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THE ECONOMIC ASSIGNMENT OF MEN TO MACHINES

by

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S Y N O P S I S

Some production shop models are developed and simulated for both stochastic and deterministic cases, using the SIMON simulation programme.

By using different service time distributions, some models have been developed, and the results obtained from these models are compared with Palm's model, for their sensitivity. The investigation shows that the behaviour of the different service time distributions is not statistically sensitive and its effect on the general behaviour of machine interference problems is insignificant.

A general distribution to be used for all practical purposes is tried. The result such as machine utilization factor obtained in this case is also not statistically significant, but the model can be used for any type of distribution, by changing the number of phases. The results agreed with the various arrival and service patterns.

Deterministic cases (King's model - using semi-automatic machines) have been analysed, using various combinations of service time. As the distribution pattern changes from constant to variable plus a constant (combined activity time), it is clear that the results such as cycle time factors obtained do vary from negative to positive percentage differences. Nevertheless, the results are not statistically significant.

A general programme has been developed for different means of arrival and service time distributions. The results show a similarity to the theoretical results.

A discussion on the production shop layout principles is carried out and the effect of walking time has also been analysed. The walking time is considerably reduced by changing the layout of the shop. Various layouts have been examined and the results indicate that the machines should be arranged in a square pattern, as far as possible.

Finally, economic analyses have been carried out for the optimum allocation of machines to operator.

A C K N O W L E D G E M E N T S

I wish to express my deep gratitude to Mr. J.R. King, who has shown great interest in this work and actively supported it at every stage. His stimulating discussions, enthusiastic guidance, valuable advice and constructive criticism have been responsible for the successful completion of this work.

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LIST OF CONTENTS

LIST OF SYMBOLS

Only those symbols used consistently in several sections are listed here.

$A_o(t)$	Arrival time or breakdown time distribution.
$A_n(t)$	Probability that n more breakdowns will occur within a time t after the last breakdown.
$a(t)$	Probability density of breakdowns.
a	Combined activity time (loading and unloading).
b	Independent activity time (cleaning, inspection, walking to next machine, etc.)
c	Constant.
C.V	Coefficient of variation.
C_o	Cost of output per unit time per machine.
C	Total cost of machine operation per time unit per machine.
C_r	Cost per unit time of operator.
C_m	Cost per unit time of working machine.
C_w	Cost per unit time of an idle machine or machine waiting for service.
C_s	Cost per unit time of service.
e_i	Expected value.
H	Ratio between independent time and combined activity time.
I	Ratio between waiting time and service time.

i_m	Idle time of the machine.
i_o	Idle time of the operator.
K	Number of stages or phases in service distribution.
k	Service constant.
L	Mean number of units in the system.
L_q	Mean number of units in the queue.
M	Number of parallel channels or number of repairmen in a service installation.
m	Machine running time per time unit.
N	Number of units in a finite calling population.
n	Number of units of machines per time unit.
o_i	Observed value.
P_n	Probability that the system is in state n after steady state conditions are reached.
P_o	Probability that the system is idle after steady state conditions are reached.
R	Ratio between combined activity time + independent activity time and running time.
r	Number of operators.
$S_o(t)$	Service time distribution.
s(t)	Probability density of service completion.
s	Service time per time unit.
T_a	Mean arrival time of breakdown machines.
T_s	Mean duration of service time.
t	Time.
$U_o(t)$	Probability of zero arrivals occurring in an interval of time t chosen at random.

$U_n(t)$	Probability of n breakdowns in interval t chosen at random.
W	Mean time the unit will be in the system.
W_q	Mean time the unit will be in the queue.
w	Waiting time per time unit.
$(\Delta t_s)^2 = \sigma^2_s$	Mean variance of distribition of service time.
$\Delta t_s = \sigma_s$	Standard deviation of service times.
$(\Delta t_a)^2 = \sigma^2_a$	Mean variance of breakdown or arrival times.
$\Delta t_a = \sigma_a$	Standard deviation of arrival or breakdown times.
$\lambda = 1/T_a$	Mean breakdown rate.
$\mu = 1/T_s$	Mean service rate.
Ω	Limiting value of the cost ratio(stochastic case).
Φ	Limiting value of the cost ratio(deterministic case)
τ	Cycle time.
φ	Coefficient of Utilization.
γ	Rate of production of a working machine.
β	Ratio between combined activity time + running time and combined activity time + independent time.
Σ	Summation.
χ	Chi.
α	Operating efficiency.

CHAPTER 1

INTRODUCTION

In many industrial processes, an operator attends a number of machines, which stop from time to time. Each time a machine stops, the operator has to do a certain amount of work before it can be put into operation. If, at any time, two or more machines are stopped simultaneously, there will be a loss of production, due to the period the machines have to wait for the operator to rectify them. In deterministic situations, a single worker is assigned to operate a number of identical semi-automatic machines, where the activities performed are repeated for each cycle. In this work, more attention is paid to the distribution pattern of the stopping of the machines and service for finite queue from finite population.

Previous work on both stochastic and deterministic cases have suggested that there is a possibility of using various distribution patterns for service time and comparing them statistically for their sensitiveness. Much of this work is reviewed in detail in chapters 2, 3 and 4. The majority of previous researchers used negative exponential and constant distributions, (finite population - limited queue) with the aid of digital computers.

This work uses the simulation technique to investigate the behaviour of the different distributions and the models are compared statistically for their sensitivity.

It is hoped that by first giving the reader an account of the other work done in this field and of the tools used in this research, the reader will be able to better appreciate the problems of production shop and the relevance of the work that is described in the subsequent chapters. Consequently, it would be impractical at this stage to give more than a brief account of the objectives of this work, leaving a fuller account of both objectives and methods until later (see chapters 5, 6 and 7).

Many previous workers in this field have emphasised the particular importance of the arrival and service time distributions for finite calling population and also considered the economic assignment of men to machines.

This exercise follows directly from the works of Palm (38), Fetter (16) and King (20,21). Various distribution patterns like normal, Erlang and constant are used. This is apparently an entirely new line of development and the results obtained indicate that distributions do not have any significant effect on the final results.

A general programme is given for using different means for arrival and service time distributions. Comparative analyses have been made for machine shop layout. Finally, economic allocation of machines to men has been carried out.

To expedite the large number of simulations required for this work, SIMON SIMULATION PROGRAMME is used. This programme, besides its usefulness for this work, is also capable of handling much of the possible future work.

CHAPTER 2

THEORY OF QUEUES

2.1 Introduction

As societies get involved in a more complex structure, it seems to become more and more difficult for anyone to avoid involuntary participation in queuing processes. The thing common to all the systems that we shall consider is a flow of customers requiring service, there being some restriction that can be provided. For example, the customers may be patients arriving at an out-patients' clinic to see a doctor. The restriction on service is again that one customer can be served at a time and it is a single server queue.

Examples of a single server queue:

a) Numerous problems connected with telephone exchanges: (if the customers' telephone calls are put into an exchange, the arrival pattern is completely random, so they will be given connection immediately, or they have to wait according to the availability of the line).

b) The breakdown of machines is approximated by a completely random series. The operator has to serve the machine (first come, first served), before going to another machine.

c) The arrival of an aircraft at a busy aerodrome. For example, if the landing strip is limited, the number of planes arriving at the airport have to be scheduled or they have to circle around before they get the clearance to land.

2.2 The Aims of An Investigation of Waiting Time

For all the examples in the previous section, congestion will occur from time to time, if there is a sufficient irregularity in the system. For example, in a single server queue, suppose that either the customer arrives irregularly, or that there is an appreciable variation in the time taken to serve a customer, or both. Then from time to time more than one customer will be at the service point at the same time and all but one of them must queue up awaiting their turn for service, and congestion occurs.

Our practical aim in investigating a system with interference is usually to improve the system by changing it in some way. For example, in many industries, several automatic or semi-automatic machines are serviced by one and the same worker. The necessary work required for each machine consists of feeding in new material and making possible adjustment, or servicing the machines due to breakdown. If the calls for service of each machine are too frequent, waiting time occurs, because of machine interference. So machine interference theory forms part of the general theory of queues. In some cases, the service facilities are unused for a large proportion of time, either because of many operators, or due to the low rate of arrival. In either case, a change in the system may be economically profitable. Alternatively, it may be that some radical modification of the system, such as changing the layout or introducing two or more operators, is necessary. It is often very useful to predict the waiting time of the machines, which is likely to occur in the modified system. A rational decision about its introduction must depend, in part, on assessing the annual profit from the additional production, obtained due to the reduction in waiting time, and comparing this with the capital cost of the machine and cost of engaging operators.

2.3 Specification of the System

a) The arrival pattern

This means both the average rate of arrival of customers and the statistical pattern of the arrival. The queue may be dynamic or static with first come first served.

Dynamic queue: Customer moves to server (stationary)

Static queue: Server moves to customer (stationary)

b) The service mechanism

This means, when service is available, how many customers can be served at a time, and how long the service takes. Usually, the latter is specified by a statistical distribution of service time.

c) The queue discipline

This means the method by which a customer is selected for service, out of all those waiting for service. The simplest queue discipline is first come first served, but there are also many other possibilities.

(d) Calling population

The units to be served by the system may come from either a finite or an infinite population.

(e) The queue state

The queue state can be described at any given time by the number of units in it. This alone, however, may not be sufficient and other parameters are necessary for a detailed study of the system, whose objective may be the evaluation of customer waiting time, length of server periods, etc.

One should, therefore, describe in detail the type of arrival pattern, the service mechanism, the queue descipline, the nature of the population and the state of the queue.

CHAPTER 3

SERVICE AND ARRIVAL DISTRIBUTIONS IN VARIOUS INTERFERENCE PROBLEMS

3.1 Introduction

In many operational situations, it is impossible to predict beforehand, how long the service operation will take before completion. Various reasons for delay may arise, in a more or less random fashion, which could not have been foreseen. An aeroplane, wishing to land, may be delayed by momentary blocking of the landing strip, or by ground fog; the telephone operator seldom knows how long the customer is going to take to finish his telephone conversation; in automatic or semi-automatic machine servicing, or loading and unlaoding of the machine, the operator seldom knows how long it will take to put the machine in working order.

It may be possible to estimate approximately the length of the service operation in other cases. For example, it is easier for a petrol station to use the same service procedure for filling up the petrol tank of a customer's car for three gallons of petrol or another customer who wants ten gallons and his tyres checked. So it may be operationally possible to consider a variety of arriving units to be indistinguishable as far as the service operation is concerned. If the various units of this general class arrive in random order and join the queue (it may be an infinite queue, or a finite queue, in which case if the queue is full, the customer will not join the queue and will go away), there will again be random fluctuations in the length of service operation. In each of these situations, the service time will be described in terms of probabilities.

3.2 Service Time Distribiton (32)

Supposing that we measure the time taken for the service operation to be completed on a series of a hundred or so units, which we have decided to treat as the same in regard to service; we could record the servicing time of a series of automatic machines, or we could record the loading and unloading of a series of semi-automatic machines, or we could record the duration of a sequence of telephone calls. By arranging this sequence of recorded times in order of decreasing length, the number of service operations that take longer than a given time can be plotted. Then, by dividing by the total number in the sample, we can obtain a curve for the probability $S_o(t)$ that the service operation on this class of unit will take longer than a certain time 't'. If the situation remains the same, another sample of measured times will yield another experimentally determined curve of probability, which will be roughly equal to the Fig. 3.1a; also, presumably, the more samples that are taken will mean a smoother curve (see Fig. 3.1b).

The probability function $S_o(t)$ is all we need for probabilistic analysis as long as there is no regular pattern in the occurence of long and short service times, as long as the distribution of the sequence of service durations is random in time.

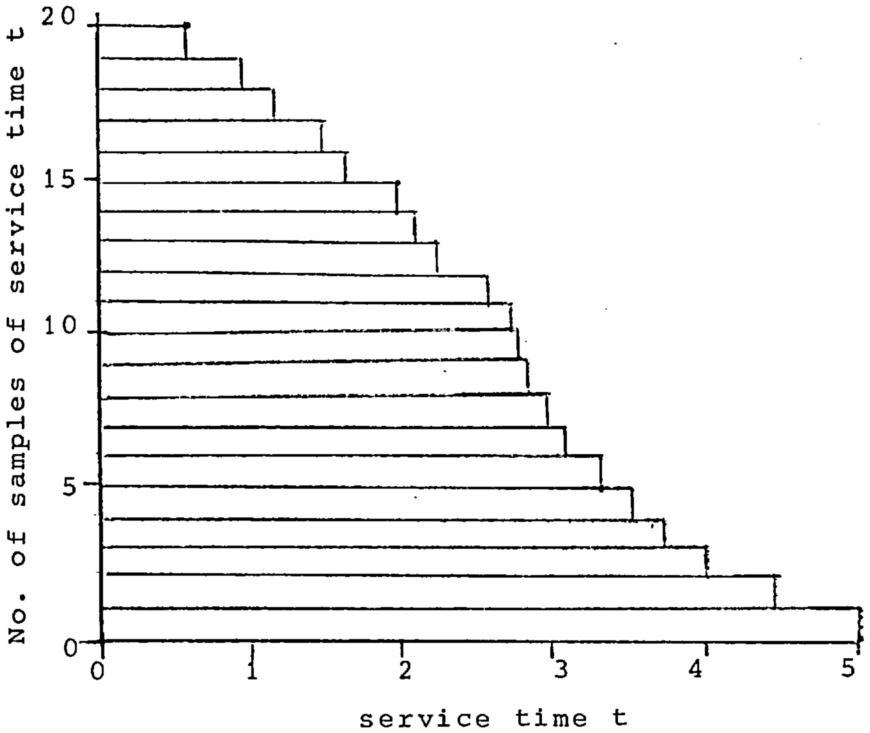


Fig. 3.1a

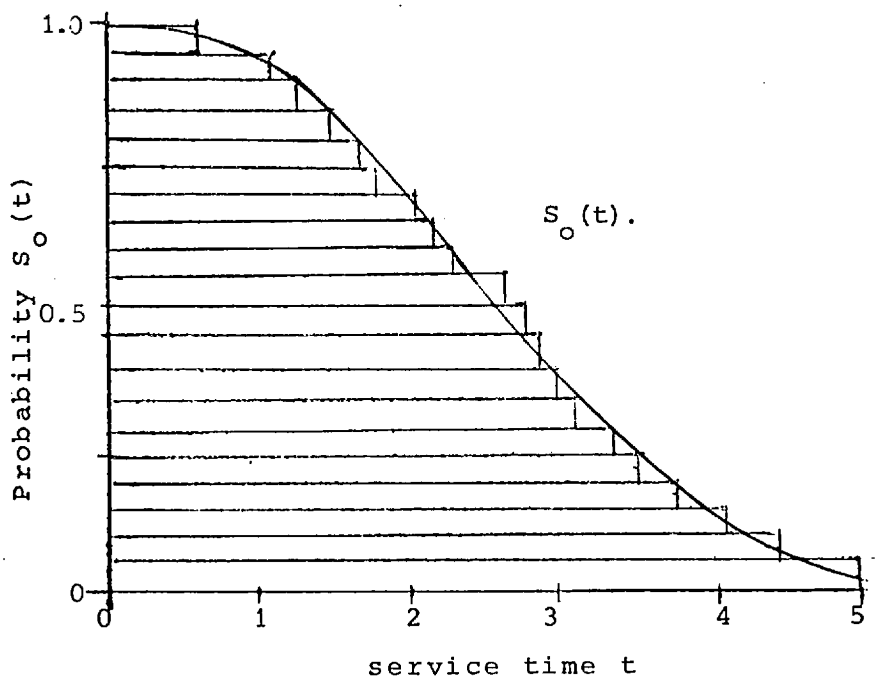


Fig. 3.1b

All curves (see Fig. 3.2) will start at unity at t = 0, for it is certain that a service operation takes longer than zero time. All of them will tend toward zero as t increases. For most cases of practical interest,

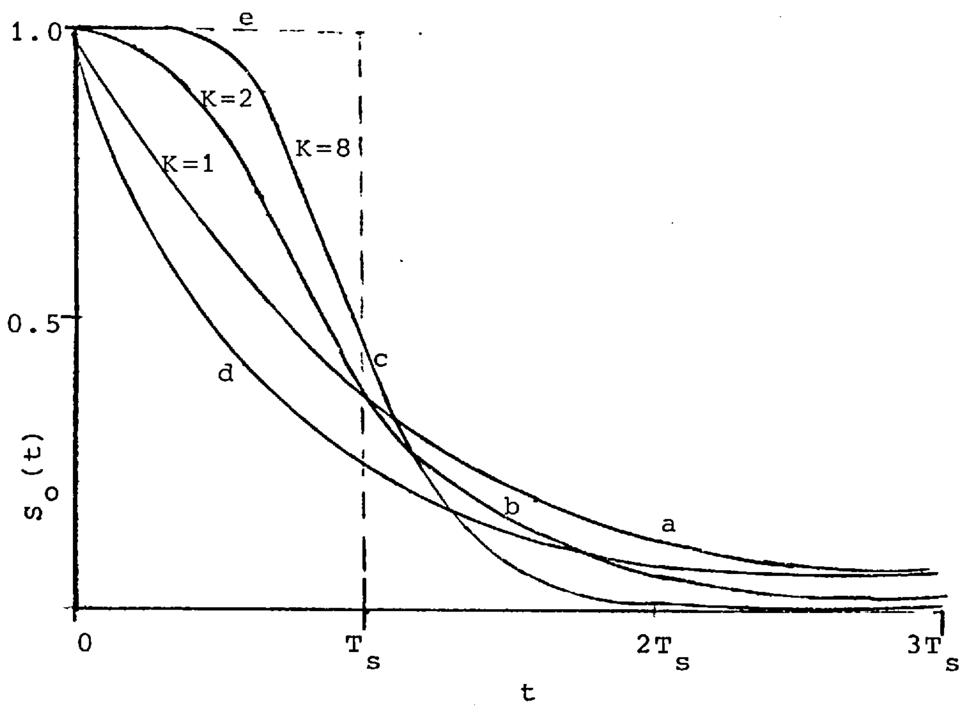


Fig. 3.2

probability $S_o(t)$ moves to zero exponentially as t goes to ∞. The smaller the variation between service times, the nearer the curve will approach a "step function" (the dashed curve), when all service operations take the same time. When the service operation on every arriving unit of the class takes exactly time T_s for completion, it is certain ($S_o = 1$) that every service time takes longer than t, if t is less than T_s, and it is certain that no service time ($S_o = 0$) is longer than t, if t is greater than T_s. Actual situations corresponding to this limiting example are very few. Most of them produce a curve for $S_o(t)$ more like curves a or b (see Fig. 3.2)

The probability density s(t) that a service operation is completed at time t is (32)

$$s(t) = -(dS_o/dt) \text{ or } S_o(t) = \int_t^\infty s(t)dt \qquad 3.1$$

(The quantity s(t) is the probability density that a service operation is completed at time t. It is a rate, since its dimensions are probability divided by time).

Suppose a whole set of service operations all started at the same instant and ended at different times then s(t) would measure the mean rate at which these operations would be ending at time t.

The average duration of the service operation is then

$$T_s = \int_0^\infty S_o(t)\ dt \qquad 3.2$$

from this it follows that the area under S_o equals T_s.

The mean square of the duration of time is

$$(t^2)_{av} = 2\int_0^\infty tS_o(t)dt \qquad 3.3$$

The mean square deviation from T_s is then

$$\int_0^\infty (t-T_s)^2\ s(t)dt = (t^2)_{av} - T_s^2 = \int_0^\infty (2t - T_s)\ S_o(t)dt$$

$$= (\Delta ts)^2 \qquad 3.4$$

Therefore, variance $= (\Delta ts)^2$ and

Standard deviation $= \Delta ts$

3.3 Constant Service Time

The service time may be assumed to be constant. This is always an idealization but, particularly in problems with very irregular arrival patterns, it often gives adequate answers. Standard deviation is zero for the constant service time case (S_o - a step function) and increases as the S_o curve departs more and more from the step-function shape.

3.4 Exponential Service Time

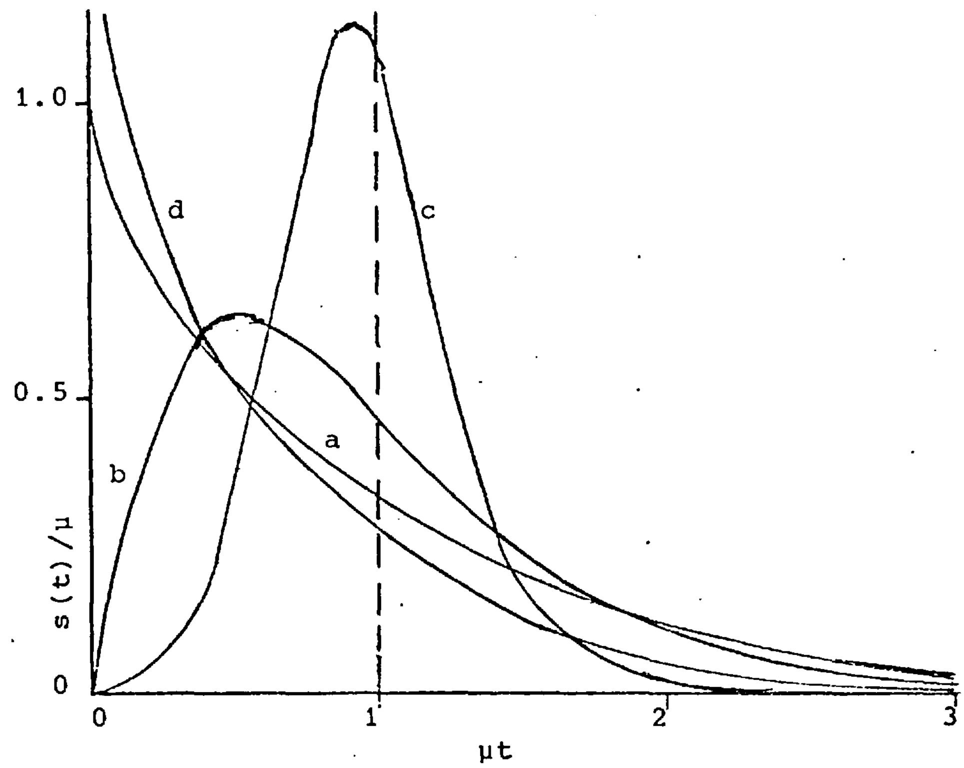
The exponential distribution is a good approximation of the distribution of the duration of telephone calls. It is likely to be a reasonable point to consider when there are a large number of customers requiring short service and a small number of customers requiring longer service. Servicing of the automatic machines also has the same pattern as telephone calls. From equation 3.2, the probability required is

$(1/T_s)\ S_o(x)\ dx.$

The product of the two is the probability that the service observation began between x and x+xdx and the service finished between time y and y + dy later. The probability that an observer coming up to a service channel at some random time and finding the service man is busy then, would find him still engaged by the same unit at time t later is

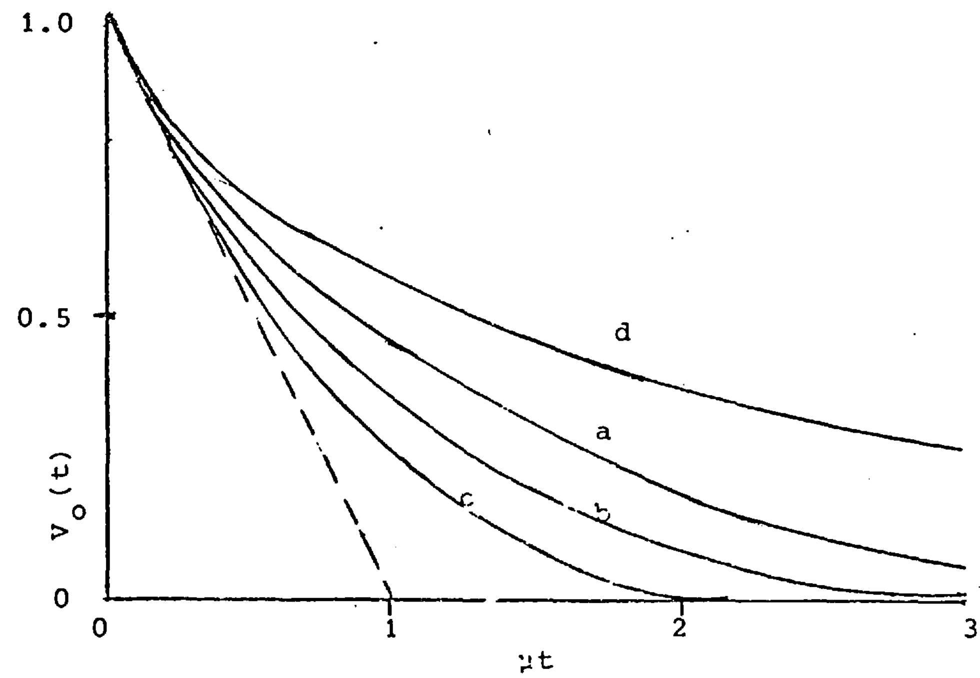
$$V_o(t) = (1/T_s) \int_o^\infty dx \int_t^\infty s(x + y)\,dy = \int_t^\infty S_o(x)\,(dx/T_s) \qquad 3.5$$

Fig. 3.2, Fig, 3,3a and Fig. 3.3b show s, S_o and V_o for different service characteristics. Curves c correspond to a situation where nearly all service operations take the same time, the limiting case, when S_o is a step function, the density is a delta function and V_o is a segment of straight line (dashed curves). This is called the constant service time case. Curves a correspond to the other limit, where probabilities S_o and V_o are equal, since the probability of prolongation of service is independent of when the service started. From equation 3.5, when $S_o = V_o$



Probability density s(t)/μ of completion of service at time t, (for service characteristics shown in Fig. 3.2)

Fig. 3.3a



Probability $V_o(t)$ that no service completion occurs in an interval of length t chosen at random, for service characteristics corresponding to those shown in Fig. 3.2.

Fig. 3.3b

$$S_o(t) = \int_t^\infty s(t)\,dt$$

$$= \int_t^\infty \mu e^{-\mu t} dt; \qquad s(t) = \mu\, e^{-\mu t}$$

$$= e^{-\mu t}$$

$\therefore$ $(dS_o/dt) = -\mu\, S_o;$

so that $S_o(t) = V_o(t) = e^{-\mu t}$ 3.6

$\Delta t_s = T_s = 1/\mu$

3.5 Normal Service Time

According to Naor (33), for a sufficiently large parameter, the exponential distribution may be approximated by a normal distribution. Probability density function for normal service time is

$$s(t) = \frac{1}{\sqrt{2\pi}\sigma_s} e^{-\frac{1}{2}\left(\frac{t - T_s}{\sigma_s}\right)^2}$$

Therefore,

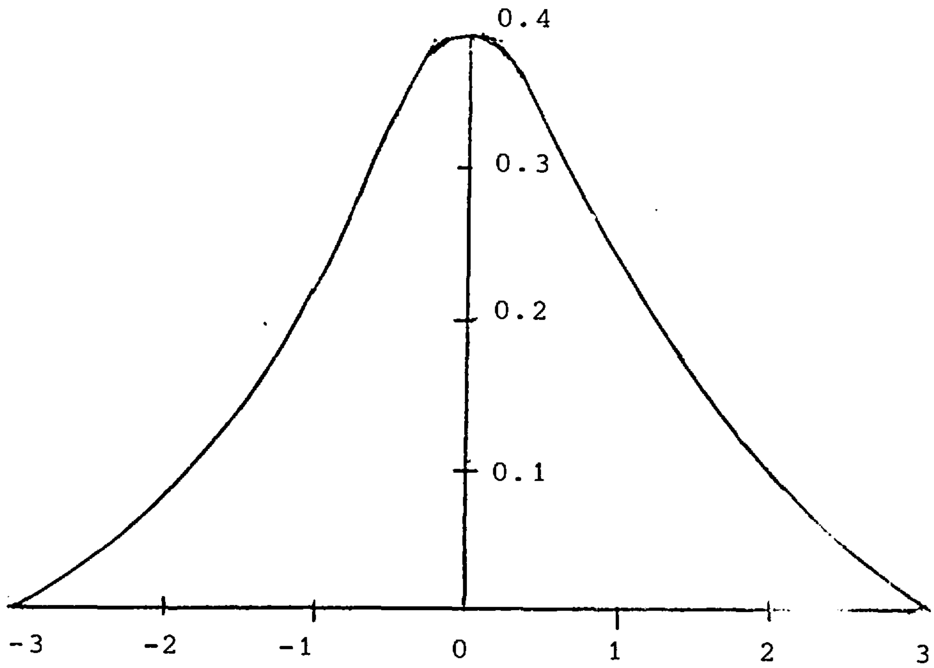
$$S_o(t) = \int_t^\infty \frac{1}{\sqrt{2\pi}\sigma_s} e^{-\frac{1}{2}\left(\frac{t - T_s}{\sigma_s}\right)^2} dt$$

$$= \frac{1}{\sqrt{2\pi}\Delta t_s} \int_t^\infty e^{-\frac{1}{2}\left(\frac{t - T_s}{\Delta t_s}\right)^2} dt \qquad 3.7$$

where $\Delta t_s = \sigma_s$, T_s is the mean and Δt_s is the standard deviation.

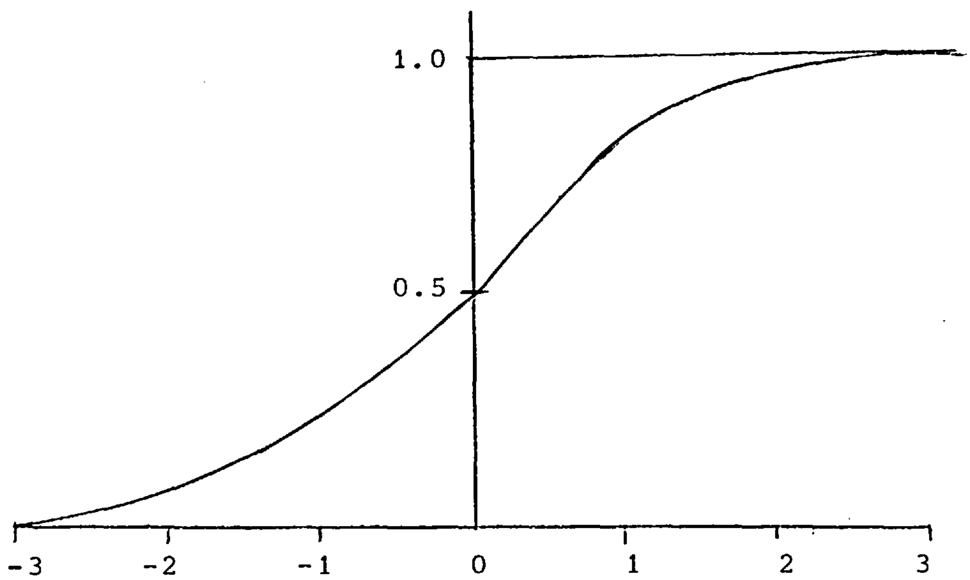
Figs. 3.4a and 3.4b show the normal density function and the normal cumulative distribution.

Standard deviation is restricted in the case of normal service time to 3σ limit, since service time cannot be negative.



Normal density function s(t)

Fig. 3.4a



The normal cumulative distribution is $1 - S_o(t)$.

Fig. 3.4b

3.6 Erlang Service Time

Many operational situations correspond to service time distributions which are different from constant, exponential and normal. Erlang distributions provide a family of service time distribiton which range all the way from the pure random exponential type to the completly regular, constant service time and approximately normal situations. They will not fit all possible service time distributions, but they will fit many of the ones that come across in practice.

The model can be built-up from exponential elements. The following rules are observed for a phase-type service with K phases.

a) Only one machine is allowed at a time in the servicing facility (one operator - all other machines have to wait in the queue.

b) The entering machine must pass through every phase of service beginning with the first phase.

c) On completion of one phase, the machine goes on to the next phase.

d) When the specified phases are finished, the machine is removed from the facility, and then only a breakdown machine is introduced to first phase.

Even though this facility is compound, it can be considered as a single service facility, since it only allows one machine in it at a time (it is not a service station with two operations).

The Erlang service time distribution function is

$$S_o(t) = e^{-K\mu t} \sum_{n=0}^{K-1} (K\mu t)^n / n!; \qquad 3.8$$

standard deviation $\Delta t_s = (1/\mu\sqrt{K})$

The expression standard deviation shows that the variability of service time diminishes as K increases. Curves b and c in Fig. 3.2 and Fig. 3.3 are for K = 2 and K = 8 respectively. Curve a is for K = 1, which is the exponential case. If $K \to \infty$ a true step function S_o is obtained, the case of constant service time.

3.7 Arrival Distribution

a) Irregular arrivals may be described in terms of probabilities. The probability density of the next arrival coming between t and dt, after the previous one is a(t)dt.

Therefore, probability of arrival time distribution is

$$A_o(t) = \int_t^{\infty} a(t)\,dt \qquad 3.9$$

The probability that no arrivals occur in an interval time t, chosen at random, if

$$U_o(t) = \lambda \int_t^{\infty} A_o(t)\,dt \qquad 3.10$$

Therefore mean rate of arrival is

$$T_a = (1/\lambda) = \int_o^{\infty} A_o(t)\,dt \qquad 3.11$$

b) Regular arrivals. The most common in application is the regular one, where the customers arrive at equally spaced intervals. In this case $A_o(t)$ is a step function

$$\begin{aligned} A_o(t) &= 1 \quad \text{when } t < Ta \\ A_o(t) &= 0 \quad \text{when } t > Ta \\ U_o(t) &= 1-(t/T_a) \quad \text{when } t < Ta \\ U_o(t) &= 0 \quad \text{when } t > Ta \end{aligned} \qquad 3.12$$

(Mean rate of arrival $\lambda = 1/T_a$, variance of arrival time $\Delta^2 ta=0$). A practical example is where the stoppage of machines is nearly regular (in semi-automatic machines) after the job is over at regular times.

c) <u>Random Arrivals</u>. The simplest arrival pattern and the most commonly useful one in application is when the arrivals are completely random. For example, when the chance of occurrence of the next arrival is independent of time of the last arrival, then

$$A_o(t) = U_o(t) = e^{-\lambda t};$$

$$a(t) = \lambda e^{-\lambda t} \qquad 3.13$$

$$\Delta t_a = T_a = (1/\lambda)$$

This arrival distribution is called the Poisson distribution or exponential arrival case (limit of the Binomial distribution) i.e. n is large and p is very small).

In the case of arrivals, it is better to know the probability that n arrivals occur within an interval of time of duration t. If this interval commences just after an arrival, the probability will be called $A_n(t)$; if the interval is placed at random in time, it will be called

$U_n(t)$.

$$A_n(t) = \int_o^t a(x) A_{n-1}(t - x)dx \text{ from equation 3.8.}$$

$$U_n(t) = \lambda\int_o^\infty dx \int_o^t a(x + y) A_{n-1}(t - y)dy$$

$$= \lambda \int_o^t A_o(x) A_{n-1}(t - x)dx \qquad 3.14$$

For exponential arrivals,

$$U_n(t) = A_n(t) = \{(\lambda t)^n/n!\}e^{-\lambda t} \qquad 3.15$$

Curves for a, A_o and V_o are similar to those for s, S_o and V_o (see Figs. 3.2, 3.3a and 3.3b).

d) Regular Arrivals with Unpunctuality (3)

Suppose that customers have appointments to arrive at equally spaced intervals t, but are unpunctual. For example, assume that the nth customer scheduled to arrive at time nt_a, actually arrives at $nt_a + \varepsilon_n$ (where ε_1, ε_2, . . variables). If the ε_i's have mean zero, there is no tendency to be on the average late or early for the appointment. If the dispersion of ε's is small, compared with t, the effect of unpunctuality is not important. If the dispersion of the ε's is large, compared with t, the series is equivalent to a completly random one.

e) Non-stationary Arrival Patterns. Assuming that customers are telephone calls put into an exchange, the arrival pattern is completly random at a rate that varies smoothly with the time of the day. In certain rush hour problems, reasonable approximation can be made to the arrival pattern by taking, say a completely random series in which the rate of arrival is to begin with t. Suddenly, t changes to t + dt, and after a certain time, returns either to t or to some other value. All these possibilities are covered by taking a stationary pattern and allowing the parameters in it, for example the arrival rates, to vary either smoothly or discontinuously.

The discussion so far shows that there is a wide variety of arrival and service patterns that can arise in application. In fact, the completely random and regular patterns are the most commonly used in applied mathematical work; other patterns usually require special investigation.

CHAPTER 4

MACHINE INTERFERENCE PROBLEMS

4.1 Queue-discipline

A queue discipline specifies the order in which customers are selected from the pool of customers, (machines or telephone calls or persons etc.), who join the queue at different points of time. The queue-disciplines investigated in this chapter are as follows.

(a) Single capacity systems.

When the service of a customer is completed, or when the service becomes available, one customer must be selected for service. This may be done on the basis of first come first served, or on some other basis, like selecting a customer at random with respect to order of arrival, or to take the last customer to arrive, rather than the first.
In the second case, when the rule for selection does not depend entirely on order of arrival there are two main possibilities. The queue-discipline may depend on some prior numbering of the customers, for example, in terms of a normal appointment time the numbering would usually be closely related, but need not be the same as the order of arrival. The other possibility is that the customers are divided into types, either with different distributions of service time, or such that the loss due to delaying a customer unit-time is different for different types of customer. Customers are then selected for service, giving customers of the first case priority, and so on.

In some extreme cases, the server may stop the service of a customer of lower priority, in order to deal with a customer of higher priority, this is called pre-emptive priority.

(b) Multi-capacity systems

Case 1

The customers are assigned to server in strict rotation. This is simple mathematically, but inefficent practically and not often realistic.

Case 2

Each customer decides on arrival which queue to join. This system is used most in Post Offices and Banks, etc. It is very effective, but difficult to analyse mathematically.

Case 3

The customers form into a single queue, a customer moving forward for service as soon as the server becomes free. Similar to case 2, this also is most effective, but mathematically difficult to deal with.

(c) Cyclic servicing

In this case, a number of machines are looked after by an operator, who walks around in one direction to inspect the machines one by one and service them and then, if a machine has stopped, take varying time to repair it.

4.2 The Measurement of Congestion

There are three main aspects, namely:

(a) the mean and the distribution of the length of time for which a customer has to queue for service.

(b) the mean and distribution of the number of customers in the system at any instant,

(c) the mean and distribution of the length of the server's busy periods.

These properties of the queueing system are related in a general way, in that all three mean values tend to increase as a system becomes more congested. But in any particular practical application, normally we need not be interested in all three quantities. Customer's queuing time or waiting time is of direct interest when there is an economic loss if the customer (in our case a machine) is kept queuing.

4.3 Population

Customers may come from either an infinite or a finite population. If the population is finite but very large so that the arrival rate is not affected by the reduction in the population caused by the customers being served, then it is considered infinite. If the population of customers is relatively small, the reduction in population size should be taken into account.

4.4 Queue state (40)

The present work investigates only queues involving finite population. For infinite queues, various results relating to measures such as the mean waiting time of customers in the system mean queue length etc. can be found in any book on queuing theory.

The following are some of the theoretical results available on various measures for finite population and finite queues (40), though the present study does not use any of these measures directly. These have been used by other researchers such as Palm (38) in obtaining values for such factors as machine utilization, waiting time and service time. The present work uses the various measures obtained by Palm (38), Fetter (16), and King (20,21) in evaluating the different approaches in machine interference problems.

<u>Case 1</u>

<u>Finite population - Finite queue - Single channel</u>

For example, limited number of machines are maintained by a single operator. The following assumptions are made.

(i) The maximum number of units in the system (in breakdown or waiting time) is limited by the number of machines in the group N.

(ii) Each serviced unit, joins the functioning population of machines immediately.

(iii) The probability of breakdown of a machine is proportional to the number of machines functioning at a given instant.

(iv) λ is the mean arrival frequency per machine, so that if all N machines are funtioning the arrival rate for the group is $N\lambda$.

The probability distribution of the random variable is

$$P_n = \left(\frac{\lambda}{\mu} \right)^n \cdot \frac{N!}{(N-n)!} \cdot P_o \qquad (4.1)$$

where $P_o = \left[\dfrac{1}{\sum_{n=o}^{N} (\frac{\lambda}{\mu})^n \frac{N!}{(N-n!)}} \right]$

The mean number of units in the system

$$L = \sum_{n=o}^{N} n \, . \, P_n \qquad (4.2)$$

Operating efficiency $\alpha = \dfrac{N-L}{N}$ ______________ (4.3)

The mean number in the queue

$$L_q = \sum_{n=1}^{N} (n-1) P_n = L - 1 + P_o \qquad (4.4)$$

Case 2

Limited queue - Finite .... population - Multi channel

For example, a machine group subject to periodic breakdowns is serviced by one of M servicemen.

The following assumptions are made.

(i) There are M servicemen working independently to serve N machines.

(ii) Service time to repair a machine is an exponentially distributed random variable with mean frequency μ.

(iii) Each machine has an average running time of u so that $\lambda = \frac{1}{u}$ (λ can be considered to be an arrival or breakdown rate).

$$P_n = \begin{cases} \left[\dfrac{N! \, \wp^n}{(N-n)! n!} \right] . P_o \; ; & n = 0, 1, 2, \ldots \ldots M \\ \left[\dfrac{N! \, \wp^n}{M! \, M^{n-M} \, (N-n)!} \right] . P_o \; ; & n = M + 1, \ldots , N \end{cases} \qquad (4.5)$$

$$P_o = \frac{1}{\sum_{n=o}^{M} \frac{N!\rho^n}{(N-n)!n!} + \sum_{n=M+1}^{N} \frac{N!\rho^n}{M!\, M^{n-M}.(N-n)!}} \quad (4.6)$$

The mean number of units in the queue

$$L_q = \sum_{n=M+1}^{N} (n - M)P_n \quad (4.7)$$

The mean number waiting for service

$$M_{in} = \sum_{n=o}^{M} (M - n)P_n \quad (4.8)$$

(M_{in} average number of empty service stations)

The average number in the system,

$$L = \sum_{n=o}^{N} n\, P_n = M + L_q - M_{in} \quad (4.9)$$

The mean waiting time in the queue

$$W_q = \frac{L_q}{\lambda(N - L)} \quad (4.10)$$

From the above discussion it is apparently clear that the calculations of state probabilities are quite involved numerically.

4.5 Machine Interference

Most of the work is done on machine interference under various titles like, machine supervision, the assignment of workers in servicing automatic machines and the productivity of several machines under the care of one operator etc. Machine interference is a problem of delayed service. A set of machines are serviced by a repairman or by a number of repairmen. From time to time a machine breaks down and a repairman is called for, to service it. This service is provided during a time interval and the machine is restored to normal work thereafter. However, it may happen that a number of machines are out of order at one and the same time. If the number exceeds the number of repairmen, the excess are not being served and have to wait for repairmen, subject to their availability. Thus, in addition the normal loss due to time spent in servicing machines, there is the interference loss, due to the fact that sometimes the broken down machine has to wait until service begins. Other machines, which have broken down before it, delay and interfere with service. It is desirable to know the fraction of time a machine spends working, being serviced, and waiting. A theoretical solution, based on a very reasonable model, was given by Palm (38), the solution being applicable to any number of machines and repairmen. The basic assumptions of Palm's model are:

(i) All machines are similar with regard to the average number of breakdowns which each experiences in its unit working time.

(ii) All repairmen are similar with regard to the skill needed to restore them to working condition.

(iii) Uninterrupted working time of a machine is an exponentially distributed random variable.

(iv) Repair time of a machine by repairmen is an exponentially distributed random variable.

(v) All random variables are independently distributed.

(vi) The system of machines and repairmen is in a state of statistical equilibrium.

