crew size of two corresponds to a minimum cost of N2983.59.

In Figure 5.2 number of job in the system for both approaches are 0.982, 0.329 and 0.052 for one, two and ten crew(s) respectively. It shows that at a minimum total maintenance cost of N2983.59, 0.329 job/day is noticed while the lowest number of jobs is witnessed when operating on ten crews. In Figures 5.3 and 5.4, lowest waiting time (0.036 day) and lowest utilization factor (5%) are achieved respectively by operating on ten crews, leading to high total maintenance cost (Figure 5.1)

TABLE 5.1: TOTAL MAINTENANCE COSTS [TC(S)] OBTAINED FOR DETERMINISTIC AND STOCHASTIC APPROACHES BY VARYING CREW SIZE (S) (SINGLE-CHANNEL IN SERIES)

CREW SIZE	TOTAL MAINTENANCE COST TC(S)		
	DETERMIMSTIC APPROACH	STOCHASTIC APPROACH MCT = [MAXIMUM SIMULATION TIME]	
		MCT = 200,000 DAYS	MCT = 400,000 DAYS
1	3944.85	3936.54	3951.14
2	2983.59	2981.72	2985.00
3	3586.71	3585.70	3587.48
4	4415.02	4414.33	4415.54
5	5318.55	5318.02	5318.94
6	6256.29	6255.87	6256.60
7	7212.46	7212.11	7212.73
8	8179.71	8179.40	8179.93
9	9154.11	9153.85	9154.93
10	10133.42	10133.18	10133.60

SOURCE: APPENDICES 2 AND 4

TABLE 5.2 NUMBER OF JOBS IN THE SYSTEM L(S) OBTAINED FOR DETERMINISTIC AND STOCHASTIC APPROACHES BY VARYING CREW SIZE (S) (SINGLE – CHANNEL IN SERIES)

CREW SIZE (S)	NUMBER OF JOBS IN THE SYSTEM L(S) PER DAY		
	DETERMINISTIC APPROACH	STOCHASTIC APPROACH [MCT = MAXIMUM SIMULATION TIME]	
		MCT = 200,000 DAYS	MCT = 400,000 DAYS
1	0.982	0.980	0.984
2	0.329	0.329	0.330
3	0.198	0.198	0.198
4	0.141	0.141	0.142
5	0.110	0.110	0.110
6	0.090	0.090	0.090
7	0.076	0.076	0.076
8	0.066	0.066	0.066
9	0.058	0.058	0.058
10	0.052	0.052	0.052

SOURCE: APPENDICES 2 AND 4

TABLE 5.3: WAITING TIME OF JOBS IN QUEUE {Wq(S)} OBTAINED FOR DETERMINISTIC AND STOCHASTIC APPROACHES BY VARYING CREW SIZE (S) (SINGLE – CHANNEL IN SERIES)

CREW SIZE (S)	WAITING TIME OF JOBS IN QUEUE {Wq(S)}		
	DETERMINISTIC APPROACH	STOCHASTIC APPROACH {MCT = MAXIMUM SIMULATION TIME}	
		MCT = 200,000 DAYS	MCT = 400,000 DAYS
1	0.671	0.669	0.673
2	0.225	0.224	0.225
3	0.135	0.135	0.135
4	0.097	0.096	0.097
5	0.075	0.075	0.075
6	0.062	0.061	0.062
7	0.052	0.052	0.052
8	0.045	0.045	0.042
9	0.040	0.040	0.040
10	0.036	0.036	0.036

SOURCE: APPENDICES 2 AND 4

TABLE 5.4: FACILITY UTILIZATION FACTOR P(S) OBTAINED FOR DETERMINISTIC AND STOCHASTIC APPROACH BY VARYING CREW SIZE (S) (SINGLE – CHANNEL IN SERIES)

CREW SIZE (S)	FACILITY UTILIZATION FACTOR P(S)		
	DETERMINISTIC APPROACH	STOCHASTIC APPROACH {MCT = MAXIMUM SIMULATION TIME}	
		MCT = 200,000 DAYS	MCT = 400,000 DAYS
1	0.496	0.495	0.496
2	0.248	0.247	0.248
3	0.165	0.165	0.165
4	0.124	0.124	0.124
5	0.099	0.099	0.099
6	0.083	0.082	0.083
7	0.071	0.071	0.71
8	0.062	0.062	0.062
9	0.055	0.055	0.055
10	0.050	0.049	0.050

SOURCE: APPENDICES 2 AND 4

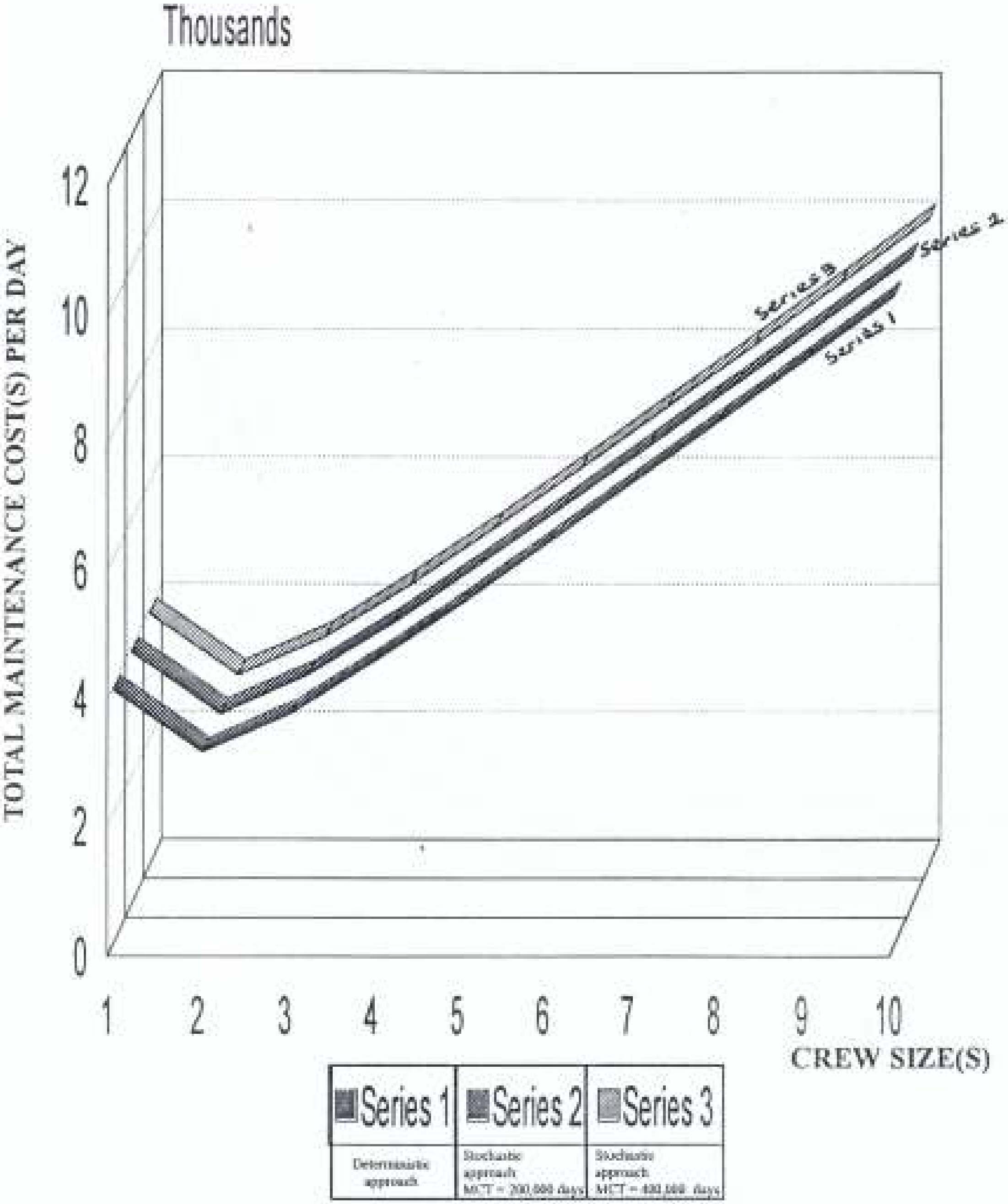


Fig. 5.1. TOTAL MAINTENANCE COST [TC(S) OBTAINED FOR DETERMINISTIC AND STOCHASTIC APPROACHES BY VARYING CREW SIZE(S) (SINGLE-CHANNEL IN SERIES)

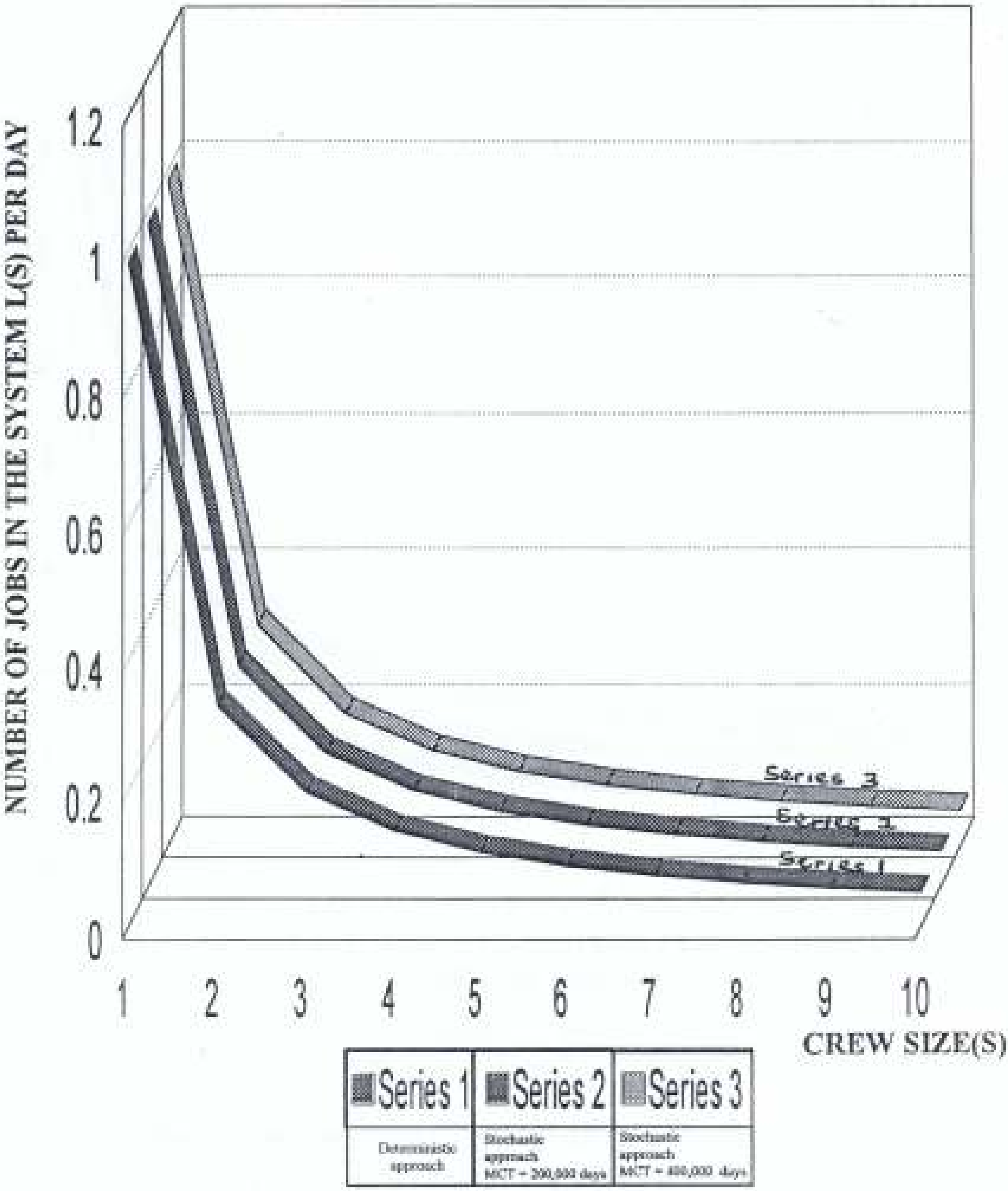


Fig. 5.2. NUMBER OF JOBS IN THE SYSTEM L(S) OBTAINED FOR DETERMINISTIC AND STOCHASTIC APPROACHES BY VARYING CREW SIZE(S) (SINGLE-CHANNEL IN SERIES)