He has given that, machining time + servicing time + waiting time = 1.

i.e.

$$m + s + w = 1 \qquad (4.11)$$

From this, he has defined the quotient

$$k = \frac{s}{m}$$

whereas Fetter (16) has given the definition of servicing constant $k = \frac{\lambda}{\mu} = \frac{m^{-1}}{s^{-1}} = \frac{s}{m}$ (4.12)

where λ - the expected number of calls for service per unit time

μ - the expected number of machines serviced per unit time

m - machine running time per unit time

s - service time per time unit

w - waiting time per time unit

Fetter also has given four physical interpretations of the servicing constant k.

(a) k may be determined, when a machine can be serviced under conditions when no waiting time occurs (one machine - one server), i.e. $k = \frac{s}{m}$

(b) k can also be determined when s and m values are obtained after a long period of record.

i.e. $k = \frac{s}{m}$

$s = km$

adding m to both sides

$$s + m = m(1 + k)$$

therefore

$$\frac{m}{m + s} = \frac{1}{1 + k}$$

$$\text{(c)} \quad k = \frac{s}{m}$$

$$m = \frac{s}{k}$$

adding s to both sides

$$m + s = \frac{s(1 + k)}{k}$$

$$\frac{s}{s + m} = \frac{k}{1 + k}$$

$$\text{(d)} \quad m + s = m(1 + k) = 1 - w$$

Palm's solutions are

waiting time

$$w = 1 - s(1 + k^{-1}) \tag{4.13}$$

service time

$$s = \frac{1 - P_o}{N}$$

State probabilities are

$$P_o = \frac{1}{\sum_{n=o}^{N} \frac{P_n}{P_o}} \tag{4.14}$$

$$\sum_{n=o}^{N} P_n = 1 \tag{4.15}$$

$$P_n = \frac{N!}{(N - n)!} k^n P_o \tag{4.16}$$

He also gives a solution for r operators to service N machines

$$w = \frac{\sum_{n=r+1}^{N} (n - r)\, P_n}{N} \qquad (4.17)$$

He has given tables for m, s and w for a single operator for various values of k from 0.01 to 0.4. But he has not given for r operators servicing N machines.

Fry (18) has solved a problem in congestion of telephone lines, the conditions of which are more or less identical to the machine interference problem. Fry's assumptions are:

(i) A group of telephone lines, having access to one common trunk line are handled in such a way that if a call requiring the use of this line originates while a call is already in use, then the second call will be delayed until the first one is finished.

(ii) All telephone calls are of equal length of time.

(iii) The telephone calls which are assigned to the group of lines are distributed individually and collectively at random.

Wright (47) uses Fry's (18) formula and converts into terms of machine interference, as follows (in our symbols)

$$I = 0.5\left\{\sqrt{(1+k^{-1} - N)^2 + 2N} - (1+k^{-1} - N)\right\}$$

where $I = \frac{w}{s}$ (4.18)

Using equation (4.18) we can obtain solutions for m, s and w.

Duvall (11) has given an empirical solution under the following assumptions.

(i) The operation performed on each of the N machines is identical under one operator's care, but the service may vary. All machines are the same.

(ii) The operator is equally available to all machines.

(iii) The operator is always attending one machine unit as long as there is at least one requiring attention.

(iv) The machine has to wait for service if required when the operator is engaged.

The general equation measuring interference factor is given by Duvall (11):

$$I = (N - 1)\, e^{-1.4N^{-0.946} . k^{-1}} \qquad (4.19)$$

The development of equation 4.19 may be analysed in the following way. It may be observed that the amount of interference in a given machine assignment will vary inversely with the ratio of machine time to service time. It may also be noted that when k is constant the amount of interference will directly vary with N. Therefore I is controlled by the two factors N and k. He also gives a final satisfactory formula for interference.

$$I = ce^{ak^{-1}}$$

Where c and a are constants varying with N.

c is developed as (N - 1) and a is developed as $-1.4N^{-0.946}$

Freeman (17) analyses that Fry is interested in calculating the expected delay in service if telephone calls, all of the same length are passed through a single channel, whereas Duvall's approach seems primarily empirical.

Ashcroft (1) found out waiting times under the following rule.

The probability of a particular machine calling for service, does not depend on the machines and also on the time which has passed since its last breakdown call for service.

The following solutions are given by Ashcroft (1). Average number of machines running is:

$$A_N = k + (N\ Y_N)^{-1} \qquad (4.20)$$

Waiting time is:

$$w = 1 - \frac{A_N}{N}\ (1 - k) \qquad (4.21)$$

Case 1

Exponential service time:

$$Y_N = 1 + (N-1)k + (N-1)\ (N-2)k^2 + (N-1)!\ k^{N-1} \qquad (4.22)$$

Case 2

Constant service time:

$$Y_N = 1 + \binom{N-1}{1}(e^k - 1) + \binom{N-1}{2}(e^k - 1)(e^{2k} - 1) + \ldots \qquad (4.23)$$

Fetter has analysed the results of Ashcroft (1), Duvall (11), Khintchine (19), Palm (38) and Wright (47) and given a table of comparison.

King (20) has used Palm's model in his work to calculate machine utilization factor m (up to six collaborating workers). His assumptions are the following.

(i) Machine stoppages occur as independent random events and may be assumed to follow a Poisson process (i.e. time between stoppages are negative exponentially distributed).

(ii) Service time of a machine is an exponentially distributed random variable.

(iii) Servicing is done on a first come first served basis.

(iv) All machines are similar for determining the optimum number of machines per worker.

Kronig (22) has reported in his paper regarding economic optimum for the number of machines which are placed under supervision of one workman. He restricted the number of machines to three. Kronig and Mondria (23) in their paper, have given a general method for any number of machines per operator.

Benson and Cox (3) have given a solution for the following problems.

(a) One operator attending a number of machines which are liable to two types of breakdown randomly, each of which has an exponential distribution of service time.

(b) A team of operators attending a number of machines which have one type of breakdown with an exponential distribution of servicing times.

(c) A team of operators attending a number of machines which have M types of breakdown, each of which has an exponential distribution of service times. Each operator is specialised in servicing one type of breakdown.

Naor (33) has considered the machine interference problem when several repairmen are in charge of a set of machines. An explicit probability distribution function, describing the various states of this system, is derived and formulae evaluating diminished productivity and related quantities are given by Naor in terms of tabulated Poisson functions. Naor (33, 34) has also reviewed previous work on this problem.

Mack (28), Mack, Murphy and Webb (29) have considered the problem of determining the efficiency of N machines looked after by a serviceman who walks around them in one direction, always taking the same time to walk to a given machine from the previous one, to inspect it, service it, and then if the machine has stopped, take a constant time to repair it.

Conway, Maxwell and Sampson (6) have given a stochastic model for cyclic servicing. In this model, a server is assigned to service N machines in rotation and the following assumptions are made:

(i) A serviceman is assigned to service machines in rotation.

(ii) These machines may or may not be of the same type, except that each is semi-automatic.

(iii) The processing time of the machines may be a chance variable or a constant processing time.

(iv) The servicing variable is either a chance variable or a negative exponential service time with a constant.

(v) The serviceman is readily available all the time.

They have considered two semi-automatic machines and given a computer programme. They have also given the results for:

1) A series of runs performed for different values of processing time with the distribution of unload-load times fixed.

2) A series of runs performed for different values of mean unload-load time with the processing time fixed.

3) A series of runs performed in which the form of the unload-load time distribution was changed, while the mean unload-load times and the processing times were fixed.

In queuing theory, it is well known that such a multi-server system provides higher machine utilization that the corresponding multiple single server system using the same number of servicemen, whereby each serviceman is assigned to supervise only machines which are marked for him. The problem here is not simply to maximise machine utilization. King (18) has determined an economic balance between the losses due to machine breakdown time on the one hand, and the costs of providing a higher level of service on the other. He has found out the optimum size of the servicing to be assigned to the machines. He has also derived equations for cost analysis (Appendix III). O'Connor (37) has discussed in his paper on establishing a method for obtaining the allocation of machines to operators, which is economically best. He has considered both automatic and semi-automatic machines in cotton and textile industries.

Eilon, Hall and King (12) have considered a practical case of optimum allocation of machines to operators. Fetter (16) considers economic assignment for a single serviceman and given an equation:

Total cost of machine operation per time unit per machine,

$$C = m\,C_m + s\,C_s + w\,C_w + \frac{C_r}{N} \qquad (4.24)$$

Where the operator has no auxiliary duties which interfere with his servicing of the machines, he assumes that output occurs only during m (machine running time), - the cost of this output is:

$$C_o = \frac{C}{m} \qquad (4.25)$$

From equation 4.35, it can be shown that

$$C_o = C_m + \frac{s}{m}\,C_s + \frac{w}{m}\,C_w + \frac{1}{mn}\cdot C_r$$

$$= C_m + kC_s + \frac{w\,C_w + C_r/N}{m} \qquad (4.26)$$

Here the objective is to minimise C_o with respect to N, the machine assignment, and since only w and m vary in equation 4.24, that N which minimises the third term in equation 4.26 is the economic assignment. Since w and m depend on N, no explicit solution can be obtained for this minimum.

O'Shaughnessy (36) analyses marginal cost for machine interference problems. He used Wright-Fry formulae for the cost analysis. King (20) has given a detailed account of cost analysis and an equation:

$$\Omega = \frac{m_{p_o}}{N(m_{p_o+1} - m_{p_o})} - \frac{p_o}{N} \qquad (4.27)$$

p_o - the optimum size of the servicing work force

Ω - is called the limiting value of the cost ratio $\frac{C_w}{C_m}$ such that above this value $p_o + 1$ and below it p_o, is the optimum number of servicemen for the N machines (see Appendix III).

Eilon (14) has considered deterministic case using semi-automatic machines and constant time distribution for both arrival and servicing. King (21) also uses the deterministic case in a different fashion. The situation considered is that of a single worker assigned to operate a number of semi-automatic machines where the activities performed are repeated each cycle. There are two types of activities that need to be considered: one is combined activity like loading and unloading the machine and the other is independent activity like cleaning, inspecting and walking to the next machine to repeat the cycle. He has assumed constant time distribution for both the running time of the machine and the activities. He has given the cycle time

$$\tau = \underset{\text{machine}}{a + t + i_m} = \underset{\text{operator}}{(a+b)n + i_o} \qquad (4.28)$$

and also the limiting value of the cost ratio:

$$\Phi = \frac{\beta - n_o}{n_o(n_o + 1 - \beta)} \qquad (4.29)$$

where

$\beta = \frac{a + t}{a + b}$

τ = cycle time

t = running time of the machine

a = combined activity time (loading and unloading)

b = independent activity time (cleaning, inspection and walking time)

i_o = idle time per cycle - operator

i_m = idle time per cycle - machine

Φ = C_w/C_r

C_w = cost per unit time of an idle machine

C_r = cost per unit time of operator

n_o = optimum number of machines

Cox and Smith (9) have suggested a solution by different types of distribution for both arrival and service times of infinite population, where as Smith (44) is the first person to treat the problem of several finite populations with different service rates for each type of customer. He assumed that the number of servers equalled the total number of machines, such that no waiting time existed. In their recent conference paper, Carpenito and White (10) have considered the allocation of non-identical machines among non-identical servers (different service rates for servers). Furthermore, to facilitate the treatment of the problem, it is assumed that both service times and running times for the machines are exponentially distributed and the travel time between the machines is negligible. Separation of service is assumed, as opposed to the pooling of servers for server collaboration. Consequently each server will be assigned to specific machines and will be responsbile for maintaining them in running order.

Very few researchers have considered the walking time of the serviceman between machines. Palm (38) has given a straightforward solution for a simple layout. He has considered one and two rows of machines, but if the layout becomes complicated no mathematical solution is possible. So it can be solved only by simulation techniques.

CHAPTER 5

SIMULATION

5.1 Introduction

Many business and operational research problems, in reality, are extremely complex in structure. From an analytical point of view, the important property is whether, or not, the analysis needs to deal with this complexity, in order to obtain useful results. In various situations, the focus is sufficient to give one useful insight into the decision problem. However, there are many situations wherein a mathematical formulation may not be feasible or possible. Consider for example the complex stochastic queuing models in a production shop. Two kinds of difficulties exist in these models and they are:

a) the number of variables and constraining relationships: these may be so large that technical and/or economic considerations make it computationally infeasible.

b) that the given model may be, from one or more points of view, such a large departure from the reality of the situation. Hence no confidence can be placed in the results of the computations.

According to Bowman and Fetter (4), the definition given to simulation is to duplicate the essence of a system or activity, without actually obtaining the reality. Simulation takes a real system - technological, human, economic - and in some sense duplicates it. However, the duplication uses paper and pencil, computers, symbols and words, in place of the real phenomena. This is not the only departure from reality. Because the simulation focuses on certain characteristics of the system, by implication, it largely ignores others. Of course it is true of any model or theory and of the methods of technology in general. Monte Carlo originally referred to analysis in a situation in which a difficult non-probablistic problem was to be solved and for which a stochastic process could be invented whose parameters satisfied the requirements of the original problem.

5.2 The Simulation Model

The simulation has been programmed to run on the Imperial College C.D.C. 6400 computer system. The program is written in FORTRAN and uses the queuing procedures of SIMON, developed by Mathewson (26) and Pace (39). The model has been designed to simulate a range of machine interference conditions, such as different distributions for breakdown and servicing times. Perhaps it is better to consider our first range of models.

5.3 General Description of the Programme

The programme can simulate a machine shop having any number of machines and operators. The programme shown in Appendix IV is for one and two operators, but can be modified for any number of operators. Since our models are stochastic in nature, a random generator is provided for breakdown of machines. Hypothetically, machines form a queue and they are labelled according to the breakdown times. If a single operator is engaged, the operator will move to the next machine, after completing the service on the previous one. When more operators are in use, the operators service the machines in rotation.

The programme may use a variety of arrival time and service time distributions. In our simulation models, we have different combinations, such as the following:

(i) Negative exponential breakdown and normal service time.

(ii) Negative exponential breakdown and Erlangian service time.

(iii) Constant breakdown and negative exponential service time with initial constant, plus independent time (constant).

(iv) Negative exponential breakdown (different means for each group) and negative exponential service times, with an initial constant (different means for each group).

(v) Negative exponential breakdown and service time distribution with walking time included.

(vi) Negative exponential breakdown and service time distributions without walking time. The walking time is shown separately for individual operators and their total time. By using this model, we can have different types of time units.

To keep the programme as general as possible, time is measured in "time units" (t.u.), which may be related to any other time scale.

Logic cycle

In all the work on SIMON simulation models, the "three phase activity cycle" is adopted as shown in the figure 5.1. Sometimes it is not necessary to follow the same order. For example, when we have a number of semi-automatic machines that are waiting to be loaded and unloaded before starting, they have to wait in a queue. So after initialisation, the "C" phase is followed, before going to the "A" phase. Afterwards, the regular phase sequence is followed. The objective of simulation is to investigate, under varying distribution conditions, varying ratios between calling rate and servicing rate and the coefficient of variation factors etc.

5.4 Programme Structure

a) Input to the programme

The programme is arranged in the following manner. Since we have to simulate between 1 and 20, or 2 and 40 machines, the main programme is used as a subroutine. Instead of distribution data, real function is used for the respective distribution. Therefore, everytime a random number is selected, it goes through the function and calculates the cumulative distribution for arrival time or service time. For selecting the random numbers, two routines, RANDO and RANDY, are used.

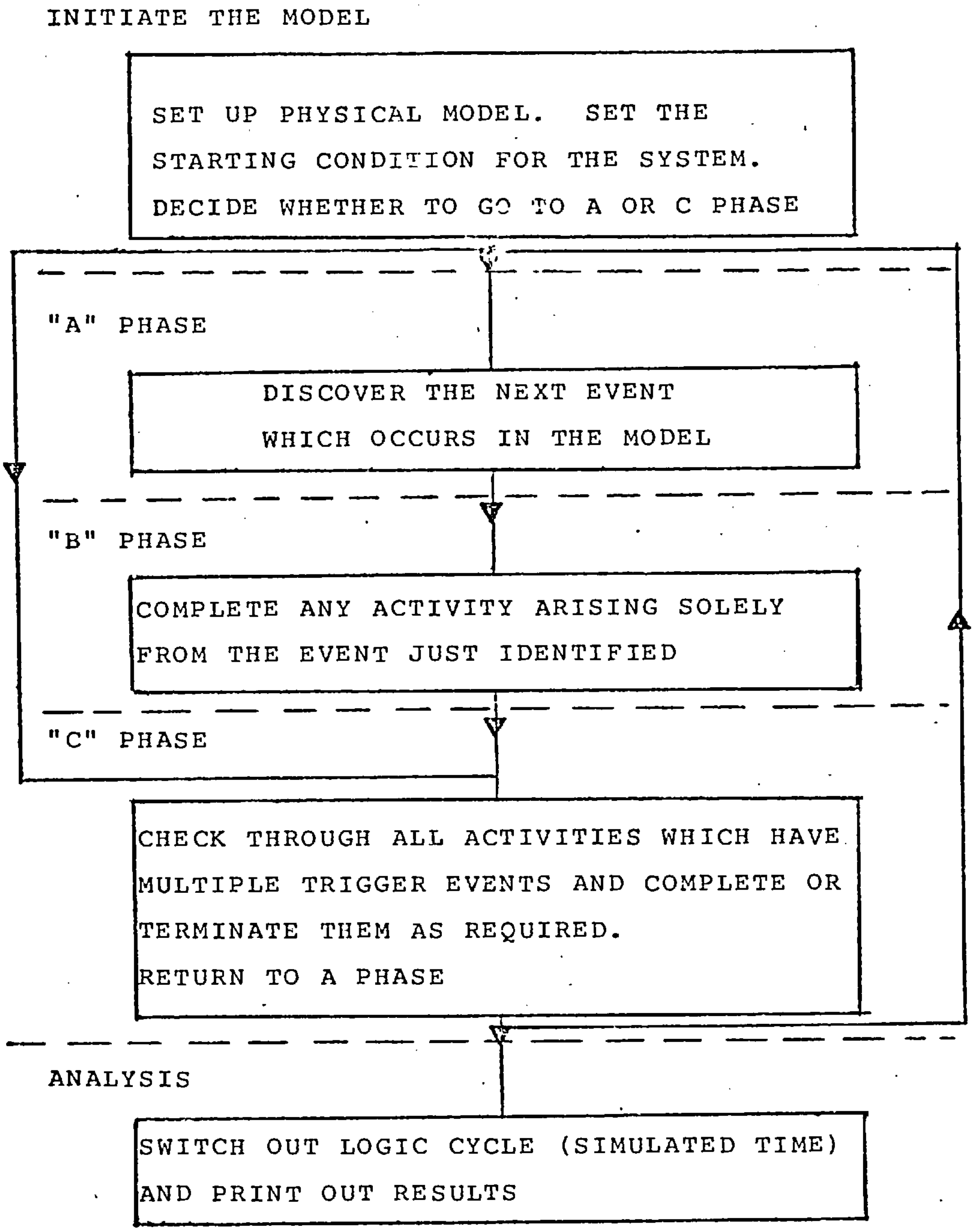

INITIATE THE MODEL
SET UP PHYSICAL MODEL. SET THE STARTING CONDITION FOR THE SYSTEM. DECIDE WHETHER TO GO TO A OR C PHASE
"A" PHASE
DISCOVER THE NEXT EVENT WHICH OCCURS IN THE MODEL
"B" PHASE
COMPLETE ANY ACTIVITY ARISING SOLELY FROM THE EVENT JUST IDENTIFIED
"C" PHASE
CHECK THROUGH ALL ACTIVITIES WHICH HAVE MULTIPLE TRIGGER EVENTS AND COMPLETE OR TERMINATE THEM AS REQUIRED.
RETURN TO A PHASE
ANALYSIS
SWITCH OUT LOGIC CYCLE (SIMULATED TIME) AND PRINT OUT RESULTS

FIG. 5.1

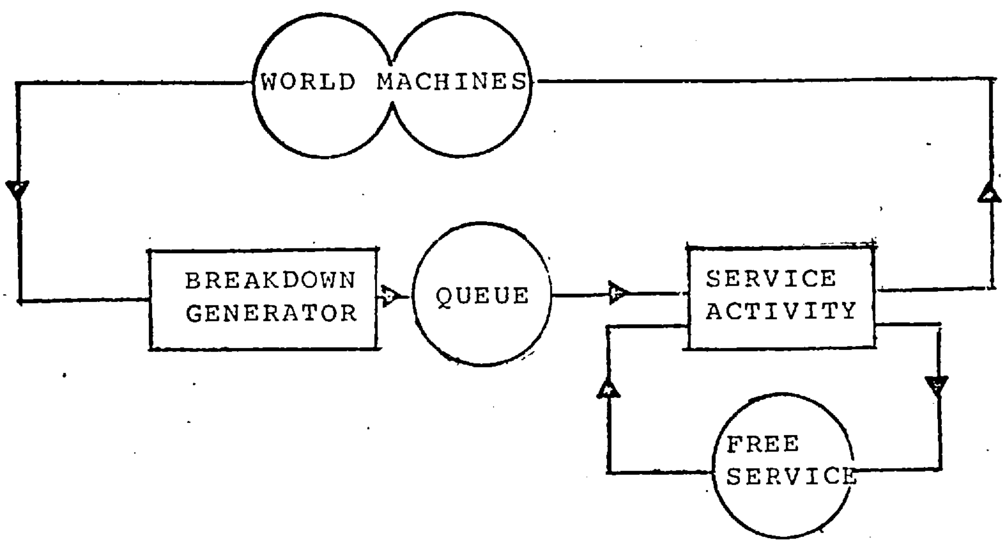

WORLD
MACHINES
BREAKDOWN GENERATOR
QUEUE
SERVICE ACTIVITY
FREE SERVICE

FIG. 5.2

b) Machine breakdown pattern

Only one breakdown pattern is built into the programme (i.e. random breakdown with mean rate λ machines per time unit). The pattern is generated by a random numbers generator and takes the form of a negative exponential distribution.

c) Constant arrival and service time

Constant time is specified for the regular arrival of the machine or the service operation in "B" phase.

d) Normal service time

The mean servicing rate and coefficient of variation factor are specified. The factor, coefficient of variation, does not exceed 0.3μ. The value of the coefficient of variation is changed in the following order 0.1μ, 0.2μ and 0.3μ. Calculation of normal service time is built into the programme as a real function. Actual service time is selected from the random numbers.

e) Erlangian service time

At first, Newton's method of finding out the root is used. But it works only when the number of phases is very small. At higher values, it failed, because tangents could not meet and always diverged. So the programme has been changed in such a way that the roots could be searched after fixing the boundaries.

The curve is divided into a hundred equal parts and the root is searched in each part. Once the approximate position of the root is established in one of the parts, which is further divided into a hundred equal parts, then the exact position of the root is searched and located. Even though the process is slow and longer computation time is involved, it is a reasonably accurate method. The programme is divided into four real functions, as shown in Appendix IV.

f) Method of operation

Having read the input data, the programme prints it out, so that the results are easily identifiable.

After all the appropriate record keeping devices have been set up, the simulation proper can begin. The programme has a three phase structure, common to all SIMON simulation. The "A" phase controls the advancement of time in the programme. The entities that cause a change in time are:

(i) the breakdown of the machines in the system;

(ii) the completion of service on a machine;

(iii) printing of operation details such as 'a machine breaks down', ' a service ends at', 'queue and free service', etc.

The "B" phase is essentially for record keeping and data generating, and can only be reached from the "A" phase. In entity (i), the data for the machine is generated and then the machine is placed in the service queue.

If the service has been completed, the records of the job are computed and added to the record keeping files. The programme continues to cycle through "A" and "B", until all have been processed.

The actual simulation proper is done in the "C" phase (initially the programme can start from the "C" phase, then it will follow the regular sequence). This largely consists of a search for a breakdown machine, and a serviceman for the service to start, otherwise the sequence of operation goes again to the "A" phase.

g) Output from the programme

The printout of the results of the simulation is always of a standard form and is designed to be easily readable by anyone familiar with this field of work.

The order of the output is as follows:

(i) A machine breaks at,

(ii) A service ends at,

(iii) Queue,

(iv) Free Serviceman.

The above information or messages can be called from any time units. For example, if the simulation time is, say, 100,000 time units, and if we want the above messages from, say, 99,900 time units, then it will start printing from that time to simulated time. The reason for knowing this information is, if, for example, at the end of simulated time, say, three or ten machines are waiting in the queue to be serviced, we may know exactly at what time the machines are broken and waiting for service. This factor can be taken into account in the final calculations. Of course, if we run the simulation for a longer time, the values will be very negligible and can be eliminated. Nevertheless, it is better to know the position.

The following information is given by the histograms of distribution of waiting times and distribution of service times: mean, standard deviation, frequency (ranges), and number of entries.

h) Calculation of the output

All the required data are obtained from the output. The relevant calculations are done and are shown in the next chapter.

i) Walking time

Two separate programmes were run for walking time models. In the first model, walking time is not added to servicing time distribution, but it has been recorded separately. The reason for this is that different time units could be used. For example, if service time is in minutes and walking time is in seconds, then it is better to calculate separately and find out the percentage of time taken away from the total service time. In the second model, the walking time is added to the service time and then the distribution of the service time is calculated. Also, the programme prints out the walking time separately.

The scale of the histograms can be changed, according to the number of machines, and the ratio between calling rate and servicing rate.

j) Programme performance

The computer time required for any simulation is largely determined by the number of operations that have to be processed, and by the complexity of different types of the distribution. For example, if the number of machines is increased and the number of phases is also increased (Erlang distribution), the total time taken to run the programme for 1 to 20 machines, in steps of 1, is approximately 50 minutes in the C.D.C. 6400 computer.

5.5 Programme Testing and Experimental Design

The testing of a simulation programme does not, in itself, contribute anything towards a great understanding of machine interference behaviour. However, it is a vitally important and lengthy task, which must be completed successfully before the programme can be put into useful work. Consequently, it is not unreasonable as an experiment in its own right.

According to Conway (7), there are three phases, in an investigation by simulation, that take place after the problem has been identified and a model formulated.

(i) Model implementation - description in a language acceptable to the appropriate computer.

(ii) Strategic planning - design of an experiment that will yield the desired information.

(iii) Tactical planning - determination of how each of the test runs, specified in the experimental design, is to be executed.

In the past, the process has been completely dominated by phase (i) and phase (ii). Phase (iii) is probably less important than (i) or (ii), but is still significant. In general, phase (iii) involves questions of efficiency of execution.

The main programme of our models has been tested with the theoretical results achieved by Fetter (16), Palm (38) & King (20,21). King has given results up to six collaborating men - see Appendix 1. The results more or less agreed with the known theoretical results. Trial runs were also made for shorter times, providing a reasonable initial check. Initially, the mean breakdown value was kept very high. It was found that numerical results of simulations tended to be either slightly on the low side or high side, but this could be accounted for by the rounding of errors, due to integer programming.

Where it was thought necessary, several simulations were performed, using the various values for the mean. The best values were selected, so that the results more or less agreed with the theoretical results.

At no stage in these tests were any serious difficulties encountered concerning the logic of the simulation programme. However, many weeks were lost in ironing out programming problems. More than 2,500 jobs were simulated.

CHAPTER 6

MODELS AND EXPERIMENTS

6.1 Introduction

In many industrial processes, an operator attends to a number of machines which stop from time to time. Whenever a machine stops, the operator has to do a certain amount of repair service before it can be restarted. If, at any time, two or more machines stop simultaneously, there will be a loss of production due to the period the machines have to wait for service by the operator. The problem of interference has been considered previously by a number of authors like Ashcroft (1), Benson and Cox (3), Fetter (16), Khintchine (19), Mack (28), Palm (38), Naor (33,34), and others who have given solutions to the problem of a general distribution of the clearing time per stoppage on the assumption that the operator is always available. The problem has been solved for an exponential distribution of arrival and service times by Palm (38). King (21) has worked out machine utilisation factors from one to six operative men, using Palm's model.

6.2 The Reason For Experimentation and Testing

According to Lloyd and Lipow (25), a test has been defined as "a subjection to conditions that show the real character of the thing". However, testing is no unique operation performed at a specific point in the development of a complex system, but is a continuing operation to provide information throughout the complete evolution of the system.

The design and analysis of the model- as it is frequently referred to in statistical literature - utilises the philosophy of the scientific method with one major addition. It associates a degree of assurance with any statements or hypotheses that are established from sample observations. This assurance is measured in terms of numerical probability, so that objective comparisons can be made.

Very often, instead of making a mathematical analysis of the behaviour of the queuing system under study, it is better to examine the process by reconstructing its behaviour using arrival times, service times, etc., derived from random numbers. This approach is particularly useful when the process is complicated, such that the mathematical solution is likely to be difficult or impossible and especially when the behaviour is required under very special and clearly defined conditions and no mathematical solution is immediately available. It is rather difficult to give a mathematical solution, particularly for most of the stochastic queuing models.

6.3 Significance of Machine Interference

Machine interference theory forms part of the general 'theory of queues'. There are essentially two main features.

(i) It deals with assemblies which contain a finite number of potential customers, such as machines breaking down from time to time and demanding service.

(ii) Attention is fixed on the average number of machines in the waiting line and on the average number of busy operators, as the determining factors in economic considerations of the assembly, fluctuations of queue size around the average are generally considered to be of no significance in these considerations and so waiting time distribution is ignored for the very same reason. All the simulation models of this work are run on the C.D.C. 6400 Computer.

6.4 Models (Normal Distribution)

In our first model, we are interested to see how far the model is sensitive to the use of normal distribution service times, instead of negative exponential service times, to the Palm (38) and Fetter (16) models.

Model 1

The following assumptions are made.

(i) All the machines are similar.

(ii) Uninterrupted working time of a machine is an exponentially distributed random variable.

(iii) Repair time of a machine by a repairman is normally distributed.

(iv) The coefficient of variation (C.V = σ_s/μ) is varied up to 3σ limit, since service time is always positive.

(v) The whole system is in statistical equilibrium. All random variables are independently distributed. (Single queue, first come first served).

Let s = service time per time unit

m = machine running time per time unit

w = waiting time per time unit

λ = calls for service per unit of machine time (expected value)

μ = machines serviced per unit of service time

k = $s/m = \lambda/\mu$ = servicing constant

C.V = $\Delta t_s/\mu = \sigma_s/\mu$ = the coefficient of variation factor

The servicing constant, k, is subject to various equivalent defintions in physical terms. The basic machine property which it describes is the ratio of λ to μ(see chapter 4).

The schematic diagram below shows the model with a single service man.

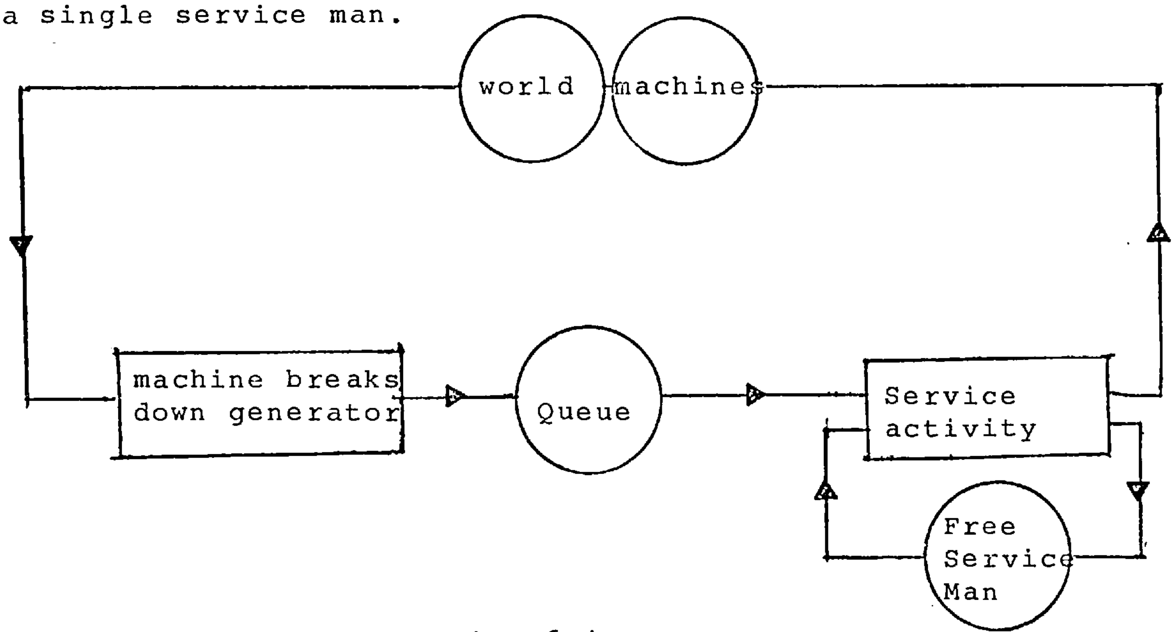


Fig. 6.1

LOGIC CYCLE

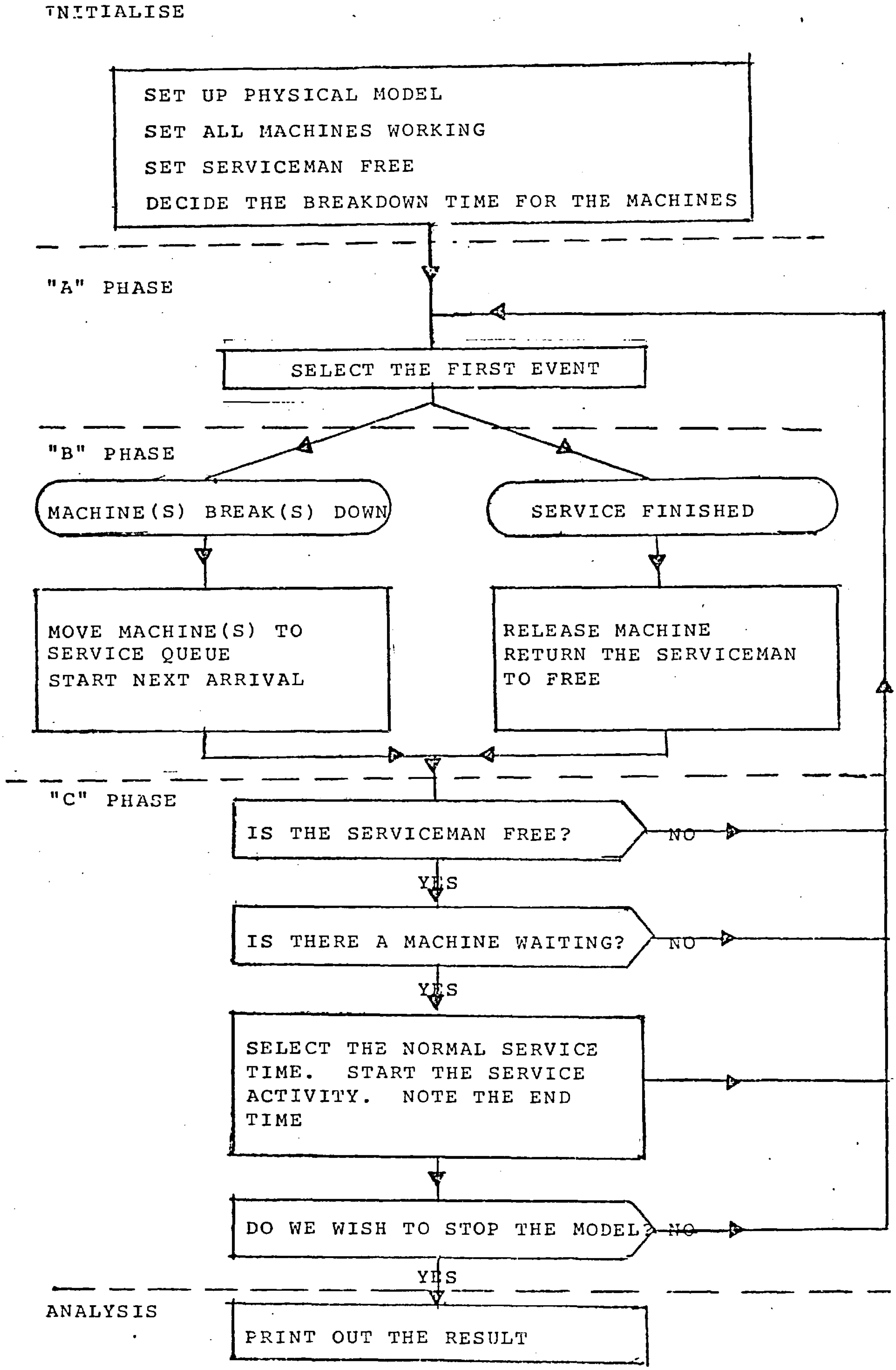


FIG. 6.2

A three phase logical cycle diagram is shown in Fig. 6.2. The programme for the above model is given in appendix IV.

Model 1

No. of machines: 1 to 20, increased in steps of 1.

No. of servicemen: 1

Distribution of breakdown times: Negative exponential times.

Designed parameter values: k is varied from 0.01 to 0.1 in steps of 0.01, and from 0.1 to 0.3 in steps of 0.1.
C.V is varied from 0.1 to 0.3 in steps of 0.1.

Simulation time: 100,000 time units.

Machine utilisation factor, waiting time and service utilisation are given in Appendix I. Curves for m, w percentage differences and service time distribution are shown in Appendix II.

Model 2

The following assumptions are made.

(i) All the machines are similar as to the average number of breakdowns which each experiences in its unit working time.

(ii) All repairmen are similar both in work and efficiency and they collaborate with each other.

(iii) Uninterrupted working time of a machine is an exponentially distributed random variable.

(iv) Repair time of a machine by repairman is normally distributed time.

(v) The system (both machines and repairmen) is in a state of equilibrium.

(vi) All broken down machines form a single queue and are being dealt with by available repairmen in the same order in which they arrived (first come first served).

The Entity-Activity Chart and Logic-Cycle are the same as shown in Figs. 6.1 and 6.2.

Model 2

No. of machines: 1 to 40 increased in steps of 2 from 2 (minimum).

No. of servicemen: 2 (Collaborating servicemen)

Distribution of breakdown times: Negative exponential times.

Distribution of expected service times: Normal times.

Duration of simulation time: 100,000 time units.

Designed parameter values: k is varied from 0.01 to 0.1 in steps of 0.01 and from 0.1 to 0.3 in steps of 0.1.
C.V. is varied from 0.1 to 0.3 in steps of 0.1

Simulation time: 100,00 time units.

Machine utilisation factor waiting time, service utilisation and curves for m, w and percentage differences are given in Appendices I and II.

6.5 Erlang Distribution Model

Erlang distribution provides a family of service time distributions which range all the way from the pure random exponential type to completely regular constant service time situation. They will fit many of the ones encountered in practice. So they can be used as a general distribution function.

An attempt to build a finite queuing model soon runs into difficulties. First breakdown of the machines is negative exponential and the service distribution is Erlangian. Considering the above factors, it appears that mathematical analysis of such a queuing model is not possible until considerable advances in queuing theory emerge. Even though a mathematical solution of the multi-machine maintenance model is not correctly feasible, it is quite possible to simulate this system. A simulation may serve two useful purposes: 1) it can be used as an operational tool to develop optimal maintenance periods and new sizes for specific cases, and 2) as a research vehicle.

Model 3

The following assumptions are made:

(i) All the machines are similar as to the average number of breakdowns which each experiences in its unit working time.

(ii) Machine stoppages occur as independent random events and may be assumed to follow a Poisson process (i.e. time between stoppages is negative exponentially distributed).

(iii) Repair time of machine by repairman is Erlang distribution.

(iv) The value of K (phases) is changed.

(v) The whole system is in statistical equilibrium. All random variables independently distributed. Single queue, first come first served.

The schematic diagram and logical cycle are shown in Figs. 6.3 and 6.4. The programme for the above model is given in Appendix IV.

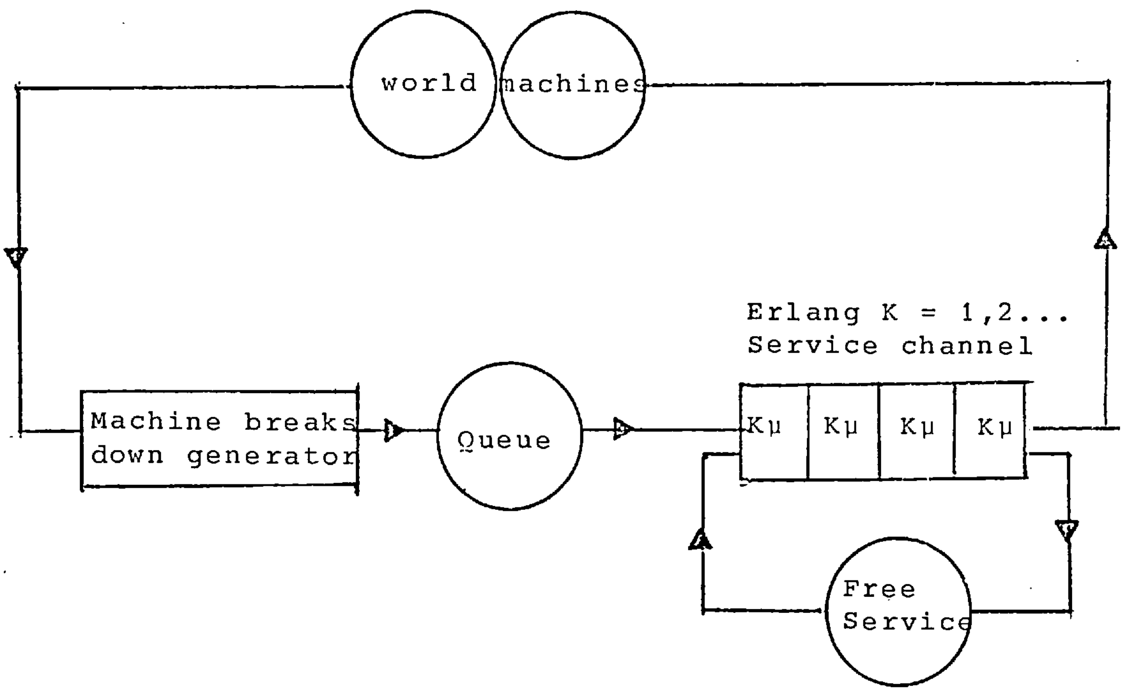


Fig. 6.3

LOGIC CYCLE

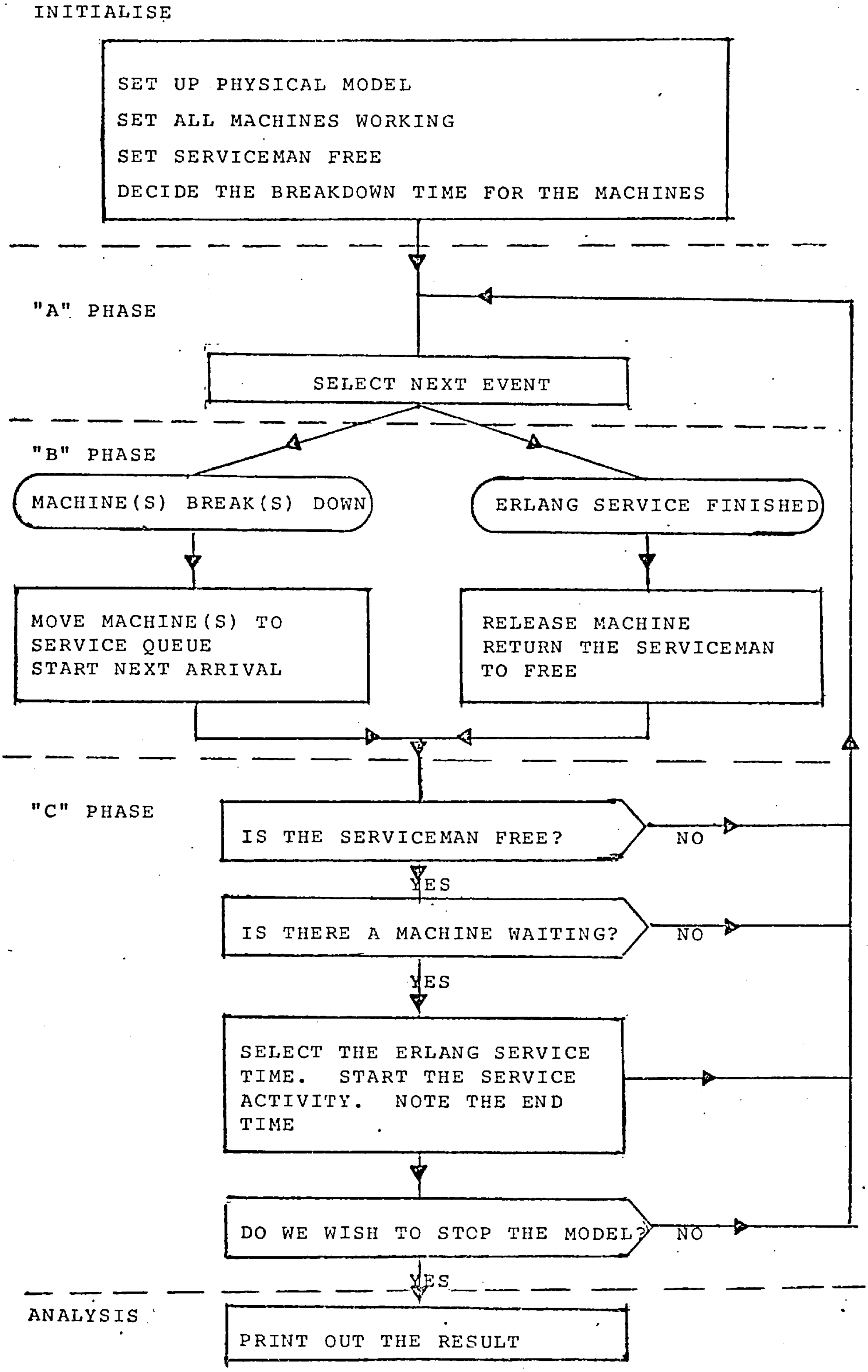


FIG. 6.4

Model 3

No. of machines: 1 to 20 increased in steps of 1.

No. of servicemen: 1

Distribution of breakdown times: Negative exponential times.

Distribution of expected service times: Erlangian times.

Duration of simulation time: 100,000 time units.

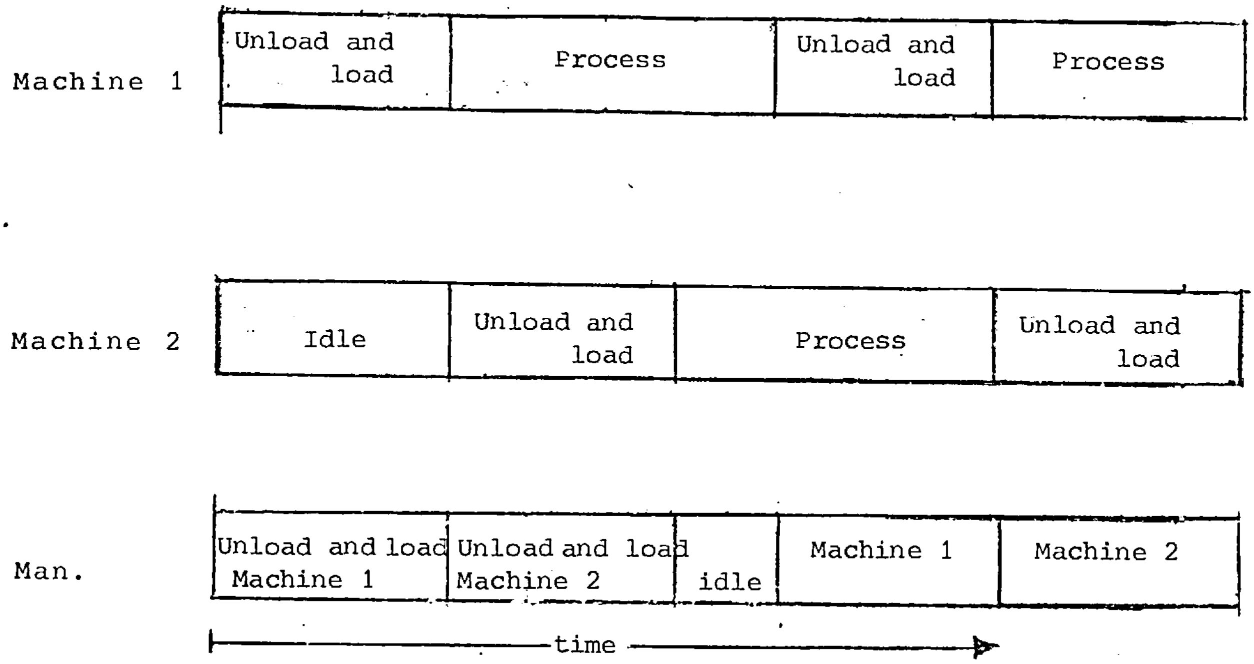
Designed parameter values: The ratio between calling rate and servicing rate is changed from 0.01 to 0.1 in steps of 0.01 and from 0.1 to 0.3 in steps of 0.1.

Stages (phases): No. of stages are taken into account 1, 2, 4, 8, 16.

Machine utilisation factor, waiting time factor and service utilisation are shown in Appendix I. Curves for m, w percentage differences and service time distribution are shown in Appendix II.

6.6 Semi-Automatic Machines

Many machine tools are classed as semi-automatic, in that although they are capable of performing a programmed process without supervision, they require manual assistance in loading and unloading of materials. Since the operator does not have to be constantly in attendance, the possibility of servicing more than one machine arises immediately. Man-machine arrangements have been handled by means of a "man-machine" chart, as shown in Fig. 6.5.



Man Machine Chart

Fig. 6.5

Realistically speaking, neither the unload-load time, nor the running time is a constant, and particularly the variability of the unload-load time can render a deterministically planned man-machine arrangement completely unfeasible.

The activities considered here are:

(i) Combined activity,

and (ii) Independent activity.

The combined activity (unload-load time) is split into a chance variable, plus a constant.

Model 4

The following assumptions are made for the simulation model.

LOGIC CYCLE

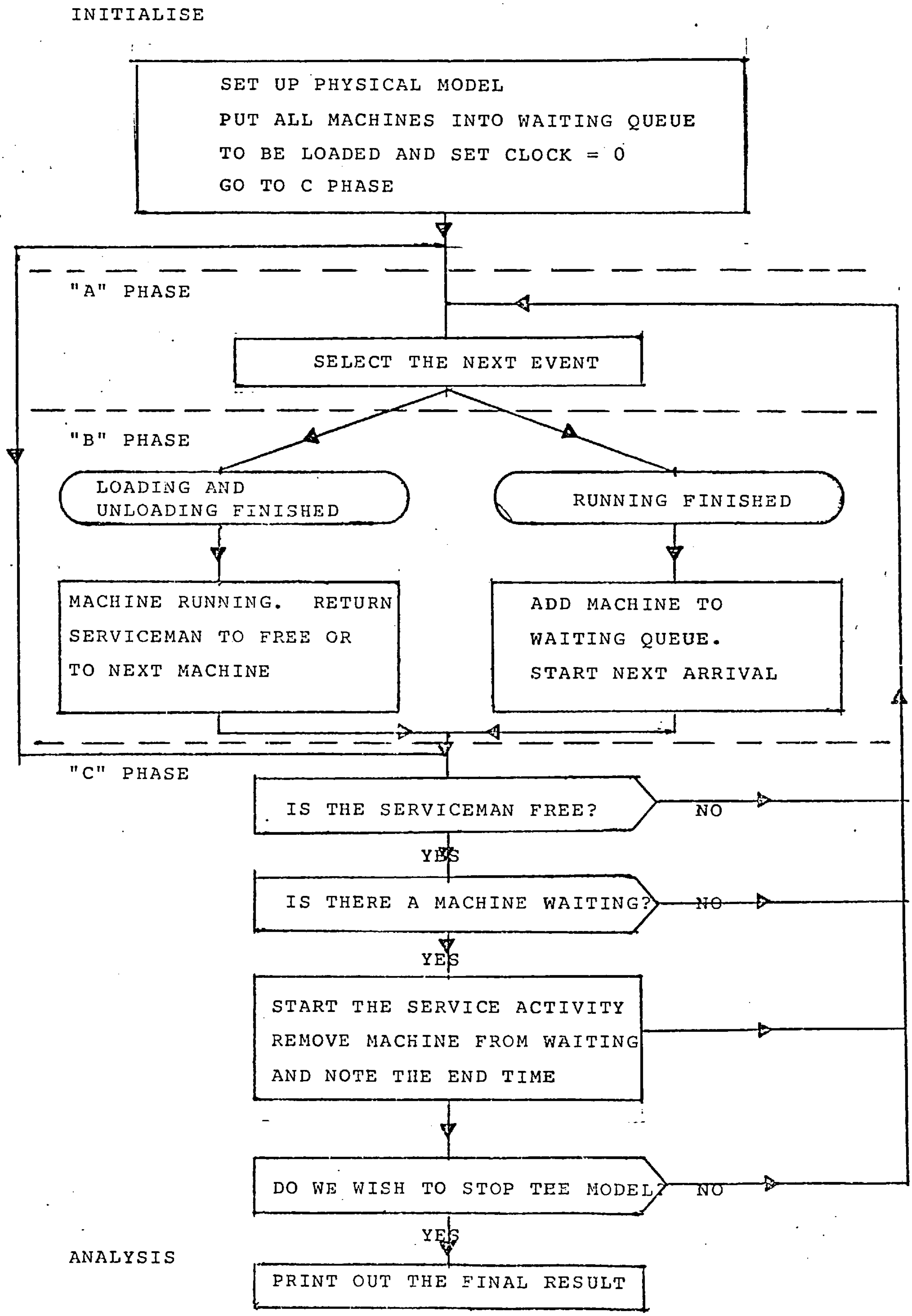


FIG. 6.6

(i) Initially all machines are waiting in a queue to be loaded and unloaded.

(ii) All machines are semi-automatic with constant running time.

(iii) Combined activity time (loading and unloading) is constant.

(iv) Independent activity time-operator (cleaning, inspection and walking to next machine) is constant.

(v) All the time the serviceman is available if he is not engaged.

(vi) Service is done on cyclic queue basis.

A three phase diagram is shown in Fig. 6.6. The computer programme for a single serviceman is given in Appendix IV.

Model 4

No. of machines: 1 to 20 increased in steps of 1.

No. of servicemen: 1

Distribution of running time: Constant.

Loading and unloading time: Constant.

Independent activity time: Constant.

Let a be the combined activity time.

Let b be the independent activity time.

Let t be the running time of the machine.

Let R be the ratio between (a+b) and t.

i.e. $$R = \frac{a + b}{t}$$

and $$H = \frac{b}{a}$$

Since the model is insensitive to changing the ratio b/a, so the value is kept as 0.5, whereas R is increased from 0.1 to 1, in steps of 0.1.

Simulation time: 100,000 time units.

The cycle factor, machine idle factor, operator idle factor and service factor are calculated in the following way.

$$\text{Cycle time } \tau = a + t + i_m = (a + b)n + i_o \quad (6.1)$$

∴ dividing the equation by the running time t

$$\frac{\tau}{t} = \frac{a}{t} + 1 + \frac{i_m}{t} = \frac{(a+b)n}{t} + \frac{i_o}{t}$$

∴ cycle factor = τ/t (6.2)

$$\text{Machine idle factor} = \frac{i_m}{t} \quad (6.3)$$

$$\text{Operator idle factor} = \frac{i_o}{t} \quad (6.4)$$

and

$$\text{Service factor} = \frac{(a+b)n}{t} \quad (6.5)$$

The above factors are given in Appendix I. The curves for cycle factor are shown in Figs. 33 and 34 (Appendix II).

Model 5

The assumptions are the same as for model 4, except that the combined activity time is negative exponential distribution. Results are shown in ppendix I.

Model 6

The following assumptions are made.

(i) Initially all machines are waiting in a queue to be loaded and unloaded.

(ii) All machines are semi-automatic with constant running time.

(iii) Combined activity time (loading and unloading) is a chance variable plus a constant.

(iv) Independent activity time-operator (cleaning, inspection and walking to next machine) is constant.

(v) Service is done on cyclic queue basis.

Model 6

No. of machines: 1 to 20, increased in steps of 1.

No. of servicemen: 1

Distribution of running time: Constant.

Loading and unloading time: A chance variable plus a constant.

Independent activity time: Constant.

Let a be the combined activity time.

Let μ be the chance variable mean.

Let c be the constant.

Let b be the independent activity time.

Let t be the running time of the machine.

$\therefore\ a = \mu + c$

μ and c are varied in proportion as shown below.

μ	c
80%a	20%a
60%a	40%a
40%a	60%a
20%a	80%a

R is increased from 0.1 to 1 in steps of 0.1 and the value of H is kept as 0.5.

Simulation running time for each model: 100,000 time units.

Cycle factor, machine idle factor, operator idle factor, service factor and percentage differences are given in Appendix 1. Service time distribution and percentage difference curves are shown in Appendix II.

Model 7

In certain cases, there may be a group of machines each differing from the other in respect of mean arrival time or mean servicing time. A simulation model has been developed which may be useful for practical purposes to evaluate the job shop conditions. The programme can work for any mean values of the same distribution.

The following assumptions are made:

(i) The machines are grouped according to their characteristics like mean breakdown and mean arrival.

(ii) Initially all machines are waiting to be loaded and unloaded.

(iii) All machines are semi-automatic with constant running time. Of course constant running time may vary according to the group.

(iv) Negative exponential service time with initial constant c.

(v) All the time the serviceman is available if he is not engaged.

(vi) A group may contain 1, 2 or 3 machines. There may be two or three groups.

LOGIC CYCLE

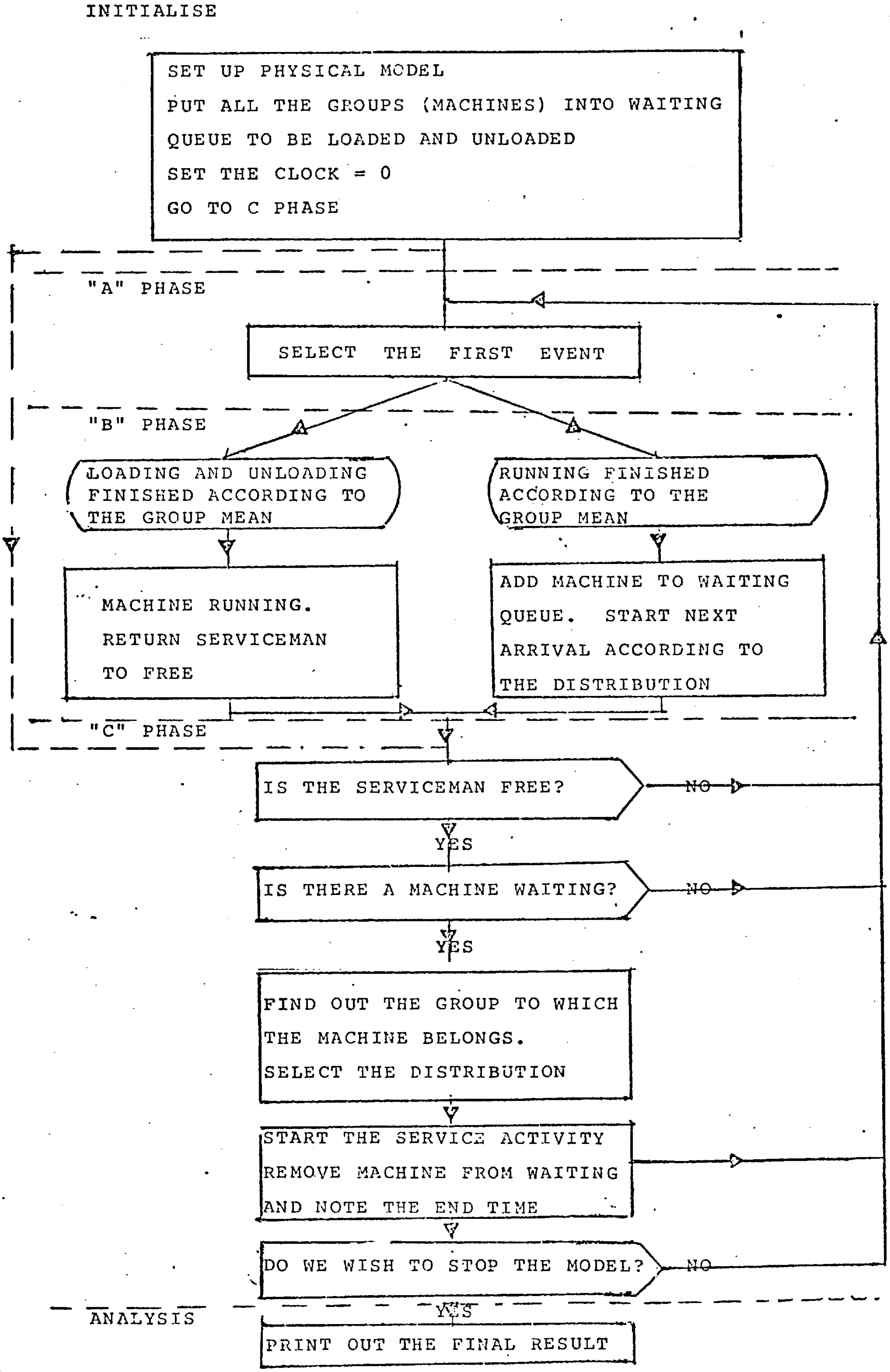


FIG. 6.7

The three phase diagram is shown in Fig. 6.7.

Model 7

No. of machines: 6

No. of groups: 3 - Each group consists of 2 machines.

No. of servicemen: 1

Distribution of arrival time: Constant arrival time. It is different for each group.

Distribution of expected loading time and unloading time:

Negative exponential times with initial constant c. Each group mean is different even though the distributions are negative exponential. The value of the initial constant is 25% of mean service time.

Simulation running time: 100,000 time units.

The ratio between calling rate and servicing rate for each group is given below:

Group 1	k = 0.01
Group 2	k = 0.02
Group 3	k = 0.03

The computer programme is shown in Appendix IV.

Two Servicemen Model

Model 8

No. of machines: 6

No. of groups: 3

No. of servicemen: 2

Distribution of arrival time: Constant arrival time. It is different for each group.

Distribution of expected loading time and unloading time:

Negative exponential times with initial constant c. Each group mean is different even though the distributions are negative exponential . The value of the initial constant is 25% of mean service time.

Simulation running time: 100,000 time units.

Computer programme of the above model is given in Appendix IV.

The ratio between calling rate and servicing rate for each group is given below:

Group 1 k = 0.01

Group 2 k = 0.02

Group 3 k = 0.03

6.7 Walking Time and Plant Layout

The immediate availability of the serviceman has been considered hitherto. The transit time has not been taken into account. The transit time is defined as the time it takes for a worker to move from one machine to another machine which requires servicing. Palm (38) has considered the transit time for a simple case. According to him the transit time can be considered as being of the form c + ed, where d is the distance the worker has to go. The constant c, which is independent of d, is the time the worker needs to finish the old jobs and start the new. Even the constant e must be determined by time studies, as it is dependent on which tools have to be moved between the machines and also, perhaps, on the practicability of moving the tools. In our case we assume that the serviceman always carries necessary tools to repair the machines. So we eliminate the constant "e" for simulation purposes. This elimination will not affect the layout performance. Not only are we interested in the total walking time of the existing layout but also of the layout of the machines which gives the minimum walking time. For more complicated layout, it is rather difficult to give mathematical proof. Instead, the simulation techniques will be useful. According to Barnes (2) and Maynard, Stegemerten and Schwab (27), the average man takes 1.75 to 2.5 seconds to walk ten feet. The average time for walking ten feet has been taken as 2 seconds for our models.

The following assumptions are made for the models 9, 10, 11 and 12.

(i) All the machines are similar as to the average number of breakdowns which each experiences in its unit working time.

(ii) Uninterrupted working time of a machine is an exponentially distributed random variable.

(iii) Repair time of a machine by repairmen is negative exponentially distributed.

(iv) The distance between each machine is constant.

(v) The worker moves only at right angles to the rows of machines.

(vi) If a machine breaks down while the serviceman is attending another machine, he will go to that machine straight away without going to the rest place.

(vii) After servicing a machine, he returns back to his resting place, if there is no machine waiting in the queue for service. But, while walking towards his resting place, if a machine breaks down then he will not go to that machine directly, but will go to the resting place instead, and from there he will go to the respective machine.

A three phase diagram is shown in Fig. 6.8.

<u>Models 9, 10, 11 and 12</u>

No. of machines: 20

No. of servicemen: 1

Distribution of arrival time: Negative exponential times.

Distribution of service time: Negative exponential times.

Walking time: 2 seconds per 10 feet. Programmes are included in the main programmes for generating walking time matrices.

k is varied from 0.01 to 0.1 in steps of 0.01 and from 0.1 to 0.3 in steps of 0.1.

Simulation running time: 100,000 time units.

Four different layouts are tried and they are shown in Figs. 6.9-6.12.

The results are given in Table 92.

The computer programmes are shown in Appendix IV.

<u>Models 13, 14, 15 and 16</u>

The assumptions are the same as the models 9, 10

11 and 12. Only the parameters are changed.

Models 13, 14, 15 and 16

No. of machines: 40

No. of servicemen: 2

Distribution of arrival time: Negative exponential times.

Distribution of service time: Negative exponential times for both the operators.

Walking time: 2 seconds per 10 feet. Programmes are included in the main programmes for generating walking time matrices.

k is varied from 0.01 to 0.1 in steps of 0.01 and from 0.1 to 0.3 in steps of 0.1.

Simulation running time: 100,000 time units.

Four different layouts are tried. They are the same as in models 9, 10, 11 and 12, except that the number of machines is 40.

The results are shown in Table 93, Appendix 1.

The computer programmes are shown in Appendix IV.

LOGIC CYCLE

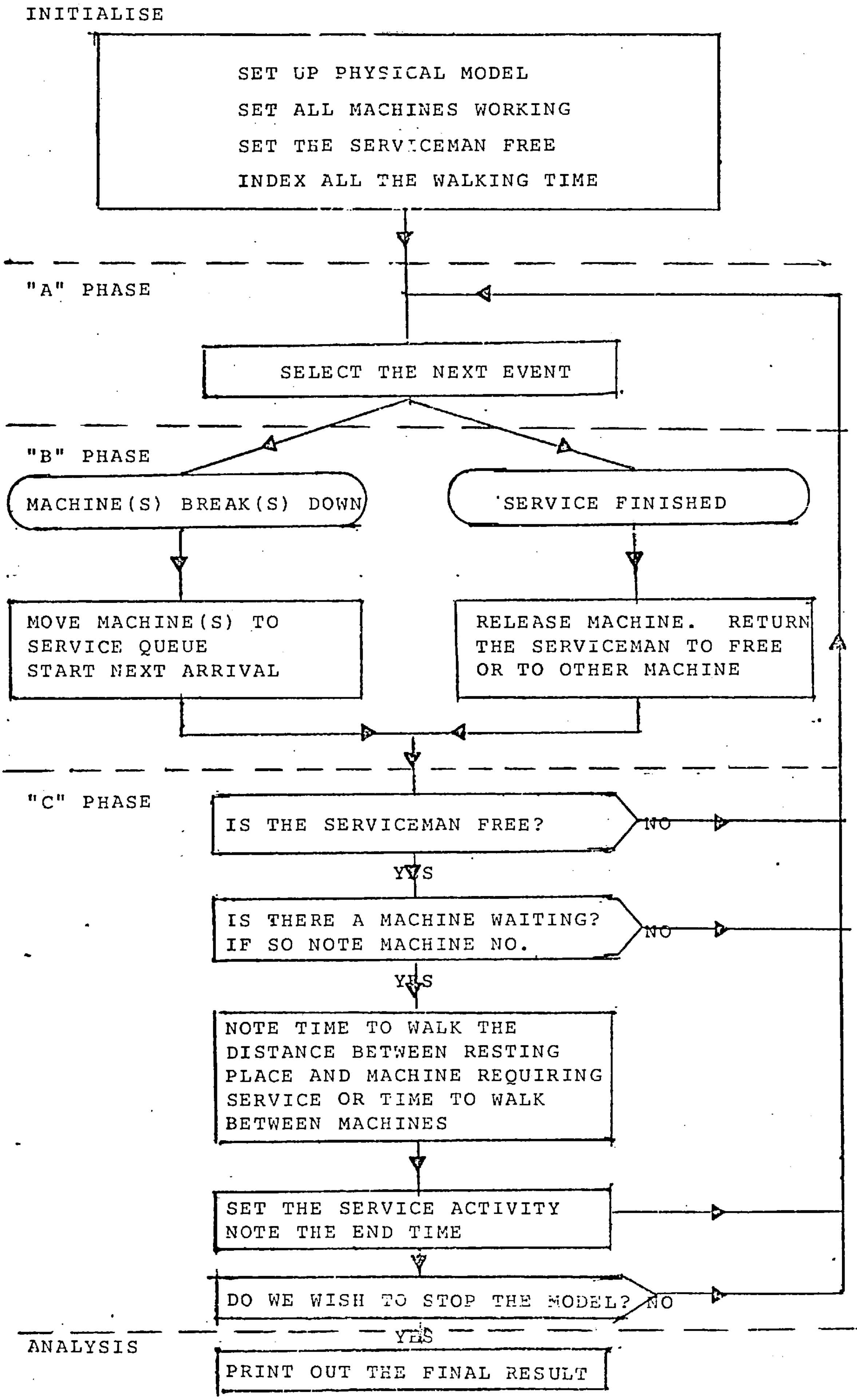
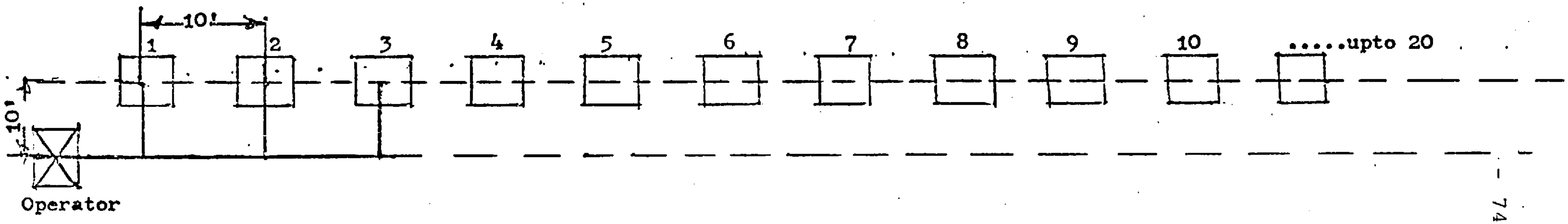


FIG. 6.8

Layout Model 9

20 Machines.



No. of rows- 1

<u>Movement:</u>

1 Resting place to machine.
Goes straight and turns 90° to machine.

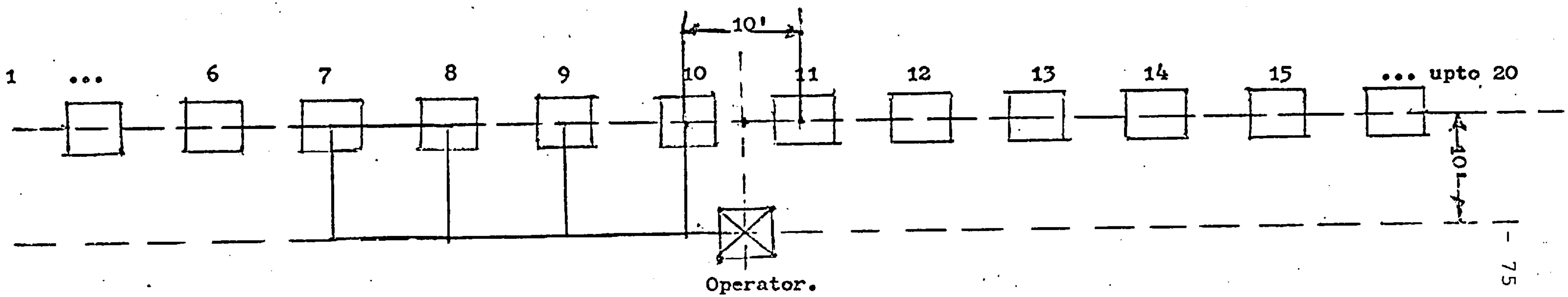
2 Machine to machine.
Case i. If machine is opposite the operator goes straight.

Case ii. If machine is not opposite then the operator comes to central line and turns right angle and walks and turns right angle to the respective machine as shown in the figure.

Fig. No. 6.9

Layout Model NO. 10

20 Machines.



The position of the operator is changed.

No. of rows- 1

<u>Movement:</u>

1 Resting place to machine.
Goes straight and turns 90° to Machine.

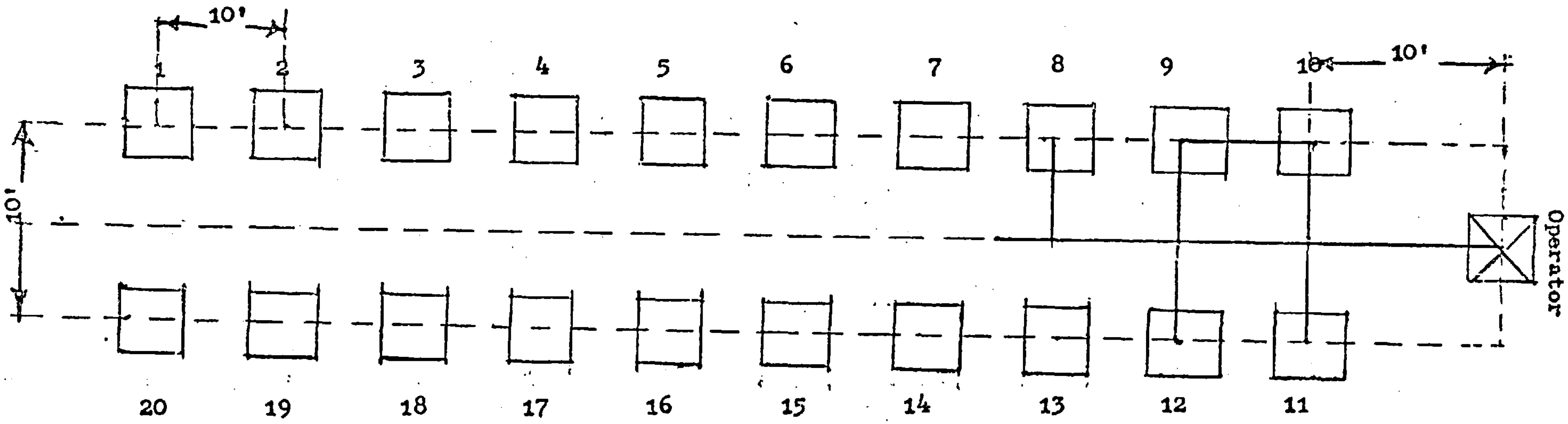
2 Machine to Machine.
Case i. If machine is opposite the operator goes straight.

Case ii. If machine is not opposite then the operator comes to central line and turns 90° and walks and turns 90° to the respective machine as shown in the figure.

Fig. No. 6.10

Layout Model No. 11

20 Machines.



No. of rows- 2

<u>Movement.</u>

1 Resting place to machine.
Goes straight and turns 90° to Machine.

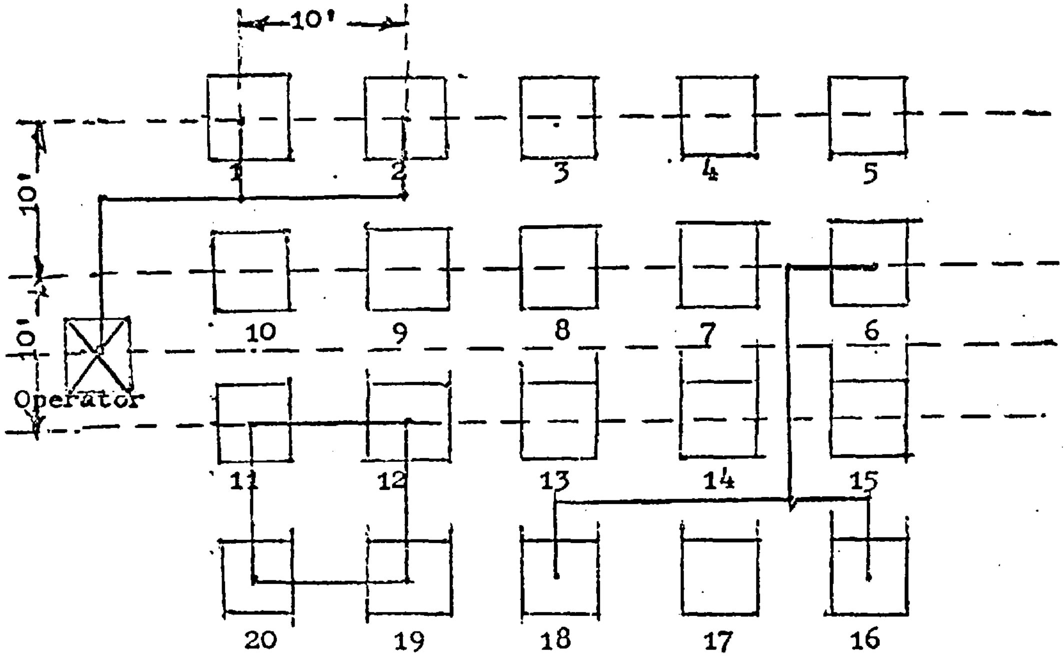
2 Machine to Machine.
Case i. If machine is opposite, the operator goes straight.

Case ii. If machine is not opposite then the operator comes to central line and turns 90° and walks and turns 90° to the respective machine as shown in the figure.

Fig. No. 6.11

Layout Model No. 12

20 Machines.



No. of rows- 4

<u>Movement.</u>

1 Resting place to machine.
Goes straight and turns 90^{o} to machine.

2 Machine to Machine.
Case i. If machine is opposite, the operator goes straight.
Case ii. If machine is not opposite then the operator comes to the central line and turns 90^{o} and walks and turns 90^{o} to the respective machine as shown in the figure.

Fig. No. 6.12

CHAPTER 7

ANALYSIS

7.1 Introduction

So far this report has concerned itself with the various distribution combinations that were used in the course of this work, and with some explanation of the nature and problems of the production shop, especially machine interference problems. It is now possible to explain in some detail the particular objective of this work, focusing our attention on the ideas that led up to each experiment. The major objective of the project is to obtain a more general understanding of machine interference behaviour using different types of distributions and compare results such as machine utilization factor or cycle time factor statistically.

7.2 General Analysis

Tests

In order to examine whether the use of service patterns different from those in Palm's and King's models has any statistically significant effect on the machine utilization factor or cycle time factor, a goodness of fit (non-parametric) test is used. This is a test of the agreement between a theoretical and sample distributions. In our case we have taken theoretical results obtained by King's (20, 21) and Palm's (36) models and compared them with the results obtained from the simulation experiments of our models. The formula for goodness of fit test is

$$\chi^2 = \Sigma \frac{(o_i - e_i)^2}{e_i}$$

where o_i is the observed value

e_i is the expected value.

The non-parametric test is used in two ways as described below:

Test 1

To keep the service constant k in the case of automatic machines or cycle time factor R in the case of semi-automatic machines constant and increase the number of machines.

Test 2

To keep the number of machines constant and increase the service constant k in the case of automatic machines or the cycle time factor R in the case of semi-automatic machines.

The null hypothesis for the above tests is that by changing the service time distribution in the case of automatic machines, the machine utilization factor does not change at 5% significance level, and in the case of semi-automatic machines the cycle time factor does not change at 5% significance level.

Apart from the goodness of fit test, comparative percentage differences between the following are calculated:

(i) Machine utilization factors of Palm's model and our models (in the case of automatic machines).

(ii) Cycle time factors of King's model and our models (in the case of semi-automatic machines).

This is in order to establish the actual variation between the models even though the above factors are not statistically different.

Automatic Machines

By using different service time distributions some models have been developed. In our first two models, the negative exponential for inter arrival between breakdown times and normal service time distributions are used. For the above models it is necessary to use the service constant as well as coefficient of variation factor. The coefficient variation factor is the ratio between standard deviation and the mean.

i.e. $$C.V = \frac{\Delta t_s}{\mu} = \frac{\sigma_s}{\mu}$$

$\Delta t_s = \sigma_s$ = Standard deviation

μ = mean

If the values of C.V and μ are given σ_s can be fixed. If the value C.V exceeds 0.3, the distribution curve is not normal and since the service time cannot be negative, the distribution curve is truncated. So the parameter C.V is always kept $\leq$ 0.3. Standard deviation is varied over 0.1μ, 0.2μ and 0.3μ. The differences between machine utilization factors for different coefficients of variation are not significant statistically. The main difference is only in the shape of service time distribution curve as shown in the summarised Table 7.1. At 0.1 the curve narrows (high peak). At 0.2 the curve expands. At 0.3 the curve expands further. The limits are stretched out and the peak is reduced as the standard deviation increases. This means that we can vary the service time by increasing the standard deviation. The following curves are drawn for different values of C.V = 0.1, 0.2 and 0.3:

(i) Machine utilization Vs Service constant

(ii) Waiting time Vs Service constant.

Generally the pattern of curves for all the three values of C.V are more or less the same.

Comparing the machine utilization factors of model 1 with Palm's model, there is no statistically significant difference. The percentage differences between them show that most of the values are on the positive side. The values lie on an average between -1 and +2 and the mean percentage difference is 1. The results are shown in the Table 7.1. Curves are drawn between percentage difference and service constant. These curves show that the percentage differences fluctuate in a random manner.

Model 2 uses forty machines and two collaborating servicemen. The non-parametric tests show that machine utilization factors of model 2 when compared to Palm's model, are not statistically significant. The percentage differences between them vary on an average -2 to +5. In general most of the values are on the positive side.

The following curves are drawn for different values of coefficient of variation:

(i) Machine utilization Vs Service constant

(ii) Waiting time Vs Service constant.

There is no appreciable change in the pattern of the above curves by changing the coefficient of variation (samples curves are given in the Fig.7.1).

By the above inference it appears that if a general distribution is used to represent all possible distributions in reality, then a comparison of results such as machine utilization factor etc. is possible for different service time distributions. In our model 3, negative exponential distribution of time between break-downs and Erlang service times are used. Since the Erlang distribution is used it is possible to change the dis-tribution curve by changing the number of phases. The service time distribution curves are shown in Table 7.1. The mean and the number of phases have been specified, since the standard deviation is the integral part (chapter 3) of the cumulative distribution, and hence it is not specified. For a constant mean and varying number of phases, the standard deviation changes as shown below:

$$\Delta t_s = \frac{1}{\sqrt{K}\ \mu}$$

If mean is 1/12 when K = 1

$$\Delta t_s = \frac{12}{1} = 12 \qquad \text{(i)}$$

When K = 2

$$\Delta t_s = \frac{12}{\sqrt{2}} = 8.48 \qquad \text{(ii)}$$

When K = 4

$$\Delta t_s = \frac{12}{2} = 6 \qquad \text{(iii)}$$

When K = 8

$$\Delta t_s = \frac{12}{\sqrt{8}} = 4.24 \qquad \text{(iv)}$$

When K = 16

$$\Delta t_s = \frac{12}{4} = 3 \qquad \text{(v)}$$

Erlang distribution provide a family of service time distributions (by changing the number of phases) which range all the way from negative exponential type to completely regular and constant service time situation. They will fit many of the ones encountered in practice. Goodness of fit tests show that machine utilization factors for different phases are not statistically significant.

When K = 1, the percentage differences show that the most of them are in the negative range. The values lie between -4% and 0%.

When K = 2, most of the values show that they are on the positive side. On an average the values lie between -3% and 4%.

When K = 4, most of the values tend to be on the positive side, lie between -4% and 3%.

When K = 8, few values lie on negative side. On an average the values vary between -3% and 3%.

When K = 16, most of the values lie on the positive side. On an average the values lie between -2% and 3%.

Utilization of machines and men

It is also useful to calculate for any specific assignment, optimal or otherwise, the machine and service utilization and also expected waiting time the machines will have to wait for service. For this purpose curves of m and w, against service constant k are drawn for the models described previously. Service utilization s has not been plotted, because it is easily calculated using the equation:

$$m + s + w = 1$$

For example, consider a case in which the number of automatic machines is 10 and they are being serviced by one operator where breakdown between machines is negative exponential, service time is normal distribution, coefficient of variation is 0.1, and service constant is 0.3, then what will be the expected utilizations?

From Table 1 (Appendix I) or from the utilization curve Fig. 2 (Appendix II)

Machine utilization, $m = 33.78\%$

Waiting time, $w = 56.22\%$

Therefore,

Service utilization, $s = 1-m-w$

$= 1-56.22-33.78$

$= 10.00\%$

Since the difference between machine utilization and waiting time factors of automatic machines of our models and theoretical models (20, 21, 36) are not statistically significant, there is no appreciable change in the pattern of the curves of m and w. So any theoretical curve of this nature can be used in determining m and w. If the service constant lies between for example 0.1 and 0.2, then either the tables can be interpolated or the results are obtained directly from the utilization curves.

Semi-automatic machines

So far we have used automatic machines for studying machine interference behaviour and the results show that the change of service time distribution does not have statistical significance on machine utilization. Therefore, in our fourth, fifth and sixth models, semi-automatic machines are used, with the following distributions:

(i) Constant running time and constant service time plus independent time.

(ii) Constant running time and variable service time plus independent time.

(iii) Constant running time and variable service time plus constant plus independent time (as shown below).

Combined Activity Time Variable + Constant = a	Independent Activity Time b (Constant)
100%a	0%a
80%a	20%a
60%a	40%a
40%a	60%a
20%a	80%a

The models are not sensitive to changing the ratio between independent time and combined activity time ($H = \frac{b}{a}$), so the value of H is kept as 0.5. The goodness of fit tests show that by changing the combined activity distribution, there is no significant change statistically in the cycle time factors for the models 4, 5 and 6. The service time distribution curves for the above models show that curve changes from negative exponential to step function (Table 7.2). The percentage difference curves show that there is wide fluctuation when the combined activity distribution is varied gradually this fluctuation localises when the variable decreases and constant increases.

Most of the percentage difference values lie on the negative side. Summarised results for the above models are shown in Table 7.2. Sample curves are shown in Fig. 7.2 for cycle time factor against R for constant running time and service time (combined activity + independent activity). For example, consider a case where five semi-automatic machines are being looked after by a service man with the following activity times:

Combined activity time (loading and unloading),

$a = 10$ time units.

Independent activity time (cleaning, inspection and walking),

$b = 5$ time units.

Running time of the machine,

$t = 150$ time units.

Then what will be the expected cycle time, idle time of the machine and the operator and service utilization?

The ratio between service time (combined activity time + independent activity time) to the running time,

$$R = \frac{a+b}{t}$$

$$= \frac{10+5}{150}$$

$$= 0.1.$$

From the Tables 38, 60 and 61 (Appendix I) the following values are obtained when R = 0.1 and the number of machines is 5.

Cycle time factor = 1.10230

Service factor = 0.500

Operator idle factor = 0.60230

Multiply these factors by the given running time, $t = 150$, to obtain the following

Cycle time, τ = 1.1023 x 150

= <u>165.34</u> time units

Machine idle

time, i_m = $\tau - a - t$

= 16.34-10-150

= <u>5.34</u> time units

Service utilization,

(a+n)n = 0.5 x 150

= <u>75</u> time units

Operator idle

time, i_o = 0.6023 x 150

= <u>90.34</u> time units

<u>Non-identical machines</u>

In the seventh and eighth models different means for breakdown and different means for service time are used. A working computer model is given so that the programme could be used to study the combined behaviour of the non-identical machines with different characteristics.