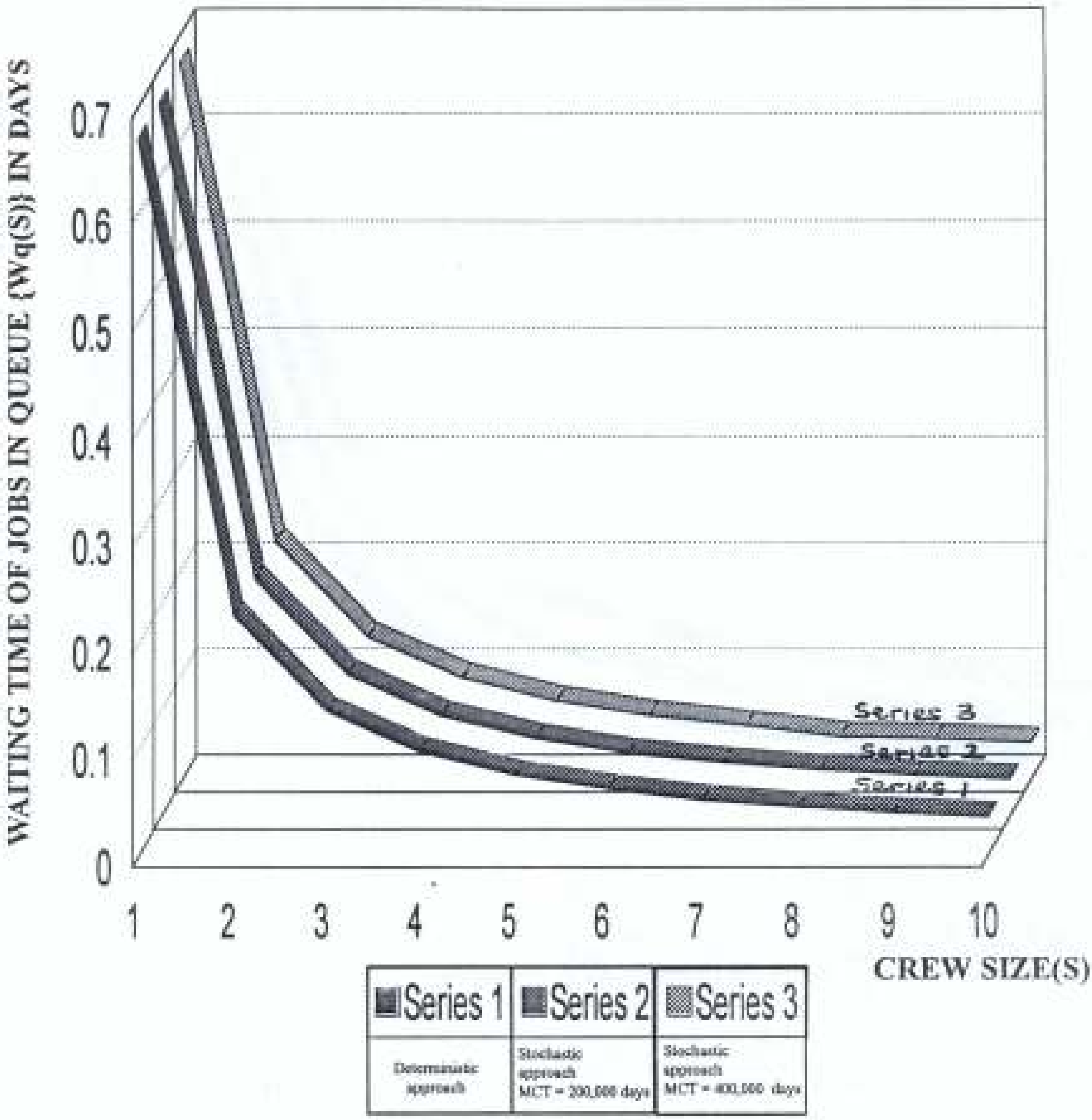


Fig. 5.3. **WAITING TIME OF JOBS IN QUENE {Wq(S)} OBTAINED FOR DETERMINISTIC AND STOCHASTIC APPROACHES BY VARYING CREW SIZE(S) (SINGLE-CHANNEL IN SERIES)**

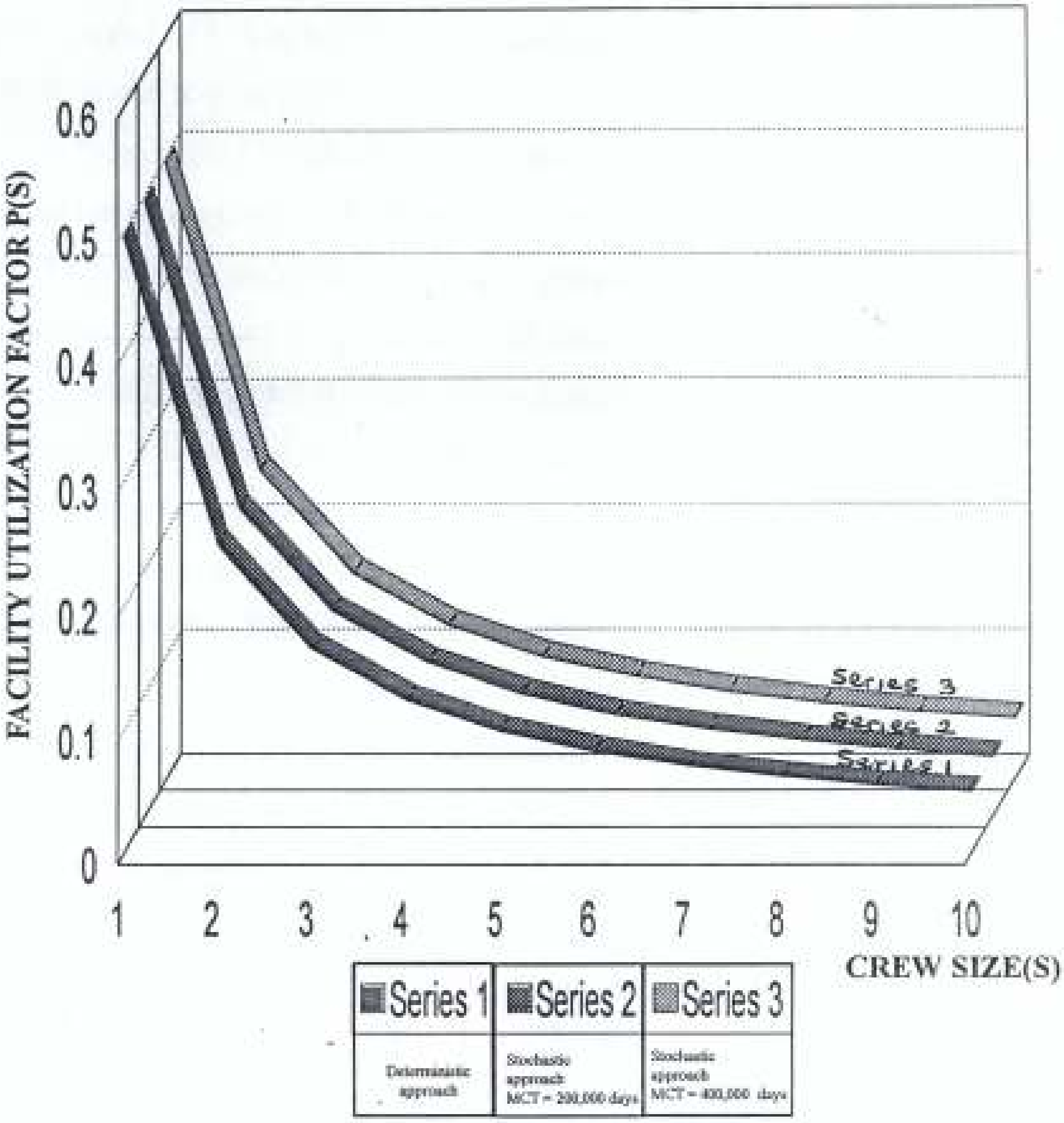


Fig. 5.4. **FACILITY UTILIZATION FACTOR P(S) OBTAINED FOR DETERMINISTIC AND STOCHASTIC APPROACHES BY VARYING CREW SIZE(S) (SINGLE-CHANNEL IN SERIES)**

Also, Tables 5.5, 5.6, 5.7, and 5.8 show the results obtained for total maintenance costs, number of jobs in the system, facility utilization factor and waiting time of jobs in queue (for deterministic model) under single channel in series and multi-channel in parallel respectively. The results are transformed into graphs which are shown in Figures 5.5, 5.6, 5.7, and 5.8 for total maintenance cost, number of jobs in the system, facility utilization factor and waiting time of jobs in queue respectively.

From Figure 5.5 one can see that the optimum maintenance cost for single-channel in series is =N=2983.59 while for multi-channel in parallel it is =N=3578.87 with both corresponding to optimum crew size (So) of two. This shows that, it is costly to operate on multi-channel system.

Also, in Figure 5.6, under single-channel in series, the number of jobs in the system decreases as the crew size increases, while in multi-channel in parallel, the number of jobs in the system decreases as the crew size increases up to four, and it remains constant (that is 0.496 job/day) for any other addition of maintenance crew. It can be seen that number of crews needed to reach the constant point in single channel system is higher than that of multi-channel in parallel. Number of jobs in the system can be better reduced using single channel in series by increasing the number of crew(s).

In the case of facility utilization factor curve in Figure 5.7, it is shown that for single channel in series, increase in crew size results into decrease in utilization factor, but for multi-channel in parallel increase in crew size, leads to decrease in utilization factor and finally reduced to zero at a crew size of four. At this point addition of more crew(s) has no effect on the system. Figure 5.8 follows the same trend as Figure 5.7, but the only difference is that, for multi-channel in parallel, addition of more crew(s) after three has no effect on the waiting time of job.

TABLE 5.5: TOTAL MAINTENANCE COST {TC(S)} OBTAINED BY VARYING CREW SIZE (S) FOR SINGLE – CHANNEL IN SERIES AND MULTI-CHANNEL IN PARALLEL (DETERMINISTIC APPROACH)

CREW SIZE (S)	TOTAL MAINTENANCE COST TC (S) (=N=)	
	SINGLE – CHANNEL IN SERIES	MULTI – CHANNEL IN PARALLEL
1	3944.85	3931.99
2	2983.59	3578.87
3	3586.71	4488.43
4	4415.02	5478.22
5	5318.55	6475.23
6	6256.29	7472.88
7	7212.46	8470.57
8	8179.71	9468.27
9	9154.11	10465.97
10	10133.42	11463.67

SOURCE: APPENDIX 2

TABLE 5.6: NUMBER OF JOBS IN THE SYSTEM {L(S)} OBTAINED BY VARYING CREW SIZE (S) FOR SINGLE – CHANNEL IN SERIES AND MULTI – CHANNEL IN PARALLEL (DETERMINISTIC APPROACH)

CREW SIZE (S)	NUMBER OF JOBS IN THE SYSTEM L(S) PER DAY	
	SINGLE – CHANNEL IN SERIES	MULTI – CHANNEL IN PARALLEL
1	0.982	0.978
2	0.329	0.528
3	0.198	0.498
4	0.141	0.496
5	0.110	0.496
6	0.090	0.496
7	0.076	0.496
8	0.066	0.496
9	0.058	0.496
10	0.052	0.496

SOURCE: APPENDIX 2

TABLE 5.7: FACILITY UTILIZATION FACTOR {P(S)} OBTAINED BY VARYING CREW SIZE (S) FOR SINGLE – CHANNEL IN SERIES AND MULTI – CHANNEL IN PARALLEL *(DETERMINISTIC APPROACH)*

CREW SIZE (S)	FACILITY UTILIZATION FACTOR P(S)	
	SINGLE – CHANNEL IN SERIES	MULTI – CHANNEL IN PARALLEL
1	0.496	0.491
2	0.248	0.098
3	0.165	0.015
4	0.124	0.002
5	0.099	0
6	0.083	0
7	0.071	0
8	0.062	0
9	0.055	0
10	0.050	0

SOURCE: APPENDIX 2

TABLE 5.8: WAITING TIME OF JOBS IN QUEUE {Wq(S)} OBTAINED BY VARYING CREW SIZE (S) FOR SINGLE – CHANNEL IN SERIES AND MULTI – CHANNEL IN PARALLEL (DETERMINISTIC APPROACH)

CREW SIZE (S)	WAITING TIME OF JOBS IN QUEUE Wq(S), DAYS PER JOB.	
	SINGLE – CHANNEL IN SERIES	MULTI – CHANNEL IN PARALLEL
1	0.671	0.666
2	0.225	0.045
3	0.135	0.004
4	0.097	0
5	0.075	0
6	0.062	0
7	0.052	0
8	0.045	0
9	0.040	0
10	0.036	0