For example, if the service time distribution is negative exponential and means are different for each group of machines as follows:

1st mean 12

2nd mean 24

3rd mean 36

then the resulting overall mean for service distribution comes to 32. Computed value also comes to 31.2.

We can also use the programme to calculate machine utilization and waiting time for each group.

<u>Walking time</u>

Until now, we have not included walking time between machines and servicing centre. From models 9 to 16, walking times are calculated. The main objectives of calculating the walking time are as follows:

(i) To know the percentage time for walking by the operator during (servicing the machines) working time of the production.

(ii) To know how the percentage of walking time varies when service constant k changes, and also when the layout changes.

Consider the results given in Table 7.3. It can be seen that for a given layout the percentage of walking time decreases, as the service constant k increases, because the total number of machines serviced by the operator is reduced. For a constant number of machines the percentage of walking time changes for different layouts, being least in the layout which is likely to give the operator the shortest distance to walk between break-downs, as one would expect. For a given problem; if walking time is considered then the machine utilization factor will be reduced. As the machine utilization factor is reduced the service constant must be increased, the new service constant can be calculated by interpolating from the machine utilization factor tables (Appendix I), using the reduced machine utilization factor.

For example, consider a case where breakdown between machines and service times are negative exponential and

No. of machines = 20

Service constant k = 0.04

No. of operators = 1

Percentage of walking time = 3%

what will be the new service constant?

From Table 57 (Appendix I) for 20 machines and service constant k = 0.04 then the machine utilization factor is 0.90013. Therefore, reduced machine utilization factor

= 0.90013 x 0.97

= 0.873

then the new service constant is 0.045 (by interpolation).

A general programme which is given in Appendix IV, can be used for any type of layouts for calculating the percentage of walking time.

Our models show that when the ratio between length and breadth of the layout approaches 1, the walking time is minimal. But it is not always possible to have a square layout. It is rather difficult to analyse layout generally because of various constraints such as distance between machines, walking space, restriction in the floor space and safety regulations, etc. This is an entirely different research project which belongs to the category of location problems.

7.3 Economic Analysis

If the ratio of machine running time to operative attention time per unit of production requires an allocation of more than one machine to an operative, then machine interference arises when there are random interruptions in the machine running time. If the interruptions are random, there is a possibility of one or more machines being broken down at the same time. As the operator can deal only with one machine at a time, the other machines whose cycles have béen interrupted must wait for service.

Economic significance of interference will be appreciated as a machine allocation increases to full operative capacity, the more are machines likely to be waiting for service and the lower is the machine running efficiency. On the other hand, if the number of machines is reduced, then the machines will more often be found all running at one time and the lower will be operative efficiency owing to enforced operative idleness. Thus, within limits, machine interference gives rise to an inverse relationship between operator and machine efficiency.

7.4 Optimum Work Force Charts

Because of the high capital costs involved, the efficiency of machine supervision is a matter of importance economically. So the number of machines being looked after by an operator should be optimal. Since the results of our models such as machine utilization factor (in the case of automatic machines) and cycle time factor (in the case of semi-automatic machines) are not statistically significant when compared to Palm's and King's models and also when optimum work force charts are prepared they approximate very closely to the theoretical charts given by King. So optimum work force charts those given by King (20, 21) are used (Appendix II). Sample charts are given in Figs. 7.3 and 7.4. As an illustration of the practical use of these charts, consider the example of the following cases:

Case 1 (automatic machines)

Consider a machine shop where breakdown between machines and service time is negative exponential. The ratio between calling rate of machines for service to service rate is 0.05. The number of operator is 1. The ratio between cost of waiting of the machine to cost of operator is 5, then, how many machines can be allotted to the operator?

Service constant k = 0.05

Number of operator = 1

Cost ratio C_w/C_r = 5

From the optimum work force chart, Fig. 25 (Appendix II) the intersection point lies between 8 and 9. So the number of machines allotted to an operator is 8.

Case 2 (semi-automatic machines)

Consider a case where,

Running time of the machine, t = 150 time units

Combined activity time, a = 10 time units

Independent activity time, b = 5 time units

Cost of waiting, C_w = 40 cost units

Cost of operator, C_r = 20 cost units

then, how many machines should be allotted to the operator?

$$\text{Cost ratio } C_w/C_r = \frac{40}{20} = 2$$

$$\beta = \frac{a+t}{a+b} = \frac{10+150}{10+5} = \frac{160}{15} = 10.60$$

From chart Fig. 35, with $C_w/C_r = 2$ and $\beta = 10.60$, the optimum number of machines allotted to the operator is 10. The chart given in Appendix II is up to 20 machines.

It may not always be possible in practice to change an existing assignment of machines. The degree of deviation from the optimum solution will give some idea about the under utilization of machines or under utilization of work force.

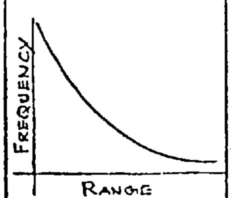
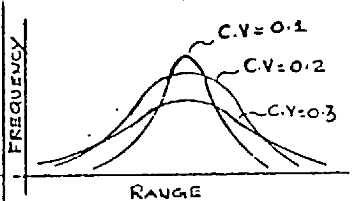
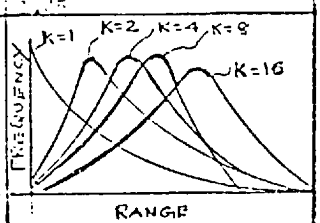
Particulars \ Models		Palm	Model 1	Model 2	Model 3
Machine Character.		Automatic	Automatic	Automatic	Automatic
No. of Machines.		20 and 40	20	40	20
No. of Servicemen.		1 and 2	1	2	1
Distribution of time between breakdowns.		Negative Exponential	Negative Exponential	Negative Exponential	Negative Exponential
Service time distribution.		Negative Exponential	Normal	Normal	Erlang
Coefficient of Variation.		-	0.1,0.2 & 0.3	0.1,0.2 & 0.3	-
No. of phases(Erlang).		-	-	-	1,2,4,8 & 16
Goodness of fit test.	Test 1		Not significant	Not significant	Not significant
	Test 2		Not significant	Not significant	Not significant
Approximate range of % age difference.	C.V=0.1	-	-2 to +2	-1 to +5	-
	C.V=0.2		-1 to +4	-1 to +5	
	C.V=0.3		-1 to +2	-2 to +5	
	Phases 1		-	-	-4 to +0
	2				-3 to +4
	4				-4 to +3
	8				-3 to +3
	16				-3 to +3
Mean % age difference.	C.V=0.1		1.06	2.13	
	C.V=0.2		0.69	2.33	
	C.V=0.3		0.79	2.10	
	Phases 1		-	-	-1.44
	2				-0.38
	4				-0.05
	8				-0.44
	16				-0.72
Std. deviation	C.V=0.1		1.57	2.63	
	C.V=0.2		1.56	2.62	
	C.V=0.3		1.33	2.52	
	Phases 1				1.88
	2				[illegible]
	4				[illegible]
	8				1.40
	16				[illegible]
Sample curves of service time distribution.					

Table 7.1 Summary of the Results for automatic machines

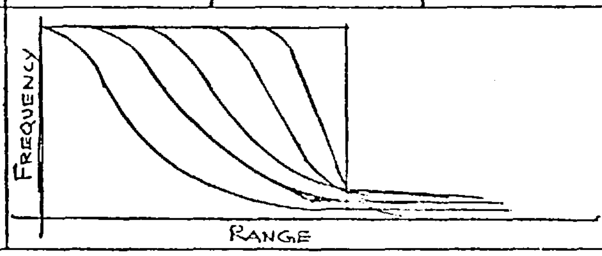
Particulars \ Models		Model 4	Model 5	Model 6
Machine Character.		Semi-automatic	Semi-automatic	Semi-automatic
No. of Machines.		20	20	20
No. of Servicemen.		1	1	1
Running time distribution.		Constant	Constant	Constant
Service time distribution. Combined activity(a) (Variable+ constant =a)	100a+ 0a		x	
	80a+ 20a			x
	60a+ 40a			x
	40a+ 60a			x
	20a+ 80a			x
	0a+100a	x		x
+Independent activity(b)		Constant	Constant	Constant
Godness of fit test.	Test 1		Not significant	Not significant
	Test 2		Not significant	Not significant
Approximate range of % age difference.	100a+ 0a		-5 to +7	
	80a+ 20a			-5 to +4
	60a+ 40a			-5 to +4
	40a+ 60a			-5 to +3
	20a+ 80a			-3 to +2
	0a+100a			
Mean % age difference.	100a+ 0a		-1.23	
	80a+ 20a			-1.93
	60a+ 40a			-2.39
	40a+ 60a			-2.71
	20a+ 80a			-2.98
	0a+100a			
Std. deviation.	100a+ 0a		4.98	
	80a+ 20a			4.11
	60a+ 40a			3.15
	40a+ 60a			2.27
	20a+ 80a			1.76
	0a+100a			
Sample curves of service time distribution.				

Table 7.2 Summary of the results for semi-automatic machines

Percentage of Walking Time.

Service Constant	Single row	Single row New Position	Two rows	Four rows
0.01	0.570	0.351	0.314	0.215
0.02	0.529	0.365	0.298	0.204
0.03	0.494	0.368	0.273	0.192
0.04	0.459	0.370	0.250	0.177
0.05	0.414	0.364	0.225	0.160
0.06	0.372	0.342	0.202	0.150
0.07	0.322	0.310	0.179	0.129
0.08	0.283	0.275	0.162	0.115
0.09	0.258	0.254	0.141	0.104
0.10	0.239	0.237	0.128	0.096
0.20	0.122	0.111	0.064	0.046
0.30	0.074	0.074	0.040	0.030

No. of servicemen. 1

No. of Machines. 20

Table 7.3 Summary of the results for percentage of walking time.

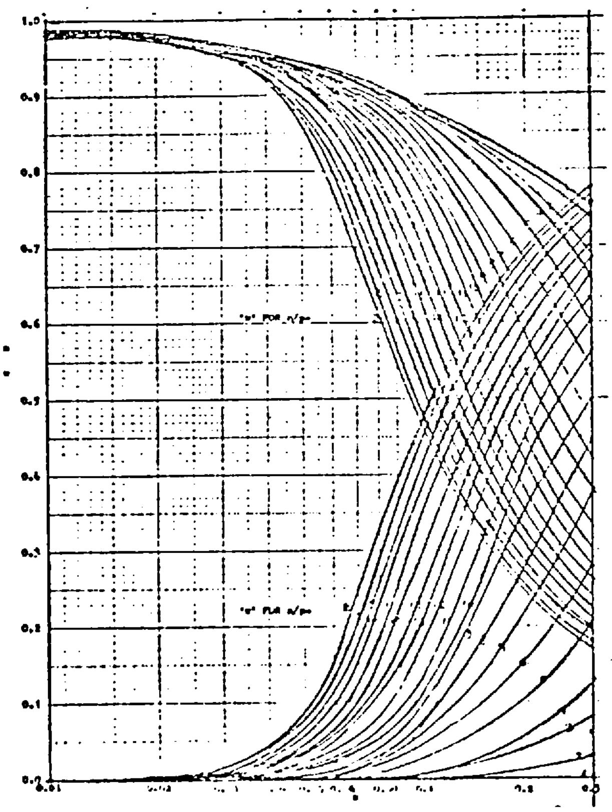


Fig. 7.1 Sample Curves for m and w

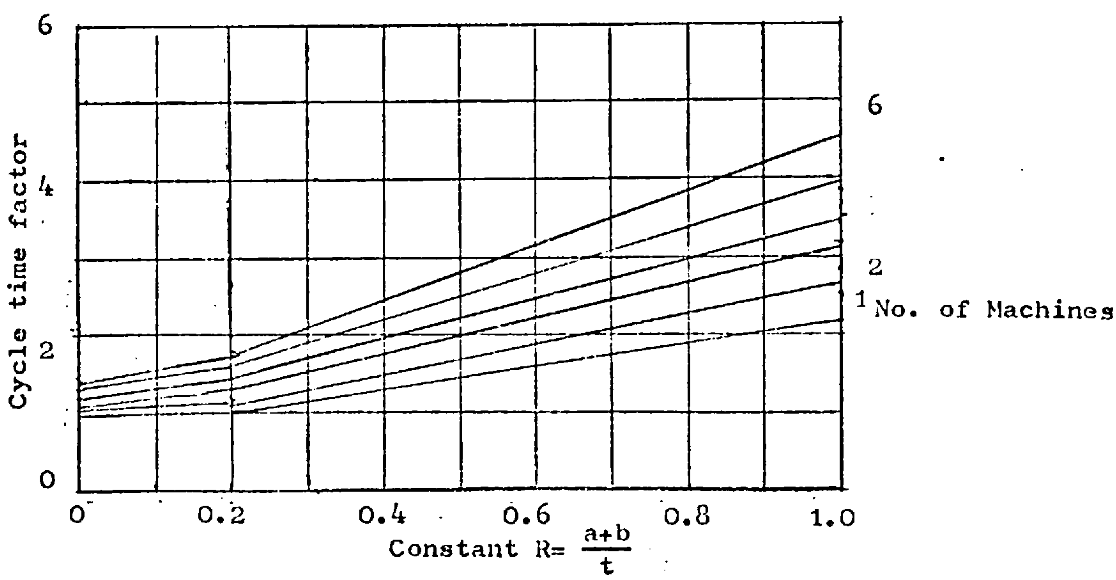


Fig 7.2 Sample curves for cycle time factor τ

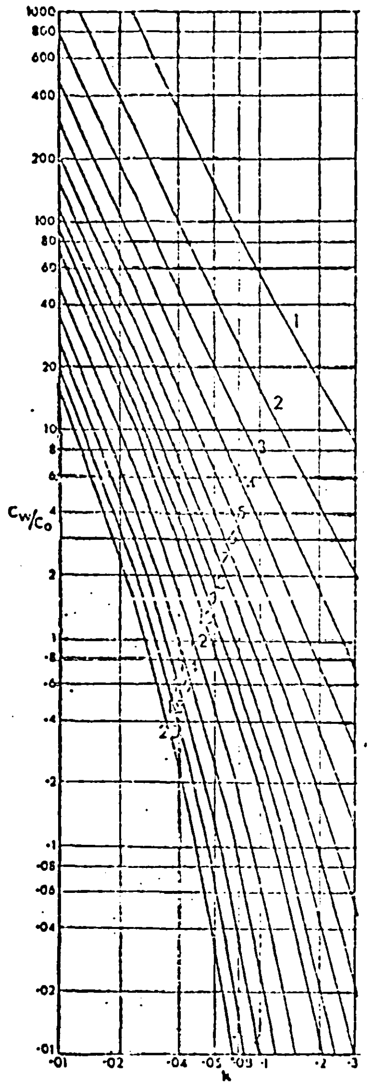


Fig. 7.3 Sample chart for determining the optimum number of machines to a single operator (Stochastic case)

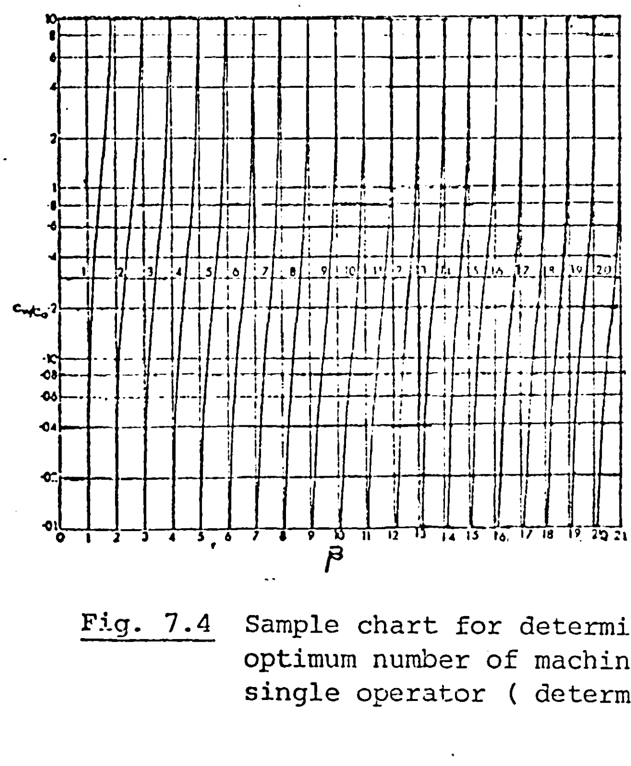


Fig. 7.4 Sample chart for determining the optimum number of machines to a single operator (determonistic case)

CHAPTER 8

CONCLUSIONS

The results from the previous chapter lead to the following conclusions. The general behaviour of machine interference (identical machines and identical servers) is not statistically sensitive to the changes in the service time distribution.

In the case of automatic machines there is no statistical difference between the machine utilization factors of different models using negative exponential, normal and Erlang service time distributions. The only difference is in the shape of the service time distribution curves. For example:

(a) in the case of a normal service time distribution, when the coefficient of variation increases, the distribution curve flattens,

(b) in the case of an Erlang service time distribution the curve moves from left to centre as the number of phases increases.

The Erlang distribution can be used to represent a wide variety of distributions. That is, by choosing the number of phases we can fit negative exponential, normal, constant or most of the distributions that may arise in practice. In this case the amount of computer time used is high and statistically the difference between the resulting machine utilization factors of the models is not significant, it is better to use a distribution such as negative exponential which takes lesser computation time. But there is a definite advantage in using the Erlang distribution for certain cases. For example, if the mean and standard deviation are different for different machines, (i.e. different in breakdown and service time distribution), the Erlang distribution can be used by choosing the number of phases to a given mean so that the required standard deviation is obtained.

Hitherto, we have discussed the machine interference behaviour of automatic machines. Let us now turn our attention to the semi-automatic machines which use constant running time and different service time as described in Chapter 7.

The variationsin cycle time factor between different models are not statistically significant. The percentage differences between cycle time factors become negative by changing the service time distribution to negative exponential. This means that the service time decreases. But when the variable decreases and constant increases (i.e. combined activity time = variable + constant), the percentage differences between cycle time factors of different models change from negative to positive and approach the value of constant service time. From the above analysis it appears that for all practical purposes the deterministic case situations can be used to calculate the following: cycle time, idle time of the machine and the operator and service utilization.

The economic assignment of machines to men can be calculated by using the optimum work force charts. Since in our models the variations in machine utilization and cycle time factors for automatic and semi-automatic machines respectively are not statistically significant, any theoretical work force charts for example those given by King (20, 21) can be used, to provide good approximate solutions.

The effect of walking time has been analysed for different layouts. An optimum solution is obtained when the ratio between length and breadth of the layout approaches 1. As far as possible, the machines should be arranged in rows so that the number of machines in each row equals the number of rows. But this is not always possible. Layout problems are generally not easy to solve. They are a particular case of the quadratic assignment problem. Up to the present time, however, the layout problem has not yet been completely solved. A general programme, given in Appendix IV, can be used for any type of layout for calculating the percentage of walking time. For a given problem; if walking time is considered, then the machine utilization factor is reduced. As the machine utilization factor is reduced the service constant must be increased, the new service constant can be calculated from machine utilization factor tables (Appendix I) or directly from the utilization curves (Appendix II), using the reduced machine utilization factor.

In the case of non-identical machines which have different breakdown and service rates as described in the previous Chapter 7, the computed results show that the service mean produced by our simulation is similar to the theoretical mean. A general programme is given which will accommodate various time distributions with specified means, since it is practically impossible to give values for all combinations.

The results of this work provide an account of the effect of various service patterns on the operation of automatic and semi-automatic machine shops. A large number of service time distributions, that are repres-entative of the practical situations, has been used in the models simulated in this work. Computer production control systems that are available to industry are mainly concerned with the monitoring of production. Computers have not yet gained wide acceptances in industry as a tool for decision making, i.e. efficient allocation of machines to operators.

After completion of this work, a research paper (10) dealing with the problem of non-identical machines to non-identical servers (servers having different servicing rates) has come to our attention. This is an interesting area of research for future investigation.

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APPENDIX I

MODEL NO.	TABLE NO.	DESCRIPTION
1	1 - 15	Negative exponential break-down and normal service times. Single operator. No. of machines: 20. C.V = 0.1, 0.2 and 0.3.
2	16 - 30	Negative exponential break-down and normal service times. Two operators. No. of machines: 40. C.V = 0.1, 0.2 and 0.3.
3	31 - 55	Negative exponential break-down and Erlang service times. Single operator. No. of machines: 20. No. of phases K = 1, 2, 4, 8 and 16.
	56 - 57	Negative exponential break-down and service times. Single operator and two operators. (King's work).
4 - 6	58 - 91	Constant running time and service time (variable + constant + independent time). Single operator. No. of machines: 20.
9 - 16	92 - 93	Percentage of walking time tables.

Table No. 1

MACHINE UTILIZATION M FOR A SINGLE SERVICEMAN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.1

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.99037	0.98155	0.97232	0.95834	0.94780	0.93734	0.92678	0.91712	0.90771	0.89866	0.81811	0.7574
2	2	0.99015	0.98020	0.97097	0.95856	0.94898	0.93917	0.92906	0.91893	0.90828	0.89833	0.80714	0.74220
3	3	0.99010	0.97954	0.97050	0.95865	0.94813	0.93764	0.92625	0.91616	0.90444	0.89286	0.78682	0.69954
4	4	0.98938	0.97928	0.95980	0.95763	0.94648	0.93508	0.92417	0.91470	0.90454	0.89263	0.77412	0.66539
5	5	0.98986	0.97917	0.95920	0.95697	0.94538	0.93270	0.92056	0.90615	0.89626	0.88219	0.73969	0.60422
6	6	0.98982	0.97900	0.95370	0.95571	0.94385	0.93011	0.91769	0.90306	0.88917	0.87154	0.68332	0.54173
7	7	0.98980	0.97874	0.96720	0.95582	0.94243	0.92796	0.91441	0.89812	0.88005	0.86175	0.63239	0.47700
8	8	0.98956	0.97828	0.95600	0.95410	0.93993	0.92419	0.90949	0.89116	0.87249	0.85142	0.58334	0.42113
9	9	0.98954	0.97789	0.96552	0.95446	0.94005	0.92299	0.90461	0.88207	0.85963	0.83354	0.52774	0.38762
10	10	0.98955	0.97771	0.95466	0.95256	0.93734	0.91963	0.89904	0.87217	0.84505	0.81401	0.47895	0.33788
11	11	0.98945	0.97739	0.95368	0.94997	0.93116	0.91140	0.88794	0.85845	0.82506	0.79117	0.43989	0.30752
12	12	0.98925	0.97693	0.96286	0.94768	0.92882	0.90615	0.87875	0.84263	0.80540	0.76421	0.40521	0.28258
13	13	0.98928	0.97658	0.96272	0.94424	0.92308	0.89533	0.86052	0.82168	0.77953	0.73474	0.37565	0.26147
14	14	0.98929	0.97628	0.95106	0.94340	0.92089	0.89050	0.84962	0.79818	0.74712	0.69325	0.34929	0.24300
15	15	0.98925	0.97599	0.95046	0.94112	0.91369	0.88130	0.83311	0.77155	0.71129	0.65283	0.32675	0.22705
16	16	0.98917	0.97554	0.95390	0.93691	0.90546	0.86018	0.81110	0.74306	0.67344	0.61520	0.30800	0.21359
17	17	0.98912	0.97552	0.95820	0.93294	0.89802	0.84775	0.78892	0.71119	0.63674	0.56074	0.28684	0.20110
18	18	0.98921	0.97551	0.95767	0.93009	0.88597	0.82910	0.75906	0.67704	0.60201	0.54914	0.27103	0.18999
19	19	0.98914	0.97461	0.95518	0.92446	0.87766	0.81293	0.72810	0.64405	0.57224	0.52220	0.25810	0.18064
20	20	0.98911	0.97431	0.95201	0.92018	0.86651	0.76980	0.69529	0.61295	0.54508	0.49751	0.24601	0.17228

Table No. 2

MACHINE WAITING TIME FOR A SINGLE SERVICEMAN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.1

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
2	2	0.00021	0.00038	0.00081	0.00116	0.00111	0.00086	0.00173	0.00292	0.00420	0.00506	0.01879	0.03329
3	3	0.00014	0.00096	0.00046	0.00204	0.00323	0.00508	0.00719	0.00855	0.00114	0.01449	0.04735	0.08205
4	4	0.00072	0.00168	0.00185	0.00202	0.00326	0.00469	0.00700	0.00838	0.00967	0.01352	0.06783	0.13293
5	5	0.00062	0.00172	0.00229	0.00344	0.00550	0.00913	0.00127	0.01646	0.02035	0.02592	0.11419	0.21518
6	6	0.00056	0.00167	0.00260	0.00550	0.00813	0.01254	0.01619	0.02273	0.02872	0.03067	0.17076	0.29737
7	7	0.00030	0.00136	0.00348	0.00571	0.01010	0.01595	0.02074	0.02931	0.03980	0.05029	0.23564	0.38125
8	8	0.00036	0.00169	0.00449	0.00793	0.01319	0.02009	0.02692	0.03722	0.04866	0.06299	0.29572	0.45404
9	9	0.00036	0.00179	0.00465	0.00694	0.01234	0.02119	0.03182	0.04703	0.06284	0.08277	0.36210	0.50142
10	10	0.00046	0.00205	0.00556	0.00864	0.01507	0.02426	0.03723	0.05693	0.07771	0.10411	0.42144	0.56225
11	11	0.00059	0.00152	0.00665	0.01111	0.02079	0.03253	0.04836	0.07161	0.09855	0.12866	0.46965	0.60173
12	12	0.00068	0.00276	0.00749	0.01317	0.02312	0.03755	0.05801	0.08815	0.11062	0.15817	0.51178	0.63420
13	13	0.00067	0.00215	0.00800	0.01722	0.02981	0.04927	0.07716	0.11060	0.14853	0.18073	0.54773	0.66171
14	14	0.00069	0.00358	0.00859	0.01833	0.03223	0.04480	0.08922	0.13592	0.18364	0.23619	0.57956	0.68567
15	15	0.00078	0.00396	0.01010	0.02033	0.03033	0.06487	0.10717	0.16477	0.22290	0.28083	0.60684	0.70637
16	16	0.00080	0.00448	0.01176	0.02457	0.04807	0.08685	0.13106	0.19604	0.26443	0.32245	0.62974	0.72400
17	17	0.00094	0.00457	0.01228	0.02846	0.05581	0.10000	0.15487	0.23062	0.30457	0.36058	0.65442	0.74016
18	18	0.00098	0.00462	0.01311	0.03154	0.06809	0.11969	0.18649	0.26754	0.34257	0.39544	0.67349	0.75453
19	19	0.00095	0.00548	0.01571	0.03761	0.07724	0.13695	0.21966	0.30240	0.37525	0.42530	0.68934	0.76680
20	20	0.00106	0.00587	0.01862	0.04223	0.08935	0.16153	0.25487	0.33702	0.40404	0.45261	0.70406	0.77779

Table No. 3

SERVICE UTILIZATION FOR A SINGLE SERVICEMAN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.1

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00902	0.01843	0.02767	0.04165	0.05219	0.06265	0.07321	0.08287	0.09228	0.10133	0.18188	0.24255
2	2	0.00964	0.01942	0.02822	0.04028	0.04991	0.05997	0.06921	0.07815	0.08752	0.09661	0.17407	0.22451
3	3	0.00976	0.01950	0.02894	0.03931	0.04864	0.05728	0.06656	0.07529	0.08414	0.09268	0.16583	0.21841
4	4	0.00940	0.01904	0.02835	0.04035	0.05026	0.06023	0.06883	0.07692	0.08579	0.09325	0.15805	0.20168
5	5	0.00952	0.01911	0.02852	0.03959	0.04912	0.05817	0.06674	0.07539	0.08339	0.09189	0.15577	0.18069
6	6	0.00962	0.01933	0.02870	0.03679	0.04902	0.05735	0.06612	0.07421	0.08211	0.08979	0.14592	0.16090
7	7	0.00990	0.01990	0.02932	0.03847	0.04747	0.05609	0.06485	0.07257	0.08015	0.08796	0.13197	0.14175
8	8	0.00996	0.02003	0.02951	0.03797	0.04688	0.05572	0.06359	0.07162	0.07885	0.08559	0.12094	0.12487
9	9	0.01008	0.02032	0.02983	0.03860	0.04761	0.05562	0.06357	0.07090	0.07753	0.08369	0.11016	0.11096
10	10	0.00999	0.02024	0.02978	0.03880	0.04759	0.05611	0.06373	0.07090	0.07724	0.08188	0.09961	0.09987
11	11	0.00996	0.02009	0.02967	0.03692	0.04805	0.05607	0.06370	0.06994	0.07539	0.08017	0.09056	0.09079
12	12	0.01007	0.02030	0.02965	0.03895	0.04806	0.05636	0.06324	0.06922	0.07398	0.07762	0.08301	0.08322
13	13	0.01005	0.02027	0.02928	0.03854	0.04711	0.05540	0.06232	0.06772	0.07194	0.07453	0.07662	0.07682
14	14	0.01075	0.02014	0.02935	0.03827	0.04688	0.05470	0.03116	0.06590	0.06924	0.07056	0.07115	0.07133
15	15	0.00997	0.02005	0.02944	0.03855	0.04698	0.05383	0.05972	0.06368	0.06581	0.06634	0.06641	0.06659
16	16	0.00993	0.01998	0.02934	0.03852	0.04647	0.05297	0.05784	0.06090	0.06213	0.06235	0.06226	0.06241
17	17	0.00994	0.01991	0.02952	0.03860	0.04617	0.05225	0.05621	0.05819	0.05869	0.05866	0.05874	0.05874
18	18	0.00981	0.01987	0.02922	0.03837	0.04594	0.05121	0.05445	0.05542	0.05542	0.05542	0.05546	0.0554
19	19	0.00991	0.01991	0.02911	0.03793	0.04510	0.05012	0.05224	0.05255	0.05251	0.05250	0.05256	0.05256
20	20	0.00983	0.01982	0.02917	0.03759	0.04414	0.04867	0.04984	0.04993	0.04986	0.04988	0.04993	0.04993

Table No. 4

The Goodness of fit test.
Negative Exponential Breakdown.
Normal Service Time.
Single Serviceman.
Coefficient of Variation = 0.1
Test 1
Keeping service coefficient constant and increasing the number of machines from 1 to 20.

No.	Service Constant.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	0.01	0.00082
2	0.02	0.01020
3	0.03	0.06717
4	0.04	0.24470
5	0.05	0.50477
6	0.06	0.75828
7	0.07	0.87923
8	0.08	0.70768
9	0.09	0.78009
10	0.10	0.80885
11	0.20	0.39183
12	0.30	0.86080

For 19 degrees of freedom, the 5% level of significance is $P(30.144 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geq 30.144$. Hence, for the 5% level of significance, χ^2=1,2,..12 are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	1	0.09056
2	2	0.02443
3	3	0.03641
4	4	0.27321
5	5	0.27886
6	6	0.20633
7	7	0.17847
8	8	0.23271
9	9	0.39988
10	10	0.43407
11	11	0.46345
12	12	0.55700
13	13	0.52044
14	14	0.49070
15	15	0.43418
16	16	0.31522
17	17	0.32238
18	18	0.26088
19	19	0.25709
20	20	0.23914

For 11 degrees of freedom, the 5% level of significance is $P(19.675 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geq 19.675$. Hence, for the 5% level of significance, χ^2=1,2,...20 are not significant.

Table No. 5

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	1	0.09	0.12	0.15	-0.33	-0.48	-0.64	-0.83	-0.95	-1.06	-1.15	-1.83	-1.53
2	2	0.02	0.02	0.10	-0.16	-0.13	-0.13	-0.16	-0.21	-0.32	-0.37	-0.45	1.63
3	3	0.02	-0.01	0.15	0.01	0.03	0.06	0.01	0.11	0.03	-0.03	0.37	2.26
4	4	0.01	0.01	0.16	0.07	0.12	0.18	0.32	0.65	0.94	1.05	2.93	5.42
5	5	0.02	0.04	0.20	0.19	0.30	0.36	0.53	0.73	1.04	1.16	3.46	5.29
6	6	0.02	0.07	0.25	0.25	0.46	0.56	0.90	1.09	1.44	1.44	1.46	5.05
7	7	0.03	0.09	0.21	0.48	0.67	0.87	1.32	1.59	1.79	2.08	3.67	3.59
8	8	0.03	0.08	0.21	0.53	0.79	1.07	1.66	2.03	2.55	2.94	0.36	2.46
9	9	0.03	0.10	0.28	0.82	1.24	1.63	2.13	2.41	2.93	3.22	-1.31	5.19
10	10	0.04	0.13	0.33	0.89	1.44	2.04	2.67	2.90	3.40	3.64	-2.41	1.54
11	11	0.04	0.16	0.37	0.92	1.31	2.01	2.74	3.18	3.50	4.01	-2.41	1.54
12	12	0.03	0.17	0.44	1.03	1.66	2.42	3.21	3.46	3.96	4.16	-2.41	1.75
13	13	0.05	0.19	0.59	1.00	1.70	2.34	2.82	3.38	3.94	4.31	-2.20	1.96
14	14	0.06	0.22	0.60	1.31	2.22	3.09	3.52	3.24	3.29	2.90	-2.15	2.06
15	15	0.07	0.26	0.73	1.50	2.28	3.50	3.78	2.93	2.33	1.63	-1.96	2.17
16	16	0.08	0.28	0.77	1.53	2.32	2.67	3.58	2.58	1.12	0.68	-1.43	2.52
17	17	0.08	0.35	0.82	1.64	2.56	3.06	3.58	1.90	0.03	0.02	-2.47	2.57
18	18	0.11	0.43	1.11	1.92	2.30	2.89	2.75	0.93	-0.90	-0.44	-2.43	2.60
19	19	0.12	0.42	1.11	1.96	2.80	3.22	1.88	0.09	-1.24	-0.41	-1.92	2.97
20	20	0.13	0.47	1.06	2.23	3.02	2.85	0.78	-0.58	-1.38	-0.31	-1.59	3.37

THE MEAN PERCENTAGE DIFFERENCE IS 1.06765

THE STD. DEVIATION IS 1.57233

NEGATIVE EXPONENTIAL BREAKDOWN

NORMAL SERVICE TIME

SINGLE SERVICEMAN

COEFFICIENT OF VARIATION 0.1

Table No. 6

MACHINE UTILIZATION M FOR A SINGLE SERVICEMAN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.2

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.98958	0.98161	0.97238	0.95853	0.94801	0.93752	0.92704	0.91728	0.90769	0.89666	0.81826	0.75863
2	2	0.99032	0.98036	0.97098	0.95848	0.94884	0.93882	0.92834	0.91858	0.90795	0.89712	0.80609	0.73964
3	3	0.99032	0.97943	0.97057	0.95857	0.94787	0.93744	0.92617	0.91509	0.90342	0.89142	0.78420	0.69945
4	4	0.98975	0.97921	0.97057	0.95731	0.94640	0.93437	0.92347	0.91466	0.90363	0.89198	0.77194	0.66387
5	5	0.98991	0.97914	0.96940	0.95653	0.94485	0.93260	0.92025	0.90760	0.89525	0.88036	0.73721	0.60149
6	6	0.98994	0.97894	0.96869	0.95575	0.94361	0.92936	0.91739	0.90261	0.88816	0.87136	0.68060	0.53974
7	7	0.99015	0.97872	0.96791	0.95562	0.94200	0.92765	0.91272	0.89662	0.87653	0.86065	0.63180	0.47799
8	8	0.99015	0.97824	0.96637	0.95401	0.93978	0.92354	0.90936	0.88993	0.87191	0.85002	0.58184	0.42164
9	9	0.98992	0.97798	0.96552	0.95420	0.93964	0.92243	0.90274	0.88078	0.86003	0.83464	0.52914	0.37481
10	10	0.98973	0.97773	0.96469	0.95231	0.93723	0.91782	0.89877	0.87057	0.84274	0.81254	0.47424	0.33778
11	11	0.98957	0.97746	0.96370	0.94949	0.92982	0.90979	0.88647	0.85604	0.82440	0.79047	0.43927	0.30744
12	12	0.98940	0.97687	0.96287	0.94755	0.92792	0.90457	0.87831	0.84033	0.80404	0.76357	0.40581	0.28252
13	13	0.98945	0.97683	0.96271	0.94354	0.92215	0.89292	0.85891	0.82015	0.77626	0.73427	0.37755	0.26138
14	14	0.98932	0.97635	0.96106	0.94284	0.91985	0.88960	0.84831	0.79806	0.74526	0.69395	0.35259	0.24294
15	15	0.98935	0.97577	0.96036	0.94040	0.91118	0.87987	0.83146	0.76977	0.71031	0.65285	0.33126	0.22700
16	16	0.98917	0.97571	0.95915	0.93613	0.90404	0.85866	0.80883	0.74093	0.67270	0.61555	0.31363	0.21410
17	17	0.98916	0.97551	0.95824	0.93251	0.89613	0.84650	0.78773	0.70902	0.63561	0.58078	0.29726	0.20103
18	18	0.98922	0.97550	0.95777	0.92972	0.88484	0.82823	0.75810	0.67575	0.60085	0.54916	0.28255	0.18593
19	19	0.98919	0.97479	0.95518	0.92361	0.87600	0.81174	0.72650	0.64374	0.57107	0.52221	0.24778	0.18052
20	20	0.98908	0.97440	0.95393	0.91902	0.86529	0.78841	0.69546	0.61262	0.54391	0.49750	0.23471	0.17211

Table No. 7

MACHINE WAITING TIME FOR A SINGLE SERVICEMAN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.2

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
2	2	0.00002	0.00927	0.00082	0.00122	0.00183	0.00092	0.00209	0.00291	0.00414	0.00583	0.01839	0.03584
3	3	0.00016	0.00069	0.00045	0.00202	0.00346	0.00518	0.00719	0.00944	0.01264	0.01603	0.04938	0.08303
4	4	0.00013	0.00041	0.00108	0.00001	0.00322	0.00522	0.00765	0.00814	0.01039	0.01380	0.07014	0.13465
5	5	0.00028	0.00088	0.00207	0.00001	0.00593	0.00899	0.01287	0.01668	0.02080	0.02801	0.10643	0.21820
6	6	0.00041	0.00130	0.00254	0.00541	0.00834	0.01325	0.01661	0.02313	0.02879	0.03965	0.17364	0.29976
7	7	0.00029	0.00191	0.00275	0.00602	0.01057	0.01604	0.02300	0.03101	0.04141	0.05131	0.23603	0.38055
8	8	0.00029	0.00246	0.00412	0.00803	0.01340	0.02089	0.02711	0.03856	0.04959	0.06464	0.29757	0.45367
9	9	0.00050	0.00253	0.00464	0.00722	0.01289	0.02185	0.03374	0.04859	0.06243	0.08173	0.36111	0.51423
10	10	0.00051	0.00246	0.00552	0.00668	0.01526	0.02613	0.03755	0.05880	0.08035	0.10581	0.42618	0.56235
11	11	0.00059	0.00252	0.00662	0.01154	0.02225	0.03416	0.04906	0.07424	0.10037	0.12945	0.47996	0.60177
12	12	0.00062	0.00329	0.00748	0.01349	0.02410	0.03900	0.05843	0.08960	0.12204	0.15883	0.51098	0.63426
13	13	0.00061	0.00344	0.00601	0.01798	0.03073	0.05173	0.07891	0.11217	0.14980	0.19132	0.54564	0.66180
14	14	0.00081	0.00360	0.00959	0.01891	0.03336	0.05570	0.09061	0.14604	0.18556	0.23550	0.57609	0.68573
15	15	0.00078	0.00444	0.00990	0.02111	0.04185	0.06634	0.10896	0.16657	0.22393	0.28092	0.60218	0.70642
16	16	0.00101	0.00451	0.01150	0.02538	0.04960	0.08839	0.13342	0.19824	0.26516	0.32220	0.62397	0.72123
17	17	0.00100	0.00466	0.01223	0.02694	0.06790	0.10135	0.15621	0.23289	0.30570	0.36053	0.64401	0.74123
18	18	0.00106	0.00470	0.01301	0.03220	0.06932	0.12062	0.18754	0.26895	0.34366	0.39541	0.66196	0.75459
19	19	0.00099	0.00548	0.01570	0.04349	0.07896	0.13824	0.22133	0.31372	0.37636	0.42535	0.69967	0.76692
20	20	*.00000	0.00605	0.01689	*.00000	0.09066	0.16307	0.25475	0.33746	0.40615	0.45262	0.71537	0.77796

Table No. 8

SERVICE UTILIZATION FOR A SINGLE SERVICEMAN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.2

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.01041	0.02082	0.02761	0.04146	0.05198	0.06247	0.07295	0.08271	0.09210	0.10111	0.18173	0.24136
2	2	0.00996	0.01035	0.02820	0.04030	0.05013	0.06026	0.06957	0.07551	0.08791	0.09705	0.17452	0.22452
3	3	0.00982	0.01988	0.02898	0.03941	0.04867	0.05735	0.06664	0.07547	0.08394	0.09255	0.16642	0.21752
4	4	0.01012	0.02038	0.02835	0.04266	0.05035	0.06041	0.06888	0.07720	0.08578	0.09422	0.15792	0.20146
5	5	0.00981	0.01956	0.02853	0.04346	0.04922	0.05841	0.06668	0.07552	0.08395	0.09161	0.15636	0.18031
6	6	0.00975	0.01976	0.02877	0.03884	0.04805	0.05739	0.06600	0.07426	0.08205	0.08999	0.14576	0.16050
7	7	0.00956	0.01937	0.02934	0.03836	0.04743	0.05611	0.06426	0.07237	0.08006	0.08894	0.13217	0.14142
8	8	0.00956	0.01930	0.02951	0.03796	0.04692	0.05557	0.06353	0.07151	0.07850	0.08534	0.12059	0.12469
9	9	0.00968	0.01949	0.02984	0.03858	0.04756	0.05572	0.06352	0.07063	0.07754	0.08363	0.10985	0.11096
10	10	0.00976	0.01981	0.02979	0.03881	0.04751	0.05605	0.06368	0.07063	0.07691	0.08165	0.09958	0.09987
11	11	0.00984	0.02002	0.02968	0.03897	0.04793	0.05605	0.06347	0.06972	0.07523	0.08008	0.09077	0.09079
12	12	0.00998	0.01984	0.02965	0.03896	0.04798	0.05643	0.06326	0.06907	0.07392	0.07760	0.08321	0.08322
13	13	0.00994	0.01973	0.02928	0.03648	0.04712	0.05535	0.06218	0.06760	0.07184	0.07441	0.07661	0.07662
14	14	0.00987	0.01985	0.02935	0.03825	0.04679	0.05464	0.06108	0.06560	0.06918	0.07055	0.07132	0.07133
15	15	0.00987	0.01979	0.02944	0.03853	0.04697	0.05379	0.05956	0.06366	0.06576	0.06633	0.06656	0.06658
16	16	0.00982	0.01978	0.02935	0.03849	0.04636	0.05295	0.05775	0.06083	0.06214	0.06225	0.06240	0.06241
17	17	0.00984	0.01983	0.02953	0.03855	0.04597	0.05215	0.05606	0.05810	0.05869	0.05869	0.05873	0.05874
18	18	0.00920	0.01980	0.02922	0.03808	0.04584	0.05002	0.05436	0.05530	0.05549	0.05543	0.05547	0.05548
19	19	0.09820	0.01973	0.02912	0.03787	0.04504	0.04852	0.05217	0.05254	0.05257	0.05251	0.05255	0.05256
20	20	0.09740	0.01955	0.02918	0.03749	0.04405	*.00000	0.04979	0.04992	0.04994	0.04988	0.04992	0.04993

Table No. 9

The Goodness of fit test.
Negative Exponential Breakdown.
Normal Service Time.
Single Serviceman.
Coefficient of Variation = 0.2
Test 1
Keeping service coefficient constant and increasing the number of machines from 1 to 20

No.	Service Constant.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	0.01	0.00097
2	0.02	0.01058
3	0.03	0.07355
4	0.04	0.22349
5	0.05	0.44043
6	0.06	0.67194
7	0.07	0.78944
8	0.08	0.61106
9	0.09	0.71958
10	0.10	0.77825
11	0.20	0.48579
12	0.30	0.70667

For 19 drgrees of freedom, the 5% level of significance is $P(30.144 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geq 30.144$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 12$ are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	1	0.08438
2	2	0.01999
3	3	0.03515
4	4	0.24196
5	5	0.22567
6	6	0.17433
7	7	0.16624
8	8	0.21694
9	9	0.30108
10	10	0.41740
11	11	0.42344
12	12	0.50913
13	13	0.46514
14	14	0.45054
15	15	0.37365
16	16	0.26883
17	17	0.27360
18	18	0.23603
19	19	0.31436
20	20	0.31389

For 11 degrees of freedom, the 5% level of significance is $P(19.675 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geq 19.675$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 20$ are not significant.