SOURCE: APPENDIX 2

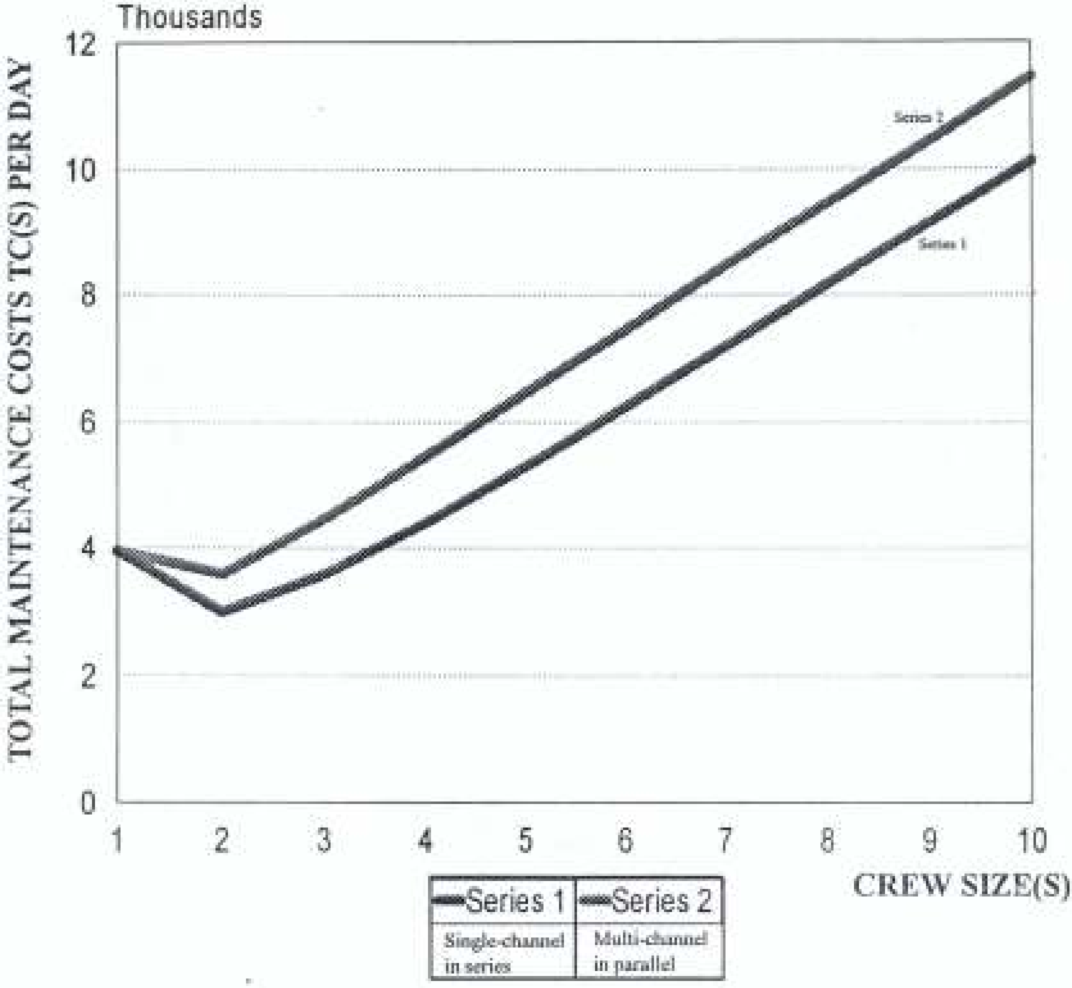


Fig. 5.5. **TOTAL MAINTENANCE COST {TC(S)} OBTAINED BY VARYING CREW SIZE(S) FOR SINGLE-CHANNEL IN SERIES AND MULTI-CHANNEL IN PARALLEL (DETERMINISTIC APPROACH)**

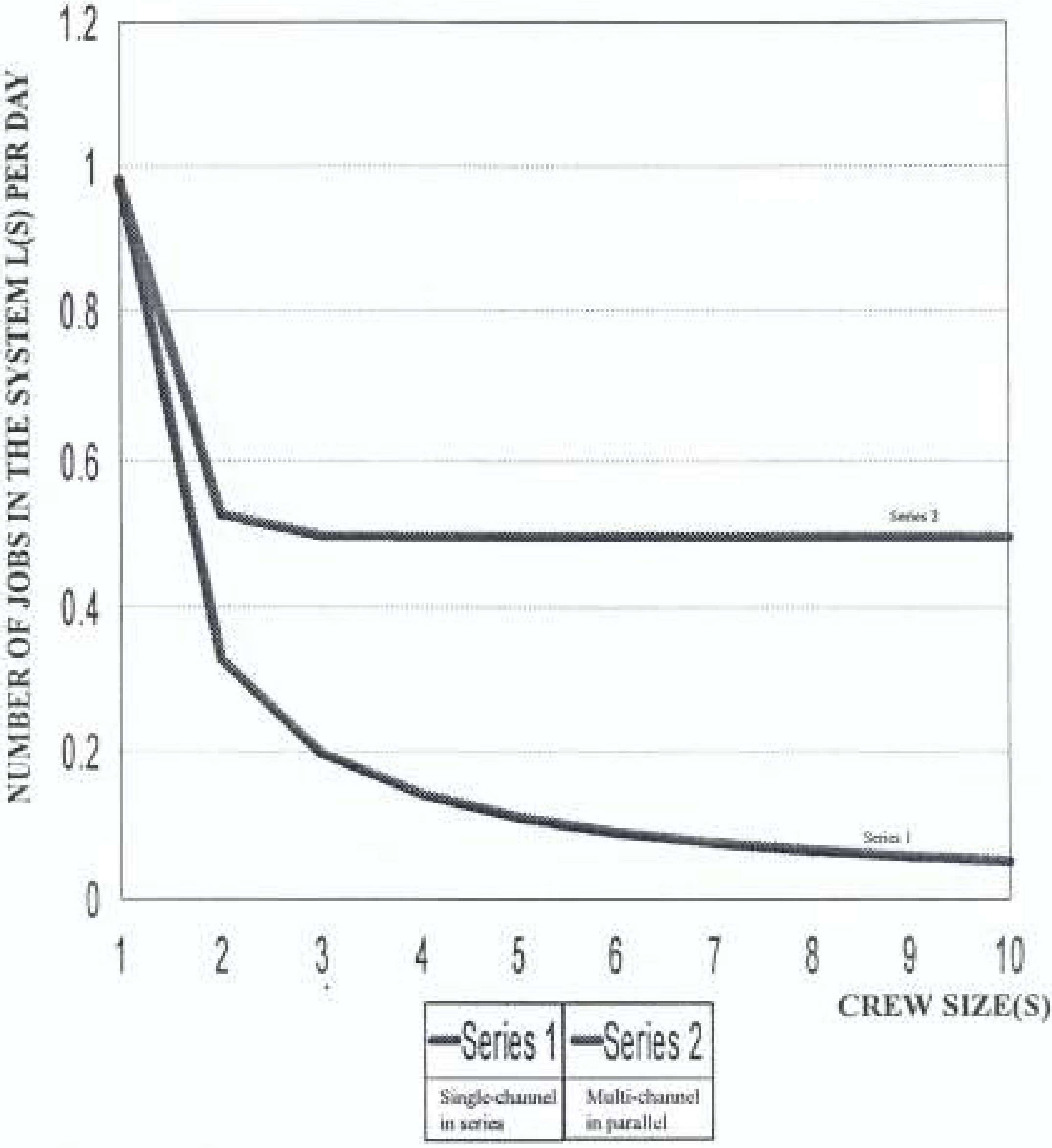


Fig. 5.6. **NUMBER OF JOBS IN THE SYSTEM {L(S)} OBTAINED BY VARYING CREW SIZE(S) FOR SINGLE-CHANNEL IN SERIES AND MULTI-CHANNEL IN PARALLEL (DETERMINISTIC APPROACH)**

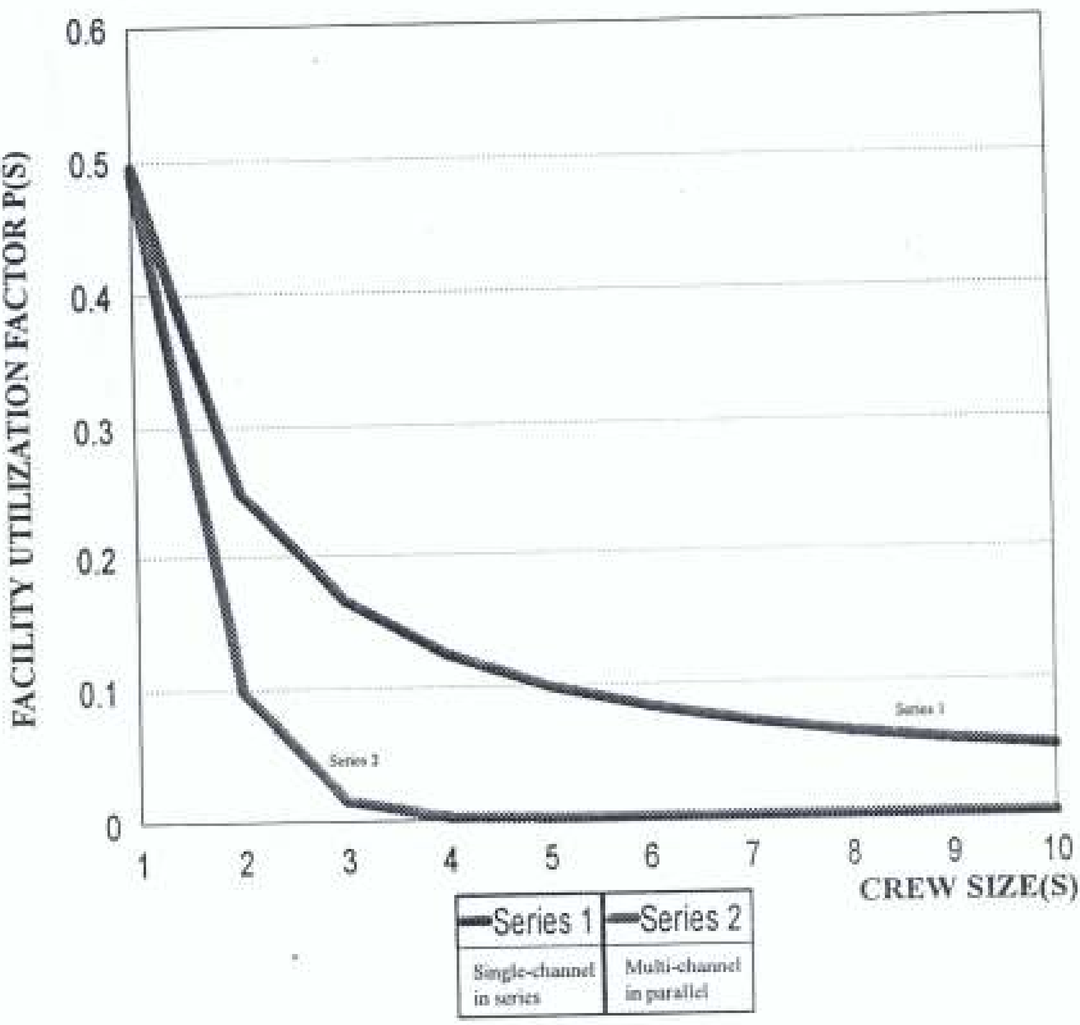


Fig. 5.7. FACILITY UTILIZATION FACTOR {P(S)} OBTAINED BY VARYING CREW SIZE(S) FOR SINGLE-CHANNEL IN SERIES AND MULTI-CHANNEL IN PARALLEL (DETERMINISTIC APPROACH)

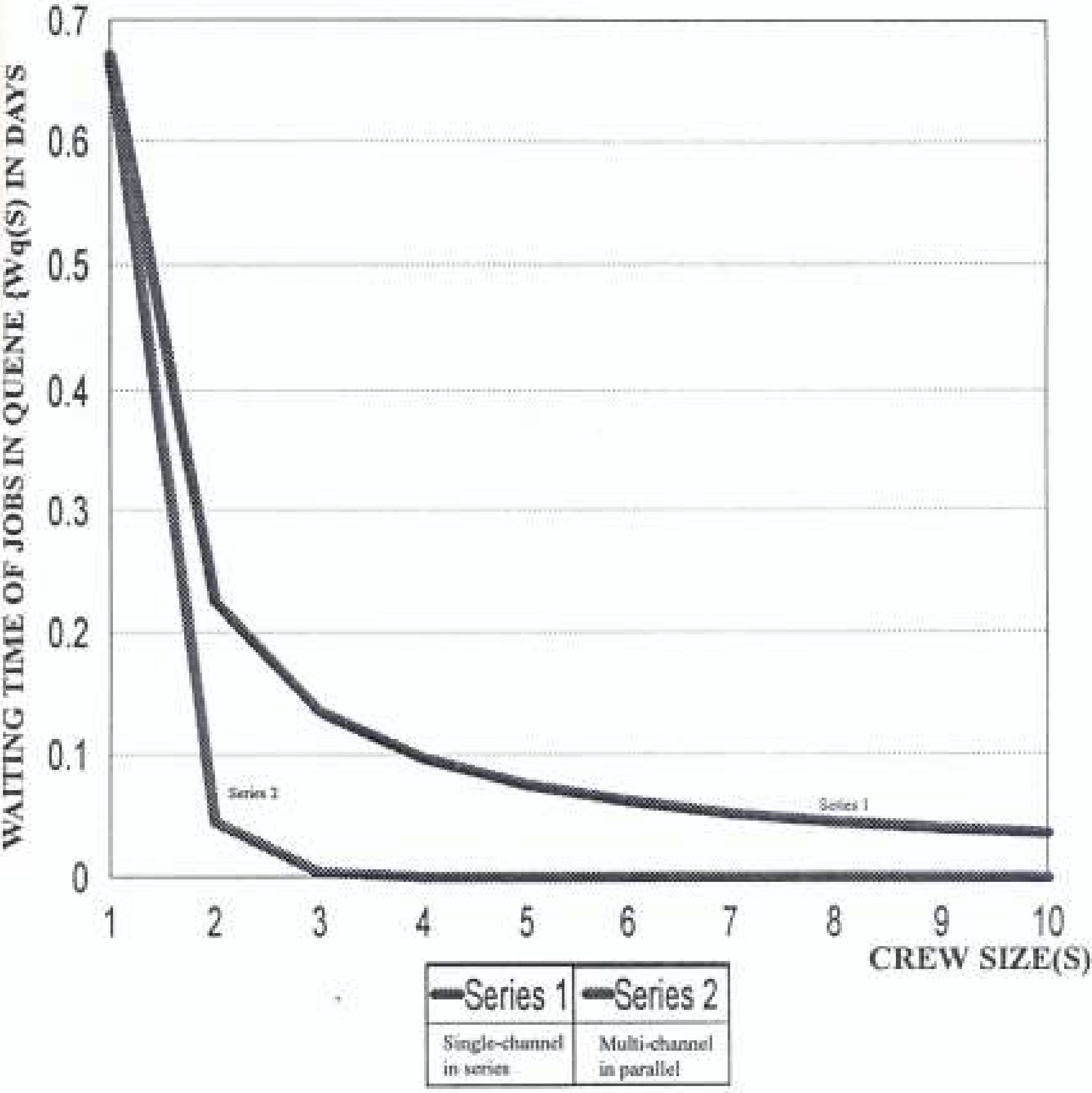


Fig. 5.8. **WAITING TIME OF JOBS IN QUENE {Wq(S)} OBTAINED BY VARYING CREW SIZE(S) FOR SINGLE-CHANNEL IN SERIES AND MULTI-CHANNEL IN PARALLEL (DETERMINISTIC APPROACH)**

Finally, in Table 5.9, the jobs in the system (LSo) under single channel is the highest (that is 0.982 job/day) followed by double channel in parallel, while single channel in series has the least number of jobs. In case of waiting time of jobs in queue, single channel has highest waiting time (WQSo) followed by single channel in series and double channel in parallel has the least waiting time of 0.045 day/job. The facility utilization factor at the optimum crew level is lowest for double channel in parallel and highest for single channel (that is 0.496), For case of total maintenance cost, it is highest for single channel, followed by double channel in parallel and least for single channel in series.

TABLE 5.9: SUMMARY OF THE RESULTS FOR EFFECTIVE CREW SIZE DETERMINATION MODELS FOR MAINTENANCE JOBSHOP (DETERMINISTIC APPROACH)

EFFECTIVE SYSTEM LAYOUT	So	Lso	WQSo	PSo	SoC_1	$LsoC_2$	TCSo (=N=)
1. Single channel	1	0.982	0.671	*0.496	997.70	2947.15	3944.85
2. Single channel in series	2	*0.329	0.225	0.248	1995.40	988.19	*2983.59
3. Double-channel in parallel	2	0.528	*0.045	0.098	1995.40	1583.47	3578.87

SOURCE: APPENDIX 2

So = Optimum or Effective crew size

LSo = Number of jobs in the system per day at So

WQSo = Waiting time in queue per job in days at So

PSo = Utilization factor (Facilities) at So

SoC_1 = Cost of using maintenance crew at So per day

$LSoC_2$ = Cost of waiting of job at So per day

TCSo = Total cost of maintenance at So per day.

The outputs obtained from the models (single channel in series and multi-channel in parallel) are succinctly described in Table 5.9 (Appendix 2), and the result obtained using simulation time of 50000, 100000, 200000 and 400000 days are presented in Table 5.10 at the optimum crew size level (So) (Appendix 4). From these results, one can deduce that on the long run the output of both deterministic and stochastic cost models are the same. Therefore, minimum maintenance cost of =N=2,983.59 per day (Figures 5.10 and 5.11) is acceptable. The higher the simulation time (MCT), the higher the time (t_s) used to process the results in the computer (Table 5.10). The deterministic model used a constant time (t_s) of 1.5 seconds for results processing. The model of computer used for the experiments is "IBM NCR System 3200".

TABLE 5.10: SUMMARY OF STOCHASTIC COST MODEL RESULTS AT OPTIMUM CREW SIZE LEVEL (SINGLE CHANNEL IN SERIES)

OPTIMUM CREW SIZE $S_O = 2$					
QUANTITY	STOCHASTIC COST MODEL				DETERMI NSTIC COST MODEL
	MAXIMUM SIMULATION TIME IN DAYS				
	50,000	100,000	200,000	400,000	
TCS_O	2,980.32	2,983.10	2,981.72	2,985.00	2,983.59
PS_O	0.247	0.248	0.247	0.248	0.248
WQS_O	0.224	0.225	0.224	0.225	0.225
LS_O	0.328	0.329	0.329	0.330	0.329
t_s	13.5mins.	27.1mins.	54.2mins.	108.2mins	1.5secs.

SOURCE: APPENDIX 4

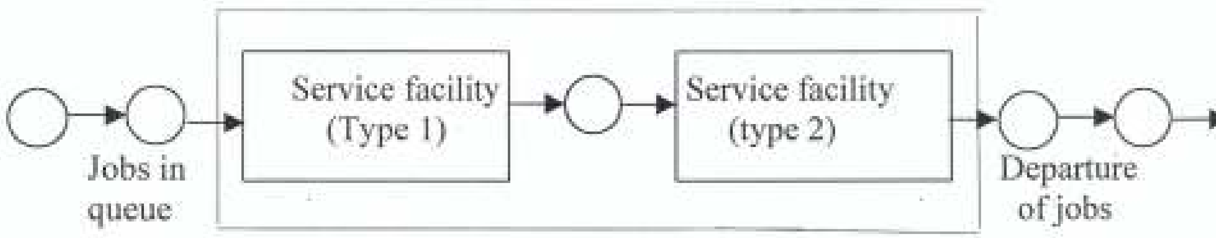
Computer type used for the experiments is IBM NCR System 3200.

t_s = time for processing the results in computer.

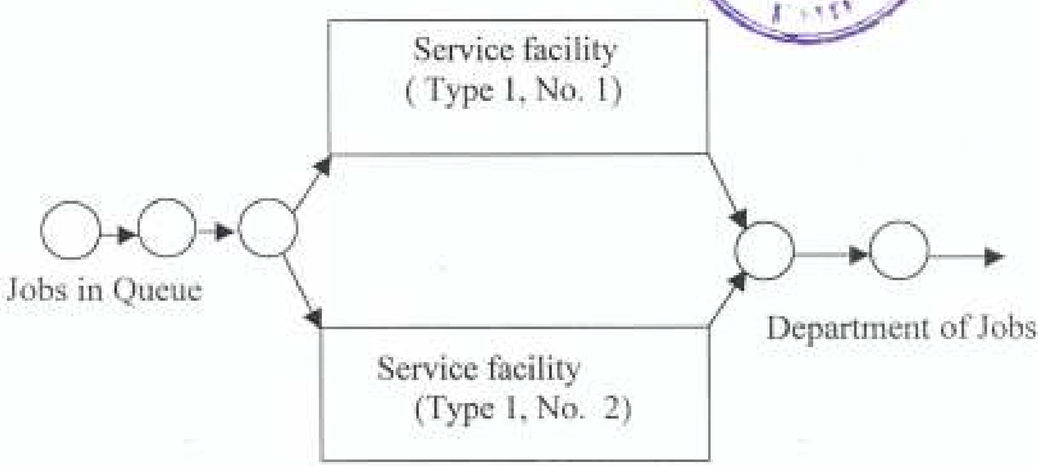
The layouts of the optimum/effective crew size from the results in Table 5.9 are shown below (Fig. 5.9a, b, and c).

The choice of a particular layout for effective crew size not only depends on the management policy but also on environmental factors such as size of competitors, size of customers, culture, government policy etc.