Table No. 10

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	1	-0.05	0.12	0.16	-0.31	-0.46	-0.62	-0.81	-0.93	-1.04	-1.12	-1.81	-1.38
2	2	0.00	0.04	0.10	-0.17	-0.15	-0.17	-0.24	-0.25	-0.36	-0.50	-0.58	1.27
3	3	0.01	-0.02	0.14	-0.00	-0.00	0.04	0.00	-0.01	-0.08	-0.19	0.04	2.25
4	4	-0.00	0.00	0.24	0.04	0.11	0.10	0.24	0.65	0.86	0.98	2.64	5.18
5	5	0.02	0.04	0.22	0.14	0.24	0.35	0.50	0.69	0.93	0.95	3.09	4.81
6	6	0.03	0.06	0.25	0.25	0.43	0.48	0.87	1.04	1.33	1.42	1.36	4.67
7	7	0.07	0.08	0.28	0.46	0.62	0.86	1.13	1.43	1.62	1.95	0.57	3.81
8	8	0.08	0.08	0.24	0.52	0.75	1.00	1.65	1.89	2.40	2.77	0.11	2.59
9	9	0.06	0.11	0.28	0.79	1.20	1.57	1.92	2.26	2.98	3.36	-1.05	1.71
10	10	0.06	0.14	0.33	[illegible]	1.42	1.84	2.64	2.71	3.11	3.45	-3.37	1.51
11	11	0.05	0.16	0.37	0.97	1.16	1.83	2.57	2.89	3.42	3.91	-2.55	1.51
12	12	0.05	0.16	0.44	0.99	1.56	2.25	3.16	3.19	3.79	4.09	-2.27	1.72
13	13	0.07	0.22	0.59	0.93	1.60	2.06	2.62	3.19	3.77	4.25	-1.71	1.94
14	14	0.07	0.23	0.60	1.25	2.11	2.93	3.36	3.22	3.03	3.01	-1.23	2.04
15	15	0.08	0.24	0.75	1.42	2.00	3.33	3.57	2.69	2.19	1.64	-0.61	2.15
16	16	0.08	0.30	0.80	1.45	2.16	2.49	3.29	2.28	1.01	0.73	0.37	2.77
17	17	0.09	0.35	0.93	1.59	2.34	2.91	3.43	1.59	-0.14	0.03	1.07	2.53
18	18	0.11	0.43	1.12	1.88	2.26	2.78	2.62	0.74	-1.09	-0.44	1.72	2.57
19	19	0.12	0.43	1.11	1.97	2.60	3.07	1.65	0.04	-1.44	-0.41	-5.84	2.90
20	20	0.12	0.48	1.26	2.10	2.88	2.67	0.80	-0.64	-1.60	-0.31	-6.11	3.27

THE MEAN PERCENTAGE DIFFERENCE IS 0.99977

THE STD. DEVIATION IS 1.56111

NEGATIVE EXPONENTIAL BREAKDOWN

NORMAL SERVICE TIME

SINGLE SERVICEMAN

COEFFICIENT OF VARIATION 0.2

Table No. 11

MACHINE UTILIZATION M FOR A SINGLE SERVICEMAN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.3

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.99103	0.98029	0.97227	0.95784	0.94725	0.93657	0.92588	0.91663	0.90775	0.89687	0.81585	0.75574
2	2	0.99025	0.98025	0.97035	0.95822	0.94839	0.93872	0.92783	0.91851	0.90738	0.89722	0.80369	0.73977
3	3	0.99013	0.97934	0.95972	0.95854	0.94756	0.93704	0.92602	0.91610	0.90434	0.89259	0.78073	0.69684
4	4	0.99057	0.97871	0.95342	0.95711	0.94550	0.93349	0.92363	0.91267	0.90161	0.88932	0.76676	0.65822
5	5	0.98938	0.97860	0.95911	0.95611	0.94488	0.93145	0.91645	0.90486	0.89151	0.87795	0.73061	0.59677
6	6	0.98931	0.97857	0.96897	0.95491	0.94261	0.92793	0.91595	0.90249	0.88523	0.86733	0.67723	0.53693
7	7	0.98979	0.97840	0.95654	0.95532	0.94113	0.92625	0.91003	0.89146	0.87449	0.85543	0.62279	0.47144
8	8	0.98951	0.97831	0.96547	0.95311	0.93784	0.92217	0.90812	0.88991	0.87048	0.84928	0.57716	0.41672
9	9	0.98942	0.97754	0.96534	0.95280	0.93764	0.92015	0.89837	0.87590	0.85245	0.82657	0.52585	0.37147
10	10	0.98950	0.97735	0.96328	0.95141	0.93448	0.91433	0.89217	0.86581	0.83890	0.81122	0.48000	0.33753
11	11	0.98933	0.97729	0.95267	0.94675	0.92819	0.90668	0.88208	0.85245	0.81872	0.78436	0.43931	0.30725
12	12	0.98940	0.97658	0.96213	0.94469	0.92423	0.89872	0.87166	0.83563	0.79856	0.75816	0.40576	0.28247
13	13	0.98931	0.97652	0.96174	0.94180	0.91911	0.89006	0.85445	0.81431	0.76917	0.72526	0.37752	0.26157
14	14	0.98910	0.97567	0.96004	0.94132	0.91611	0.88398	0.83976	0.78987	0.73707	0.68679	0.35259	0.24333
15	15	0.98835	0.97522	0.95304	0.93680	0.90806	0.87401	0.82361	0.75932	0.69929	0.64434	0.33130	0.22748
16	16	0.98530	0.97505	0.95785	0.93309	0.89813	0.85368	0.79955	0.72764	0.66266	0.60870	0.31366	0.21416
17	17	0.98839	0.97502	0.95675	0.92906	0.89113	0.84211	0.77792	0.69717	0.62662	0.57391	0.29566	0.20209
18	18	0.98838	0.97485	0.95616	0.92747	0.88033	0.82250	0.75203	0.66331	0.59285	0.54320	0.28099	0.19127
19	19	0.98891	0.97368	0.95423	0.92051	0.86996	0.80380	0.71933	0.63202	0.56378	0.51670	0.26443	0.18371
20	20	0.98835	0.97335	0.95159	0.91779	0.86088	0.78067	0.68754	0.60180	0.53631	0.49243	0.25445	0.17370

Table No. 12

MACHINE WAITING TIME FOR A SINGLE SERVICEMAN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.3

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00000	0.00036	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00000
2	2	0.00000	0.00019	0.00042	0.00105	0.00078	0.00065	0.00161	0.00183	0.00369	0.00447	0.01921	0.03328
3	3	0.00000	0.00119	0.00095	0.00168	0.00334	0.00526	0.00678	0.00791	0.01065	0.01240	0.05158	0.08511
4	4	0.00000	0.00227	0.00193	0.00218	0.00379	0.00571	0.00711	0.00949	0.01194	0.01641	0.07732	0.14069
5	5	0.00025	0.00236	0.00216	0.00394	0.00575	0.00997	0.01424	0.01967	0.02463	0.02999	0.11440	0.22356
6	6	0.00037	0.00219	0.00209	0.00597	0.00904	0.01456	0.01778	0.02285	0.03229	0.04240	0.17708	0.30291
7	7	0.00056	0.00162	0.00364	0.00607	0.01129	0.01749	0.02573	0.03614	0.04505	0.05639	0.24512	0.38758
8	8	0.00074	0.00166	0.00472	0.00871	0.01493	0.02194	0.02804	0.03799	0.05946	0.06483	0.30264	0.45756
9	9	0.00077	0.00212	0.00456	0.00834	0.01440	0.02362	0.03687	0.05333	0.07017	0.08974	0.36435	0.51765
10	10	0.00042	0.00253	0.00671	0.00940	0.01764	0.02926	0.04383	0.06336	0.08420	0.10665	0.42060	0.56262
11	11	0.00050	0.00272	0.00747	0.01375	0.02331	0.03678	0.05401	0.07740	0.10676	0.13533	0.47007	0.60197
12	12	0.00063	0.00313	0.00775	0.01564	0.02733	0.04457	0.06448	0.09482	0.13733	0.16425	0.51115	0.63432
13	13	0.00070	0.00326	0.00814	0.01933	0.03323	0.05360	0.08285	0.11766	0.15901	0.20033	0.54580	0.66162
14	14	0.00096	0.00421	0.01015	0.01989	0.03647	0.06102	0.09884	0.14398	0.19378	0.24277	0.57621	0.68535
15	15	0.00105	0.00473	0.01123	0.02427	0.04465	0.07187	0.11650	0.17698	0.23499	0.28947	0.60224	0.70595
16	16	0.00105	0.00400	0.01243	0.02822	0.05520	0.09210	0.14245	0.21139	0.27531	0.32905	0.62404	0.72343
17	17	0.00108	0.00505	0.01374	0.03215	0.06261	0.10548	0.16588	0.24471	0.31470	0.36736	0.64570	0.73817
18	18	0.00107	0.00522	0.01429	0.03410	0.07366	0.12622	0.19363	0.28144	0.35169	0.40133	0.66363	0.75326
19	19	0.00119	0.00635	0.01635	0.04140	0.08469	0.14612	0.22858	0.31547	0.38368	0.43075	0.68311	0.76374
20	20	0.00130	0.00672	0.01890	0.04437	0.09495	0.17075	0.26269	0.34826	0.41378	0.45765	0.69571	0.77638

Table No. 13

SERVICE UTILIZATION FOR A SINGLE SERVICEMAN-(NORMAL SERVICE TIME, Q MODEL)

COEFFICIENT OF VARIATION FACTOR 0.3

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.01058	0.01835	0.02772	0.04215	0.05274	0.06342	0.07411	0.08336	0.09224	0.10112	0.19414	0.24426
2	2	0.01011	0.01956	0.02863	0.04073	0.05083	0.06063	0.07056	0.07966	0.08893	0.09671	0.17710	0.22695
3	3	0.00998	0.01947	0.02933	0.03978	0.04910	0.05770	0.06720	0.07599	0.08501	0.09501	0.16769	0.21805
4	4	0.01019	0.01902	0.02865	0.04071	0.05071	0.06080	0.06926	0.07784	0.08645	0.09427	0.15592	0.20109
5	5	0.00987	0.01904	0.02873	0.03995	0.04937	0.05856	0.06731	0.07551	0.08366	0.09206	0.15459	0.17967
6	6	0.00982	0.01924	0.02894	0.03912	0.04835	0.05751	0.06627	0.07466	0.08248	0.09027	0.14469	0.16016
7	7	0.00965	0.01998	0.02952	0.03861	0.04758	0.05626	0.06424	0.07240	0.08046	0.08818	0.13209	0.14098
8	8	0.00965	0.02003	0.02981	0.03818	0.04723	0.05589	0.06384	0.07210	0.07906	0.08594	0.12020	0.12452
9	9	0.00981	0.02034	0.03010	0.03886	0.04790	0.05623	0.06376	0.07077	0.07738	0.08369	0.10980	0.11088
10	10	0.00992	0.02012	0.03001	0.03919	0.04786	0.05641	0.06400	0.07083	0.07690	0.08213	0.09939	0.09985
11	11	0.01007	0.01999	0.02966	0.03950	0.04850	0.05654	0.06391	0.07085	0.07542	0.08031	0.09062	0.09078
12	12	0.00997	0.02029	0.03007	0.03947	0.04844	0.05671	0.06386	0.06955	0.07411	0.07759	0.08307	0.08321
13	13	0.00989	0.02022	0.03012	0.03687	0.04766	0.05612	0.06270	0.06803	0.07152	0.07441	0.07668	0.07681
14	14	0.00994	0.02012	0.02981	0.03879	0.04742	0.05590	0.06140	0.06615	0.06915	0.07044	0.07120	0.07132
15	15	0.00996	0.02005	0.02973	0.03893	0.04729	0.05412	0.05979	0.06370	0.06572	0.06619	0.06646	0.06657
16	16	0.01005	0.01995	0.02972	0.03669	0.04667	0.05322	0.05800	0.06097	0.06203	0.06225	0.06230	0.06241
17	17	0.00993	0.01993	0.02951	0.03879	0.04626	0.05241	0.05620	0.05812	0.05868	0.05873	0.05964	0.05874
18	18	0.00995	0.01993	0.02956	0.03843	0.04601	0.05128	0.05434	0.05525	0.05546	0.05547	0.05538	0.05547
19	19	0.00990	0.01997	0.02942	0.03609	0.04535	0.05006	0.05209	0.05251	0.05254	0.05255	0.05246	0.05255
20	20	0.00985	0.01993	0.02951	0.03784	0.04427	0.04858	0.04977	0.04994	0.04991	0.04992	0.04964	0.04992

Table No. 14

The Goodness of fit test.
Negative Exponential Breakdown.
Normal Service Time.
Coefficient of Variation = 0.3
Single Serviceman.
Test 1
Keeping service coefficient constant and increasing the number of machines from 1 to 20.

No.	Service Constant.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	0.01	0.00064
2	0.02	0.00655
3	0.03	0.05063
4	0.04	0.15429
5	0.05	0.26729
6	0.06	0.39281
7	0.07	0.40749
8	0.08	0.39136
9	0.09	0.52849
10	0.10	0.51917
11	0.20	0.23658
12	0.30	0.57047

For 19 degrees of freedom, the 5% level of significance is $P(30.144 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geq 30.144$. Hence, for the 5% level of significance, χ^2=1,2,...12 are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	1	0.10883
2	2	0.02476
3	3	0.02526
4	4	0.15443
5	5	0.13470
6	6	0.12313
7	7	0.07870
8	8	0.17887
9	9	0.17009
10	10	0.27971
11	11	0.28696
12	12	0.32958
13	13	0.26593
14	14	0.23480
15	15	0.18059
16	16	0.12164
17	17	0.17150
18	18	0.19914
19	19	0.21244
20	20	0.24471

For 11 degrees of freedom, the 5% level of significance is $P(19.675 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geq 19.675$. Hence, for the 5% level of significance, χ^2=1,2,...20 are not significant.

Table No. 15

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	1	0.09	-0.01	0.14	-0.38	-0.54	-0.72	-0.93	-1.00	-1.06	-1.12	-2.10	-1.75
2	2	0.03	0.02	0.09	-0.20	-0.19	-0.18	-0.30	-0.26	-0.42	-0.49	-0.88	1.29
3	3	0.02	-0.03	0.06	-0.01	-0.03	-0.00	-0.02	0.10	0.02	-0.06	-0.40	1.87
4	4	0.08	-0.05	0.12	0.02	0.02	0.01	0.26	0.43	0.61	0.68	1.95	4.28
5	5	0.02	-0.02	0.19	0.09	0.25	0.22	0.30	0.37	0.51	0.67	2.16	3.99
6	6	0.02	0.02	0.28	0.17	0.33	0.33	0.71	1.02	0.99	0.95	0.56	4.12
7	7	0.03	0.05	0.17	0.42	0.53	0.69	0.83	0.84	1.15	1.33	-0.86	2.39
8	8	0.02	0.09	0.15	0.42	0.57	0.85	1.51	1.89	2.31	2.68	-0.70	1.39
9	9	0.02	0.06	0.26	0.64	0.98	1.32	1.43	1.70	2.07	2.36	-1.66	0.80
10	10	0.05	0.10	0.19	0.77	1.13	1.45	1.89	2.15	2.64	3.29	-2.20	1.43
11	11	0.03	0.15	0.27	0.59	0.98	1.48	2.06	2.46	2.70	3.11	-2.54	1.45
12	12	0.05	0.13	0.37	0.71	1.15	1.58	2.38	2.60	3.08	3.35	-2.28	1.71
13	13	0.05	0.18	0.49	0.74	1.27	1.74	2.09	2.45	2.55	2.97	-1.71	2.02
14	14	0.04	0.16	0.49	1.09	1.69	2.33	2.31	2.16	1.90	1.94	-1.23	2.20
15	15	0.05	0.18	0.56	1.04	1.65	2.64	2.59	1.30	0.60	0.31	-0.59	2.37
16	16	0.05	0.23	0.66	1.12	1.49	1.90	2.11	0.45	-0.50	-0.39	0.38	2.80
17	17	0.07	0.30	0.77	1.21	1.77	2.38	2.14	-0.11	-1.56	-1.15	0.53	3.07
18	18	0.09	0.36	0.95	1.63	1.74	2.07	1.80	-1.11	-2.41	-1.52	1.16	3.29
19	19	0.09	0.72	1.01	1.57	1.90	2.06	0.65	-1.78	-2.70	-1.46	0.49	4.72
20	20	0.10	0.37	1.01	1.96	2.35	1.66	-0.34	-2.39	-2.97	-1.33	1.78	4.22

THE MEAN PERCENTAGE DIFFERENCE IS 0.70922

THE STD. DEVIATION IS 1.33010

NEGATIVE EXPONENTIAL BREAKDOWN

NORMAL SERVICE TIME

SINGLE SERVICEMAN

COEFFICIENT OF VARIATION 0.3

Table No. 16

MACHINE UTILIZATION M FOR 2 COLLABORTING SERVICEMEN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.1

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.99041	0.98049	0.97151	0.96271	0.95387	0.94494	0.93611	0.92785	0.91883	0.91045	0.83656	0.76656
2	4	0.99061	0.98100	0.97141	0.96193	0.95300	0.94382	0.93439	0.92654	0.91504	0.90987	0.83349	0.76108
3	6	0.99040	0.98070	0.97098	0.96137	0.95216	0.94330	0.93408	0.92508	0.91542	0.90633	0.81790	0.72806
4	8	0.99084	0.97983	0.96995	0.96017	0.94590	0.94064	0.93163	0.91945	0.91054	0.90417	0.80119	0.68509
5	10	0.98998	0.97959	0.96928	0.95914	0.94873	0.93884	0.92816	0.91734	0.90610	0.89471	0.77731	0.61606
6	12	0.98986	0.97943	0.96899	0.95862	0.94792	0.93702	0.92601	0.91466	0.90413	0.88894	0.74510	0.53427
7	14	0.98998	0.97954	0.96913	0.95869	0.94743	0.93565	0.92360	0.91036	0.89533	0.88766	0.68090	0.46685
8	16	0.99000	0.97957	0.96916	0.95818	0.94638	0.93414	0.92047	0.90566	0.89079	0.87375	0.62187	0.40424
9	18	0.99012	0.97962	0.96922	0.95807	0.94606	0.93331	0.91955	0.90306	0.88380	0.86455	0.55762	0.36173
10	20	0.99013	0.97968	0.96871	0.95727	0.94492	0.93139	0.91565	0.89564	0.87155	0.84075	0.50260	0.32085
11	22	0.99115	0.97974	0.96901	0.95731	0.94400	0.92869	0.91006	0.88430	0.85446	0.81963	0.45514	0.29911
12	24	0.99019	0.97960	0.96898	0.95694	0.94359	0.92656	0.90411	0.87472	0.83562	0.78133	0.41665	0.27565
13	26	0.99005	0.97949	0.96794	0.95549	0.94059	0.92192	0.89513	0.85092	0.80311	0.73566	0.38475	0.25646
14	28	0.99007	0.97926	0.96751	0.95362	0.93561	0.91282	0.87922	0.83269	0.76552	0.68977	0.35726	0.23348
15	30	0.99008	0.97925	0.96712	0.95192	0.93378	0.90431	0.85740	0.79962	0.72293	0.64654	0.33359	0.22614
16	32	0.98996	0.97967	0.96598	0.95016	0.92967	0.89271	0.83260	0.76623	0.67964	0.60735	0.31244	0.20544
17	34	0.98991	0.97865	0.96504	0.94754	0.92105	0.87715	0.80031	0.71946	0.64059	0.57209	0.29342	0.19350
18	36	0.98995	0.97854	0.96474	0.94479	0.91212	0.85282	0.76372	0.68115	0.60552	0.54067	0.27647	0.18255
19	38	0.98996	0.97844	0.96370	0.94231	0.90140	0.82757	0.72771	0.64640	0.58460	0.51339	0.26138	0.17380
20	40	0.98994	0.97815	0.96354	0.94021	0.88946	0.79792	0.69288	0.61509	0.54560	0.48902	0.25005	0.16548

Table No. 17

MACHINE WAITING TIME FOR 2 COLLABORTING SERVICEMEN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.1

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.00000	0.00001	0.00001	0.00001	0.00002	0.00001	0.00001	0.00002	0.00000	0.00000	0.00001	0.00001
2	4	0.00000	0.00002	0.00001	0.00006	0.00011	0.00022	0.00000	0.00038	0.00033	0.00061	0.00479	0.01076
3	6	0.00000	0.00001	0.00008	0.00018	0.00025	0.00045	0.00096	0.00132	0.00259	0.00240	0.01517	0.04447
4	8	0.00059	0.00007	0.00019	0.00030	0.00051	0.00109	0.00197	0.00396	0.00430	0.00607	0.03458	0.10222
5	10	0.00051	0.00017	0.00028	0.00079	0.00062	0.00197	0.00349	0.00525	0.00740	0.01061	0.06519	0.18970
6	12	0.00052	0.00017	0.00048	0.00108	0.00184	0.00335	0.00576	0.00807	0.01076	0.01763	0.10553	0.29985
7	14	0.00015	0.00020	0.00050	0.00139	0.00269	0.00527	0.00806	0.01261	0.01821	0.01909	0.18278	0.39668
8	16	0.00004	0.00028	0.00070	0.00191	0.00410	0.00725	0.01197	0.01639	0.02526	0.03442	0.25369	0.47096
9	18	0.00000	0.00027	0.00095	0.00239	0.00489	0.00827	0.01366	0.02193	0.03382	0.04948	0.33138	0.52733
10	20	0.00000	0.00041	0.00149	0.00331	0.00607	0.01131	0.01862	0.03041	0.04705	0.07148	0.39750	0.57331
11	22	0.00000	0.00049	0.00142	0.00359	0.00762	0.01448	0.02446	0.04267	0.06578	0.09585	0.45404	0.61012
12	24	0.00000	0.00052	0.00162	0.00404	0.00842	0.01622	0.03093	0.05333	0.08692	0.13780	0.49990	0.64111
13	26	0.00000	0.00203	0.00239	0.00536	0.01141	0.01728	0.04102	0.07090	0.12265	0.18814	0.53840	0.66674
14	28	0.00000	0.00079	0.00271	0.00713	0.01522	0.02724	0.05778	0.09940	0.16391	0.23904	0.57138	0.69521
15	30	0.00000	0.00088	0.00324	0.00904	0.01829	0.03975	0.08074	0.14528	0.21060	0.28792	0.59981	0.70730
16	32	0.00013	0.00108	0.00429	0.01087	0.02269	0.05225	0.10711	0.17784	0.25798	0.33023	0.62516	0.73216
17	34	0.00015	0.00128	0.00508	0.01334	0.03143	0.06883	0.14195	0.22189	0.30066	0.36916	0.64782	0.74777
18	36	0.00013	0.00146	0.00550	0.01615	0.04057	0.09443	0.16116	0.26338	0.33900	0.40364	0.66803	0.76154
19	38	0.00013	0.00161	0.00650	0.01876	0.05197	0.12120	0.21981	0.30097	0.36290	0.43405	0.68604	0.77365
20	40	0.00023	0.00192	0.00685	0.02122	0.06460	0.15269	0.25716	0.33499	0.40327	0.46104	0.70000	0.78450

Table No. 18

SERVICE UTILIZATION FOR 2 COLLABORATING SERVICEMEN (NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.1

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.00991	0.01950	0.02848	0.03726	0.04011	0.05505	0.06388	0.07213	0.08206	0.08955	0.16343	0.23141
2	4	0.00961	0.01898	0.02858	0.03601	0.04669	0.05596	0.06737	0.07308	0.08163	0.08952	0.16472	0.22816
3	6	0.00971	0.01929	0.02894	0.03845	0.04759	0.05625	0.06496	0.07360	0.08259	0.09127	0.16693	0.22753
4	8	0.00937	0.02010	0.02966	0.03953	0.04929	0.05827	0.06740	0.07657	0.08516	0.09376	0.16423	0.21269
5	10	0.00951	0.02033	0.03034	0.04007	0.05065	0.05919	0.06835	0.07741	0.08650	0.09468	0.15750	0.19222
6	12	0.00962	0.02040	0.03053	0.04030	0.05024	0.05963	0.06831	0.07725	0.08511	0.09343	0.14937	0.16585
7	14	0.00987	0.02026	0.03032	0.04001	0.04968	0.05913	0.06834	0.07701	0.08546	0.09325	0.13832	0.14247
8	16	0.00996	0.02015	0.03014	0.03991	0.04952	0.05861	0.06756	0.07573	0.08395	0.09183	0.12424	0.12490
9	18	0.01009	0.01991	0.02983	0.03954	0.04905	0.05842	0.06679	0.07499	0.08288	0.08997	0.11100	0.11094
10	20	0.00999	0.01991	0.02980	0.03942	0.04901	0.05739	0.06633	0.07395	0.08140	0.08777	0.09990	0.09994
11	22	0.00993	0.01977	0.02957	0.03910	0.04838	0.05683	0.06548	0.07303	0.07976	0.08452	0.09082	0.09077
12	24	0.01007	0.01968	0.02940	0.03902	0.04799	0.05682	0.06496	0.07195	0.07746	0.08097	0.08325	0.08320
13	26	0.01005	0.01848	0.02967	0.03915	0.04800	0.06080	0.06385	0.07018	0.07424	0.07620	0.07665	0.07660
14	28	0.00997	0.01995	0.02978	0.03925	0.04817	0.05994	0.06300	0.06791	0.07057	0.07119	0.07136	0.07131
15	30	0.00995	0.01987	0.02964	0.03904	0.04793	0.05594	0.06186	0.06512	0.06647	0.06654	0.06660	0.06656
16	32	0.00991	0.01995	0.02973	0.03897	0.04764	0.05504	0.06009	0.06195	0.06238	0.06242	0.06244	0.06240
17	34	0.00994	0.02007	0.02988	0.03912	0.04752	0.05402	0.05774	0.05863	0.05875	0.05875	0.05876	0.05873
18	36	0.00992	0.02000	0.02976	0.03906	0.04731	0.05275	0.05512	0.05547	0.05548	0.05549	0.05550	0.05547
19	38	0.00991	0.01995	0.02970	0.03887	0.04663	0.05123	0.05248	0.05255	0.05250	0.05256	0.05258	0.05255
20	40	0.00983	0.01993	0.02961	0.03857	0.04594	0.04939	0.04995	0.04992	0.04993	0.04994	0.04995	0.04992

Table No. 19

The Goodness of fit test.
Negative Exponential Breakdown.
Normal Service Time.
Two Servicemen.
Coefficient of Variation = 0.1
Test 1
Keeping service coefficient constant and increasing the number of machines from 1 to 40.

No.	Service Constant.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	0.01	0.00291
2	0.02	0.04376
3	0.03	0.25054
4	0.04	0.89249
5	0.05	1.99999
6	0.06	2.79173
7	0.07	2.87846
8	0.08	3.12679
9	0.09	2.78613
10	0.10	2.47274
11	0.20	2.82420
12	0.30	1.34828

For 19 degrees of freedom, the 5% level of significance is $P(30.144<\chi^2<\infty) = 0.05$ and the rejection region is $\chi^2\geq 30.144$. Hence, for the 5% level of significance, $\chi^2 = 1,2,\ldots 12$ are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	2	0.00308
2	4	0.19768
3	6	0.48794
4	8	0.86776
5	10	1.04152
6	12	1.12746
7	14	1.10248
8	16	1.01684
9	18	1.19650
10	20	1.41110
11	22	1.69222
12	24	1.91531
13	26	1.86992
14	28	1.65988
15	30	1.42588
16	32	1.22238
17	34	1.00574
18	36	0.80554
19	38	0.70944
20	40	0.065934

For 11 degrees of freedom, the 5% level of significance is $P(19.675<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2\geq 19.675$. Hence, for the 5% level of significance, $\chi^2=1,2,\ldots 20$ are not significant.

Table No. 20

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	2	0.03	0.01	0.07	0.12	0.16	0.16	0.16	0.21	0.15	0.15	0.39	-0.08
2	4	0.06	0.10	0.14	0.19	0.29	0.37	0.41	0.62	0.75	0.91	2.43	4.21
3	6	0.05	0.11	0.19	0.29	0.45	0.67	0.86	1.08	1.24	1.48	4.34	6.42
4	8	0.03	0.06	0.17	0.34	0.48	0.77	1.02	1.17	1.61	1.91	6.53	8.54
5	10	0.03	0.07	0.21	0.41	0.65	1.02	1.36	1.75	2.15	2.59	8.69	7.71
6	12	0.03	0.11	0.28	0.56	0.89	1.31	1.62	2.39	3.15	3.47	10.64	3.61
7	14	0.05	0.17	0.41	0.77	1.20	1.70	2.34	2.98	3.63	5.15	9.66	0.09
8	16	0.06	0.22	0.53	0.96	1.49	2.16	2.99	3.72	4.70	5.64	6.55	-1.64
9	18	0.09	0.30	0.67	1.20	1.89	2.77	3.82	4.65	5.84	6.56	4.26	-1.64
10	20	0.10	0.33	0.75	1.39	2.26	3.34	4.50	5.67	6.64	7.05	2.40	-1.78
11	22	0.11	0.40	0.93	1.70	2.70	3.94	5.30	6.29	7.19	7.75	0.97	-1.24
12	24	0.13	0.46	1.08	1.99	3.27	4.78	6.19	7.40	7.76	6.51	0.39	-0.73
13	26	0.13	0.49	1.14	2.20	3.63	5.38	6.95	8.07	7.08	4.45	0.17	0.02
14	28	0.14	0.53	1.27	2.41	3.97	5.67	7.12	7.70	5.63	2.39	0.08	-1.94
15	30	0.16	0.59	1.43	2.67	4.53	6.20	[illegible]	6.67	4.00	0.66	0.09	1.76
16	32	0.16	0.73	1.52	2.97	5.05	6.56	6.35	4.94	2.05	-0.61	-0.03	-1.35
17	34	0.16	0.67	1.64	3.23	5.14	6.64	5.03	3.09	0.64	-1.47	-0.23	-1.31
18	36	0.18	0.74	1.86	3.53	5.42	5.64	3.38	1.55	-0.32	-1.94	-0.47	-1.18
19	38	0.20	0.81	2.01	3.93	5.58	5.08	1.82	0.47	0.89	-2.09	-0.67	-0.93
20	40	0.21	0.87	2.28	4.45	5.75	3.96	0.43	-0.24	-1.07	-2.51	0.02	-0.71

THE MEAN PERCENTAGE DIFFERENCE IS 2.13634

THE STD. DEVIATION IS 2.63204

NEGATIVE EXPONENTIAL BREAKDOWN

NORMAL SERVICE TIME

TWO SERVICEMEN

COEFFICIENT OF VARIATION 0.1

Table No. 21

MACHINE UTILIZATION M FOR 2 COLLABORTING SERVICEMEN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.2

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.99059	0.98096	0.97211	0.96347	0.95477	0.94599	0.93740	0.92930	0.92046	0.91154	0.83857	0.77179
2	4	0.99072	0.98127	0.97185	0.96256	0.95364	0.94486	0.93554	0.92741	0.91929	0.91126	0.83252	0.76332
3	6	0.99052	0.98096	0.97129	0.96168	0.95272	0.94389	0.93485	0.92579	0.91678	0.90714	0.81851	0.72884
4	8	0.99011	0.98004	0.97029	0.96046	0.95054	0.94096	0.93125	0.92132	0.91220	0.90155	0.80090	0.68719
5	10	0.99005	0.97976	0.96949	0.95936	0.94898	0.93889	0.92653	0.91664	0.90605	0.89539	0.77927	0.61764
6	12	0.98993	0.97961	0.96929	0.95888	0.94820	0.93744	0.92625	0.91568	0.90435	0.89024	0.74613	0.53632
7	14	0.99004	0.97957	0.96914	0.95849	0.94728	0.93579	0.92359	0.91066	0.89657	0.88176	0.69139	0.46262
8	16	0.99007	0.97967	0.96917	0.95862	0.94663	0.93502	0.92111	0.90706	0.89060	0.87420	0.62595	0.40596
9	18	0.99020	0.97993	0.96947	0.95832	0.94606	0.93326	0.91973	0.90339	0.88486	0.86082	0.56261	0.36317
10	20	0.99020	0.97985	0.96890	0.95745	0.94546	0.93223	0.91492	0.89533	0.87085	0.84111	0.50699	0.32801
11	22	0.99023	0.97993	0.96933	0.95750	0.94470	0.92833	0.90963	0.88635	0.85485	0.82112	0.46220	0.30009
12	24	0.99027	0.97995	0.96913	0.95734	0.94416	0.92796	0.90479	0.87576	0.83582	0.78433	0.42053	0.27653
13	26	0.99013	0.97958	0.96846	0.95547	0.94093	0.92224	0.89688	0.86062	0.80705	0.74044	0.39577	0.25709
14	28	0.99013	0.97931	0.96769	0.95420	0.93714	0.91280	0.88061	0.83535	0.76902	0.69459	0.36073	0.23131
15	30	0.99016	0.97935	0.96695	0.95225	0.93374	0.90431	0.85933	0.80163	0.72838	0.65182	0.33644	0.22652
16	32	0.99004	0.97907	0.96648	0.95071	0.93054	0.89454	0.83384	0.76310	0.68535	0.61261	0.31502	0.20046
17	34	0.98998	0.97871	0.96536	0.94736	0.92062	0.87754	0.80193	0.72387	0.64617	0.57728	0.29589	0.19535
18	36	0.98998	0.97870	0.96460	0.94466	0.91268	0.85442	0.76714	0.68556	0.61066	0.54595	0.28364	0.18480
19	38	0.99006	0.97863	0.96380	0.94262	0.90364	0.82932	0.73285	0.65090	0.57965	0.51825	0.26935	0.17545
20	40	0.98999	0.97847	0.96330	0.94057	0.89067	0.80041	0.69885	0.61914	0.55160	0.49329	0.24985	0.16698

Table No. 22

MACHINE WAITING TIME FOR 2 COLLABORTING SERVICEMEN-(NORMAL SERVICE TIME, Q MODEL)

COEFFICIENT OF VARIATION FACTOR 0.2

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.00000	0.00001	0.00001	0.00001	0.00002	0.00002	0.00001	0.00002	0.00001	0.00002	0.00001	0.00000
2	4	0.00000	0.00001	0.00001	0.00008	0.00024	0.00006	0.00006	0.00043	0.00054	0.00052	0.00401	0.01169
3	6	0.00000	0.00001	0.00008	0.00013	0.00018	0.00055	0.00107	0.00152	0.00137	0.00246	0.01535	0.04545
4	8	0.00000	0.00007	0.00021	0.00045	0.00067	0.00137	0.00205	0.00301	0.00371	0.00560	0.03566	0.10077
5	10	0.00015	0.00007	0.00041	0.00091	0.00148	0.00248	0.00368	0.00470	0.00840	0.01059	0.06370	0.19119
6	12	0.00091	0.00013	0.00037	0.00109	0.00180	0.00302	0.00591	0.00765	0.01110	0.01692	0.10528	0.29775
7	14	0.00040	0.00028	0.00070	0.00168	0.00331	0.00531	0.00846	0.01279	0.01835	0.02537	0.17104	0.39470
8	16	0.00036	0.00032	0.00087	0.00174	0.00414	0.00332	0.01170	0.01734	0.02506	0.03461	0.25013	0.46920
9	18	0.00011	0.00032	0.00090	0.00237	0.00522	0.00876	0.01399	0.02210	0.03282	0.04974	0.32636	0.52586
10	20	0.00004	0.00040	0.00153	0.00345	0.00505	0.01032	0.01928	0.03134	0.04844	0.07095	0.39308	0.57212
11	22	0.00076	0.00046	0.00136	0.00373	0.00730	0.01490	0.02549	0.04107	0.06595	0.09481	0.44696	0.60912
12	24	0.00000	0.00053	0.00172	0.00400	0.00826	0.01566	0.03078	0.05281	0.08731	0.13501	0.49620	0.64024
13	26	0.00000	0.00065	0.00206	0.00566	0.01147	0.02171	0.03973	0.06952	0.11891	0.18363	0.53436	0.66609
14	28	0.00000	0.00089	0.00275	0.00681	0.01500	0.03112	0.05675	0.09714	0.15069	0.23395	0.56790	0.69735
15	30	0.00000	0.00091	0.00363	0.00901	0.01866	0.04014	0.07916	0.13362	0.20525	0.28166	0.59694	0.70690
16	32	0.00014	0.00111	0.00399	0.01059	0.02211	0.05973	0.10641	0.17515	0.25229	0.32503	0.62253	0.73712
17	34	0.00018	0.00135	0.00496	0.01324	0.03201	0.06877	0.14060	0.21746	0.29507	0.36402	0.64533	0.74590
18	36	0.00031	0.00142	0.00581	0.01653	0.04033	0.09305	0.17786	0.25897	0.33362	0.39862	0.66085	0.75972
19	38	0.00012	0.00158	0.00667	0.01872	0.04990	0.11067	0.21470	0.29653	0.36777	0.42923	0.67806	0.77199
20	40	0.00027	0.00170	0.00725	0.02106	0.06363	0.15034	0.25122	0.33092	0.39845	0.45682	0.70019	0.78309

Table No. 23

SERVICE UTILIZATION FOR 2 COLLABORTING SERVICEMEN (NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.2

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.01046	0.01913	0.02788	0.03652	0.04521	0.05399	0.06259	0.07068	0.07953	0.08844	0.16142	0.22824
2	4	0.00995	0.01872	0.02814	0.03742	0.04612	0.05508	0.06440	0.07216	0.08017	0.08822	0.16347	0.22499
3	6	0.00980	0.01903	0.02863	0.03799	0.04710	0.05553	0.06408	0.07269	0.08185	0.09040	0.16614	0.22571
4	8	0.01015	0.01989	0.02950	0.03909	0.04879	0.05767	0.06670	0.07567	0.08409	0.09285	0.16344	0.21204
5	10	0.00980	0.02017	0.03010	0.03973	0.04953	0.05863	0.06779	0.07666	0.08555	0.09402	0.15703	0.19117
6	12	0.00916	0.02026	0.03034	0.04003	0.04990	0.05924	0.06784	0.07667	0.08455	0.09284	0.14859	0.16593
7	14	0.00956	0.02015	0.03016	0.03983	0.04941	0.05890	0.06795	0.07655	0.08507	0.09287	0.13757	0.14268
8	16	0.00957	0.02001	0.02996	0.03964	0.04923	0.05836	0.06719	0.07558	0.08344	0.09119	0.12392	0.12484
9	18	0.00969	0.01975	0.02963	0.03931	0.04871	0.05798	0.06628	0.07451	0.08232	0.08944	0.11103	0.11097
10	20	0.00976	0.01975	0.02957	0.03910	0.04859	0.05745	0.06580	0.07333	0.08071	0.08733	0.09993	0.09987
11	22	0.00901	0.01961	0.02931	0.03877	0.04800	0.05677	0.06488	0.07258	0.07920	0.08407	0.09084	0.09072
12	24	0.00988	0.01952	0.02915	0.03866	0.04758	0.05638	0.06443	0.07141	0.07687	0.08066	0.08327	0.08323
13	26	0.00994	0.01977	0.02948	0.03887	0.04760	0.05605	0.06339	0.06966	0.07404	0.07593	0.07687	0.07682
14	28	0.00987	0.01980	0.02956	0.03899	0.04786	0.05608	0.06264	0.06751	0.07029	0.07116	0.07137	0.07134
15	30	0.00987	0.01974	0.02942	0.03874	0.04760	0.05555	0.06151	0.06475	0.06637	0.06652	0.06662	0.06658
16	32	0.00962	0.01982	0.02953	0.03870	0.04735	0.05473	0.05975	0.06175	0.06236	0.06236	0.06245	0.06242
17	34	0.00984	0.01994	0.02968	0.03890	0.04717	0.05369	0.05747	0.05857	0.05876	0.05879	0.05878	0.05875
18	36	0.00971	0.01988	0.02959	0.03881	0.04699	0.05253	0.05498	0.05547	0.05550	0.05543	0.05551	0.05548
19	38	0.00982	0.01979	0.02953	0.03866	0.04646	0.05101	0.05245	0.05257	0.05258	0.05252	0.05259	0.05256
20	40	0.00974	0.01983	0.02945	0.03837	0.04570	0.04925	0.04993	0.04994	0.04995	0.04989	0.04996	0.04993

Table No. 24

The Goodness of fit test.
Negative Exponential Breakdown.
Normal Service Time.
Two Servicemen.
Coefficient of Variation = 0.2
Test 1
Keeping service coefficient constant and increasing the number of machines from 1 to 40.

No.	Service Constant.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	0.01	0.00323
2	0.02	0.04493
3	0.03	0.25550
4	0.04	0.91273
5	0.05	2.07191
6	0.06	2.90325
7	0.07	3.05164
8	0.08	3.38247
9	0.09	2.98935
10	0.10	2.54602
11	0.20	3.14785
12	0.30	1.43923

For 19 degrees of freedom, the 5% level of significance is $P(30.144<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2\geqslant 30.144$. Hence, for the 5% level of significance, χ^2=1,2,...12 are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	2	0.00982
2	4	0.23642
3	6	0.51508
4	8	0.91928
5	10	1.07929
6	12	1.18365
7	14	1.09953
8	16	1.09355
9	18	1.25915
10	20	1.43329
11	22	1.76805
12	24	2.00377
13	26	2.04224
14	28	1.81433
15	30	1.54456
16	32	1.35690
17	34	1.05845
18	36	0.86620
19	38	0.77749
20	40	0.68703

For 11 degrees of freedom, the 5% level of significance is $P(19.675<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2\geqslant 19.675$. Hence, for the 5% level of significance, χ^2=1,2,...20 are not significant.