a. Single Channel



b. Single Channel, in Series



c. Double Channel, in parallel

Fig. 5.9: Physical Layouts of the Maintenance Jobshop

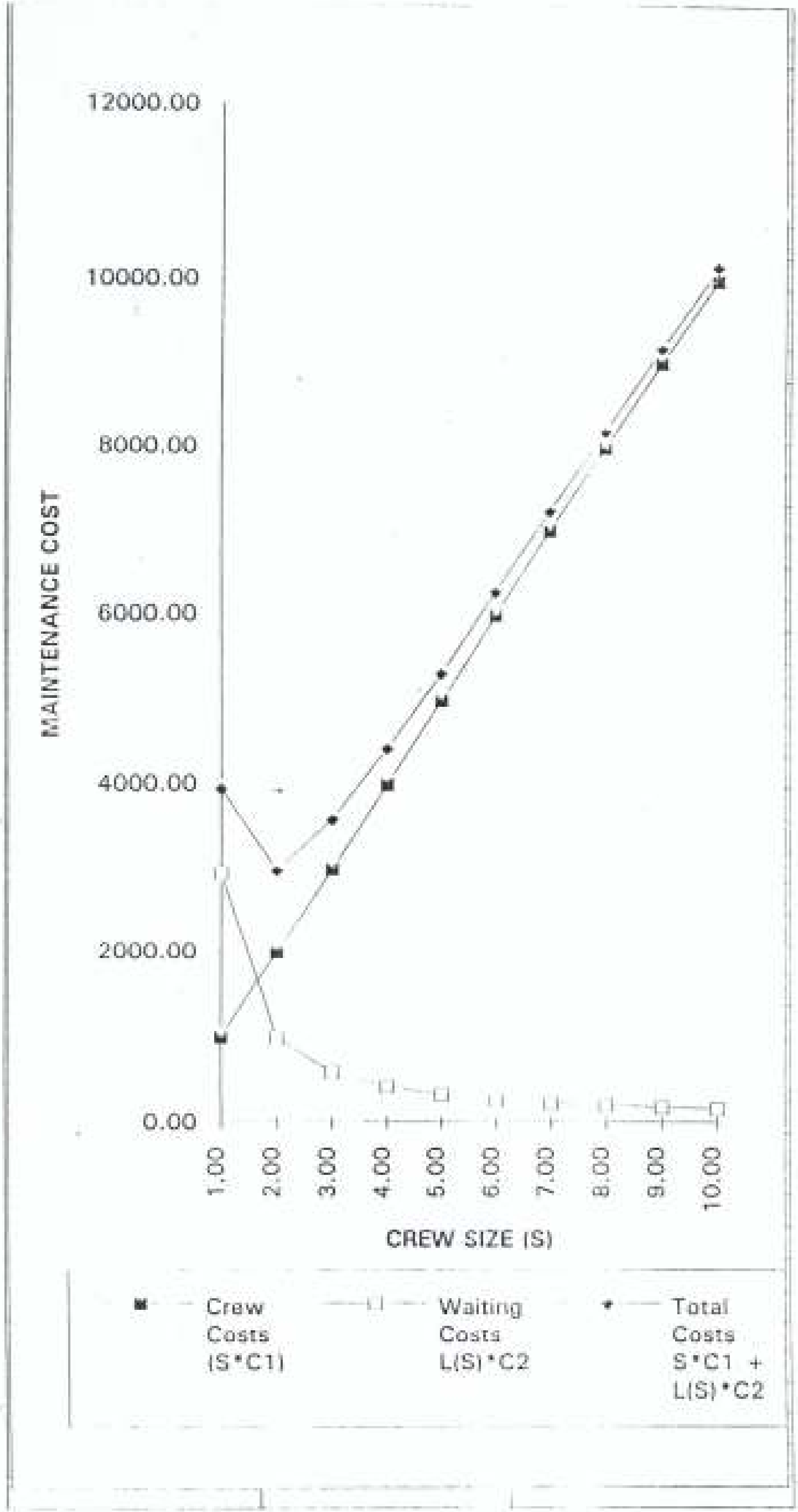


FIG.5.10 MAINTENANCE COSTS GRAPH SHOWING OPTIMUM CREW SIZE (So)
SINGLE CHANNEL IN SERIES – DETERMINISTIC APPROACH

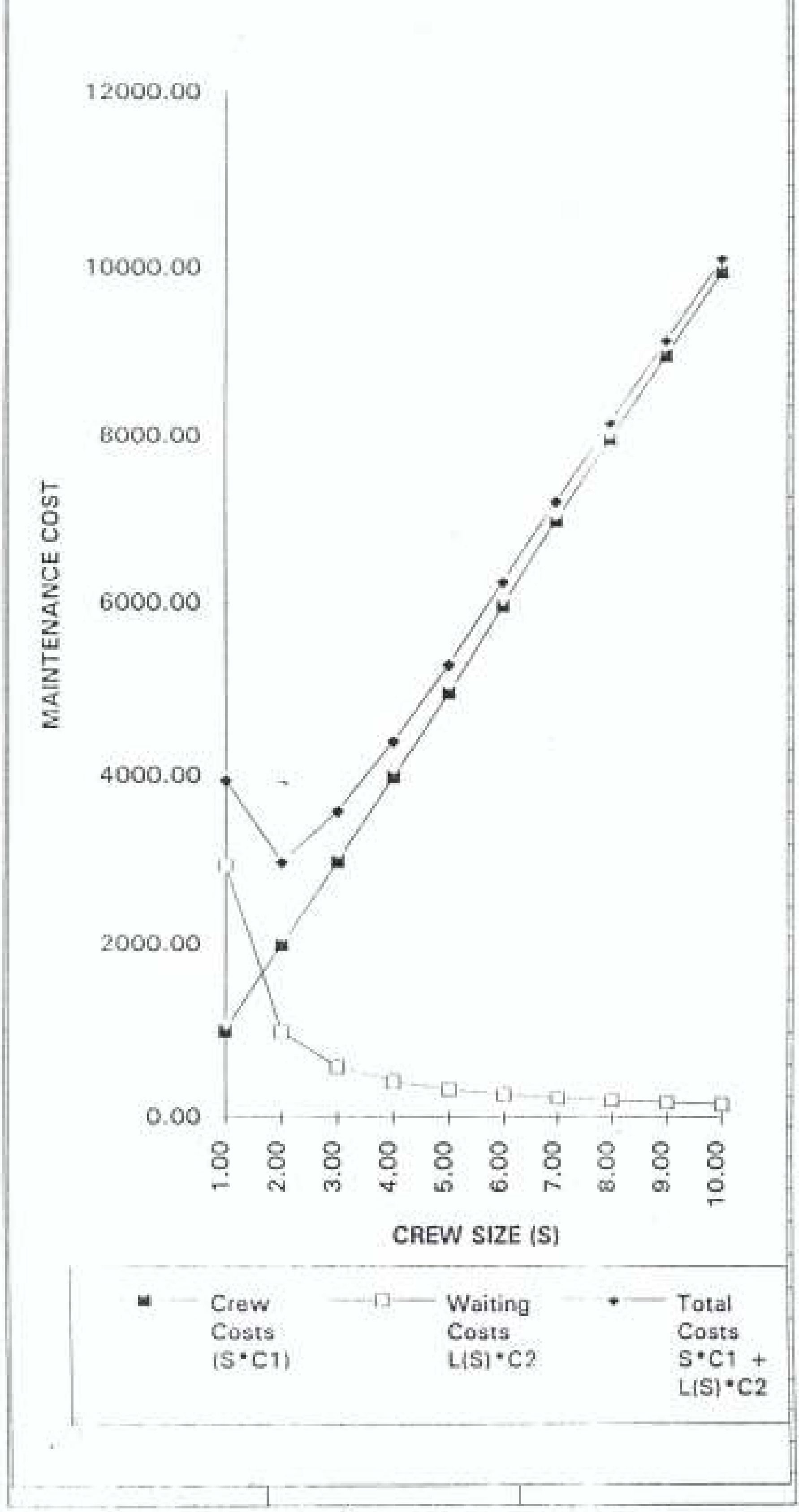


FIG.5.11 MAINTENANCE COSTS GRAPH SHOWING OPTIMUM CREW SIZE (So)
SINGLE CHANNEL IN SERIES (STOCHASTIC APPROACH)

The possible management policies for choice of a particular layout are discussed below:

5.1 CHOICE OF EFFECTIVE CREW SIZE BASED ON THE NUMBER OF JOBS IN THE SYSTEM (LSo)

If the choice of crew size for effective maintenance operation is based on the number of jobs in the system (i.e number of jobs in queue plus number of jobs in service facility), then:

For single channel, the number of jobs in the system per day is 0.982 which is 0.982 x 5 per week = 4.910. Therefore, for single channel, number of jobs in the system per week is approximately five.

Similarly for single channel in series number of jobs in the system per week is 0.329 x 5 = 1.645 ≅ 2 jobs.

Also, for multi-channel, in parallel, number of jobs in the system per week is 0.528 x 5 = 2.640 ≅ 3 jobs.

If the management decision in choosing an optimum crew size is based on the minimum jobs in the system, the layout (b) which has 2 units of job per week in the system waiting for service is preferred. Hence, single channel in series is chosen (Fig. 5.9b)

5.2 CHOICE OF EFFECTIVE CREW SIZE BASED ON WAITING TIME OF JOB IN QUEUE (WQSo)

If the management decision on choice of crew size for effective operation of maintenance jobshop is based on minimum waiting time in the queue, then;

For single channel, waiting time (Table 5.9) is 0.671 days

= 0.671 x 6hours

= 4.026 hours

For single channel, a job is waiting in queue for 4.026 hours in a day before entering service facility. Similarly, for single channel in series waiting time in queue is 0.225 day.

= 0.225 x 6 hours

= 1.350 hours

Therefore, it shows that, a job will wait for 1.350 hours in a day before entering service facility.

Also, in multichannel (in parallel) waiting time in queue is 0.045 day.

= 0.045 x 6 hours

= 0. 270 hours

= 0.270 x 60 minutes

= 16.2 minutes

Hence, a job will wait in queue for 16.2 minutes before entering the service facility. When these results are critically observed, the layout in Fig. 5.9c for multi channel in parallel is the most appropriate for having least waiting time of 16.2 minutes.

5.3 CHOICE OF EFFECTIVE CREW SIZE BASED ON UTILIZATION OF SERVICE FACILITY (PSo)

If the selection of effective crew size is based on the maximum utilization of service facility, single channel, should be chosen because it has highest percentage of utilization of service facility which is 49.6% (Table 5.9).

Single channel in series has percentage utilization of 22.5%, while Multi-channel, in parallel has the least percentage utilization of 4.5%. Therefore, single channel layout will be selected based on maximum utilization of service facility. (Fig. 5.9a)

5.4 CHOICE OF EFFECTIVE CREW SIZE BASED ON MAINTENANCE COSTS (TCSo)

As cost is very important in engineering, management will like to find ways of reducing the maintenance cost in order to maximise profit. Therefore, management ultimate decision is always based on how to operate within minimum possible maintenance cost. Hence, there is a need for the determination of effective crew that corresponds to such minimum cost target.

The minimum cost of maintenance is obtained by balancing the cost of using crew size (s) with the waiting cost of maintenance job(s). This is shown in Appendix 2 for single channel model by varying the number of crew from one to ten. The results obtained are transformed into graph (Fig 5.10). It gives optimum crew size of two (2) (seven men per crew). This results to operation on single channel in series, with a minimum maintenance cost of =N=2983.59 per day (Table 5.9). With this effective crew size of two, the higher cost of =N=3578.87 per day is incurred when operating on double channel in parallel, while for single channel, maintenance cost amounts to =N=3944.85 incurred for seven-man crew.

Observing these results, if management decision is based on minimum maintenance cost, single channel in series layout (Fig. 5.9b) is the best option which gives a maintenance cost of =N=2983.59 per day.

5.5. CHOICE OF EFFECTIVE CREW SIZE BASED ON HIGHEST RATINGS

The maintenance management possible decisions are summarised in Table 5.9 by the use of asterisk. It can be observed that single channel in series has the highest ratings of two (2), while both single channel and double channel in parallel have one (1). Therefore, if management decision is based on the highest ratings, the layout in Fig. 5.9b will be chosen

5.6 OTHER CONSIDERATIONS

If maintenance management, after considering the level of maintenance activities in rival jobshops in the environment sees that they are still ahead of them, operating on single channel will be economical to the management despite high waiting time. The resources to be used for the procurement of equipment and tools for the additional crew may be diverted to other important needs.

On the other hand, if the level of competition is very high that it can affect adversely the jobshop operational effectiveness on the long run, strategic implementation of the multi-channel in parallel layout (Fig. 5.9c) must be carried out. This will make the job to stay for not more than 16.2 minutes before entering the service facilities.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The survival of any maintenance jobshop depends greatly on how best the maintenance management can implement the results obtained from the models developed for effectiveness of various strategic decisions. By well implementation of the results obtained from the model (model for effective crew size determination in maintenance operations), analytical and judgmental solution can be proffered for other problem areas such as service demand forecasting, spare parts planning, operation planning and tools/equipment planning. By properly addressing all these problem areas, it will result to high response rate to the maintenance jobshop. Hence, the goal of establishing such a jobshop will come into reality.

Also, the following conclusions can be drawn from the results obtained by using the model developed for maintenance crew size determination in F.U.T.A. mechanical maintenance workshop.

(i) The use of existing crew size can cope with present response rate of jobs to the workshop. That is, operating on single channel, is effective for the system.

(ii) When the cost of maintenance is considered, for the jobshop, the crew size that will generate minimum maintenance cost is two. At this optimum crew size of two based on single channel, in series, the response rate of jobs will be higher to the jobshop. This may be used when there is a lot of competition among rival jobshops.

(iii) During festivals, many customers usually report their vehicles for repair works. This will lead to a long queue of jobs. During this period, the maintenance operation can be changed to double channel in parallel, so that the waiting time of jobs will reduce drastically as indicated in the results of the models.

(iv) Spare parts, tools and equipment must be adequate to cater for additional maintenance crew size.

6.2 RECOMMENDATIONS

The following recommendations are suggested based on the results obtained from the study.

(i) The mechanical jobshop under study should intensify efforts towards training of their maintenance personnel so that a single crew will be able to cope with jobs reported under various conditions. Thus, the effective use of resources will be enhanced.

(ii) If the jobshop is interested in operating on single channel in series spare parts should be adequate and tools and equipment well taken care of to guard against "tandem" queue in the system. Tandem means blocking of jobs access to second facility due to facility failure [23].

Management can operate on two shifts in order that only one facility (tools and equipment) could be used by both crews.

(iv) It is suggested that the jobshop should not operate on two channels in parallel, because it is costly. It may be done after a thorough service demand forecasting has been carried out.

(v) For effective operation of the system, reliable spare parts inventory model should be developed for economic replenishment. Worn out parts can be maintained or repaired. Tools and equipment must be in good condition always.

REFERENCES

(1) 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

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

(3) Aderoba A.A. (1997): Tools of Engineering Management, Vol. II: Engineering works Management. Besade Publication, Ondo.

(4) Billy E. G. (1976). Introduction to Operations research, A Computer - orientated Algorithmic Approach. McGraw-Hill., U.S.A.

(5) British Stardard Institution (1974). Glossary of maintenance in Terotechnology. BS 3811: 74.

(6) Chapman C.B, Cooper D.F. and Page M.T. (1987). Management for Engineers. John Wiley and Sons Ltd., U. S. A.

(7) Gopalakrishman P. and Benerji A.K. (1991). Maintenance and spare parts Management. Prentice-Hall of India. Privated Ltd. New Delhi.

(8) Graybeal W.J. and Pooch W.U. (1980). Simulation Principles and Methods. Winthrop., U. S. A.

(9) Hunt R. (1988).Computers and Common Sense, Prentice Hall Inc., United Kingdom.

(10) Higgins, and Marrow (1977). Maintenance Engineering Handbook - McGraw-Hill Inc., U.S.A.

(11) Holmes B.J. (1985). A Complete text Basic Programming. Guernsey Press Co. Ltd., Great Britain.

(12) Howard E. (1988). Computer-Aided System Engineering. Prentice-Hall Inc., U. S. A.

(13) Kelly A. and Harris M.J (1978). Management of Industrial Maintenance. Butter worth and Co. (Publishers) Ltd. London.

(14) Lindley R. H. (1988). Maintenance Engineering Handbook. Mc-Graw-Hill Inc., U.S.A.

(15) Olorunniwo F.O. (1986). "Overview of productivity of Scheme", NIIE Short course, University of Ibandan.

(16) Olorunniwo F.O. (1989). "Setting Maintenance Productivity Measurement System", Motor Professional: Journal of the Institute of Motor Industry, Singapore.

(17) Priel V.Z. (1974). Systematic Maintenance Organisation, Macdonald and Evans Ltd, London.

(18) Ray W. (1979). Production and Operations Management: Principles and Techniques. Holt, Rinechart and Winston Ltd. East Sussex BN 213 UN.

(19) 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.

(20) Richard I. L., David S.R., Joel P. S. and Everette S.G. (1989). Quantitative Approaches to Management. McGraw-Hill, Inc., Singapore.

(21) Shaw L. (1976) " Busy Period Control of Queues Based on Waiting times at arrivals". The journal of operations research Society of America. Vol. 24, No. 3, pp. 543-548.

(22) Steven A. and Frain T. (1977). Appraisal of shops performance management Handbook for plant Engineer: McGraw-Hill, Inc. New York.

(23) Taha H.A. (1987). Operation Research- An Introduction. Macmillan, Inc., New York.

(24) Taha H. A. (1988). Simulation Modelling And Simnet. Prentice-Hall Inc. U. S. A

(25) 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.

(26) Thomas H. N. (1966). Computer Simulation Techniques, John Wiley and Sons Inc., U. S. A.

APPENDIX 1 CREW SIZE DETERMINATION USING DETERMINISTIC APPROACH

```
' QBASIC
 CLS  ' This clears the Screen
'          EFFECTIVE CREW SIZE DETERMINATION IN MAINTENANCE
'             OPERATIONS USING DETERMINISTIC APPROACH
'         ******************************************************
20  DIM L(20), V1(20), V2(20), V3(20), P(20)
30  INPUT "WHAT IS THE VALUE OF LAMBDA AND MU="; LAB, MU
40  INPUT "WHAT IS THE VALUE OF ACCEPTABLE RESPONSE RATE="; WQA
50  INPUT "WHAT IS THE AVERAGE COST PER CREW SIZE="; G
60  INPUT "WHAT IS THE AVERAGE COST OF WAITING PER JOB="; H
65  INPUT "Enter Filename For Results:"; n$
'=================================================== OPEN n$ FOR OUTPUT
AS #1
70  IF (LAB >= MU) GOTO 240
75  REM------------------------------------------------
80  REM CALCULATE UTILIZATION FACTOR (P)
85  REM------------------------------------------------
90  P = LAB / MU
95  REM------------------------------------------------
100 REM CALCULATE EXPECTED WAITING TIME (WQ)
105 REM------------------------------------------------
110 WQ = P / (MU - LAB)
115 REM------------------------------------------------
120 REM CALCULATE NO OF JOBS IN THE MAINTENANCE JOBSHOP (L)
125 REM------------------------------------------------
130 L = LAB * WQ + P
135 REM------------------------------------------------
140 REM CALCULATE NO OF MAINTENANCE CREW SIZE REQUIRED (S)
145 REM------------------------------------------------
150 S = INT(WQ / WQA) + 1
155 REM----------------------------
156 PRINT "              APPENDIX  2"
157 PRINT
240 PRINT "QUEUEING MODEL NOT VALID IF LAMBDA >=MU"
250 FOR K = 1 TO 10
260 L(K) = LAB / (K * MU - LAB)
261 WQ(K) = P / (K * MU - LAB)
265 REM--------------------------------
270 REM CALCULATE COSTS OF CREW SIZE (K)
275 REM--------------------------------
280 V1(K) = G * K
285 REM--------------------------------
290 REM CALCULATE COSTS OF WAITING
295 REM--------------------------------
300 V2(K) = L(K) * H
305 REM--------------------------------
310 REM CALCULATE TOTAL MAINTENANCE COST
315 REM--------------------------------
320 V3(K) = V1(K) + V2(K)
325 P(K) = LAB / (K * MU)
330 NEXT K
335 PRINT "--------------------------------------------"
CLS
338 PRINT "******************************************************************"
339 PRINT "     CREW SIZE DETERMINATION IN MAINTENANCE JOBSHOP RESULTS"
   PRINT "           SINGLE CHANNEL---DETERMINISTIC APPROACH      "
340 PRINT "******************************************************************"
341 PRINT "        ARRIVAL RATE OF JOB  (LAMBDA)          "
342 PRINT USING "#.###"; TAB(15); LAB
343 PRINT "--------------------------------"
```

```
344 PRINT "        SERVICE RATE OF JOB  (MU)            "
345 PRINT USING "#.###"; TAB(15); MU
346 PRINT "------------------------------------------"
347 PRINT "        ACCEPTANCE RESPONSE RATE (WQA)        "
348 PRINT USING "#.###"; TAB(15); WQA
350 PRINT "------------------------------------------"
351 PRINT "        UTILIZATION (FACTOR) OF MTCE. CREW (P) "
352 PRINT USING "#.###"; TAB(15); P
353 PRINT "------------------------------------------"
354 PRINT "        EFFECTIVE CREW SIZE (S)              "
355 PRINT USING "#"; TAB(15); S
356 PRINT "------------------------------------------"
357 PRINT "        EXPECTED WAITING TIME (WQ)           "
358 PRINT USING "#.###"; TAB(15); WQ
359 PRINT "------------------------------------------"
360 PRINT "        NO OF JOBS IN THE SYSTEM (L)         "
361 PRINT USING "#.##"; TAB(15); L
362 PRINT "------------------------------------------"
363 PRINT
    SHELL "PAUSE"
364 PRINT "QUEUEING MODEL NOT VALID IF LAMBDA > =MU :   CONTD."
384 CLS

385 PRINT "    *****************************************************************"
390 PRINT "      MAINTENANCE COSTS OBTAINED BY VARING MAINTENANCE CREW SIZE"
392 PRINT "      SINGLE CHANNEL IN SERIES ---DETERMINISTIC APPROACH              "
395 PRINT "     *****************************************************************"
396 PRINT "     CREW SIZE    CREW SIZE COSTS    WAITING COSTS   TOTAL COSTS"
397 PRINT "        S              S*C1          L(S)*C2        S*C1 +L(S)*C2"
398 PRINT "     *****************************************************************"
399 FOR K = 1 TO 10
400 PRINT USING "#####.##"; TAB(4); K; TAB(21); V1(K); TAB(38); V2(K); TAB(54); V3(K)
401 NEXT K
  SHELL "PAUSE"
405 CLS
407 PRINT "  EFFECT OF VARYING S ON L, P AND WQ (SINGLE CHANNEL IN SERIES)"
408 PRINT "              DETERMINISTIC APPROACH"
440 PRINT "       *****************************************************************"
450 PRINT "       CREW SIZE    NO JOB WAITING    UTILIZATION FACTOR   WAITING TIME"
460 PRINT "           S           L(S)              P(S)              WQ(S)   "
470 PRINT "       *****************************************************************"
480 FOR K = 1 TO 10
490 PRINT USING "###.###"; TAB(8); K; TAB(22); L(K); TAB(42); P(K); TAB(61); WQ(K)
500 NEXT K
  SHELL "PAUSE"
  CLS
510 RESTORE
520 INPUT " WHAT IS THE VALUE OF PZERO AND S="; A, S
525 'CALCULATE THE UTILISATION FACTOR (PS)
530  SFACT = 362880
535  NFACT = 40320
540  PS = (((LAB / MU) ^ S) * S * MU * A) / (SFACT * (S * MU - LAB))
545  LS = ((LAB * MU * (LAB / MU) ^ S) * A) / (NFACT * (S * MU - LAB) ^ 2) + LAB / MU
550  LQS = LS - LAB / MU
560  WS = LS / LAB
565  WQS = LQS / LAB
570 'CALCULATE TOTAL COSTS AT OPTIMUM CREW (SO)
575  TCS = S * G + LS * H
     CLS
576  PRINT #1, "      *****************************************************************"
577  PRINT #1, "      RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE  S"
578  PRINT #1, "                    DETERMINISTIC APPROACH"
```

```
579 PRINT #1, "      ******************************************************************"
580 PRINT #1, "      THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= "; A
582 PRINT #1, " [CREW SIZE]   [JOB WAITING]   [UTIL.FACTOR]  [WAITING TIME]  [TOT. MTCE.COST]"
583 PRINT #1, "      S            L(S)           P(S)          WQ(S)         TC(S)"
627 PRINT #1, USING "####.###"; TAB(3); S; TAB(17); LS; TAB(33); PS; TAB(49); WQS; TAB(65); TCS
    CLS
628 CLOSE
    SHELL "PAUSE"
    PRINT ; TAB(25); "YOUR RESULTS ARE IN THE FILE NAMED "; n$
630 END
```

APPENDIX 2 RESULTS GENERATED USING DETERMINISTIC APPROACH

QUEUEING MODEL NOT VALID IF LAMBDA > =MU

****

CREW SIZE DETERMINATION IN MAINTENANCE JOBSHOP RESULTS
SINGLE CHANNEL—DETERMINISTIC APPROACH

****

ARRIVAL RATE OF JOB (LAMBDA)
0.725

SERVICE RATE OF JOB (MU)
1.463

ACCEPTANCE RESPONSE RATE (WQA)
1.530

UTILIZATION (FACTOR) OF MTCE. CREW (P)
0.496

EFFECTIVE CREW SIZE (S)
1

EXPECTED WAITING TIME (WQ)
0.671

NO OF JOBS IN THE SYSTEM (L)
0.98

QUEUEING MODEL NOT VALID IF LAMBDA > =MU : CONTD.

****

MAINTENANCE COSTS OBTAINED BY VARING MAINTENANCE CREW SIZE
SINGLE CHANNEL IN SERIES —DETERMINISTIC APPROACH

****

CREW SIZE S	CREW SIZE COSTS S*C1	WAITING COSTS L(S)*C2	TOTAL COSTS S*C1 +L(S)*C2
1.00	997.70	2947.15	3944.85
2.00	1995.40	988.19	2983.59
3.00	2993.10	593.61	3586.71
4.00	3990.80	424.22	4415.02
5.00	4988.50	330.05	5318.55
6.00	5986.20	270.09	6256.29
7.00	6983.90	228.56	7212.46
8.00	7981.60	198.11	8179.71
9.00	8979.30	174.81	9154.11
10.00	9977.00	156.42	10133.42

EFFECT OF VARYING S ON L, P AND WQ (SINGLE CHANNEL IN SERIES)
DETERMINISTIC APPROACH

****

CREW SIZE S	NO JOB WAITING L(S)	UTILIZATION FACTOR P(S)	WAITING TIME WQ(S)
1.000	0.982	0.496	0.671
2.000	0.329	0.248	0.225
3.000	0.198	0.165	0.135
4.000	0.141	0.124	0.097
5.000	0.110	0.099	0.075
6.000	0.090	0.083	0.062
7.000	0.076	0.071	0.052
8.000	0.066	0.062	0.045
9.000	0.058	0.055	0.040
10.000	0.052	0.050	0.036

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .5

[CREW SIZE] S	[JOB WAITING] L(S)	[UTIL.FACTOR] P(S)	[WAITING TIME] WQ(S)	[TOT. MTCE.COST] TC(S)
1.000	0.978	0.491	0.666	3931.991

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .6001

[CREW SIZE] S	[JOB WAITING] L(S)	[UTIL.FACTOR] P(S)	[WAITING TIME] WQ(S)	[TOT. MTCE.COST] TC(S)
2.000	0.528	0.098	0.045	3578.871

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .6003

[CREW SIZE] S	[JOB WAITING] L(S)	[UTIL.FACTOR] P(S)	[WAITING TIME] WQ(S)	[TOT. MTCE.COST] TC(S)
3.000	0.498	0.015	0.004	4488.429

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .6188

[CREW SIZE] S	[JOB WAITING] L(S)	[UTIL.FACTOR] P(S)	[WAITING TIME] WQ(S)	[TOT. MTCE.COST] TC(S)
4.000	0.496	0.002	0.000	5478.224