Table No. 25

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	2	0.05	0.06	0.13	0.20	0.25	0.28	0.30	0.37	0.33	0.27	0.63	0.33
2	4	0.07	0.13	0.19	0.26	0.36	0.48	0.53	0.71	0.89	1.07	2.68	4.52
3	6	0.06	0.14	0.22	0.34	0.51	0.73	0.94	1.16	1.39	1.57	4.42	6.54
4	8	0.03	0.08	0.21	0.37	0.55	0.81	1.09	1.38	1.79	2.06	6.49	8.87
5	10	0.04	0.10	0.23	0.43	0.66	1.02	1.40	1.89	2.15	2.67	8.97	7.63
6	12	0.04	0.13	0.31	0.58	0.92	1.35	1.84	2.50	3.17	3.62	10.79	4.00
7	14	0.06	0.17	0.41	0.76	1.18	1.72	2.34	3.01	3.70	4.45	10.06	0.47
8	16	0.07	0.23	0.53	1.00	1.51	2.26	2.96	3.86	4.66	5.69	7.70	-1.23
9	18	0.10	0.31	0.69	1.23	1.89	2.76	3.84	4.89	5.65	6.60	5.21	-1.45
10	20	0.11	0.35	0.77	1.41	2.31	3.44	4.48	5.64	6.55	7.09	3.30	-1.43
11	22	0.12	0.42	0.96	1.72	2.78	3.90	5.25	6.54	7.24	7.94	2.54	-0.92
12	24	0.14	0.48	1.10	2.04	3.34	4.69	6.27	7.53	[illegible]	6.92	1.28	-0.43
13	26	0.14	0.50	1.19	2.20	3.67	5.41	7.16	8.31	7.61	5.12	1.22	0.27
14	28	0.15	0.53	1.29	2.47	4.03	5.67	7.29	8.04	6.32	3.15	1.05	-2.85
15	30	0.16	0.60	1.41	2.70	4.52	6.20	7.04	6.94	4.75	1.48	0.95	1.94
16	32	0.16	0.64	1.57	3.03	5.15	6.78	6.49	5.35	2.91	0.25	0.81	-3.78
17	34	0.17	0.68	1.68	3.26	5.16	6.69	5.29	3.73	1.51	-0.57	0.61	-0.37
18	36	0.19	0.76	1.84	3.52	5.46	6.03	[illegible]	2.20	0.56	-1.02	2.11	-0.21
19	38	0.21	0.93	2.02	3.97	5.84	5.30	2.54	1.16	0.04	-1.16	2.36	0.01
20	40	0.22	0.90	2.26	4.49	5.89	4.23	1.70	0.42	-0.20	-1.16	-0.06	0.19

THE MEAN PERCENTAGE DIFFERENCE IS 2.33184

THE STD. DEVIATION IS 2.62403

NEGATIVE EXPONENTIAL BREAKDOWN

NORMAL SERVICE TIME

TWO SERVICEMEN

COEFFICIENT OF VARIATION 0.2

Table No. 26

MACHINE UTILIZATION M FOR 2 COLLABORTING SERVICEMEN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.3

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.99059	0.98105	[illegible]	0.96376	0.95499	0.94638	0.93771	0.92962	0.92075	0.91175	0.83929	0.77233
2	4	0.99054	0.98111	0.97160	0.96224	0.95352	0.94445	0.93479	0.92705	0.91861	0.91063	0.83180	0.76292
3	6	0.99052	0.98087	0.97120	0.96160	0.95251	0.94378	0.93475	0.92533	0.91649	0.90719	0.81708	0.72743
4	8	0.99010	0.97995	0.97014	0.96021	0.95036	0.94091	0.93061	0.92065	0.91056	0.90002	0.79801	0.68468
5	10	0.99030	0.97962	0.96933	0.95914	0.94900	0.93864	0.92809	0.91768	0.90510	0.89345	0.77573	0.61520
6	12	0.98991	0.97945	0.95902	0.95885	0.94756	0.93704	0.92655	0.91436	0.90260	0.88907	0.74346	0.53194
7	14	0.98995	0.97952	0.95392	0.95832	0.94710	0.93510	0.92287	0.90923	0.89612	0.88196	0.68613	0.45978
8	16	0.99630	0.97954	0.95906	0.95802	0.94582	0.93394	0.92069	0.90659	0.89093	0.87325	0.62220	0.40361
9	18	0.99014	0.97980	0.95912	0.95741	0.94590	0.93237	0.91896	0.90161	0.88232	0.85619	0.55918	0.36107
10	20	0.99017	0.97974	0.95957	0.95668	0.94421	0.93045	0.91276	0.89385	0.86766	0.83853	0.50280	0.32606
11	22	0.99017	0.97970	0.95874	0.95676	0.94398	0.92886	0.90985	0.88140	0.85165	0.81713	0.45715	0.29646
12	24	0.99021	0.97980	0.96860	0.95711	0.94323	0.92604	0.90292	0.87295	0.83327	0.78051	0.41834	0.27508
13	26	0.99009	0.97940	0.95757	0.95466	0.93982	0.92113	0.89391	0.85620	0.80277	0.73652	0.38612	0.25587
14	28	0.99005	0.97907	0.96723	0.95324	0.93532	0.91242	0.87657	0.83034	0.76652	0.69107	0.35842	0.23949
15	30	0.99006	0.97909	0.96676	0.95119	0.93197	0.90176	0.85607	0.79347	0.72396	0.64751	0.33455	0.22555
16	32	0.98994	0.97880	0.95552	0.94993	0.92745	0.88865	0.82977	0.75949	0.68162	0.60117	0.31319	0.20455
17	34	0.98984	0.97840	0.96483	0.94584	0.91835	0.87313	0.79791	0.71967	0.64217	0.57292	0.29406	0.19369
18	36	0.98992	0.97824	0.95416	0.94311	0.90832	0.84991	0.76315	0.68115	0.60710	0.54164	0.27708	0.18313
19	38	0.98934	0.97816	0.95257	0.94024	0.89921	0.82373	0.72694	0.64636	0.57607	0.51405	0.26200	0.17322
20	40	0.98983	0.97787	0.96008	0.93722	0.88565	0.79439	0.69260	0.61497	0.55282	0.48932	0.25415	0.16198

Table No. 27

MACHINE WAITING TIME FOR 2 COLLABORTING SERVICEMEN-(NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.3

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.00000	0.00001	0.00001	0.00001	0.00002	0.00000	0.00001	0.00002	0.00001	0.00001	0.00008	0.00008
2	4	0.00000	0.00001	0.00001	0.00001	0.00002	0.00003	0.00000	0.00040	0.00055	0.00059	0.00458	0.00955
3	6	0.00000	0.00001	0.00009	0.00010	0.00021	0.00040	0.00062	0.00144	0.00162	0.00191	0.01663	0.05632
4	8	0.00000	0.00006	0.00018	0.00047	0.00057	0.00121	0.00181	0.00210	0.00486	0.00683	0.03619	0.10359
5	10	0.00015	0.00010	0.00039	0.00060	0.00112	0.00235	0.00345	0.00514	0.00897	0.01214	0.06717	0.19351
6	12	0.00027	0.00015	0.00041	0.00100	0.00236	0.00338	0.00563	0.00857	0.01250	0.01775	0.09616	0.30241
7	14	0.00040	0.00018	0.00065	0 00160	0.00315	0.00575	0.00807	0.01370	0.01840	0.02475	0.17228	0.39755
8	16	0.00034	0.00033	0.00078	0.00199	0.00453	0.00730	0.01110	0.02744	0.02504	0.02674	0.25322	0.47152
9	18	0.00005	0.00032	0.00115	0.00317	0.00502	0.00929	0.01353	0.02342	0.03485	0.05195	0.32986	0.52796
10	20	0.00000	0.00039	0.00166	0.00374	0.00683	0.01180	0.01895	0.03251	0.05135	0.07407	0.39733	0.57497
11	22	0.00000	0.00048	0.00176	0.00426	0.00777	0.01397	0.02504	0.04578	0.06902	0.09867	0.45207	0.61075
12	24	0.00000	0.00055	0.00194	0.00397	0.00895	0.01731	0.03049	0.05530	0.08966	0.13561	0.49844	0.64170
13	26	0.00006	0.00063	0.00238	0.00526	0.01220	0.02249	0.03039	0.07388	0.12326	0.18729	0.53707	0.66731
14	28	0.00000	0.00098	0.00301	0.00749	0.01660	0.03122	0.05665	0.10152	0.16307	0.23771	0.57025	0.69918
15	30	0.00000	0.00103	0.00397	0.00977	0.02017	0.04255	0.07904	0.13661	0.20965	0.28591	0.59888	0.70787
16	32	0.00001	0.00122	0.00468	0.01104	0.02492	0.05660	0.10637	0.17873	0.25500	0.32941	0.62440	0.73273
17	34	0.00022	0.00151	0.00521	0.01502	0.03422	0.07297	0.14056	0.22169	0.29906	0.36833	0.64720	0.74756
18	36	0.00013	0.00169	0.00598	0.01778	0.04395	0.09748	0.17779	0.26339	0.33740	0.40287	0.66744	0.76137
19	38	0.00016	0.00168	0.00735	0.02085	0.05408	0.12521	0.21471	0.30107	0.37135	0.43238	0.68544	0.77422
20	40	0.00032	0.00011	0.0092	0.02413	0.06844	0.15631	0.25123	0.33509	0.39722	0.46074	0.69592	0.78809

Table No. 28

SERVICE UTILIZATION FOR 2 COLLABORATING SERVICEMEN (NORMAL SERVICE TIME, C MODEL)

COEFFICIENT OF VARIATION FACTOR 0.3

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.01053	0.01894	0.02761	0.03623	0.04459	0.05363	0.06228	0.07036	0.07924	0.08824	0.16063	0.22759
2	4	0.01011	0.01888	0.02839	0.03775	0.04646	0.05552	0.06485	0.07251	0.08084	0.08878	0.16362	0.22753
3	6	0.00996	0.01912	0.02871	0.03810	0.04728	0.05582	0.06453	0.07332	0.08189	0.09090	0.16629	0.22625
4	8	0.01018	0.01999	0.02968	0.03932	0.04907	0.05768	0.06694	0.07615	0.08457	0.09314	0.16380	0.21173
5	10	0.00985	0.02028	0.03028	0.04006	0.04986	0.05901	0.06802	0.07715	0.08593	0.09441	0.15708	0.19123
6	12	0.00982	0.02040	0.03057	0.04025	0.05014	0.05958	0.06811	0.07707	0.08490	0.09321	0.16038	0.16563
7	14	0.00965	0.02036	0.03043	0.04008	0.04974	0.05915	0.06844	0.07702	0.08543	0.09329	0.14159	0.14267
8	16	0.00966	0.02013	0.03016	0.03999	0.04964	0.05876	0.06779	0.07597	0.08403	0.09199	0.12468	0.12484
9	18	0.00981	0.01988	0.02983	0.03952	0.04908	0.05834	0.06674	0.07497	0.08285	0.08986	0.11096	0.11097
10	20	0.00982	0.01987	0.02977	0.03938	0.04892	0.05775	0.06612	0.07364	0.08099	0.08740	0.09986	0.09987
11	22	0.01007	0.01973	0.02959	0.03896	0.04825	0.05717	0.06533	0.07282	0.07933	0.08420	0.09078	0.09079
12	24	0.00997	0.01965	0.02937	0.03892	0.04782	0.05665	0.06472	0.07165	0.07707	0.08078	0.08322	0.08322
13	26	0.00989	0.01998	0.02965	0.03906	0.04798	0.05638	0.06373	0.06992	0.07397	0.07619	0.07681	0.07682
14	28	0.00993	0.01995	0.02976	0.03927	0.04808	0.05636	0.06274	0.06764	0.07041	0.07122	0.07133	0.07133
15	30	0.00996	0.01988	0.02967	0.03904	0.04786	0.05569	0.06163	0.06492	0.06639	0.06659	0.06657	0.06659
16	32	0.01005	0.01998	0.02980	0.03903	0.04763	0.05475	0.05979	0.06178	0.06238	0.06242	0.06241	0.06242
17	34	0.00994	0.02009	0.02996	0.03914	0.04743	0.05390	0.05751	0.05864	0.05877	0.05875	0.05874	0.05875
18	36	0.00995	0.02007	0.02986	0.03911	0.04723	0.05261	0.05507	0.05546	0.05550	0.05549	0.05548	0.05549
19	38	0.00990	0.01996	0.02978	0.03891	0.04671	0.05106	0.05244	0.05257	0.05256	0.05256	0.05256	0.05256
20	40	0.00985	0.02002	0.02972	0.03865	0.04591	0.04930	0.04992	0.04994	0.04995	0.04994	0.04993	0.04993

Table No. 29

The Goodness of fit test.
Negative Exponential Breakdown.
Normal Service Time.
Two Servicemen.
Coefficient of Variation = 0.3
Test No. 1
Keeping service coefficient constant and increasing the number of machines from 1 to 40.

No.	Service Constant.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	0.01	0.00729
2	0.02	0.04044
3	0.03	0.22448
4	0.04	0.81479
5	0.05	1.81161
6	0.06	2.53062
7	0.07	2.70029
8	0.08	2.94348
9	0.09	2.65036
10	0.10	2.30874
11	0.20	2.70630
12	0.30	1.30771

For 19 degrees of freedom, the 5% level of significance is $P(30.144 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 30.144$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 12$ are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	2	0.01246
2	4	0.22465
3	6	0.48220
4	8	0.82403
5	10	0.96192
6	12	1.06894
7	14	0.98105
8	16	1.02780
9	18	1.13854
10	20	1.28488
11	22	1.58271
12	24	1.82114
13	26	1.79673
14	28	1.58837
15	30	1.34816
16	32	1.11056
17	34	0.89246
18	36	0.71595
19	38	0.62124
20	40	0.56230

For 11 degrees of freedom, the 5% level of significance is $P(19.675 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 19.675$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 20$ are not significant.

Table No. 30

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	2	0.05	0.07	0.13	0.23	0.27	0.32	0.34	0.40	0.36	0.29	0.72	0.40
2	4	0.07	0.11	0.16	0.22	0.35	0.43	0.45	0.68	0.81	1.06	2.59	4.46
3	6	0.06	0.13	0.21	0.33	0.49	0.72	0.93	1.11	1.36	1.58	4.23	6.34
4	8	0.03	0.05	0.19	0.34	0.53	0.80	1.02	1.31	1.61	1.59	6.11	6.48
5	10	0.03	0.08	0.21	0.41	0.66	1.00	1.35	1.79	2.04	2.45	8.47	7.20
6	12	0.03	0.11	0.28	0.56	0.85	1.31	1.87	2.35	2.97	3.46	10.39	3.16
7	14	0.05	0.17	0.39	0.74	1.16	1.65	2.26	2.86	3.65	4.47	9.22	-0.15
8	16	0.07	0.22	0.52	0.94	1.42	2.14	2.91	3.83	4.71	5.58	7.05	-1.80
9	18	0.09	0.29	0.66	1.13	1.87	2.66	3.75	4.66	5.65	6.27	4.57	-2.02
10	20	0.10	0.34	0.74	1.35	2.18	3.24	4.24	5.46	6.16	6.76	2.44	-2.02
11	22	0.12	0.40	0.90	1.64	2.70	3.46	5.27	5.94	6.43	7.42	1.42	-1.46
12	24	0.13	0.46	1.05	2.01	3.23	4.67	6.05	7.19	7.56	6.42	0.75	-0.95
13	26	0.13	0.49	1.14	2.12	3.55	5.29	6.81	7.72	7.03	4.57	0.53	-0.21
14	28	0.14	0.51	1.25	2.36	3.87	5.62	6.80	7.46	5.97	2.58	0.41	0.59
15	30	0.16	0.56	1.35	2.59	4.33	5.90	6.64	6.52	4.15	0.51	0.39	1.50
16	32	0.15	0.62	1.47	2.94	4.60	6.07	5.97	4.85	2.35	-0.47	0.23	-1.67
17	34	0.16	0.65	1.62	3.04	4.88	6.15	4.76	3.11	0.89	-1.32	-0.02	-1.21
18	36	0.16	0.71	1.80	3.35	5.03	5.47	3.31	1.55	-0.06	-1.80	-0.25	-1.11
19	38	0.20	0.78	1.92	3.70	5.32	4.59	1.71	0.45	-0.58	-1.56	-0.44	-1.26
20	40	0.20	0.84	1.91	4.12	5.30	3.44	0.42	-0.25	0.02	-1.95	1.66	-2.81

THE MEAN PERCENTAGE DIFFERENCE IS 2.10003

THE STD. DEVIATION IS 2.52878

NEGATIVE EXPONENTIAL BREAKDOWN

NORMAL SERVICE TIME

TWO SERVICEMEN

COEFFICIENT OF VARIATION 0.3

Table No. 31

MACHINE UTILIZATION M FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 1

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.99029	0.98020	0.97033	0.96055	0.95057	0.94067	0.93066	0.92123	0.91125	0.90381	0.84050	0.76696
2	2	0.98987	0.97932	0.96833	0.95675	0.94509	0.93399	0.92398	0.91345	0.90092	0.88928	0.80285	0.71678
3	3	0.98924	0.97728	0.96602	0.95416	0.94083	0.92952	0.91741	0.90508	0.89056	0.87636	0.75306	0.65168
4	4	0.98914	0.97685	0.96469	0.95235	0.93910	0.92527	0.91355	0.89653	0.88288	0.86650	0.73314	0.59324
5	5	0.98983	0.97837	0.96625	0.95255	0.93858	0.92502	0.91011	0.89537	0.87780	0.86015	0.68015	0.54270
6	6	0.98969	0.97820	0.96574	0.95184	0.93861	0.92120	0.90450	0.88539	0.86580	0.84555	0.62494	0.47799
7	7	0.98950	0.97721	0.96552	0.95183	0.93669	0.91891	0.90010	0.88178	0.86003	0.83757	0.57861	0.43510
8	8	0.98934	0.97701	0.96245	0.94662	0.92887	0.90956	0.88893	0.86321	0.84117	0.81995	0.54636	0.38414
9	9	0.98936	0.97676	0.96290	0.94603	0.92831	0.90823	0.89474	0.85750	0.82751	0.79854	0.50266	0.34782
10	10	0.98886	0.97525	0.95991	0.94029	0.91822	0.89295	0.86526	0.83560	0.80720	0.78056	0.46346	0.31616
11	11	0.98920	0.97593	0.95966	0.93727	0.91180	0.88386	0.85398	0.81864	0.77892	0.74623	0.42477	0.28862
12	12	0.98885	0.97432	0.95687	0.93365	0.90399	0.87360	0.83896	0.80412	0.75969	0.71627	0.39249	0.26920
13	13	0.98879	0.97384	0.95553	0.92866	0.89765	0.86259	0.82785	0.77594	0.73252	0.68354	0.36320	0.25037
14	14	0.98549	0.97337	0.95244	0.92510	0.89603	0.85723	0.80995	0.75535	0.70169	0.64995	0.33900	0.23609
15	15	0.98871	0.97281	0.95175	0.92452	0.89048	0.84965	0.78986	0.72676	0.66943	0.61693	0.31575	0.22074
16	16	0.98864	0.97305	0.95151	0.92075	0.88046	0.82944	0.76884	0.69455	0.63946	0.58674	0.29772	0.21095
17	17	0.98874	0.97239	0.94864	0.91821	0.87146	0.81388	0.74613	0.66980	0.60775	0.55339	0.27952	0.19469
18	18	0.98846	0.97254	0.95044	0.91245	0.86084	0.79241	0.71762	0.64335	0.57748	0.52769	0.26458	0.18359
19	19	0.98832	0.97118	0.94449	0.90760	0.84712	0.77700	0.69450	0.61553	0.54806	0.50203	0.25102	0.17749
20	20	0.98784	0.96922	0.94206	0.90012	0.83701	0.75470	0.66770	0.59073	0.52498	0.47875	0.23591	0.16777

Table No. 32

MACHINE WAITING TIME FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 1

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00001	0.00000	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
2	2	0.00024	0.00045	0.00115	0.00001	0.00467	0.00607	0.00728	0.00824	0.00089	0.01397	0.03320	0.06059
3	3	0.00031	0.00168	0.00286	0.00466	0.00820	0.00997	0.01304	0.01760	0.01282	0.02889	0.08316	0.14112
4	4	0.00027	0.00174	0.00366	0.00570	0.00840	0.01231	0.01556	0.02326	0.02886	0.03645	0.11124	0.20707
5	5	0.00027	0.00151	0.00375	0.00753	0.01152	0.01638	0.02210	0.02847	0.03829	0.04730	0.17077	0.28481
6	6	0.00066	0.00231	0.00536	0.00967	0.01388	0.02187	0.03024	0.04187	0.05376	0.06644	0.23543	0.36725
7	7	0.00059	0.00280	0.00479	0.00901	0.01559	0.02510	0.03611	0.04723	0.06147	0.07739	0.29319	0.42696
8	8	0.00102	0.00363	0.00873	0.01522	0.02394	0.03489	0.04664	0.06470	0.08003	0.09626	0.33651	0.49327
9	9	0.00064	0.00215	0.00725	0.01474	0.02389	0.03646	0.05265	0.07290	0.09607	0.11918	0.39000	0.54169
10	10	0.00103	0.00438	0.00725	0.02070	0.03384	0.05129	0.07147	0.09572	0.11875	0.14959	0.43834	0.58413
11	11	0.00075	0.00381	0.01027	0.02330	0.04030	0.05053	0.08376	0.11293	0.14799	0.17735	0.46511	0.62073
12	12	0.00122	0.00560	0.01027	0.02720	0.04836	0.07120	0.09915	0.12866	0.16857	0.20930	0.52491	0.64771
13	13	0.00115	0.00628	0.01315	0.02299	0.05549	0.08308	0.11665	0.15872	0.19928	0.24556	0.56055	0.67293
14	14	0.00162	0.00663	0.01499	0.03655	0.05775	0.08953	0.13494	0.16147	0.23220	0.29333	0.59020	0.69278
15	15	0.00140	0.00744	0.01805	0.03685	0.06329	0.09727	0.15261	0.21212	0.26717	0.31658	0.61776	0.71279
16	16	0.00141	0.00707	0.01897	0.04129	0.07365	0.11900	0.17536	0.24173	0.30022	0.35234	0.64991	0.72673
17	17	0.00144	0.00776	0.02204	0.04386	0.08344	0.13568	0.20000	0.27401	0.33495	0.38895	0.66178	0.74635
18	18	0.00169	0.00769	0.02052	0.04989	0.09473	0.15849	0.22929	0.30291	0.36798	0.41757	0.67968	0.76092
19	19	0.00188	0.00802	0.02659	0.05541	0.10887	0.17504	0.25536	0.33323	0.40009	0.43497	0.69646	0.76995
20	20	0.00233	0.01096	0.02861	0.06204	0.11991	0.19866	0.28387	0.35920	0.42542	0.47190	0.71019	0.78229

Table No. 33

SERVICE UTILIZATION FOR A SINGLE SERVICEMAN-(EPLANG SERVICE TIME, C MODEL)

MUMBER OF PHASES 1

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00970	0.01980	0.02966	0.03944	0.04942	0.05932	0.06931	0.07876	0.08874	0.09618	0.15949	0.21301
2	2	0.00989	0.02023	0.03052	0.02324	0.05024	0.05994	0.06874	0.07831	0.08819	0.09675	0.16385	0.22063
3	3	0.01045	0.02104	0.03112	0.04096	0.05097	0.06011	0.06951	0.07732	0.08662	0.09475	0.16384	0.20720
4	4	0.01063	0.02141	0.03165	0.04195	0.05250	0.06242	0.07086	0.08021	0.08826	0.09705	0.15562	0.19664
5	5	0.00990	0.02012	0.03000	0.03992	0.04990	0.05860	0.06779	0.07616	0.08391	0.09255	0.14908	0.17249
6	6	0.00965	0.01949	0.02866	0.03849	0.04751	0.05693	0.06496	0.07274	0.08044	0.08881	0.13963	0.15496
7	7	0.00991	0.01999	0.02969	0.03916	0.04772	0.05598	0.06379	0.07098	0.07850	0.08504	0.12860	0.13794
8	8	0.00964	0.01936	0.02882	0.03816	0.04719	0.05555	0.06443	0.07209	0.07880	0.08379	0.11681	0.12259
9	9	0.01000	0.02009	0.02965	0.03923	0.04780	0.05531	0.06261	0.06920	0.07642	0.08226	0.10714	0.11049
10	10	0.01009	0.02037	0.02982	0.03901	0.04794	0.05576	0.06327	0.06866	0.07405	0.07685	0.09820	0.09971
11	11	0.01005	0.02026	0.02987	0.03943	0.04790	0.05561	0.06226	0.06843	0.07309	0.07642	0.09012	0.09065
12	12	0.00992	0.02006	0.02988	0.03915	0.04765	0.05500	0.06187	0.06722	0.07154	0.07443	0.08261	0.08309
13	13	0.00966	0.01988	0.02948	0.03835	0.04686	0.05433	0.06030	0.06534	0.06820	0.07090	0.07625	0.07670
14	14	0.00990	0.02000	0.02951	0.03835	0.04622	0.05319	0.05921	0.06317	0.06601	0.06762	0.07080	0.07122
15	15	0.00989	0.01975	0.02928	0.03823	0.04623	0.05268	0.05759	0.06113	0.06340	0.06449	0.06649	0.06647
16	16	0.00995	0.01988	0.02916	0.03796	0.04569	0.05156	0.05580	0.05872	0.06032	0.06092	0.06237	0.06272
17	17	0.00982	0.01985	0.02932	0.03793	0.04519	0.05044	0.05387	0.05613	0.05730	0.05766	0.05870	0.05876
18	18	0.00985	0.01977	0.02904	0.03766	0.04443	0.04910	0.05209	0.05374	0.05454	0.05474	0.05544	0.05544
19	19	0.00980	0.01979	0.02892	0.03699	0.04401	0.04796	0.05014	0.05124	0.05185	0.05220	0.05252	0.05257
20	20	0.00983	0.01982	0.02933	0.03784	0.04308	0.04664	0.04843	0.04907	0.04960	0.04975	0.04990	0.04994

Table No. 34

The Goodness of fit test.
Negative Exponential Breakdown.
Erlang Service Time.
Single Serviceman.
No. of phases 1
Test No. 1
Keeping service coefficient constant and increasing the number of machines from 1 to 20.

No.	Service Constant.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	0.01	0.00016
2	0.02	0.00192
3	0.03	0.00628
4	0.04	0.02200
5	0.05	0.06369
6	0.06	0.15497
7	0.07	0.39071
8	0.08	0.80767
9	0.09	1.07484
10	0.10	0.96794
11	0.20	2.52756
12	0.30	1.51965

For 19 degrees of freedom, the 5% level of significance is $P(30.144 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 30.144$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 12$ are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	1	0.05962
2	2	0.07393
3	3	0.36086
4	4	0.36572
5	5	0.37845
6	6	0.67238
7	7	0.54960
8	8	0.42195
9	9	0.32450
10	10	0.29320
11	11	0.33783
12	12	0.27742
13	13	0.33071
14	14	0.32756
15	15	0.38148
16	16	0.39716
17	17	0.48694
18	18	0.51299
19	19	0.51406
20	20	0.47104

For 11 degrees of freedom, the 5% level of significance is $P(19.675 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 19.675$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 20$ are not significant.

Table No. 35

THE PERCENTAGE DIFFERENCES ARE
SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	1	0.02	-0.02	-0.06	-0.10	-0.19	-0.29	-0.42	-0.51	-0.67	-0.58	0.86	2.31
2	2	-0.01	-0.07	-0.18	-0.35	-0.54	-0.68	-0.71	-0.81	-1.13	-1.37	-0.98	-1.56
3	3	-0.07	-0.24	-0.33	-0.46	-0.74	-0.76	-0.94	-1.19	-1.51	-1.88	-3.94	-4.74
4	4	-0.07	-0.24	-0.37	-0.48	-0.66	-0.87	-0.83	-1.35	-1.48	-1.91	-2.52	-6.01
5	5	0.01	-0.04	-0.11	-0.28	-0.42	-0.47	-0.61	-0.69	-1.04	-1.37	-4.69	-5.43
6	6	0.01	-0.02	-0.05	-0.16	-0.10	-0.40	-0.52	-0.89	-1.23	-1.58	-7.20	-7.33
7	7	0.00	-0.07	0.04	0.06	0.05	-0.11	-0.27	-0.25	-0.52	-0.79	-7.99	-5.51
8	8	-0.00	-0.04	-0.16	-0.26	-0.39	-0.53	-0.64	-1.17	-1.13	-0.86	-5.99	-6.54
9	9	0.01	-0.02	0.01	-0.07	-0.02	0.01	-0.11	-0.79	-0.91	-1.10	-5.96	-5.61
10	10	-0.03	-0.12	-0.16	-0.41	-0.63	-0.92	-1.19	-1.41	-1.24	-0.62	-5.57	-4.99
11	11	0.02	0.01	-0.02	-0.43	-0.80	-1.07	-1.19	-1.60	-2.29	-1.90	-5.77	-4.70
12	12	-0.01	-0.10	-0.17	-0.49	-1.06	-1.23	-1.46	-1.26	-1.91	-2.36	-5.48	-3.07
13	13	0.00	-0.09	-0.16	-0.67	-1.10	-1.40	-1.66	-2.37	-2.33	-2.95	-5.44	-2.35
14	14	-0.02	-0.08	-0.30	-0.66	-0.54	-0.77	-1.80	-2.30	-2.59	-3.66	-5.03	-0.88
15	15	0.02	-0.07	-0.18	-0.24	-0.32	-0.29	-1.61	-3.05	-3.70	-3.95	-5.26	-0.67
16	16	0.02	0.03	-0.00	-0.22	-0.51	-1.00	-1.81	-3.43	-3.98	-3.96	-4.72	1.26
17	17	0.05	0.03	-0.06	0.03	-0.48	-1.05	-2.03	-4.03	-4.52	-4.69	-4.96	-0.60
18	18	0.03	0.12	0.35	-0.01	-0.51	-1.66	-2.86	-4.09	-4.94	-4.33	-4.71	-0.86
19	19	0.03	0.06	-0.02	0.10	-0.78	-1.34	-2.83	-4.34	-5.41	-4.10	-4.61	1.17
20	20	-0.05	-0.06	0.00	-0.00	-0.49	-1.72	-3.22	-4.19	-5.02	-4.15	-4.03	0.67

THE MEAN PERCENTAGE DIFFERENCE IS -1.44791

THE STD. DEVIATION IS 1.28861

NEGATIVE EXPONENTIAL BREAKDOWN

ERLANG SERVICE TIME

NO. OF PHASES 1

SINGLE SERVICEMAN

Table No. 36

MACHINE UTILIZATION M FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 2

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.99009	0.98956	0.35374	0.95678	0.94844	0.93607	0.93238	0.91746	0.90774	0.89884	0.81535	0.74960
2	2	0.99004	0.97851	0.35752	0.95721	0.94669	0.93542	0.92451	0.91443	0.90175	0.89039	0.79345	0.72183
3	3	0.98953	0.97893	0.36775	0.95614	0.94582	0.93162	0.92067	0.90971	0.89783	0.88434	0.77164	0.67186
4	4	0.98934	0.97836	0.36704	0.95544	0.94299	0.93071	0.91926	0.90609	0.89434	0.88135	0.74909	0.63468
5	5	0.98930	0.97804	0.36620	0.95426	0.94098	0.92766	0.91268	0.89841	0.88459	0.86842	0.71223	0.57123
6	6	0.98989	0.97803	0.35680	0.95484	0.94115	0.92547	0.91085	0.89443	0.87622	0.85884	0.67247	0.50058
7	7	0.98952	0.97846	0.36675	0.95272	0.93681	0.92100	0.90532	0.88583	0.86552	0.84532	0.61621	0.44562
8	8	0.98976	0.97761	0.35477	0.95025	0.93435	0.91527	0.89776	0.87882	0.85770	0.83499	0.56366	0.39523
9	9	0.98941	0.97734	0.35479	0.95029	0.93288	0.91333	0.89224	0.86916	0.84373	0.81861	0.51851	0.36180
10	10	0.98923	0.97610	0.36276	0.94649	0.93123	0.90696	0.88238	0.85222	0.82796	0.79827	0.47447	0.32072
11	11	0.98939	0.97616	0.35123	0.94197	0.92024	0.89537	0.86843	0.83987	0.80918	0.77058	0.43471	0.29385
12	12	0.98909	0.97573	0.35973	0.93902	0.91615	0.89008	0.85519	0.82066	0.78859	0.74624	0.40300	0.26960
13	13	0.98726	0.97474	0.35754	0.93738	0.91100	0.87713	0.83685	0.79772	0.75950	0.71422	0.37496	0.25130
14	14	0.98889	0.97425	0.35703	0.93454	0.90639	0.86961	0.82217	0.77426	0.72293	0.67915	0.34228	0.23555
15	15	0.98890	0.97336	0.35414	0.92856	0.89726	0.85830	0.80758	0.74514	0.68784	0.64021	0.32083	0.21920
16	16	0.98877	0.97249	0.35252	0.92401	0.88515	0.84288	0.78779	0.71354	0.65207	0.60561	0.30317	0.20860
17	17	0.98891	0.97245	0.35045	0.91917	0.87465	0.81997	0.76314	0.66238	0.61627	0.57111	0.28541	0.20446
18	18	0.98885	0.97284	0.35100	0.91491	0.86613	0.80406	0.73619	0.65068	0.58327	0.54002	0.27084	0.18679
19	19	0.98869	0.97218	0.34751	0.91045	0.85295	0.73540	0.70953	0.62051	0.55543	0.51374	0.25741	0.17726
20	20	0.98842	0.97116	0.34534	0.90400	0.84408	0.76475	0.63155	0.59153	0.52470	0.48959	0.24645	0.16799

Table No. 37

MACHINE WAITING TIME FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 2

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00001	0.00000	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
2	2	0.00006	0.00020	0.00100	0.00081	0.00126	0.00218	0.00318	0.00444	0.00691	0.02095	0.04841	0.04659
3	3	0.00020	0.00075	0.00173	0.00397	0.00517	0.00018	0.01882	0.01385	0.01698	0.02153	0.05000	0.10691
4	4	0.00016	0.00112	0.00221	0.00374	0.00591	0.00837	0.01136	0.01567	0.01876	0.02275	0.09479	0.16850
5	5	0.00025	0.00169	0.00363	0.00553	0.00930	0.01411	0.02036	0.02626	0.03199	0.03905	0.13439	0.25293
6	6	0.00042	0.00195	0.00354	0.00587	0.01027	0.01688	0.02340	0.03018	0.04154	0.05192	0.18520	0.34279
7	7	0.00052	0.00198	0.00409	0.00892	0.01544	0.02284	0.03033	0.04179	0.05435	0.06692	0.25324	0.41472
8	8	0.00057	0.00276	0.00640	0.01135	0.01833	0.02888	0.03842	0.05026	0.06398	0.08066	0.31788	0.46115
9	9	0.00067	0.00228	0.00665	0.01064	0.01925	0.03066	0.04437	0.05997	0.07907	0.09799	0.37310	0.52832
10	10	0.00076	0.00354	0.06735	0.01420	0.02080	0.03683	0.05391	0.07736	0.09589	0.12044	0.42652	0.57944
11	11	0.00058	0.00323	0.00820	0.01804	0.03117	0.04707	0.06601	0.09036	0.11153	0.14913	0.47500	0.61539
12	12	0.00098	0.00378	0.01019	0.02113	0.03525	0.05328	0.08142	0.11034	0.13445	0.17680	0.51403	0.64720
13	13	0.00287	0.00519	0.01282	0.02353	0.04104	0.06724	0.10052	0.13467	0.16924	0.21193	0.54845	0.67190
14	14	0.00119	0.00547	0.01323	0.02657	0.04650	0.07565	0.11676	0.15986	0.20706	0.25084	0.58660	0.69314
15	15	0.00117	0.00654	0.01651	0.03257	0.05600	0.08823	0.13318	0.19176	0.24709	0.29379	0.61280	0.71424
16	16	0.00124	0.00742	0.01774	0.03744	0.06866	0.10470	0.15511	0.22605	0.28609	0.33242	0.63460	0.72900
17	17	0.00131	0.00742	0.01962	0.04247	0.07980	0.12858	0.18146	0.25975	0.32527	0.37024	0.65608	0.73681
18	18	0.00123	0.00706	0.01959	0.04679	0.08653	0.14545	0.21123	0.29416	0.36133	0.40349	0.67385	0.75775
19	19	0.00144	0.00791	0.02309	0.05185	0.10213	0.16545	0.23916	0.32711	0.39209	0.43369	0.69019	0.77020
20	20	0.00178	0.00913	0.02552	0.05848	0.11202	0.18751	0.26912	0.35854	0.42544	0.46038	0.70377	0.78209

Table No. 38

SERVICE UTILIZATION FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, Q MODEL)

NUMBER OF PHASES 2

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00990	0.02087	0.03075	0.04121	0.05155	0.06192	0.07236	0.08253	0.09225	0.10115	0.18464	0.25039
2	2	0.00990	0.02119	0.03106	0.04198	0.05205	0.06240	0.07231	0.08113	0.09134	0.07666	0.12814	0.23158
3	3	0.01027	0.02032	0.03352	0.03989	0.04901	0.05820	0.06051	0.07644	0.08519	0.09413	0.16836	0.22123
4	4	0.01050	0.02052	0.03075	0.04082	0.05110	0.06092	0.06938	0.07824	0.08686	0.09540	0.15612	0.19682
5	5	0.00985	0.02027	0.03017	0.04021	0.04972	0.05823	0.06696	0.07533	0.08342	0.09233	0.15338	0.17564
6	6	0.00969	0.02002	0.02966	0.03929	0.04855	0.05765	0.06575	0.07375	0.08224	0.09324	0.14233	0.15623
7	7	0.00986	0.01956	0.02916	0.03836	0.04775	0.05616	0.06435	0.07238	0.08013	0.09776	0.13055	0.13966
8	8	0.00967	0.01963	0.02923	0.03840	0.04732	0.05585	0.06362	0.07092	0.07832	0.08435	0.11846	0.12362
9	9	0.00992	0.01988	0.02956	0.03907	0.04767	0.05601	0.06339	0.07087	0.07720	0.08340	0.10839	0.10988
10	10	0.01001	0.02036	0.02989	0.03931	0.04797	0.05612	0.06371	0.07042	0.07615	0.08129	0.09901	0.09984
11	11	0.01003	0.02061	0.03042	0.03999	0.04859	0.05656	0.06356	0.06977	0.07490	0.07929	0.09029	0.09076
12	12	0.00993	0.02044	0.03043	0.03985	0.04860	0.05664	0.06339	0.06900	0.07351	0.07696	0.08297	0.08320
13	13	0.00987	0.02007	0.02964	0.03909	0.04796	0.05563	0.06263	0.06761	0.07126	0.07385	0.07659	0.07680
14	14	0.00993	0.02028	0.02974	0.03889	0.04711	0.05454	0.06107	0.06588	0.06832	0.07001	0.07112	0.07131
15	15	0.00993	0.02010	0.02935	0.03887	0.04674	0.05347	0.05924	0.06308	0.06507	0.06600	0.06637	0.06656
16	16	0.00999	0.02009	0.02974	0.03855	0.04619	0.05242	0.05710	0.06041	0.06184	0.06197	0.06223	0.06240
17	17	0.00988	0.02013	0.02992	0.03836	0.04555	0.05145	0.05540	0.05787	0.05846	0.05865	0.05856	0.05873
18	18	0.00992	0.02010	0.02941	0.03830	0.04534	0.05049	0.05258	0.05516	0.05540	0.05549	0.05531	0.05546
19	19	0.00987	0.01991	0.02940	0.03770	0.04492	0.04915	0.05131	0.05238	0.05249	0.05257	0.05240	0.05254
20	20	0.00980	0.01971	0.02914	0.03752	0.04390	0.04774	0.04933	0.04993	0.04986	0.04993	0.04978	0.04992

Table No. 39

The Goodness of fit test.
Negative Exponential Breakdown.
Erlang Service Time.
Single Serviceman.
No. of phases 2
Test No. 1
Keeping service coefficient constant and increasing the number of machines from 1 to 20.

No.	Service Constant.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	0.01	0.00051
2	0.02	0.00989
3	0.03	0.00645
4	0.04	0.01155
5	0.05	0.02190
6	0.06	0.03637
7	0.07	0.04594
8	0.08	0.03415
9	0.09	0.54807
10	0.10	0.21729
11	0.20	0.58739
12	0.30	0.39886

For 19 degrees of freedom, the 5% level of significance is $P(30.144<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2 \geqslant 30.144$. Hence, for the 5% level of significance, $\chi^2=1,2,\ldots 12$ are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	1	0.13319
2	2	0.08487
3	3	0.06507
4	4	0.00682
5	5	0.00754
6	6	0.04294
7	7	0.07282
8	8	0.13171
9	9	0.10430
10	10	0.15060
11	11	0.12527
12	12	0.11719
13	13	0.06158
14	14	0.07672
15	15	0.07182
16	16	0.08410
17	17	0.17786
18	18	0.20430
19	19	0.22418
20	20	0.28283

For 11 degrees of freedom, the 5% level of significance is $P(19.675<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2 \geqslant 19.675$. Hence, for the 5% level of significance, $\chi^2=1,2,\ldots 20$ are not significant.