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .6065

[CREW SIZE]	[JOB WAITING]	[UTIL.FACTOR]	[WAITING TIME]	[TOT. MTCE.COST]
S	L(S)	P(S)	WQ(S)	TC(S)
5.000	0.496	0.000	0.000	6475.227

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .6188

[CREW SIZE]	[JOB WAITING]	[UTIL.FACTOR]	[WAITING TIME]	[TOT. MTCE.COST]
S	L(S)	P(S)	WQ(S)	TC(S)
6.000	0.496	0.000	0.000	7472.875

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .6142

[CREW SIZE]	[JOB WAITING]	[UTIL.FACTOR]	[WAITING TIME]	[TOT. MTCE.COST]
S	L(S)	P(S)	WQ(S)	TC(S)
7.000	0.496	0.000	0.000	8470.571

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .6188

[CREW SIZE]	[JOB WAITING]	[UTIL.FACTOR]	[WAITING TIME]	[TOT. MTCE.COST]
S	L(S)	P(S)	WQ(S)	TC(S)
8.000	0.496	0.000	-0.000	9468.271

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .6402

[CREW SIZE]	[JOB WAITING]	[UTIL.FACTOR]	[WAITING TIME]	[TOT. MTCE.COST]
S	L(S)	P(S)	WQ(S)	TC(S)
9.000	0.496	0.000	-0.000	%10465.972

****

RESULTS FOR MULTI-CHANNEL IN PARALLEL BY VARYING CREW SIZE S
DETERMINISTIC APPROACH

****

THE VALUE OF PROBABILITY OF NO JOB IN THE SYSTEM (PZERO)= .6096

[CREW SIZE]	[JOB WAITING]	[UTIL.FACTOR]	[WAITING TIME]	[TOT. MTCE.COST]
S	L(S)	P(S)	WQ(S)	TC(S)
10.000	0.496	0.000	-0.000	%11463.671

APPENDIX 3 CREW SIZE DETERMINATION USING STOCHASTIC APPROACH

```
'
'
'            QBASIC: CLS 'this clear the screen

'         CREW SIZE DETERMINATION  USING STOCHASTIC APPROACH
'                  (NEXT- EVENT- ORIENTED MODEL)

'*******************************************************************

      'THESE  ARE THE PARAMETERS USED IN THE MODEL

 '******************************************************************

 'AT    =  time of next arrival of repair job
 'C1    =  average cost of using a maintenance per unit time
 'C2    =  average cost of waiting of job per unit time
 'CLOCK =  current clock time
 'MCT   =  maximum time to run simulation
 'NQ    =  current number of job in the queue
 'TIDT  =  total idle time of maintenance facilities
 'TNJEO =  total number of jobs which enter the queue
 'TWT   =  total waiting time of all jobs
 'TISF  =  total time in service facility for all jobs
 'TIS   =  total time for all jobs in the system
 'TNA   =  total number of jobs
 'MQL   =  maximum queue length
 'L     =  total number of jobs in the system per unit time
 'TC    =  total maintenance costs
 'S     =  crew size
 'ST    =  time of next depature of finished job
 'WQ    =  number of jobs in queue
 'POTB  =  utilization factor of service facility
 'P     =  utilization factor of service facility

'****************************************************************************

    INPUT "WHAT IS THE ARRIVAL RATE (LAMBDA)          "; LAM

    INPUT "WHAT IS THE SERVICE RATE (MU )             "; MU

    INPUT "WHAT IS THE MAXIMUM SIMULATION TIME(MCT)   "; MCT

    INPUT "WHAT IS THE COST OF USING A CREW SIZE (C1)"; C1

    INPUT "WHAT IS THE WAITING COST PER JOB (C2)      "; C2

    INPUT "Enter Filename for Results: "; n$

    OPEN n$ FOR OUTPUT AS #1

'   set initial condition
    CLOCK = 0!
    AT = 0!
    NQ = 0!
    TNJEQ = 0!
    TWT = 0!
    TIDT = 0!
    TNA = 1
    MQL = 0
 '  generate time of next departure

3 IX = RND((1))
   ST = CLOCK + (-1 / MU) * LOG(IX)
 '  generate time of next arrival
```

```
4      IX = RND((1))
     AT = CLOCK + (-1 / LAM) * LOG(IX)

'    if next event is an arrival  goto statement  6   otherwise goto
'    goto statement  16

5      IF (ST >= AT) THEN 6 ELSE 16

'    update total waiting time,clock,and number of arrivals

6 TWT = TWT + NQ * (AT - CLOCK)
      PRINT "CLOCK="; CLOCK
7      CLOCK = AT
     TNA = TNA + 1

'if next event is both an arrival and a departure goto statement 9
'otherwise  goto statement 10

8    IF (ST = AT) THEN 9 ELSE 10

'if queue is empty goto 17 o'wise   22

16     IF (NQ = 0) THEN 17 ELSE 22
'update clock time ,total waiting time , number of arrival
17     CLOCK = ST
18     TIDT = TIDT + (AT - CLOCK)
19     CLOCK = AT
20     TNA = TNA + 1

'if maximum clock time is exceeded, goto 15 ,else return to 3
'to generate the time of the next departure

9    IF (CLOCK > MCT) THEN 15 ELSE 3

'update clock, total waiting time, number in queue

22    TWT = TWT + NQ * (ST - CLOCK)
23      CLOCK = ST
24      NQ = NQ - 1

'  generate time of next departure

25    IX = RND((1))
      ST = CLOCK + (-1 / MU) * LOG(IX)

'if maximum clocktime is exceeded goto 15 else return to 5

26    IF (CLOCK > MCT) THEN 15 ELSE 5

 'update number in queue , maxmum queue length, and total number in queue

10    NQ = NQ + 1

 'if the maximum num. in the queue exceeds the longest queue
 'length to date  (MQL)set MQL=NQ and goto 13,else go directly to  13

11      IF (NQ > MQL) THEN 12 ELSE 13
12    MQL = NQ
13    TNJEQ = TNJEQ + 1

'if maximum clock time is exceeded ,goto 15 else return to 4 togenerate
'next arrival
```

```
14   IF (CLOCK > MCT) THEN 15 ELSE 4

' calculate and print statistics

15     TISF = CLOCK - TIDT
       TIS = TISF + TWT
       ATIS = TIS / TNA
       ATISF = TISF / TNA
       ATIQ = TWT / TNA
       ATEQ = TWT / TNJEQ
       POTB = TISF / CLOCK
        PRINT #1, "      APPENDIX 4"
        PRINT #1,
    PRINT #1, "**********************************"
    PRINT #1, "THE VALUE OF LAB IS"; LAM
    PRINT #1, "THE VALUE OF MU IS "; MU
    PRINT #1, "THE VALUE OF MCT "; MCT
    PRINT #1, "THE VALUE OF TISF   "; TISF
    PRINT #1, "THE VALUE OF TIS    "; TIS
    PRINT #1, "THE VALUE OF ATIS (Ws) "; ATIS
    PRINT #1, "THE VALUE OF ATISF (1/MU)"; ATISF
    PRINT #1, "THE VALUE OF ATEQ (Ww)"; ATEQ
    PRINT #1, "THE VALUE OF TIDT  "; TIDT
    PRINT #1, "THE VALUE OF POTB (P)   "; POTB
    PRINT #1, "THE VALUE OF MQL"; MQL
    PRINT #1, "THE VALUE OF ATIQ (Wq)   "; ATIQ
    PRINT #1, "THE VALUE OF TWT IS"; TWT
    PRINT #1, "THE VALUE OF TNJEQ IS "; TNJEQ
    PRINT #1, "THE VALUE OF CLOCK "; CLOCK
PRINT #1, "*********************************************"

 PRINT #1, : PRINT #1,
   SHELL "PAUSE"

   'to calculate the optimum crew size by varing the crew size (S) from 1-10
 'to calculate the optimum crew size by varing the crew size (S) from 1-10FOR
K = 1 TO 10

    FOR S = 1 TO 10

'  calculate average number of jobs in the system

        L(S) = POTB / (S - POTB)

  'calculate the waiting costs of jobs (Cwait)

        G(S) = C2 * L(S)

   'calculate the costs of using a maintenace crew (Ccrew)

        H(S) = C1 * S

   'calculate total maintenace costs <TC(S)>

         TC(S) = H(S) + G(S)

     'calculate utilization factor <P(S)>

         P(S) = TISF / (S * CLOCK)


      'calculate expected waiting time(WQ(S))
```

```
        WQ(S) = POTB * ATISF / (S - POTB)

    NEXT S

   PRINT #1, "MAINTENANCE COSTS OBTAINED BY VARING MAINTENANCE CREW SIZE (S)"
   PRINT #1, "        USING  STOCHASTIC MODEL  APROACH (SINGLE CHANNEL)
 "
   PRINT #1,
   PRINT #1,
"*********************************************************************"
   PRINT #1, "  CREW SIZE    CREW SIZE COSTS    WAITING COSTS    TOTAL COSTS"
   PRINT #1, "      S                Ccrew           Cwait              TC(S)"
   PRINT #1,
"*********************************************************************"
       FOR S = 1 TO 10
   PRINT #1, USING "#####.##"; TAB(4); S; TAB(21); H(S); TAB(38); G(S);
TAB(54); TC(S)
   NEXT S
  PRINT #1, : PRINT #1,
    SHELL "PAUSE"
   PRINT #1, "THE EFFECT OF VARING S ON L, P AND WQ USING STOCHASTIC MODEL"
   PRINT #1,
"****************************************************************************"
   PRINT #1, "    CREW SIZE     NUM. JOB WAITING    UTILIZATION FACTOR
WAITING TIME"
   PRINT #1, "        S                L(S)                     P(S)         WQ
(S)"
   PRINT #1,
"****************************************************************************"
         FOR S = 1 TO 10
   PRINT #1, USING "###.###"; TAB(8); S; TAB(22); L(S); TAB(42); P(S);
TAB(61); WQ(S)
   NEXT S
   CLOSE
   SHELL "PAUSE"
   CLS
   PRINT ; TAB(20); "Y O U R   R E S U L T S   A R E  I N  T H E  F I L E  N A
M E D   "; n$
   END
```

APPENDIX 4 RESULTS GENERATED USING STOCHASTIC APPROACH

****
THE VALUE OF LAB IS .725
THE VALUE OF MU IS 1.463
THE VALUE OF MCT 50000
THE VALUE OF TISF 24716.52
THE VALUE OF TIS 49180.66
THE VALUE OF ATIS (Ws) 1.360386
THE VALUE OF ATISF (1/MU) .6836832
THE VALUE OF ATEQ (Ww) 1.370233
THE VALUE OF TIDT 25284.17
THE VALUE OF POTB (P) .4943236
THE VALUE OF MQL 15
THE VALUE OF ATIQ (Wq) .6767024
THE VALUE OF TWT IS 24464.14
THE VALUE OF TNJEQ IS 17854
THE VALUE OF CLOCK 50000.68
****

MAINTENANCE COSTS OBTAINED BY VARING MAINTENANCE CREW SIZE (S) USING STOCHASTIC MODEL APROACH (SINGLE CHANNEL IN SERIES)
Maximum Simulation Time (MCT) = 50,000 days

CREW SIZE S	CREW SIZE COSTS Ccrew	WAITING COSTS Cwait	TOTAL COSTS TC(S)
1.00	997.70	2932.65	3930.35
2.00	1995.40	984.92	2980.32
3.00	2993.10	591.84	3584.94
4.00	3990.80	423.02	4413.82
5.00	4988.50	329.13	5317.63
6.00	5986.20	269.35	6255.55
7.00	6983.90	227.95	7211.85
8.00	7981.60	197.58	8179.18
9.00	8979.30	174.35	9153.65
10.00	9977.00	156.01	10133.01

THE EFFECT OF VARING S ON L, P AND WQ USING STOCHASTIC MODEL

CREW SIZE S	NUM. JOB WAITING L(S)	UTILIZATION FACTOR P(S)	WAITING TIME WQ (S)
1.000	0.978	0.494	0.668
2.000	0.328	0.247	0.224
3.000	0.197	0.165	0.135
4.000	0.141	0.124	0.096
5.000	0.110	0.099	0.075
6.000	0.090	0.082	0.061
7.000	0.076	0.071	0.052
8.000	0.066	0.062	0.045
9.000	0.058	0.055	0.040
10.000	0.052	0.049	0.036

```
*********************************
THE VALUE OF LAB IS .725
THE VALUE OF MU IS  1.463
THE VALUE OF MCT  100000
THE VALUE OF TISF   49537.43
THE VALUE OF TIS    98696.54
THE VALUE OF ATIS (Ws)  1.361144
THE VALUE OF ATISF (1/MU) .6831807
THE VALUE OF ATEQ (Ww) 1.372278
THE VALUE OF TIDT   50462.93
THE VALUE OF POTB (P)    .4953725
THE VALUE OF MQL 15
THE VALUE OF ATIQ (Wq)    .6779632
THE VALUE OF TWT IS 49159.11
THE VALUE OF TNJEQ IS  35823
THE VALUE OF CLOCK  100000.4
*********************************************
```

MAINTENANCE COSTS OBTAINED BY VARING MAINTENANCE CREW SIZE (S)
USING STOCHASTIC MODEL APROACH (SINGLE CHANNEL IN SERIES)
Maximum Simulation Time (MCT) = 100,000 days

CREW SIZE S	CREW SIZE COSTS Ccrew	WAITING COSTS Cwait	TOTAL COSTS TC(S)
1.00	997.70	2944.98	3942.68
2.00	1995.40	987.70	2983.10
3.00	2993.10	593.35	3586.45
4.00	3990.80	424.04	4414.84
5.00	4988.50	329.91	5318.41
6.00	5986.20	269.98	6256.18
7.00	6983.90	228.47	7212.37
8.00	7981.60	198.03	8179.63
9.00	8979.30	174.74	9154.04
10.00	9977.00	156.36	10133.36

THE EFFECT OF VARING S ON L, P AND WQ USING STOCHASTIC MODEL

CREW SIZE S	NUM. JOB WAITING L(S)	UTILIZATION FACTOR P(S)	WAITING TIME WQ (S)
1.000	0.982	0.495	0.671
2.000	0.329	0.248	0.225
3.000	0.198	0.165	0.135
4.000	0.141	0.124	0.097
5.000	0.110	0.099	0.075
6.000	0.090	0.083	0.061
7.000	0.076	0.071	0.052
8.000	0.066	0.062	0.045
9.000	0.058	0.055	0.040
10.000	0.052	0.050	0.036

```
********************************
THE VALUE OF LAB IS .725
THE VALUE OF MU IS  1.463
THE VALUE OF MCT  200000
THE VALUE OF TISF    98970.56
THE VALUE OF TIS     196589.8
THE VALUE OF ATIS (Ws)  1.356222
THE VALUE OF ATISF (1/MU) .6827722
THE VALUE OF ATEQ (Ww) 1.373661
THE VALUE OF TIDT    101030.1
THE VALUE OF POTB (P)    .4948511
THE VALUE OF MQL 15
THE VALUE OF ATIQ (Wq)    .6734496
THE VALUE OF TWT IS 97619.22
THE VALUE OF TNJEQ IS  71065
THE VALUE OF CLOCK  200000.7
*******************************************
```

MAINTENANCE COSTS OBTAINED BY VARING MAINTENANCE CREW SIZE (S)
USING STOCHASTIC MODEL APROACH (SINGLE CHANNEL IN SERIES)
Maximum Simulation Time (MCT) = 200,000 days

CREW SIZE S	CREW SIZE COSTS Ccrew	WAITING COSTS Cwait	TOTAL COSTS TC(S)
1.00	997.70	2938.84	3936.54
2.00	1995.40	986.32	2981.72
3.00	2993.10	592.60	3585.70
4.00	3990.80	423.54	4414.33
5.00	4988.50	329.52	5318.02
6.00	5986.20	269.67	6255.87
7.00	6983.90	228.21	7212.11
8.00	7981.60	197.80	8179.40
9.00	8979.30	174.55	9153.85
10.00	9977.00	156.18	10133.18

THE EFFECT OF VARING S ON L, P AND WQ USING STOCHASTIC MODEL

CREW SIZE S	NUM. JOB WAITING L(S)	UTILIZATION FACTOR P(S)	WAITING TIME WQ (S)
1.000	0.980	0.495	0.669
2.000	0.329	0.247	0.224
3.000	0.198	0.165	0.135
4.000	0.141	0.124	0.096
5.000	0.110	0.099	0.075
6.000	0.090	0.082	0.061
7.000	0.076	0.071	0.052
8.000	0.066	0.062	0.045
9.000	0.058	0.055	0.040
10.000	0.052	0.049	0.036

APPENDIX 4

****
THE VALUE OF LAB IS .725
THE VALUE OF MU IS 1.463
THE VALUE OF MCT 400000
THE VALUE OF TISF 198435.9
THE VALUE OF TIS 393744.6
THE VALUE OF ATIS (Ws) 1.356253
THE VALUE OF ATISF (1/MU) .6835122
THE VALUE OF ATEQ (Ww) 1.381738
THE VALUE OF TIDT 201564.3
THE VALUE OF POTB (P) .4960895
THE VALUE OF MQL 19
THE VALUE OF ATIQ (Wq) .6727405
THE VALUE OF TWT IS 195308.7
THE VALUE OF TNJEQ IS 141350
THE VALUE OF CLOCK 400000.2
****

MAINTENANCE COSTS OBTAINED BY VARING MAINTENANCE CREW SIZE (S)
USING STOCHASTIC MODEL APROACH (SINGLE CHANNEL, IN SERIES)
Maximum Simulation Time (MCT) = 400,000days

CREW SIZE S	CREW SIZE COSTS Ccrew	WAITING COSTS Cwait	TOTAL COSTS TC(S)
1.00	997.70	2953.44	3951.14
2.00	1995.40	989.60	2985.00
3.00	2993.10	594.38	3587.48
4.00	3990.80	424.74	4415.54
5.00	4988.50	330.44	5318.94
6.00	5986.20	270.40	6256.60
7.00	6983.90	228.83	7212.73
8.00	7981.60	198.33	8179.93
9.00	8979.30	175.01	9154.31
10.00	9977.00	156.60	10133.60

THE EFFECT OF VARING S ON L, P AND WQ USING STOCHASTIC MODEL

CREW SIZE S	NUM. JOB WAITING L(S)	UTILIZATION FACTOR P(S)	WAITING TIME WQ (S)
1.000	0.984	0.496	0.673
2.000	0.330	0.248	0.225
3.000	0.198	0.165	0.135
4.000	0.142	0.124	0.097
5.000	0.110	0.099	0.075
6.000	0.090	0.083	0.062
7.000	0.076	0.071	0.052
8.000	0.066	0.062	0.045
9.000	0.058	0.055	0.040
10.000	0.052	0.050	0.036

Probability of zero units in the system (P_0)

$\frac{\lambda}{k\mu}$	Number of Channels (k)									
	1	2	3	4	5	6	7	8	9	10
.02	.98000	.96078	.94176	.92312	.90484	.88692	.86936	.85214	.83527	.81873
.04	.96000	.92308	.88692	.85214	.81873	.78663	.75578	.72615	.69768	.67032
.06	.94000	.88679	.83526	.78663	.74082	.69768	.65705	.61878	.58275	.54881
.08	.92000	.85185	.78659	.72614	.67032	.61878	.57121	.52729	.48675	.44933
.10	.90000	.81818	.74074	.67031	.60653	.54881	.49659	.44933	.40657	.36788
.12	.88000	.78571	.69753	.61876	.54881	.48675	.43171	.38289	.33960	.30119
.14	.86000	.75439	.65679	.57116	.49659	.43171	.37531	.32628	.28365	.24660
.16	.84000	.72414	.61837	.52720	.44931	.38289	.32628	.27801	.23693	.20190
.18	.82000	.69492	.58214	.48660	.40653	.33959	.28365	.23693	.19790	.16530
.20	.80000	.66667	.54795	.44910	.36782	.30118	.24659	.20189	.16530	.13534
.22	.78000	.63934	.51567	.41445	.33277	.26711	.21437	.17204	.13807	.11080
.24	.76000	.61290	.48519	.38214	.30105	.23688	.18636	.14660	.11532	.09072
.26	.74000	.58730	.45540	.35284	.27233	.21007	.16200	.12492	.09632	.07427
.28	.72000	.56250	.42918	.32548	.24633	.18628	.14082	.10645	.08045	.06081
.30	.70000	.53846	.40346	.30017	.22277	.16517	.12241	.09070	.06720	.04978
.32	.68000	.51515	.37913	.27676	.20144	.14644	.10639	.07728	.05612	.04076
.34	.66000	.49254	.35610	.25510	.18211	.12981	.09247	.06584	.04687	.03337
.36	.64000	.47059	.33431	.23505	.16460	.11505	.08035	.05609	.03915	.02732
.38	.62000	.44928	.31367	.21649	.14872	.10195	.06981	.04778	.03269	.02236
.40	.60000	.42857	.29412	.19929	.13433	.09032	.06064	.04069	.02729	.01830
.42	.58000	.40845	.27559	.18336	.12128	.07998	.05267	.03465	.02279	.01498
.44	.56000	.38889	.25802	.16860	.10944	.07080	.04573	.02950	.01902	.01226
.46	.54000	.36986	.24135	.15491	.09870	.06265	.03968	.02511	.01587	.01003
.48	.52000	.35135	.22554	.14221	.08895	.05540	.03442	.02136	.01324	.00820
.50	.50000	.33333	.21053	.13043	.08010	.04896	.02984	.01816	.01104	.00671

SOURCE: RICHARD et.al, (24)

APPENDIX 6

istribution of χ^2

grees of edom ν	Probability of a deviation greater than χ^2										
	0.99	0.95	0.90	0.80	0.70	0.50	0.30	0.20	0.10	0.05	0.01
1	.000157	.00393	.0158	.0642	.148	.455	1.074	1.642	2.706	3.841	6.635
2	.0201	.103	.211	.446	.713	1.386	2.408	3.219	4.605	5.991	9.210
3	.115	.352	.584	1.005	1.424	2.366	3.665	4.642	6.251	7.815	11.345
4	.297	.711	1.064	1.649	2.195	3.357	4.878	5.989	7.779	9.488	13.277
5	.554	1.145	1.610	2.343	3.000	4.351	6.064	7.289	9.236	11.070	15.086
6	.872	1.635	2.204	3.070	3.828	5.348	7.231	8.558	10.645	12.592	16.812
7	1.239	2.167	2.833	3.822	4.671	6.346	8.383	9.803	12.017	14.067	18.475
8	1.646	2.733	3.490	4.594	5.527	7.344	9.524	11.030	13.362	15.507	20.090
9	2.088	3.325	4.168	5.380	6.393	8.343	10.656	12.242	14.684	16.919	21.666
10	2.558	3.940	4.865	6.179	7.267	9.342	11.781	13.442	15.987	18.307	23.209
11	3.053	4.575	5.578	6.989	8.148	10.341	12.899	14.631	17.275	19.675	24.725
12	3.571	5.226	6.304	7.807	9.034	11.340	14.011	15.812	18.549	21.026	26.217
13	4.107	5.892	7.042	8.634	9.926	12.340	15.119	16.985	19.812	22.362	27.688
14	4.660	6.571	7.790	9.467	10.821	13.339	16.222	18.151	21.064	23.685	29.141
15	5.229	7.261	8.547	10.307	11.721	14.339	17.322	19.311	22.307	24.996	30.578
16	5.812	7.962	9.312	11.152	12.624	15.338	18.418	20.465	23.542	26.296	32.000

SOURCE: GRAYBEAL & POOCH, (9).

APPENDIX 7

FEDERAL UNIVERSITY OF TECHNOLOGY, AKU

DEPARTMENT OF MECHANICAL/PRODUCTION ENGINEERING

MEMO

From: Coordinator, MEE	To: The Bursar
Ref FUTA/MEE/BURS/034	Date: 4/12/97.

SUBJECT: LETTER OF INTRODUCTION
KAREEM, B. (MATRIC NO. MEE/88/1488)

This is to certify that Mr. Kareem, B. is a postgraduate student of this department. He needs your assistance in obtaining information for his M.Eng. Thesis from your department. The title of the Thesis is "Model for crew size determination in maintenance jobshop".

Please, kindly assist him.

Dr. O. P. Fapetu,
Coordinator.

APPENDIX 8

FEDERAL UNIVERSITY OF TECHNOLOGY, AKUR

DEPARTMENT OF MECHANICAL/PRODUCTION ENGINEERING

MEMO

From: Coordinator, MEE	To: Ag. Director, Computer Centre
Ref: FUTA/MEE/D-SP/011	Date: 4 - 12 - 97.

SUBJECT: LETTER OF INTRODUCTION
KAREEM, B. (MATRIC NO. MEE/88/1488)

The above named student is presently engaged in M.Eng. Thesis titled "Model for crew size determination in maintenance jobshop". This project requires the use of Computer for running queueing programme.

I shall be grateful if Computer facilities are extended to Mr. Kareem for the said purpose.

Thank you.

Dr. O. P. Fapetu,
Coordinator.