Table No. 40

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	1	0.00	0.04	-0.17	-0.29	-0.41	-0.56	-0.23	-0.91	-1.06	-1.13	-2.16	-2.55
2	2	0.01	-0.15	-0.22	-0.30	-0.37	-0.53	-0.65	-0.70	-1.04	-1.25	-2.14	-1.16
3	3	-0.04	-0.07	-0.15	-0.26	-0.22	-0.58	-0.59	-0.60	-0.70	-0.98	-1.56	-1.79
4	4	-0.05	-0.09	-0.13	-0.16	-0.25	-0.29	-0.21	-0.30	-0.20	-0.17	-0.40	0.55
5	5	0.02	-0.08	-0.11	-0.10	-0.17	-0.19	-0.33	-0.35	-0.27	-0.42	-0.41	-0.46
6	6	0.03	-0.03	0.05	0.16	0.17	0.06	0.15	0.13	-0.04	-0.03	-0.15	-2.85
7	7	0.01	0.06	0.16	0.15	0.07	0.12	0.31	0.20	0.11	0.13	-1.91	-3.22
8	8	0.04	0.02	0.04	0.12	0.19	0.10	0.35	0.62	0.81	0.95	-3.02	-3.84
9	9	0.02	0.09	0.21	0.39	0.47	0.57	0.73	0.91	1.03	1.37	-3.04	-1.82
10	10	0.01	-0.03	0.13	0.25	0.77	0.63	0.77	0.55	1.30	1.64	-3.33	-3.62
11	11	0.04	0.03	0.12	0.07	0.12	0.21	0.48	0.95	1.51	1.30	-3.56	-2.98
12	12	0.02	0.05	0.08	0.08	0.27	0.61	0.44	0.77	1.79	1.73	-2.95	-2.93
13	13	-0.15	0.09	0.05	0.27	0.37	0.26	-0.01	0.37	1.27	1.40	-2.38	-1.99
14	14	0.02	0.01	0.18	0.36	0.61	0.67	0.17	0.14	-0.06	0.81	-4.12	-1.07
15	15	0.04	-0.01	0.07	0.15	0.44	0.80	0.60	-0.59	-1.05	-0.33	-3.74	-1.36
16	16	0.04	-0.03	0.10	0.13	0.02	0.61	0.61	-1.50	-2.09	-0.89	-2.98	0.13
17	17	0.05	0.04	0.11	0.14	-0.11	-0.31	0.20	-2.23	-3.18	-1.64	-2.96	4.28
18	18	0.07	0.15	0.41	0.26	0.33	-0.22	-0.34	-3.00	-3.99	-2.10	-2.49	0.87
19	19	0.07	0.17	0.30	0.42	-0.10	-0.27	-0.72	-3.57	-4.14	-2.02	-2.18	1.04
20	20	0.06	0.14	0.35	0.43	0.35	-0.42	-1.21	-4.06	-5.07	-1.88	-1.42	0.80

THE MEAN PERCENTAGE DIFFERENCE IS -0.38687

THE STD. DEVIATION IS 1.27760

NEGATIVE EXPONENTIAL BREAKDOWN

ERLANG SERVICE TIME

NO. OF PHASES 2

SINGLE SERVICEMAN

Table No. 41

MACHINE UTILIZATION H FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 4

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.98947	0.97909	0.96911	0.95864	0.94822	0.93773	0.92732	0.91735	0.90753	0.89879	0.81656	0.75191
2	2	0.98964	0.97904	0.96850	0.95804	0.94737	0.93687	0.92568	0.91588	0.90441	0.89303	0.80137	0.72653
3	3	0.98972	0.97924	0.96843	0.95744	0.94618	0.93442	0.92244	0.91080	0.89933	0.88785	0.77745	0.68063
4	4	0.98956	0.97856	0.96761	0.95657	0.94409	0.93239	0.92229	0.91063	0.89861	0.88583	0.75587	0.64330
5	5	0.98979	0.97852	0.96673	0.95557	0.94276	0.92995	0.91573	0.90294	0.88847	0.87345	0.72864	0.58470
6	6	0.98956	0.97853	0.96707	0.95537	0.94260	0.92802	0.91385	0.89923	0.88160	0.86388	0.67599	0.51257
7	7	0.98934	0.97890	0.96742	0.95455	0.94014	0.92459	0.90384	0.89013	0.87139	0.85182	0.62194	0.45249
8	8	0.98964	0.97830	0.96574	0.95234	0.93674	0.91980	0.90279	0.88530	0.86534	0.84188	0.57153	0.39752
9	9	0.98959	0.97830	0.96615	0.95231	0.93705	0.91644	0.89617	0.87509	0.85196	0.82657	0.52114	0.35568
10	10	0.98926	0.97701	0.96440	0.94972	0.93425	0.91349	0.89152	0.86216	0.83300	0.80582	0.47193	0.32142
11	11	0.98933	0.97708	0.96303	0.94615	0.92426	0.90122	0.87703	0.84766	0.81805	0.78050	0.43130	0.29928
12	12	0.98919	0.97667	0.96175	0.94308	0.92234	0.89622	0.86390	0.83031	0.79730	0.75538	0.39699	0.26995
13	13	0.98929	0.97594	0.95925	0.94124	0.91505	0.88420	0.84721	0.80995	0.76690	0.72379	0.37132	0.24888
14	14	0.98921	0.97564	0.95745	0.93912	0.91208	0.87991	0.83267	0.78547	0.73262	0.68575	0.34457	0.23283
15	15	0.98906	0.97487	0.95711	0.93422	0.90330	0.86952	0.81928	0.75690	0.69436	0.64521	0.32317	0.21925
16	16	0.98871	0.97371	0.95575	0.92990	0.89544	0.84927	0.79717	0.72532	0.66087	0.60618	0.30378	0.20564
17	17	0.98890	0.97372	0.95371	0.92627	0.88515	0.83300	0.77418	0.69255	0.62471	0.57078	0.28566	0.19230
18	18	0.98873	0.97376	0.95473	0.92254	0.87661	0.81740	0.74854	0.66088	0.58898	0.53945	0.27080	0.18309
19	19	0.98869	0.97343	0.95043	0.91647	0.86446	0.79891	0.71825	0.63022	0.56107	0.51230	0.25917	0.17626
20	20	0.98856	0.97265	0.94323	0.91249	0.85516	0.77489	0.68653	0.60058	0.53364	0.48669	0.24647	0.16678

Table No. 42

MACHINE WAITING TIME FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 4

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
2	2	0.00010	0.00008	0.00005	0.00051	0.00138	0.00171	0.00289	0.00393	0.00570	0.00777	0.02195	0.04019
3	3	0.00029	0.00060	0.00128	0.00276	0.00423	0.00772	0.01072	0.01337	0.01589	0.01880	0.05376	0.09777
4	4	0.00021	0.00096	0.00171	0.00274	0.00506	0.00680	0.00828	0.01129	0.01494	0.01937	0.08708	0.15646
5	5	0.00026	0.00133	0.00301	0.00441	0.00777	0.01149	0.01697	0.02167	0.02774	0.03444	0.11587	0.23773
6	6	0.00044	0.00154	0.00345	0.00552	0.00902	0.01436	0.01991	0.02679	0.03622	0.04654	0.17995	0.32927
7	7	0.00041	0.00162	0.00352	0.00692	0.01228	0.01916	0.02682	0.03754	0.04818	0.06031	0.24620	0.40745
8	8	0.00046	0.00222	0.00517	0.00935	0.01615	0.02417	0.03350	0.04333	0.05568	0.07260	0.30884	0.47826
9	9	0.00057	0.00198	0.00444	0.00689	0.01520	0.02566	0.04035	0.05417	0.07053	0.08970	0.36986	0.53349
10	10	0.00077	0.00285	0.00589	0.01120	0.01809	0.03015	0.04455	0.06731	0.09072	0.11301	0.42889	0.57884
11	11	0.00055	0.00253	0.00673	0.01429	0.02754	0.04256	0.05954	0.08281	0.10667	0.13943	0.47816	0.61004
12	12	0.00056	0.00312	0.01791	0.01740	0.02933	0.04719	0.07259	0.10063	0.12881	0.16740	0.51984	0.64693
13	13	0.00084	0.00410	0.01127	0.01993	0.03728	0.06013	0.09059	0.12214	0.16134	0.20219	0.55191	0.67440
14	14	0.00082	0.00424	0.01197	0.02221	0.04123	0.08561	0.10604	0.14851	0.19849	0.24384	0.58414	0.69593
15	15	0.00095	0.00510	0.01310	0.02694	0.04988	0.07682	0.12136	0.17948	0.24015	0.28858	0.61030	0.71426
16	16	0.00122	0.00631	0.01470	0.03155	0.05822	0.09800	0.14536	0.21390	0.27716	0.33156	0.63385	0.73202
17	17	0.00128	0.00627	0.01650	0.03527	0.06899	0.11521	0.17002	0.24341	0.31679	0.37051	0.65633	0.74903
18	18	0.00131	0.00627	0.01534	0.03912	0.07782	0.13175	0.19765	0.28394	0.35555	0.40508	0.67371	0.76150
19	19	0.00143	0.00673	0.02026	0.04577	0.09057	0.15144	0.23008	0.31727	0.38638	0.43515	0.68830	0.77125
20	20	0.00160	0.00770	0.02163	0.07994	0.10083	0.17696	0.26386	0.34948	0.41643	0.46339	0.70363	0.78335

Table No. 43

SERVICE UTILIZATION FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 4

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.01052	0.02090	0.03088	0.04135	0.05177	0.06221	0.07267	0.08265	0.09216	0.10121	0.18343	0.24808
2	2	0.01026	0.02068	0.03115	0.04145	0.05125	0.06142	0.07123	0.08019	0.08989	0.09920	0.17668	0.23328
3	3	0.00999	0.02016	0.03029	0.03980	0.04899	0.05786	0.06684	0.07583	0.08478	0.09335	0.16579	0.22160
4	4	0.01021	0.02048	0.03068	0.04069	0.05085	0.06081	0.06943	0.07806	0.08645	0.09480	0.15705	0.20024
5	5	0.00995	0.02015	0.03020	0.04002	0.04947	0.05856	0.06730	0.07539	0.08379	0.09211	0.15549	0.17757
6	6	0.00988	0.01993	0.02950	0.03911	0.04838	0.05762	0.06624	0.07395	0.08216	0.08958	0.14406	0.15816
7	7	0.00965	0.01948	0.02906	0.03853	0.04758	0.05625	0.06434	0.07233	0.08043	0.08767	0.13186	0.14006
8	8	0.00970	0.01948	0.02909	0.03834	0.04711	0.05603	0.06371	0.07137	0.07848	0.08552	0.11963	0.12422
9	9	0.00984	0.01972	0.02941	0.03880	0.04775	0.05590	0.06348	0.07074	0.07751	0.08373	0.10900	0.11083
10	10	0.00997	0.02014	0.02971	0.03908	0.04766	0.05636	0.06393	0.07053	0.07628	0.08117	0.09918	0.09974
11	11	0.01012	0.02039	0.03019	0.03956	0.04820	0.05622	0.06343	0.06953	0.07528	0.08007	0.09052	0.09068
12	12	0.01025	0.02021	0.02034	0.03952	0.04833	0.05659	0.06351	0.06906	0.07389	0.07722	0.08317	0.08312
13	13	0.00987	0.01996	0.02948	0.03883	0.04767	0.05567	0.06220	0.06791	0.07176	0.07402	0.07677	0.07672
14	14	0.00997	0.02012	0.02958	0.03867	0.04669	0.05448	0.06129	0.06602	0.06889	0.07041	0.07129	0.07124
15	15	0.00999	0.02003	0.02980	0.03884	0.04682	0.05366	0.05934	0.06362	0.06549	0.06621	0.06653	0.06649
16	16	0.01007	0.01998	0.02955	0.03855	0.04634	0.05273	0.05747	0.06078	0.06197	0.06226	0.06237	0.06234
17	17	0.00992	0.02001	0.02979	0.03846	0.04586	0.05179	0.05580	0.05804	0.05850	0.05871	0.05871	0.05867
18	18	0.00996	0.01997	0.02933	0.03834	0.04557	0.05085	0.05381	0.05518	0.05547	0.05547	0.05549	0.05541
19	19	0.00988	0.01984	0.02931	0.03776	0.04497	0.04965	0.05167	0.05251	0.05255	0.05255	0.05253	0.05249
20	20	0.00982	0.01965	0.02909	0.03757	0.04401	0.04815	0.04961	0.04994	0.04993	0.04992	0.04990	0.04987

Table No. 44

The Goodness of fit test.
Negative Exponential Breakdown.
Erlang Service Time.
Single Serviceman.
No. of phases 4
Test No. 1
Keeping service coefficient constant and increasing the number of machines from 1 to 20.

No.	Service Constant.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	0.01	0.00039
2	0.02	0.00435
3	0.03	0.02738
4	0.04	0.08379
5	0.05	0.14356
6	0.06	0.20834
7	0.07	0.22810
8	0.08	0.28839
9	0.09	0.49445
10	0.10	0.45621
11	0.20	0.56540
12	0.30	0.30686

For 19 degrees of freedom, the 5% level of significance is $P(30.144 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 > 30.144$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 12$ are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{ei}$
1	1	0.11457
2	2	0.03430
3	3	0.01758
4	4	0.02745
5	5	0.04675
6	6	0.01686
7	7	0.04670
8	8	0.14355
9	9	0.21653
10	10	0.28044
11	11	0.25618
12	12	0.30899
13	13	0.21873
14	14	0.17687
15	15	0.13311
16	16	0.09675
17	17	0.12845
18	18	0.17973
19	19	0.16591
20	20	0.19777

For 11 degrees of freedom, the 5% level of significance is $P(19.675 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 > 19.675$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 20$ are not significant.

Table No. 45

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	1	-0.06	-0.13	-0.16	-0.30	-0.44	-0.59	-0.78	-0.93	-1.05	-1.13	-2.01	-2.25
2	2	-0.04	-0.10	-0.16	-0.22	-0.30	-0.37	-0.51	-0.54	-0.75	-0.95	-1.16	-0.52
3	3	-0.02	-0.04	-0.08	-0.12	-0.18	-0.28	-0.40	-0.48	-0.54	-0.59	-0.82	-0.50
4	4	-0.02	-0.07	-0.07	-0.04	-0.13	-0.11	0.12	0.20	0.27	0.28	0.51	1.92
5	5	0.01	-0.03	-0.05	0.04	0.02	0.06	0.00	0.15	0.17	0.16	1.89	1.89
6	6	0.01	0.02	0.08	0.22	0.33	0.34	0.48	0.66	0.58	0.55	0.38	-0.60
7	7	0.05	0.10	0.23	0.34	0.42	0.51	0.70	0.69	0.79	0.90	-1.00	-1.73
8	8	0.05	0.09	0.18	0.34	0.45	0.59	0.91	1.36	1.77	1.79	-1.67	-3.28
9	9	0.03	0.14	0.35	0.59	0.92	1.13	1.19	1.60	2.02	2.36	-2.54	-3.48
10	10	0.01	0.06	0.30	0.59	1.10	1.36	1.81	1.72	1.92	2.60	-3.84	-3.41
11	11	0.03	0.12	0.31	0.52	0.56	0.87	1.48	1.88	2.62	2.60	-4.32	-1.19
12	12	0.03	0.14	0.33	0.52	0.95	1.30	1.47	1.95	2.92	2.95	-4.39	-2.80
13	13	0.05	0.13	0.23	0.63	0.82	1.07	1.23	1.90	2.25	2.76	-3.33	-2.93
14	14	0.06	0.16	0.33	0.85	1.25	1.86	1.45	1.59	1.28	1.79	-3.47	-2.21
15	15	0.05	0.14	0.30	0.76	1.12	2.11	2.05	0.88	-0.11	0.45	-3.03	-1.34
16	16	0.03	0.09	0.44	0.77	1.19	1.37	1.80	0.13	-0.76	-0.60	-2.78	-1.29
17	17	0.05	0.17	0.45	0.91	1.09	1.27	1.65	-0.77	-1.86	-1.69	-2.87	-1.92
18	18	0.06	0.25	0.80	1.09	1.31	1.44	1.33	-1.47	-3.05	-2.20	-2.51	-1.13
19	19	0.07	0.29	0.61	1.08	1.25	1.44	0.50	-2.06	-3.17	-2.30	-1.51	0.47
20	20	0.07	0.30	0.77	1.37	1.67	0.91	-0.49	-2.59	-3.45	-2.48	-1.41	0.07

THE MEAN PERCENTAGE DIFFERENCE IS 0.05005

THE STD. DEVIATION IS 1.40065

NEGATIVE EXPONENTIAL BREAKDOWN

ERLANG SERVICE TIME

NO. OF PHASES 8

SINGLE SERVICEMAN

Table No. 46

MACHINE UTILIZATION M FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 8

SERVICING CONSTANT K

N/C	M	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.98950	0.97920	0.35307	0.95866	0.94820	0.93773	0.92723	0.91740	0.90765	0.89892	0.81760	0.75231
2	2	0.98980	0.97926	0.35544	0.95321	0.94617	0.93776	0.92957	0.91748	0.90603	0.89498	0.80521	0.73053
3	3	0.98991	0.97931	0.35359	0.95858	0.94715	0.93649	0.92446	0.91305	0.90050	0.88906	0.78111	0.68866
4	4	0.98959	0.97907	0.35800	0.95696	0.94557	0.93307	0.92296	0.91319	0.90039	0.88895	0.76402	0.64848
5	5	0.98934	0.97891	0.35744	0.95579	0.94422	0.93162	0.91846	0.90630	0.89243	0.87606	0.73328	0.58719
6	6	0.98990	0.97889	0.35755	0.95558	0.94312	0.92916	0.91574	0.90131	0.88479	0.86803	0.67747	0.51839
7	7	0.99011	0.97938	0.35763	0.95557	0.94121	0.92657	0.91077	0.89335	0.87572	0.85701	0.62796	0.45336
8	8	0.99005	0.97880	0.36520	0.95377	0.93859	0.92259	0.90636	0.88823	0.87001	0.84523	0.57783	0.40390
9	9	0.98933	0.97843	0.35545	0.95352	0.93904	0.92053	0.90058	0.87888	0.85701	0.83120	0.52356	0.36013
10	10	0.98556	0.97767	0.36496	0.95127	0.93535	0.91615	0.89550	0.86746	0.83707	0.81001	0.47741	0.32357
11	11	0.98956	0.97759	0.35408	0.94805	0.92757	0.90603	0.88206	0.85162	0.82226	0.78696	0.43893	0.29542
12	12	0.98947	0.97713	0.35245	0.94583	0.92566	0.90005	0.87094	0.83605	0.80044	0.76144	0.40321	0.27090
13	13	0.98939	0.97659	0.35054	0.94265	0.91952	0.88937	0.85417	0.81679	0.77397	0.72953	0.37471	0.25267
14	14	0.98948	0.97624	0.35003	0.94149	0.91625	0.88473	0.84152	0.79427	0.74034	0.69061	0.34811	0.23357
15	15	0.98919	0.97533	0.35877	0.93720	0.90726	0.87463	0.82570	0.76545	0.70410	0.64681	0.32492	0.21994
16	16	0.98893	0.97465	0.35777	0.93362	0.89899	0.85373	0.80313	0.73320	0.66584	0.61051	0.30724	0.20635
17	17	0.98916	0.97445	0.35576	0.92959	0.89234	0.84046	0.78252	0.70218	0.62739	0.57556	0.28737	0.19598
18	18	0.98902	0.97480	0.35577	0.92711	0.88140	0.82374	0.75493	0.66898	0.59335	0.54390	0.27252	0.18362
19	19	0.98898	0.97397	0.35222	0.92068	0.87108	0.80556	0.72167	0.63857	0.56352	0.51626	0.25876	0.17666
20	20	0.98834	0.97397	0.35129	0.91613	0.86160	0.78249	0.69047	0.60659	0.53624	0.49105	0.24789	0.16724

Table No. 47

MACHINE WAITING TIME FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 8

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
2	2	0.00013	0.00017	0.00038	0.00151	0.00118	0.00151	0.00001	0.00323	0.00500	0.00691	0.01926	0.03516
3	3	0.00023	0.00069	0.00125	0.00519	0.00408	0.00568	0.00876	0.01138	0.01509	0.01819	0.05131	0.08973
4	4	0.00019	0.00053	0.00136	0.00257	0.00385	0.00638	0.00784	0.00921	0.01358	0.01695	0.07823	0.14897
5	5	0.00033	0.00010	0.00247	0.00440	0.00653	0.00983	0.01445	0.01852	0.02364	0.03210	0.11036	0.23298
6	6	0.00043	0.00128	0.00303	0.00550	0.00871	0.01338	0.01815	0.02438	0.03290	0.04200	0.17794	0.32266
7	7	0.00033	0.00123	0.00332	0.00607	0.01138	0.01726	0.02490	0.03430	0.04409	0.05497	0.24023	0.40605
8	8	0.00035	0.00174	0.00481	0.00811	0.01443	0.02159	0.03009	0.04027	0.05143	0.06943	0.30195	0.47212
9	9	0.00044	0.00200	0.00420	0.00783	0.01331	0.02349	0.03598	0.05055	0.06533	0.08506	0.36720	0.52901
10	10	0.00059	0.00241	0.00550	0.00981	0.01706	0.02757	0.04079	0.06197	0.08643	0.10849	0.42315	0.57665
11	11	0.00047	0.00223	0.00597	0.01275	0.02442	0.03797	0.05454	0.07893	0.10239	0.13289	0.47040	0.61387
12	12	0.00064	0.00289	0.00764	0.01499	0.02624	0.04340	0.06579	0.09500	0.12586	0.16107	0.51367	0.64555
13	13	0.00085	0.00362	0.01007	0.02796	0.03312	0.05507	0.08366	0.11543	0.15428	0.19622	0.54857	0.67058
14	14	0.00067	0.00381	0.01042	0.02011	0.03690	0.06065	0.09737	0.13977	0.19051	0.23889	0.58065	0.69516
15	15	0.00092	0.00475	0.01158	0.02418	0.04569	0.07154	0.11483	0.17067	0.23020	0.29691	0.60859	0.71354
16	16	0.00111	0.00551	0.01284	0.02796	0.05463	0.09333	0.13919	0.20588	0.27189	0.32726	0.63042	0.73129
17	17	0.00100	0.00565	0.01456	0.03193	0.06175	0.10757	0.16150	0.23978	0.31397	0.36577	0.65396	0.74573
18	18	0.00111	0.00537	0.01436	0.03475	0.07297	0.12522	0.19095	0.27582	0.35117	0.40069	0.67207	0.76095
19	19	0.00123	0.00630	0.01842	0.04154	0.08393	0.14462	0.22637	0.30893	0.38392	0.43125	0.68875	0.77083
20	20	0.00142	0.00648	0.01964	0.04640	0.09444	0.16914	0.25980	0.34350	0.41383	0.45908	0.70224	0.78287

Table No. 48

SERVICE UTILIZATION FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 8

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.01039	0.02079	0.03092	0.04133	0.05179	0.06226	0.07276	0.08259	0.09214	0.10107	0.19240	0.24766
2	2	0.01007	0.02057	0.03118	0.04028	0.05065	0.06073	0.07042	0.07929	0.08897	0.09811	0.17553	0.23431
3	3	0.00986	0.02000	0.03017	0.03623	0.04877	0.05763	0.06678	0.07557	0.08441	0.09275	0.16758	0.22159
4	4	0.01012	0.02040	0.03062	0.04047	0.05058	0.06055	0.06920	0.07760	0.08603	0.09410	0.15775	0.20255
5	5	0.00983	0.02097	0.03009	0.03981	0.04925	0.05855	0.06709	0.07518	0.08397	0.09184	0.15636	0.17983
6	6	0.00977	0.01983	0.02939	0.03892	0.04817	0.05746	0.06611	0.07431	0.08231	0.08997	0.14459	0.15895
7	7	0.00956	0.01939	0.02905	0.03836	0.04741	0.05617	0.06433	0.07235	0.08019	0.08802	0.13179	0.14059
8	8	0.00960	0.01937	0.02899	0.03812	0.04698	0.05582	0.06355	0.07150	0.07856	0.08534	0.12022	0.12398
9	9	0.00973	0.01957	0.02935	0.03865	0.04765	0.05598	0.06344	0.07057	0.07766	0.08372	0.10924	0.11086
10	10	0.00983	0.01992	0.02954	0.03892	0.04759	0.05628	0.06371	0.07057	0.07650	0.08150	0.09944	0.09978
11	11	0.00987	0.02018	0.02995	0.03920	0.04801	0.05600	0.06340	0.06945	0.07537	0.08015	0.09067	0.09071
12	12	0.00989	0.01998	0.02991	0.03918	0.04808	0.05655	0.06327	0.06895	0.07400	0.07749	0.08312	0.08315
13	13	0.00976	0.01960	0.02939	0.02939	0.04736	0.05556	0.06217	0.06779	0.07175	0.07425	0.07672	0.07675
14	14	0.00985	0.01995	0.02950	0.03840	0.04685	0.05462	0.06111	0.06596	0.06915	0.07050	0.07124	0.07127
15	15	0.00969	0.01987	0.02965	0.03862	0.04685	0.05383	0.05947	0.06368	0.06570	0.06628	0.06649	0.06652
16	16	0.00996	0.01984	0.02943	0.03842	0.04638	0.05294	0.05768	0.06092	0.06227	0.06223	0.06234	0.06236
17	17	0.00984	0.01990	0.02968	0.03648	0.04591	0.05195	0.05596	0.05804	0.05864	0.05867	0.05867	0.05869
18	18	0.00987	0.01983	0.02927	0.03814	0.04563	0.05104	0.05412	0.05520	0.05548	0.05541	0.05541	0.05543
19	19	0.00979	0.01973	0.02926	0.03778	0.04499	0.04982	0.05196	0.05250	0.05256	0.05249	0.05249	0.05251
20	20	0.00974	0.01955	0.02907	0.03747	0.04396	0.04837	0.04973	0.04991	0.04993	0.04987	0.04987	0.04989

Table No. 49

The Goodness of fit test.
Negative Exponential Breakdown.
Erlang Service Time.
Single Serviceman.
No. of phases 8
Test No. 1
Keeping service coefficient constant and increasing the number of machines from 1 to 20.

No.	Service Constant.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	0.01	0.00076
2	0.02	0.00810
3	0.03	0.04677
4	0.04	0.15690
5	0.05	0.29274
6	0.06	0.41987
7	0.07	0.49033
8	0.08	0.42830
9	0.09	0.62183
10	0.10	0.61097
11	0.20	0.33893
12	0.30	0.24354

For 19 degrees of freedom, the 5% level of significance is $P(30.144<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2\geqslant 30.144$. Hence, for the 5% level of significance, χ^2=1,2,...12 are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	1	0.10848
2	2	0.01496
3	3	0.00836
4	4	0.07446
5	5	0.08636
6	6	0.03623
7	7	0.07243
8	8	0.15215
9	9	0.26513
10	10	0.32380
11	11	0.33432
12	12	0.39575
13	13	0.33892
14	14	0.31413
15	15	0.23555
16	16	0.14278
17	17	0.18361
18	18	0.19437
19	19	0.18014
20	20	0.19710

For 11 degrees of freedom, the 5% level of significance is $P(19.675<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2\geqslant 19.675$. Hence, for the 5% level of significance, χ^2=1,2,...20 are not significant.

Table No. 50

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	1	-0.05	-0.12	-0.19	-0.30	-0.44	-0.60	-0.79	-0.92	-1.04	-1.12	-1.89	-2.20
2	2	-0.02	-0.08	-0.16	-0.20	-0.22	-0.28	-0.11	-0.37	-0.57	-0.74	-0.69	0.03
3	3	0.03	-0.03	-0.06	-0.00	-0.05	-0.06	-0.16	-0.23	-0.41	-0.45	-0.35	0.67
4	4	-0.01	-0.01	-0.03	0.00	0.02	-0.04	0.19	0.48	0.47	0.64	1.59	2.74
5	5	0.02	0.01	0.02	0.06	0.18	0.24	0.30	0.53	0.61	0.46	2.54	2.32
6	6	0.02	0.06	0.14	0.24	0.38	0.46	0.69	0.89	0.94	1.03	0.60	0.53
7	7	0.06	0.15	0.25	0.45	0.54	0.72	0.92	1.06	1.29	1.52	-0.04	-1.54
8	8	0.07	0.15	0.23	0.49	0.65	0.90	1.31	1.70	2.26	2.19	-0.58	-1.73
9	9	0.06	0.15	0.39	0.72	1.13	1.36	1.68	2.04	2.62	2.93	-2.09	-2.27
10	10	0.04	0.13	0.36	0.76	1.22	1.65	2.27	2.35	2.42	3.13	-2.73	-2.76
11	11	0.05	0.18	0.41	0.72	0.92	1.41	2.06	2.36	3.15	3.45	-2.63	-2.46
12	12	0.06	0.19	0.40	0.81	1.31	1.74	2.29	2.66	3.32	3.80	-2.59	-2.46
13	13	0.06	0.19	0.37	0.83	1.71	1.66	2.06	2.77	3.19	3.57	-2.44	-1.45
14	14	0.06	0.22	0.50	1.10	1.71	2.42	2.53	2.73	2.35	2.51	-2.48	-1.90
15	15	0.07	0.20	0.55	1.08	1.56	2.71	2.85	2.12	1.29	0.70	-2.51	-1.03
16	16	0.05	0.19	0.65	1.17	1.59	1.90	2.57	1.22	-0.02	-0.09	-1.68	-0.95
17	17	0.09	0.24	0.67	1.27	1.91	2.18	2.74	0.61	-1.44	-0.87	-2.29	-0.05
18	18	0.09	0.36	0.97	1.59	1.57	2.23	2.19	-0.27	-2.33	-1.39	-1.59	-0.84
19	19	0.10	0.35	0.81	1.55	2.03	2.29	0.98	-0.76	-2.74	-1.54	-1.67	0.70
20	20	0.10	0.43	0.98	1.78	2.44	1.69	0.05	-1.61	-2.98	-1.61	-0.84	0.35

THE MEAN PERCENTAGE DIFFERENCE IS 0.44692

THE STD. DEVIATION IS 1.40370

NEGATIVE EXPONENTIAL BREAKDOWN

ERLANG SERVICE TIME

NO. OF PHASES 8

SINGLE SERVICEMAN

Table No. 51

MACHINE UTILIZATION M FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 16

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.98956	0.97920	0.96907	0.95862	0.94815	0.93767	0.92727	0.91746	0.90600	0.63907	0.81833	0.75324
2	2	0.98933	0.97929	0.96368	0.95633	0.94864	0.93845	0.92823	0.91819	0.90727	0.89647	0.80560	0.73118
3	3	0.98989	0.97933	0.96918	0.95886	0.94786	0.93728	0.92626	0.91430	0.90269	0.89022	0.78257	0.69441
4	4	0.98975	0.97911	0.96782	0.95700	0.94620	0.93378	0.92346	0.91430	0.90297	0.89102	0.77030	0.65553
5	5	0.98939	0.97919	0.96782	0.95612	0.94455	0.93244	0.92012	0.90724	0.89496	0.87902	0.73616	0.58878
6	6	0.98976	0.97897	0.96773	0.95564	0.94369	0.92938	0.91698	0.90268	0.88742	0.87091	0.67844	0.52417
7	7	0.99016	0.97946	0.96772	0.95571	0.94165	0.92740	0.91163	0.89526	0.87615	0.85965	0.63075	0.46116
8	8	0.99013	0.97896	0.96659	0.95390	0.93939	0.92337	0.90843	0.88876	0.87138	0.84842	0.57768	0.40460
9	9	0.98983	0.97847	0.96582	0.95397	0.93924	0.92168	0.90240	0.88045	0.85937	0.83401	0.52637	0.36258
10	10	0.98954	0.97793	0.96540	0.95200	0.93677	0.91712	0.89840	0.86930	0.84108	0.81145	0.47875	0.32848
11	11	0.98960	0.97756	0.96460	0.94908	0.92900	0.90879	0.88550	0.85477	0.82418	0.78934	0.43769	0.29608
12	12	0.98955	0.97710	0.96375	0.94709	0.92739	0.90301	0.87661	0.83940	0.80394	0.76370	0.40258	0.27550
13	13	0.98951	0.97678	0.96157	0.94335	0.92150	0.89256	0.85841	0.81987	0.77769	0.73181	0.37249	0.25444
14	14	0.98956	0.97630	0.95983	0.94255	0.91836	0.86671	0.84671	0.79763	0.74434	0.69199	0.34735	0.23826
15	15	0.98931	0.97532	0.95987	0.93952	0.90982	0.87854	0.82970	0.76872	0.70530	0.64996	0.32577	0.22163
16	16	0.98904	0.97498	0.95849	0.93542	0.90222	0.85712	0.80793	0.73957	0.66988	0.61309	0.30632	0.21088
17	17	0.98926	0.97516	0.95720	0.93194	0.89537	0.84461	0.78706	0.70775	0.63206	0.57720	0.28979	0.20058
18	18	0.98919	0.97537	0.95753	0.92905	0.88402	0.82675	0.75716	0.67455	0.59720	0.54466	0.27312	0.18839
19	19	0.98910	0.97453	0.95366	0.92279	0.87425	0.81031	0.72536	0.64313	0.56679	0.51772	0.26121	0.17842
20	20	0.98902	0.97432	0.95262	0.91846	0.86455	0.78693	0.69429	0.61188	0.53884	0.49223	0.24829	0.16882

Table No. 52

MACHINE WAITING TIME FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, C MODEL)

NUMBER OF PHASES 16

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
2	2	0.00005	0.00026	0.00039	0.00120	0.00104	0.00107	0.00197	0.00306	0.00452	0.00615	0.01969	0.03458
3	3	0.00027	0.00073	0.00080	0.00001	0.00341	0.00526	0.00708	0.01019	0.01320	0.01749	0.05072	0.08568
4	4	0.00013	0.00049	0.00164	0.00246	0.00334	0.00572	0.00761	0.00856	0.01116	0.01477	0.07207	0.14275
5	5	0.00030	0.00078	0.00222	0.00413	0.00629	0.00918	0.01297	0.01717	0.02133	0.02932	0.10766	0.23022
6	6	0.00048	0.00124	0.00292	0.00548	0.00822	0.01317	0.01697	0.02303	0.03052	0.03904	0.17577	0.31577
7	7	0.00027	0.00115	0.00329	0.00583	0.01090	0.01643	0.02386	0.03240	0.04176	0.05235	0.23704	0.39768
8	8	0.00029	0.00170	0.00451	0.00807	0.01372	0.02098	0.02812	0.03900	0.05042	0.06623	0.30166	0.47084
9	9	0.00047	0.00200	0.00393	0.00742	0.01318	0.02252	0.03418	0.04888	0.06311	0.08228	0.36404	0.52670
10	10	0.00058	0.00221	0.00522	0.00918	0.01574	0.02675	0.03797	0.06012	0.08226	0.10695	0.42178	0.57187
11	11	0.00130	0.00260	0.00565	0.01190	0.02310	0.03515	0.05125	0.07560	0.10057	0.13002	0.47171	0.61133
12	12	0.00062	0.00323	0.00694	0.01393	0.02466	0.04049	0.06003	0.09153	0.12215	0.15578	0.51437	0.64146
13	13	0.00076	0.00375	0.00913	0.01818	0.03133	0.05203	0.07945	0.11246	0.15054	0.19379	0.55085	0.66891
14	14	0.00062	0.00406	0.00982	0.01917	0.03482	0.05673	0.09234	0.13649	0.18646	0.23739	0.58147	0.69057
15	15	0.00063	0.00494	0.01000	0.02190	0.04330	0.06767	0.11079	0.16766	0.22489	0.28372	0.60779	0.71194
16	16	0.00104	0.00521	0.01224	0.02612	0.05139	0.08390	0.13434	0.19957	0.26795	0.32460	0.63140	0.72684
17	17	0.00090	0.00499	0.01326	0.02953	0.05867	0.10331	0.15694	0.23416	0.33926	0.36405	0.65159	0.74081
18	18	0.00096	0.00423	0.01319	0.03267	0.07021	0.12219	0.18854	0.27022	0.34738	0.39965	0.67152	0.75625
19	19	0.00112	0.00575	0.01713	0.03937	0.08077	0.13972	0.22255	0.30436	0.38071	0.42971	0.68634	0.76914
20	20	0.00124	0.00576	0.01836	0.04410	0.09146	0.16457	0.25592	0.33819	0.41128	0.45783	0.70188	0.78136

Table No. 53

SERVICE UTILIZATION FOR A SINGLE SERVICEMAN-(ERLANG SERVICE TIME, [illegible] MODEL)

NUMBER OF PHASES 16

SERVICING CONSTANT K

N/C	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	1	0.01041	0.02079	0.03096	0.04137	0.05184	0.06232	0.07272	0.08251	0.09199	0.10092	0.18166	0.24675
2	2	0.01002	0.02045	0.03093	0.04047	0.05032	0.06048	0.06980	0.07875	0.08821	0.09738	0.17471	0.23423
3	3	0.00984	0.01994	0.03002	0.04113	0.04873	0.05746	0.06666	0.07552	0.08403	0.09229	0.16671	0.21991
4	4	0.01012	0.02040	0.03054	0.04054	0.05046	0.06050	0.06893	0.07731	0.08567	0.09421	0.15763	0.20172
5	5	0.00961	0.02003	0.02996	0.03975	0.04916	0.05838	0.06691	0.07556	0.08371	0.09166	0.15618	0.18100
6	6	0.00976	0.01978	0.02929	0.03888	0.04809	0.05745	0.06605	0.07429	0.08206	0.09005	0.14579	0.16606
7	7	0.00957	0.01939	0.02899	0.03846	0.04745	0.05617	0.06431	0.07232	0.08009	0.08800	0.13221	0.14114
8	8	0.00958	0.01934	0.02890	0.03803	0.04689	0.05565	0.06345	0.07224	0.07820	0.08535	0.12066	0.12456
9	9	0.00970	0.01953	0.02925	0.03861	0.04758	0.05580	0.06342	0.07067	0.07752	0.08371	0.10959	0.11072
10	10	0.00978	0.01986	0.02938	0.03682	0.04749	0.05613	0.06363	0.07055	0.07666	0.08160	0.09947	0.09965
11	11	0.00910	0.01984	0.02975	0.03902	0.04790	0.05606	0.06345	0.06963	0.07525	0.08014	0.09060	0.09059
12	12	0.00983	0.01967	0.02971	0.03898	0.04795	0.05650	0.06336	0.06907	0.07391	0.07752	0.08305	0.08304
13	13	0.00973	0.01947	0.02930	0.03847	0.04717	0.05541	0.06214	0.06767	0.07177	0.07440	0.07666	0.07665
14	14	0.00982	0.01964	0.02935	0.03828	0.04682	0.05456	0.06085	0.06583	0.06920	0.07062	0.07118	0.07117
15	15	0.00986	0.01974	0.04012	0.03858	0.04688	0.05379	0.05951	0.06362	0.06575	0.06632	0.06644	0.06643
16	16	0.00992	0.01981	0.02936	0.03646	0.04639	0.05298	0.05773	0.06086	0.06217	0.06231	0.06228	0.06228
17	17	0.00982	0.01985	0.02954	0.03853	0.04596	0.05208	0.05600	0.05803	0.05868	0.05875	0.05862	0.05861
18	18	0.00985	0.01980	0.02923	0.03808	0.04577	0.05106	0.05430	0.05523	0.05542	0.05549	0.05536	0.05536
19	19	0.00976	0.01972	0.02921	0.03784	0.04498	0.04997	0.05209	0.05251	0.05250	0.05257	0.05245	0.05244
20	20	0.00974	0.01992	0.02902	0.03744	0.04399	0.04850	0.04979	0.04994	0.04988	0.04994	0.04983	0.04982

Table No. 54

The Goodness of fit test.
Negative Exponential Breakdown.
Erlang Service Time.
Single Serviceman.
No. of phases 16
Test No. 1
Keeping service coefficient constant and increasing the number of machines from 1 to 20.

No.	Service Constant	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	0.01	0.00098
2	0.02	0.01002
3	0.03	0.06265
4	0.04	0.20579
5	0.05	0.39272
6	0.06	0.59814
7	0.07	0.71912
8	0.08	0.56058
9	0.09	0.72732
10	0.10	0.72947
11	0.20	0.36945
12	0.30	0.25882

For 19 degrees of freedom, the 5% level of significance is $P(30.144 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 30.144$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 12$ are not significant.

Test No. 2
Keeping machines constant and increasing the service constant.

No.	No. of Machines	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	1	0.10112
2	2	0.01071
3	3	0.01711
4	4	0.15399
5	5	0.12056
6	6	0.06807
7	7	0.08697
8	8	0.18231
9	9	0.29370
10	10	0.35932
11	11	0.40906
12	12	0.49523
13	13	0.44714
14	14	0.41915
15	15	0.33134
16	16	0.23035
17	17	0.25319
18	18	0.22528
19	19	0.21213
20	20	0.21834

For 11 degrees of freedom, the 5% level of significance is $P(19.675 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 19.675$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 20$ are not significant.

Table No. 55

THE PERCENTAGE DIFFERENCES ARE

SERVICING CONSTANT K

N/C	N	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30
1	1	-0.05	-0.12	-0.19	-0.30	-0.44	-0.61	-0.78	-0.91	-1.03	-1.10	-1.80	-2.08
2	2	-0.01	-0.07	-0.14	-0.19	-0.17	-0.21	-0.25	-0.29	-0.43	-0.57	-0.64	0.12
3	3	0.00	-0.03	0.00	0.03	-0.00	0.02	0.01	-0.10	-0.16	-0.72	-0.17	1.51
4	4	-0.00	-0.01	-0.05	0.00	0.09	0.04	0.24	0.61	0.76	0.87	2.42	3.86
5	5	0.02	0.04	0.05	0.10	0.21	0.33	0.48	0.63	0.90	0.79	2.94	2.60
6	6	0.02	0.06	0.16	0.24	0.44	0.48	0.82	1.04	1.24	1.37	0.74	1.65
7	7	0.07	0.16	0.26	0.46	0.58	0.81	1.03	1.27	1.57	1.63	0.41	0.16
8	8	0.05	0.16	0.27	0.51	0.73	0.98	1.54	1.76	2.42	2.58	-0.61	-1.56
9	9	0.06	0.16	0.42	0.77	1.15	1.49	1.88	2.22	2.50	3.28	-1.57	-1.61
10	10	0.05	0.16	0.41	0.83	1.37	1.76	2.60	2.57	2.91	3.32	-2.46	-1.29
11	11	0.06	0.17	0.47	0.83	1.07	1.72	2.46	2.74	3.79	3.83	-2.90	-1.58
12	12	0.06	0.18	0.49	0.94	1.50	2.07	2.96	3.07	3.77	4.11	-3.05	-0.80
13	13	0.07	0.21	0.47	0.91	1.53	2.02	2.56	3.15	3.69	3.90	-3.02	-0.76
14	14	0.09	0.23	0.56	1.22	1.94	2.88	3.16	3.16	2.90	2.71	-2.69	0.07
15	15	0.08	0.19	0.67	1.33	1.65	3.17	3.35	2.55	2.04	1.19	-2.25	-0.27
16	16	0.06	0.22	0.72	1.37	1.95	2.31	3.13	2.10	0.59	0.73	-1.97	1.22
17	17	0.10	0.32	0.82	1.53	2.25	2.68	3.34	1.41	-0.70	-0.59	-1.47	2.30
18	18	0.11	0.41	1.10	1.81	2.17	2.60	2.40	0.56	-1.69	-1.22	-1.67	1.73
19	19	0.11	0.41	0.95	1.78	2.40	2.89	1.49	-0.05	-2.18	-1.26	-0.74	1.70
20	20	0.12	0.47	1.12	2.04	2.79	2.47	0.63	-0.76	-2.51	-1.37	-0.68	1.30

THE MEAN PERCENTAGE DIFFERENCE IS 0.72747

THE STD. DEVIATION IS 1.45263

NEGATIVE EXPONENTIAL BREAKDOWN

ERLANG SERVICE TIME

NO. OF PHASES 16

SINGLE SERVICEMAN

Table No. 56

MACHINE UTILISATION % FOR 2 COLLABORATING SERVICEMEN - (EXPONENTIAL SERVICE TIME, PALM MODEL)

SERVICING CONSTANT K

N/P	N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	2	0.99009	0.98038	0.97086	0.96153	0.95237	0.94339	0.93457	0.92592	0.91742	0.90909	0.83333	0.76923
2	4	0.99008	0.98037	0.97083	0.96145	0.95222	0.94313	0.93419	0.92536	0.91665	0.90806	0.82759	0.75539
3	6	0.99009	0.98035	0.97075	0.96126	0.95186	0.94253	0.93326	0.92403	0.91483	0.90565	0.81410	0.72376
4	8	0.99008	0.98031	0.97062	0.96096	0.95129	0.94157	0.93179	0.92190	0.91189	0.90175	0.79189	0.67429
5	10	0.99008	0.98025	0.97043	0.96054	0.95049	0.94023	0.92971	0.91887	0.90769	0.89613	0.75962	0.60991
6	12	0.99007	0.98018	0.97020	0.95999	0.94945	0.93547	0.92696	0.91483	0.90203	0.88849	0.71658	0.53914
7	14	0.99006	0.98010	0.96991	0.95932	0.94815	0.93624	0.92343	0.90959	0.89460	0.87840	0.66415	0.47247
8	16	0.99004	0.97999	0.96957	0.95851	0.94656	0.93347	0.91899	0.90290	0.88503	0.86528	0.60667	0.41661
9	18	0.99003	0.97987	0.96917	0.95755	0.94465	0.93008	0.91346	0.89446	0.87284	0.84850	0.54998	0.37027
10	20	0.99001	0.97974	0.96871	0.95642	0.94236	0.92594	0.90661	0.88388	0.85746	0.82739	0.49859	0.33332
11	22	0.98999	0.97959	0.96818	0.95511	0.93963	0.92093	0.89817	0.87071	0.83833	0.80146	0.45425	0.30302
12	24	0.98997	0.97942	0.96757	0.95358	0.93641	0.91486	0.88780	0.85446	0.81497	0.77067	0.41661	0.27777
13	26	0.98995	0.97923	0.96689	0.95182	0.93258	0.90752	0.87510	0.83467	0.78726	0.73570	0.38460	0.25641
14	28	0.98992	0.97902	0.96613	0.94979	0.92805	0.89665	0.85969	0.81110	0.75561	0.69802	0.35714	0.23809
15	30	0.98990	0.97879	0.96527	0.94744	0.92268	0.88795	0.84122	0.78381	0.72108	0.65958	0.33333	0.22222
16	32	0.98987	0.97854	0.96430	0.94473	0.91631	0.87512	0.81948	0.75337	0.68522	0.62224	0.31250	0.20833
17	34	0.98983	0.97826	0.96323	0.94160	0.90875	0.85984	0.79457	0.72066	0.64969	0.58728	0.29411	0.19607
18	36	0.98980	0.97796	0.96202	0.93797	0.89978	0.84191	0.76693	0.68762	0.61579	0.55525	0.27777	0.18518
19	38	0.98976	0.97764	0.96066	0.93376	0.88916	0.82124	0.73740	0.65495	0.58428	0.52623	0.26315	0.17543
20	40	0.98973	0.97728	0.95914	0.92887	0.87668	0.79801	0.70705	0.62385	0.55539	0.49997	0.25000	0.16666

Table No. 57

CHINE INITIALISATION M FOR A SINGLE SERVICEMAN – (EXPONENTIAL SERVICE TIME, PALM MODEL)

	SERVICING CONSTANT K											
N	0.01000	0.02000	0.03000	0.04000	0.05000	0.06000	0.07000	0.08000	0.09000	0.10000	0.20000	0.30000
1	0.99009	0.98039	0.97087	0.96153	0.95238	0.94339	0.93457	0.92592	0.91743	0.90909	0.83333	0.76923
2	0.98999	0.98001	0.97004	0.96011	0.95022	0.94038	0.93059	0.92087	0.91121	0.90163	0.81081	0.73033
3	0.98989	0.97962	0.96918	0.95859	0.94788	0.93706	0.92616	0.91519	0.90417	0.89311	0.78389	0.68408
4	0.98979	0.97921	0.96826	0.95696	0.94534	0.93342	0.92122	0.90879	0.89615	0.88334	0.75207	0.63118
5	0.98969	0.97879	0.96729	0.95521	0.94256	0.92938	0.91570	0.90156	0.88700	0.87209	0.71513	0.57356
6	0.98958	0.97835	0.96627	0.95332	0.93953	0.92491	0.90950	0.89335	0.87654	0.85914	0.67346	0.51567
7	0.98948	0.97789	0.96518	0.95129	0.93620	0.91993	0.90251	0.88402	0.86455	0.84422	0.62820	0.46045
8	0.98937	0.97742	0.96402	0.94909	0.93255	0.91438	0.89464	0.87340	0.85082	0.82710	0.58122	0.41100
9	0.98925	0.97692	0.96280	0.94670	0.92852	0.90818	0.88573	0.86130	0.83513	0.80754	0.53474	0.35551
10	0.98914	0.97641	0.96149	0.94412	0.92407	0.90124	0.87566	0.84756	0.81730	0.78541	0.49080	0.33277
11	0.98903	0.97587	0.96010	0.94130	0.91914	0.89345	0.86428	0.83198	0.79717	0.76069	0.45077	0.30297
12	0.98891	0.97531	0.95861	0.93823	0.91368	0.88470	0.85142	0.81442	0.77471	0.73355	0.41523	0.27773
13	0.98879	0.97472	0.95703	0.93468	0.90761	0.87488	0.83695	0.79481	0.75001	0.70435	0.38410	0.25640
14	0.98866	0.97411	0.95533	0.93122	0.90085	0.86386	0.82076	0.77316	0.72333	0.67370	0.35697	0.23809
15	0.98854	0.97347	0.95350	0.92719	0.89333	0.85152	0.80279	0.74959	0.69512	0.64233	0.33328	0.22222
16	0.98841	0.97280	0.95154	0.92278	0.88495	0.83778	0.78304	0.72438	0.66596	0.61106	0.31248	0.20833
17	0.98828	0.97209	0.94943	0.91791	0.87563	0.82255	0.76162	0.69793	0.63653	0.58061	0.29411	0.19607
18	0.98814	0.97135	0.94715	0.91256	0.86526	0.80580	0.73873	0.67077	0.60749	0.55158	0.27777	0.18518
19	0.98800	0.97057	0.94470	0.90665	0.85378	0.78756	0.71469	0.64346	0.57942	0.52434	0.26315	0.17543
20	0.98786	0.96976	0.94204	0.90013	0.84110	0.76794	0.68991	0.61654	0.55273	0.49906	0.24999	0.16666

Table No. 58

CYCLE TIME FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

CONSTANT SERVICE TIME+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/R	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	1.09989	1.19976	1.29961	1.39944	1.49925	1.59904	1.69881	1.79856	1.89830	1.99800
2	1.10049	1.20012	1.30019	1.40028	1.50038	1.60048	1.70060	1.80072	1.90085	2.00100
3	1.10110	1.20048	1.30078	1.40112	1.50150	1.80108	2.10042	2.39952	2.69838	2.99707
4	1.10170	1.20084	1.30136	1.60218	2.00050	2.39928	2.79762	3.19551	3.59297	3.98999
5	1.10230	1.20120	1.50135	2.00040	2.49875	2.99640	3.49335	3.98953	4.48514	4.97998
6	1.10290	1.20156	1.80081	2.39904	2.99625	3.59243	4.18761	4.78173	5.37436	5.96697
7	1.10350	1.40140	2.10036	2.79720	3.49299	4.18739	4.88039	5.57196	6.26216	6.95095
8	1.10411	1.60112	2.39892	3.19468	3.98899	4.78126	5.57171	6.36026	7.14703	7.93193
9	1.10472	1.80072	2.69757	3.59208	4.48423	5.37405	6.26155	7.14563	8.02946	8.90991
10	1.10533	2.00023	2.99595	3.98880	4.97873	5.96577	6.94993	7.93109	8.90946	9.88488
11	1.10594	2.19956	3.29406	4.38503	5.47247	6.55640	7.63683	8.71362	9.78703	10.85686
12	1.20582	2.39880	3.59190	4.78079	5.96547	7.14595	8.32227	9.49423	10.66216	11.82583
13	1.30559	2.59792	3.88947	5.17607	6.45771	7.73441	9.00623	10.27292	11.53496	12.79179
14	1.40525	2.79692	4.13677	5.57087	6.94920	8.32180	9.68873	11.04968	12.40514	13.75475
15	1.50480	2.99580	4.48380	5.96519	7.43990	8.90311	10.36975	11.82452	13.27297	14.71471
16	1.60424	3.19456	4.78056	6.35902	7.92993	9.49333	11.04930	12.59744	14.13838	15.67167
17	1.70357	3.39320	5.07705	6.75238	8.41917	10.07748	11.72738	13.36843	15.00135	16.62563
18	1.80279	3.59172	5.37327	7.14526	8.90766	10.66054	12.40359	14.13750	15.86169	17.57656
19	1.90190	3.79012	5.66922	7.53766	9.39540	11.24252	13.07913	14.90465	16.72000	18.52452
20	2.00090	3.98840	5.96490	7.92957	9.88238	11.82342	13.75280	15.66987	17.57568	19.46947

Table No. 59

MACHINE IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

CONSTANT SERVICE TIME+INDEPENDENT TIME

CONSTANT P=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00055	0.00024	0.00039	0.00056	0.00075	0.00096	0.00119	0.00144	0.00171	0.00200
3	0.00113	0.00056	0.00091	0.00131	0.00175	0.20144	0.40091	0.60016	0.79919	0.99800
4	0.00173	0.00090	0.00146	0.20144	0.50075	0.79964	1.09811	1.39615	1.69378	1.99099
5	0.00232	0.00125	0.20144	0.60056	0.99900	1.39676	1.79384	2.19022	1.58595	2.98098
6	0.00292	0.00163	0.50090	0.99920	1.49650	1.99279	2.48810	2.98237	3.47568	3.96797
7	0.00352	0.20144	0.80089	1.39736	1.99324	2.58775	3.18098	3.77260	4.36297	4.95195
8	0.00413	0.40116	1.09901	1.79504	2.48924	3.18162	3.87220	4.56093	5.24784	5.93293
9	0.00473	0.60076	1.39766	2.19224	2.98448	3.77410	4.56204	5.34728	6.13027	6.91091
10	0.00534	0.80024	1.69604	2.58696	3.47598	4.36613	5.25942	6.13173	7.01027	7.88589
11	0.00595	0.99960	1.99415	2.98519	3.97272	4.95676	5.93732	6.91426	7.88764	8.85786
12	0.10583	1.19884	2.29199	3.38095	4.46572	5.54631	6.62276	7.69487	8.76297	9.82653
13	0.20560	1.39796	2.58956	3.77623	4.95796	6.13477	7.30672	8.47356	9.63568	10.79279
14	0.30526	1.59696	2.88686	4.17103	5.44945	6.72216	7.98922	9.25032	10.50595	11.75576
15	0.40481	1.79584	3.18389	4.56535	5.94019	7.30847	8.67024	10.02516	11.37378	12.71572
16	0.50425	1.99460	3.48065	4.95918	6.43018	7.89369	9.34979	10.79808	12.23919	13.67267
17	0.60358	2.19324	3.77714	5.35254	6.91942	8.47784	10.02787	11.56907	13.10216	14.62663
18	0.70280	2.39176	4.07336	5.74542	7.40791	9.06090	10.70448	12.33814	13.96270	15.57758
19	0.80191	2.59016	4.36931	6.13782	7.89565	9.64288	11.37962	13.10529	14.82061	16.52553
20	0.90091	2.78844	4.66499	6.52973	8.38263	10.22378	12.05329	13.87051	15.67649	17.47047

Table No. 60

SERVICE UTILIZATION FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

CONSTANT SERVICE TIME+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
2	0.20000	0.40000	0.60000	0.80000	1.00000	1.20000	1.40000	1.60000	1.80000	2.00000
3	0.30000	0.60000	0.90000	1.20000	1.50000	1.80000	2.10000	2.39952	2.69838	2.99707
4	0.40000	0.80000	1.20000	1.60000	2.00000	2.39928	2.79762	3.19551	3.59297	3.98999
5	0.50000	1.00000	1.50000	2.00000	2.49875	2.99640	3.49335	3.98958	4.48514	4.97998
6	0.60000	1.20000	1.80000	2.39904	2.99625	3.59243	4.18761	4.78173	5.37466	5.96697
7	0.70000	1.40000	2.10000	2.79720	3.49299	4.18739	4.88039	5.57196	6.26216	6.95095
8	0.80000	1.60000	2.39892	3.19488	3.98899	4.78126	5.57171	6.36026	7.14753	7.93193
9	0.90000	1.80000	2.69757	3.59208	4.48423	5.37405	6.26155	7.14663	8.02946	8.90991
10	1.00000	2.00000	2.99595	3.98880	4.97673	5.96577	6.94993	7.93109	8.90346	9.88488
11	1.10000	2.19956	3.29406	4.38503	5.47247	6.55640	7.63683	8.71362	9.78703	10.85686
12	1.20000	2.39680	3.59190	4.78075	5.96547	7.14595	8.32227	9.49423	10.66216	11.82583
13	1.30000	2.59792	3.89947	5.17607	6.45771	7.73441	9.00623	10.27292	11.53486	12.79179
14	1.40000	2.79692	4.18677	5.57087	6.94920	8.32180	9.68873	11.04968	12.40514	13.75475
15	1.50000	2.99580	4.48380	5.96519	7.43990	8.92811	10.36975	11.82452	13.27297	14.71471
16	1.60000	3.19456	4.78056	6.35902	7.92993	9.49333	11.04930	12.59744	14.13838	15.67167
17	1.70000	3.39320	5.07705	6.75238	8.41917	10.07748	11.72738	13.36843	15.00135	16.62563
18	1.80000	3.59172	5.37327	7.14526	8.90766	10.66054	12.40399	14.13750	15.86189	17.57658
19	1.90000	3.79012	5.66922	7.53766	9.39540	11.24252	13.07913	14.90465	16.72000	18.52452
20	2.00000	3.98840	5.96490	7.92957	9.86238	11.82342	13.75[illegible]	15.66987	17.57568	19.46947

Table No. 61

SERMAN IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

CONSTANT SERVICE TIME+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.99989	0.99976	0.99961	0.99944	0.99925	0.99904	0.99881	0.99856	0.99830	0.99800
2	0.90049	0.80012	0.70019	0.60028	0.50038	0.40048	0.30060	0.20072	0.10085	0.00100
3	0.80110	0.60048	0.40078	0.20112	0.00150	0.00108	0.00042	-0.00000	-0.00000	-0.00000
4	0.70170	0.40084	0.10136	0.00128	0.00050	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
5	0.60230	0.20120	0.00135	0.00040	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
6	0.50290	0.00156	0.00081	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
7	0.40350	0.00140	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
8	0.30411	0.00112	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
9	0.20472	0.00072	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
10	0.10533	0.00026	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
11	0.00594	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
12	0.00582	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
13	0.00559	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
14	0.00525	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
15	0.00480	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
16	0.00424	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
17	0.00357	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
18	0.00279	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
19	0.00190	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
20	0.00090	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000

Table No. 62

CYCLE TIME FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(100)+CONSTANT(0))+INDEPENDENT TIME
CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	1.08054	1.17900	1.27541	1.35486	1.48044	1.58794	1.66811	1.76934	1.85545	1.95543
2	1.10377	1.20775	1.32231	1.45670	1.60024	1.72534	1.84409	1.99262	2.13182	2.31928
3	1.12175	1.24663	1.38239	1.55756	1.75602	1.94340	2.15690	2.40455	2.62847	2.92105
4	1.11967	1.27714	1.49989	1.76554	2.08458	2.40964	2.71787	3.15631	3.55154	3.98801
5	1.11949	1.31363	1.62685	1.93993	2.51578	2.85130	3.17146	3.83119	4.23470	4.77490
6	1.14503	1.36394	1.82455	2.34911	2.91686	3.46251	4.09569	4.68899	5.22472	6.05665
7	1.14509	1.46800	2.03691	2.70298	3.40811	4.05537	4.48168	5.23399	5.87442	6.82790
8	1.15873	1.57563	2.32293	3.00369	4.13583	4.94557	5.58210	6.43151	6.89211	7.79481
9	1.18102	1.81494	2.76300	3.54904	4.63924	5.52148	6.24077	7.28233	7.89141	8.97528
10	1.20506	1.94970	2.83209	3.84697	4.80545	5.80758	6.75194	7.63761	8.40751	9.62775
11	1.23481	2.04037	3.05537	3.96661	5.19953	6.13826	6.81439	7.89639	8.92665	10.16053
12	1.28379	2.26769	3.56323	4.63173	5.80721	6.93633	7.78447	9.12133	10.32468	11.34938
13	1.32194	2.42142	3.68839	4.88194	6.10052	7.42218	8.50679	9.77450	10.83545	12.16766
14	1.47394	2.84037	4.31062	5.57196	7.32989	8.55416	9.7[illegible]	11.11244	12.28633	13.59245
15	1.48612	2.95210	4.39178	5.75932	7.29951	8.67328	10.[illegible]	11.53581	12.79490	14.69230
16	1.58462	3.03973	4.60790	6.13236	7.90541	9.17621	10.61431	12.22111	13.73864	15.70929
17	1.67261	3.18823	4.84485	6.44081	8.21019	9.78099	11.19230	12.88901	14.60701	16.36822
18	1.76553	3.50060	5.06899	6.69842	8.65544	10.80458	11.77279	13.52108	15.03829	16.57566
19	1.85592	3.56000	5.41859	6.96579	8.88248	11.04686	12.02276	13.91976	16.15578	18.51371
20	1.88941	3.88186	5.43562	7.48452	9.44769	10.90039	12.68932	15.16529	16.64190	19.03915

Table No. 63

MACHINE IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(100)+CONSTANT(0))+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00098	0.00480	0.02205	0.05387	0.09113	0.12578	0.16153	0.20933	0.25821	0.32676
3	0.01929	0.04791	0.09025	0.16085	0.27042	0.36947	0.49454	0.64071	0.77707	0.96257
4	0.02428	0.08366	0.20060	0.36952	0.55963	0.81861	1.04055	1.36668	1.66359	1.99000
5	0.02751	0.12411	0.33315	0.56255	1.01467	1.28131	1.53744	2.06354	2.38655	2.61868
6	0.04408	0.16998	0.52798	0.95912	1.43100	1.88537	2.41271	2.90609	3.35198	4.04654
7	0.05026	0.27567	0.74673	1.31652	1.92009	2.47377	2.84049	3.48523	4.03131	4.84973
8	0.06374	0.38531	1.03280	1.62725	2.61693	3.32411	3.88329	4.62570	5.02659	5.81684
9	0.08085	0.61509	1.45474	2.15434	3.12172	3.90596	4.54343	5.46952	6.01275	6.97508
10	0.10916	0.75521	1.54885	2.46074	3.32364	4.22519	5.07263	5.86908	6.56271	7.65881
11	0.13679	0.85552	1.77668	2.60377	3.72647	4.57821	5.19332	6.17647	7.11234	8.22993
12	0.18673	1.97698	2.26508	3.24322	4.32096	5.35499	6.13239	7.35733	8.45525	9.39971
13	0.22622	1.23445	2.40328	3.50487	4.62875	5.84759	6.84816	8.01974	8.99664	10.22478
14	0.37031	1.63728	3.00168	4.17151	5.80185	6.93978	8.09049	9.31571	10.40301	11.61216
15	0.39019	1.75419	3.09749	4.37184	5.80666	7.08946	8.39993	9.75763	10.93028	12.69925
16	0.48575	1.84879	3.39260	4.74486	6.46879	7.59469	8.94442	10.44864	11.87045	13.71644
17	0.57454	1.99981	3.55831	5.05957	6.72572	8.20186	9.52953	11.12635	12.74213	14.39786
18	0.66740	2.30553	3.78567	5.32396	7.17170	9.19720	10.11347	11.76282	13.19717	14.64482
19	0.75607	2.37150	4.13132	5.59677	7.41067	9.46053	10.38371	12.17908	14.29772	16.52850
20	0.79513	2.60628	4.16235	6.10458	7.96777	9.34948	11.04872	13.39593	14.79784	17.07267

Table No. 64

SERVICE UTILIZATION FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(100)+CONSTANT(0))+INDEPENDENT TIME
CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.08108	0.17959	0.27605	0.35553	0.48119	0.58873	0.66895	0.77022	0.85637	0.95640
2	0.20667	0.40703	0.60185	0.80711	1.01982	1.20086	1.36696	1.56858	1.74936	1.98815
3	0.30905	0.59831	0.87848	1.16848	1.46186	1.72473	1.99031	2.29512	2.55617	2.87982
4	0.38378	0.77645	1.20015	1.58759	1.98375	2.36892	2.71473	3.15631	3.55154	3.98801
5	0.46267	0.95088	1.47256	1.89171	2.51185	2.85130	3.17146	3.63119	4.23479	4.77490
6	0.60912	1.16781	1.78489	2.34704	2.91686	3.46251	4.09569	4.68899	5.22472	6.05665
7	0.66779	1.35143	2.03691	2.70298	3.40811	4.05537	4.48168	5.23399	5.87442	6.82790
8	0.76464	1.52869	2.32293	3.00369	4.13583	4.94557	5.58210	6.43151	6.89211	7.79481
9	0.90662	1.80685	2.76300	3.54904	4.63924	5.52148	6.24077	7.23233	7.89141	8.97528
10	0.96505	1.94970	2.83209	3.84697	4.80545	5.80758	6.75194	7.63761	8.40751	9.62775
11	1.06290	2.04037	3.05537	3.96661	5.19953	6.13026	6.81439	7.89639	8.92665	10.16053
12	1.17240	2.26763	3.56323	4.63173	5.80721	6.93633	7.78447	9.12133	10.32488	11.34988
13	1.25292	2.42142	3.68839	4.68194	6.10052	7.42218	8.50679	9.77450	10.83545	12.16766
14	1.46119	2.84037	4.31062	5.57196	7.32989	8.55416	9.79486	11.11244	12.28633	13.59245
15	1.48009	2.95210	4.39178	5.75932	7.29951	8.67328	10.07780	11.53581	12.79490	14.69230
16	1.58462	3.03973	4.68790	6.13236	7.90541	9.17621	10.61471	12.22111	13.73864	15.70929
17	1.67261	3.18823	4.84485	6.44081	8.21019	9.78099	11.19230	12.88901	14.60701	16.36822
18	1.76553	3.50062	5.06899	6.69842	8.65544	10.80458	11.77279	13.52108	15.03829	16.57566
19	1.85592	3.56000	5.41859	6.96579	8.88248	11.04686	12.02276	13.91976	16.15578	18.51371
20	1.88941	3.88186	5.43562	7.48452	9.44769	10.90039	12.68932	15.16529	16.64190	19.03915

Table No. 65

S.MAN IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(100)+CONSTANT(0))+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/R	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.99946	0.99941	0.99936	0.99932	0.99926	0.99921	0.99916	0.99912	0.99907	0.99902
2	0.89710	0.80166	0.72046	0.64958	0.58042	0.52448	0.47713	0.42404	0.38246	0.33113
3	0.81270	0.64161	0.50391	0.36008	0.29496	0.21867	0.16659	0.10943	0.07031	0.04123
4	0.73589	0.50068	0.29974	0.17795	0.10083	0.04072	0.00313	-0.00000	-0.00000	-0.00000
5	0.65682	0.36275	0.15429	0.04821	0.00393	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
6	0.53592	0.19613	0.03967	0.00268	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
7	0.47730	0.11657	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
8	0.39411	0.04675	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
9	0.27420	0.00806	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
10	0.24901	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
11	0.17190	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
12	0.11140	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
13	0.06902	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
14	0.01275	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
15	0.00303	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
16	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
17	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
18	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
19	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
20	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000

Table No. 66

The Goodness of fit test.
Constant Running Time.
Service Time:
Variable Time(100)+Constant(0)+Independent Time.
Single Serviceman.
Test No. 1
Keeping the ratio R(Service Time/Running Time) constant and increasing the number of machines from 1 to 20.

No.	Ratio R	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	0.1	0.05414
2	0.2	0.11546
3	0.3	0.18305
4	0.4	0.24801
5	0.5	0.19551
6	0.6	0.20571
7	0.7	0.48805
8	0.8	0.32376
9	0.9	0.39341
10	1.0	0.24178

For 19 degrees of freedom, the 5% level of significance is $P(30.144<\chi^2<\infty)$ =0.05 and the rejection region is $\chi^2>30.144$. Hence, for the 5% level of significance, χ^2=1,2,...10 are not significant.

Test No. 2
Keeping machines constant and increasing the ratio R.

No.	No. of Machines.	$\chi^2=\sum\frac{(o_i-e_i)^2}{ei}$
1	1	0.00579
2	2	0.13034
3	3	0.08468
4	4	0.05890
5	5	0.08863
6	6	0.04107
7	7	0.09529
8	8	0.04029
9	9	0.02239
10	10	0.08597
11	11	0.40955
12	12	0.10666
13	13	0.19641
14	14	0.03961
15	15	0.05118
16	16	0.06804
17	17	0.10781
18	18	0.21610
19	19	0.27040
20	20	0.32978

For 9 degrees of freedom, the 5% level of significance is $P(16.919<\chi^2<\infty)$=0.05 and the rejection region is $\chi^2>19.675$. Hence, for the 5% level of significance, χ^2=1,2,...20 are not significant.

Table No. 67

THE PERCENTAGE DIFFERENCES ARE

N/P	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1	-1.76	-1.73	-1.86	-3.19	-1.25	-0.69	-1.81	-1.62	-2.26	-2.13
2	0.30	0.64	1.70	4.03	6.66	7.80	8.44	10.66	12.15	15.01
3	1.88	3.84	6.27	11.17	17.00	7.90	2.69	0.21	-2.59	-2.54
4	1.63	6.35	15.26	10.20	4.20	0.43	-2.85	-1.23	-1.15	-0.05
5	1.56	9.36	6.36	-3.02	0.68	-4.84	-9.21	-3.97	-5.59	-4.12
6	3.62	13.51	1.32	-2.08	-2.65	-3.62	-2.20	-1.94	-2.79	1.50
7	3.77	4.75	-3.00	-3.37	-2.43	-3.15	-8.17	-6.07	-6.19	-1.77
8	4.95	-1.59	-3.17	-5.98	3.68	3.44	0.19	1.12	-3.57	-1.73
9	6.91	0.79	2.43	-1.20	3.46	2.74	-0.33	1.90	-1.72	0.73
10	9.02	-2.52	-5.47	-3.56	-3.48	-2.65	-2.85	-3.70	-5.63	-2.60
11	11.65	-7.24	-7.25	-9.54	-4.99	-6.38	*0.77	-9.38	-8.79	-6.41
12	6.47	-5.47	-0.80	-3.12	-2.65	-2.93	-6.46	-3.93	-3.16	-4.02
13	1.25	-6.79	-5.17	-5.68	-5.53	-4.04	-5.55	-4.85	-6.06	-4.68
14	4.89	1.55	2.96	0.02	5.48	2.79	1.10	0.57	-0.96	-1.18
15	-1.11	-1.46	-2.05	-3.45	-1.89	-2.64	-2.82	-2.44	-3.60	-0.15
16	-1.21	-4.85	-1.94	-3.56	-0.31	-3.34	-3.94	-2.99	-2.83	0.24
17	-1.82	-6.04	-4.57	-4.61	-2.48	-2.94	-4.56	-3.59	-2.63	-1.55
18	-2.07	-2.54	-5.66	-6.25	-2.03	1.35	-5.09	-4.36	-5.19	-5.69
19	-2.42	-6.07	-4.42	-7.59	-5.46	-1.74	-8.08	-6.61	-3.37	-0.06
20	-5.57	-2.67	-6.87	-5.61	-4.40	-7.81	-7.73	-3.22	-5.31	-2.21

THE MEAN PERCENTAGE DIFFERENCE IS -1.23647

THE STD. DEVIATION IS 4.98360

VARIABLE(100)+CONSTANT(0)+INDEPENDENT TIME

Table No. 68

CYCLE TIME FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(80)+CONSTANT(20))+INDEPENDENT TIME
CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/F	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	1.08366	1.18159	1.27796	1.35988	1.48074	1.58603	1.66683	1.76828	1.85489	1.95758
2	1.10208	1.20252	1.31062	1.43335	1.56432	1.68648	1.79698	1.93661	2.06864	2.24130
3	1.11532	1.23170	1.35769	1.51556	1.71670	1.91464	2.06522	2.32331	2.54359	2.87251
4	1.11320	1.25265	1.43975	1.68008	2.03222	2.37300	2.26276	3.18892	3.58562	3.96429
5	1.11406	1.27454	1.56459	1.90333	2.48405	2.85073	3.25934	3.77548	4.13441	4.76376
6	1.13814	1.32386	1.80450	2.36523	2.92057	3.54627	4.04093	4.70047	5.21708	5.97465
7	1.12662	1.43127	2.05466	2.65736	3.37185	4.11535	4.59282	5.31047	5.91617	6.75121
8	1.14760	1.64268	2.36272	3.10561	3.98663	4.79640	5.51915	6.35834	6.96614	7.75624
9	1.14736	1.79243	2.69108	3.46398	4.59077	5.47908	6.12265	7.15534	7.73067	8.76495
10	1.18611	1.98856	2.93156	3.61717	4.78905	5.64528	6.57125	7.48037	8.40122	9.62067
11	1.19206	2.07555	3.08306	4.04008	5.17265	6.19644	6.93511	8.01779	9.09771	10.37670
12	1.23446	2.25179	3.47884	4.61024	5.77834	6.87087	7.77494	9.16844	10.33936	11.70825
13	1.29639	2.48291	3.74318	4.84450	6.13638	7.44265	8.54737	9.69420	10.91557	12.27798
14	1.41769	2.84086	4.17269	5.62725	6.88733	8.40339	9.47588	10.77382	11.86337	13.54134
15	1.45746	2.92843	4.48800	5.71460	7.32938	8.96012	9.53757	11.36384	12.76228	14.58440
16	1.57279	3.13720	4.65747	6.08463	7.60211	9.30671	10.41257	12.14751	14.02374	15.62302
17	1.62922	3.31523	5.01223	6.37008	8.15097	9.90904	11.26374	12.59774	14.13588	16.34158
18	1.72567	3.32629	5.11600	6.65591	8.73554	10.42357	11.75046	13.58841	14.79070	16.61597
19	1.82598	3.71356	5.42055	7.01446	8.92833	10.91946	12.11460	14.33539	16.16651	18.39539
20	1.92111	3.81204	5.68078	7.58799	9.31603	11.25295	13.03366	15.04022	16.51464	18.65401

Table No. 69

MACHINE IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(80)+CONSTANT(20))+INDEPENDENT TIME

CONSTAN R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00082	0.00174	0.01259	0.03340	0.06228	0.09145	0.11983	0.15760	0.19828	0.25589
3	0.01433	0.03562	0.06538	0.12658	0.22327	0.32823	0.40682	0.56507	0.70138	0.91580
4	0.01759	0.05849	0.14689	0.29086	0.53547	0.78160	0.97040	1.39171	1.62345	1.97232
5	0.02172	0.08688	0.27350	0.52609	0.98768	1.28091	1.60724	2.01966	2.30681	2.81011
6	0.03637	0.13109	0.50679	0.97092	1.43372	1.95509	2.36614	2.91610	3.34588	3.97685
7	0.03140	0.23955	0.76144	1.27789	1.88992	2.52719	2.93619	3.55958	4.06883	4.78531
8	0.05310	0.43932	1.06759	1.71763	2.48807	3.19598	3.82630	4.55999	5.09347	5.78187
9	0.05080	0.59408	1.39210	2.07763	3.07903	3.86901	4.44028	5.35659	5.86810	6.78678
10	0.08982	0.78573	1.63776	2.43331	3.30913	4.25900	4.91199	5.72386	6.55827	7.65260
11	0.09649	0.89088	1.80283	2.67236	3.70151	4.63169	5.30223	6.28622	7.26712	8.43011
12	0.13973	1.06402	2.18792	3.22453	4.29428	5.29382	6.12306	7.39966	8.46989	9.71506
13	0.20105	1.29184	2.45436	3.46994	4.66024	5.86680	6.88633	7.94376	9.07049	10.32715
14	0.31745	1.63746	2.87359	4.22322	5.39106	6.79097	7.79528	8.93922	10.01052	11.56720
15	0.36109	1.73170	3.18743	4.33052	5.83674	7.35976	8.26979	9.60137	10.90061	12.60148
16	0.47473	1.94416	3.36297	4.73065	6.12219	7.71688	8.75578	10.37819	12.13944	13.82252
17	0.53377	2.11980	3.71558	4.99206	6.66831	8.32029	9.59379	10.84997	12.29622	14.37176
18	0.63029	2.14055	3.83046	5.28293	7.24559	8.83930	10.09190	11.82609	12.95934	14.68301
19	0.73018	2.51683	4.13286	5.64190	7.45257	9.34093	10.46959	12.57384	14.30786	16.41424
20	0.82509	2.61956	4.39353	6.20391	7.84498	9.68285	11.37205	13.27931	14.67609	16.71152

Table No. 70

SERVICE UTILIZATION FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(80)+CONSTANT(20))+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.03419	0.18218	0.27860	0.36055	0.48148	0.58683	0.66767	0.76316	0.85582	0.95855
2	0.20361	0.40276	0.59738	0.80134	1.00563	1.19175	1.35609	1.55995	1.74279	1.97306
3	0.30464	0.59306	0.87896	1.16521	1.48285	1.76211	1.97231	2.27820	2.53043	2.87251
4	0.38462	0.77814	1.17429	1.56025	1.99106	2.37033	2.62761	3.18892	3.50562	3.96429
5	0.46446	0.94146	1.45938	1.89097	2.48405	2.85073	3.25934	3.77548	4.13441	4.76376
6	0.61401	1.16060	1.79171	2.36523	2.92057	3.54627	4.04093	4.70047	5.21708	5.97465
7	0.67046	1.34705	2.05468	2.65736	3.37185	4.11535	4.59282	5.31047	5.91617	6.75121
8	0.76117	1.63343	2.36272	3.10561	3.98663	4.79640	5.51015	6.35634	6.96614	7.75624
9	0.87416	1.79243	2.69108	3.46398	4.59077	5.47908	6.12265	7.15534	7.73067	8.76495
10	0.96879	1.98858	2.93156	3.81717	4.78905	5.84528	6.57125	7.48037	8.40122	9.62067
11	1.05776	2.07955	3.08306	4.04008	5.17265	6.19644	6.93511	8.01779	9.09771	10.37670
12	1.14405	2.25179	3.47884	4.61024	5.77834	6.87087	7.77494	9.16344	10.33996	11.70025
13	1.24785	2.48291	3.74318	4.84450	6.13638	7.44265	8.54737	9.69420	10.91557	12.27798
14	1.41327	2.84088	4.17269	5.62725	6.88733	8.40339	9.47568	10.77382	11.86337	13.54134
15	1.45638	2.92843	4.48800	5.71460	7.32938	8.96012	9.93757	11.36384	12.76228	14.58440
16	1.57279	3.13720	4.65747	6.08463	7.60211	9.30671	10.41257	12.14751	14.02374	15.82392
17	1.62922	3.31523	5.01223	6.37008	8.15097	9.90904	11.26374	12.59774	14.13588	16.34158
18	1.72567	3.32628	5.11600	6.65591	8.73554	10.42357	11.75046	13.58841	14.79070	16.61597
19	1.82598	3.71356	5.42055	7.01446	8.92833	10.91948	12.11460	14.33539	16.16651	18.39539
20	1.92111	3.81204	5.68078	7.58799	9.31603	11.25295	13.03366	15.04022	16.51464	18.65401

Table No. 71

S.MAN IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(80)+CONSTANT(20))+INDEPENDENT TIME
CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.99946	0.99941	0.99936	0.99932	0.99926	0.99921	0.99917	0.99912	0.99907	0.99902
2	0.89547	0.79[illegible]76	0.71325	0.63281	0.55869	0.49474	0.44089	0.37666	0.32586	0.26824
3	0.81068	0.64164	0.47873	0.34635	0.23365	0.15254	0.09291	0.04511	0.01316	-0.00000
4	0.72858	0.47351	0.26546	0.11983	0.04116	0.00267	-0.00000	-0.00000	-0.00000	-0.00000
5	0.64960	0.33303	0.10522	0.01236	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
6	0.52412	0.16326	0.01279	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
7	0.45616	0.08422	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
8	0.36651	0.00926	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
9	0.27321	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
10	0.21733	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
11	0.13430	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
12	0.09041	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
13	0.04355	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
14	0.02442	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
15	0.00108	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
16	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
17	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
18	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
19	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
20	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000

Table No. 72

The Goodness of fit test.
Constant Running time.
Service Time:
Variable Time(80)+Constant(20)+Independent Time.
Single Serviceman.
Test No. 1
Keeping the ratio R(Service Time/Running Time) constant and increasing the number of machines from 1 to 20.

No.	Ratio R	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	0.1	0.03397
2	0.2	0.07671
3	0.3	0.08663
4	0.4	0.22524
5	0.5	0.17183
6	0.6	0.11664
7	0.7	0.51561
8	0.8	0.31702
9	0.9	0.46309
10	1.0	0.20501

For 19 degrees of freedom, the 5% level of significance is $P(30.144<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2\geqslant 30.144$. Hence, for the 5% level of significance, χ^2=1,2,...10 are not significant.

Test No. 2

Keeping machines constant and increasing the ratio R.

No.	No. of Machines.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	1	0.00525
2	2	0.06760
3	3	0.06790
4	4	0.12621
5	5	0.08313
6	6	0.02772
7	7	0.06860
8	8	0.01485
9	9	0.02742
10	10	0.10670
11	11	0.27992
12	12	0.09404
13	13	0.16876
14	14	0.04130
15	15	0.07224
16	16	0.08903
17	17	0.15641
18	18	0.25794
19	19	0.19640
20	20	0.26032

For 9 degrees of freedom, the 5% level of significance is $P(16.919<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2\geqslant 19.675$. Hence, for the 5% level of significance, χ^2=1,2,...20 are not significant.

Table No. 73

THE PERCENTAGE DIFFERENCES ARE

N/P	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1	-1.48	-1.51	-1.67	-2.83	-1.23	-0.81	-1.88	-1.68	-2.29	-2.02
2	0.14	0.20	0.00	2.36	4.26	5.37	5.67	7.55	8.83	12.01
3	1.29	2.60	4.38	8.17	14.33	6.31	-1.68	-3.18	-5.74	-4.16
4	1.04	4.31	10.63	4.86	1.59	-1.10	*9.12	-0.21	-2.43	-0.64
5	1.07	6.11	4.21	-4.85	-0.59	-4.86	-6.70	-5.37	-7.82	-4.34
6	3.20	10.18	2.20	-1.41	-2.53	-1.28	-3.50	-1.70	-2.04	0.13
7	2.10	2.13	-2.16	-5.00	-3.47	-1.72	-5.89	-4.69	-5.53	-2.87
8	3.95	2.61	-1.51	-2.79	-0.06	0.32	-0.94	-0.03	-2.53	-2.21
9	3.86	-0.46	-0.24	-3.57	2.38	1.95	-2.22	0.12	-3.72	-1.63
10	7.31	-0.53	-2.15	-4.30	-3.81	-2.02	-5.45	-5.68	-5.70	-2.67
11	7.79	-5.46	-6.41	-7.87	-5.48	-5.49	-9.19	-7.99	-7.04	-4.42
12	2.38	-6.13	-3.15	-3.57	-3.14	-3.85	-6.58	-3.43	-3.02	-1.06
13	-0.70	-4.43	-3.76	-6.41	-4.98	-3.77	-5.09	-5.63	-5.37	-4.02
14	0.89	1.57	-0.74	1.01	-0.89	0.98	-2.20	-2.50	-4.37	-1.55
15	-3.15	-2.25	0.09	-4.20	-1.49	0.58	-4.17	-3.90	-3.85	-0.89
16	-1.96	-1.80	-2.57	-4.31	-4.13	-1.97	-5.76	-3.57	-0.81	0.97
17	-4.36	-2.30	-1.28	-5.66	-3.19	-1.67	-3.95	-5.77	-5.77	-1.71
18	-4.28	-7.39	-4.79	-6.85	-1.93	-2.22	-5.27	-3.88	-6.75	-5.47
19	-3.99	-2.02	-4.79	-6.94	-4.97	-2.87	-7.37	-3.82	-3.31	-0.70
20	-3.99	-4.42	-4.76	-4.31	-5.73	-4.82	-5.23	-4.02	-6.04	-4.19

THE MEAN PERCENTAGE DIFFERENCE IS -1.93399

THE STD. DEVIATION IS 4.11035

VARIABLE(80)+CONSTANT(20)+INDEPENDENT TIME

Table No. 74

CYCLE TIME FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(60)+CONSTANT(40))+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	1.08502	1.18372	1.28090	1.36542	1.48104	1.58292	1.66400	1.76616	1.85257	1.95941
2	1.10066	1.20006	1.30365	1.41469	1.53333	1.65190	1.74708	1.88316	2.00825	2.17673
3	1.10943	1.21810	1.33361	1.46724	1.64717	1.84043	2.01497	2.28136	2.54590	2.88576
4	1.10871	1.23501	1.40087	1.63105	1.98452	2.36360	2.68115	3.10798	3.51497	3.94329
5	1.10932	1.24600	1.49713	1.91260	2.46160	2.84199	3.27864	3.71637	4.21307	4.79145
6	1.12401	1.30124	1.77264	2.32844	2.89937	3.52653	3.99806	4.70621	5.21023	5.92285
7	1.11838	1.37742	2.06510	2.68137	3.37250	4.08328	4.56863	5.28970	5.88041	6.71609
8	1.13436	1.59709	2.37590	3.07648	3.97328	4.76221	5.51199	6.24676	6.88373	7.73975
9	1.13723	1.81656	2.73473	3.53477	4.52929	5.43241	6.11571	6.90847	7.70330	8.71727
10	1.15469	1.94660	2.86635	3.83680	4.64581	5.81150	6.59416	7.56269	8.53889	9.65559
11	1.16747	2.10227	3.04452	4.13463	5.09460	6.11894	7.05376	8.31609	9.21628	10.43767
12	1.22490	2.30339	3.46212	4.61817	5.73675	6.78097	7.70448	9.18892	10.32765	11.66637
13	1.27806	2.47283	3.76706	4.80500	6.18625	7.52116	8.40981	9.80049	10.93617	12.36163
14	1.41796	2.77027	4.10685	5.47975	6.99844	8.38697	9.39986	10.69014	11.89762	13.56628
15	1.48955	2.88482	4.41505	5.75452	7.29600	8.69658	10.00848	11.42808	12.89246	14.61294
16	1.56690	3.08039	4.62376	6.09902	7.72918	9.15705	10.48019	12.25510	13.83367	15.64943
17	1.63248	3.30911	4.89233	6.38719	8.11058	9.86606	11.17831	12.70792	14.32659	16.36220
18	1.69362	3.34275	5.02338	6.59661	8.72433	10.31872	11.52457	13.32304	14.81895	16.72290
19	1.85217	3.64453	5.47919	7.06749	8.98972	10.85403	12.32868	14.23130	15.95459	18.27638
20	1.90134	3.81191	5.69919	7.44971	9.45703	11.29123	12.89048	14.84867	16.53118	18.77898

Table No. 75

MACHINE IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(60)+CONSTANT(40))+INDEPENDENT TIME

CONSTAN R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00055	0.79994	0.00638	0.01832	0.03602	0.05810	0.07791	0.10837	0.14087	0.19369
3	0.00972	0.63471	0.04248	0.08407	0.16068	0.25767	0.35632	0.52205	0.69679	0.92283
4	0.01281	0.45127	0.10717	0.24157	0.49033	0.77318	1.01126	1.33126	1.63517	1.95740
5	0.01627	0.30408	0.21079	0.53033	0.96977	1.27329	1.62236	1.97260	2.36951	2.83093
6	0.02373	0.12471	0.47769	0.94069	1.41601	1.94041	2.33035	2.92090	3.34015	3.93412
7	0.02300	0.24024	0.77041	1.29822	1.89045	2.49833	2.93215	3.53223	4.03826	4.75347
8	0.03775	0.00251	1.07887	1.60153	2.47632	3.16627	3.81950	4.46270	5.02056	5.76880
9	0.03874	0.00375	1.43075	2.14161	3.02428	3.82640	4.43437	5.13760	5.84374	6.74472
10	0.05574	0.00606	1.57908	2.45241	3.35852	4.22820	4.93235	5.80390	6.67789	7.68397
11	0.07207	0.01011	1.76732	2.75788	3.62956	4.55955	5.41051	6.55669	7.37482	8.48460
12	0.12771	0.01692	2.17287	3.23111	4.25613	5.21341	6.05953	7.41743	8.45938	9.68473
13	0.18169	0.02154	2.47663	3.43293	4.70757	5.93951	6.75873	8.04109	9.08760	10.40307
14	0.31723	0.02639	2.81398	4.08651	5.49532	6.78377	7.72273	8.91970	10.04022	11.58954
15	0.39075	0.02530	3.11908	4.36718	5.80468	7.11047	8.33542	9.65551	11.02459	12.62574
16	0.46923	0.03316	3.33301	4.71388	6.24134	7.57864	8.81805	10.43120	11.96023	13.66033
17	0.53685	0.04170	3.60318	5.03619	6.62973	8.28100	9.51623	10.95296	12.47696	14.39116
18	0.59869	0.04751	3.74225	5.22712	7.23519	8.74029	9.87857	11.57603	12.96692	14.78420
19	0.75490	0.04565	4.18909	5.69096	7.51220	9.27723	10.67336	12.53156	14.10585	16.30534
20	0.80622	0.07227	4.41124	6.07284	7.97794	9.71931	11.23792	13.09516	14.69185	16.82806

- 183 -

Table No. 76

SERVICE UTILIZATION FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(60)+CONSTANT(40))+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.08656	0.18431	0.28154	0.36610	0.48178	0.58372	0.66484	0.76704	0.85350	0.96039
2	0.20131	0.40012	0.59589	0.79414	0.99617	1.16926	1.34008	1.55145	1.73675	1.96624
3	0.30077	0.56339	0.87539	1.15169	1.46376	1.75104	1.97898	2.28136	2.54590	2.68576
4	0.38579	0.78374	1.17762	1.56119	1.98075	2.36369	2.66115	3.10798	3.51407	3.94329
5	0.46799	0.94192	1.43543	1.91260	2.46160	2.84199	3.27884	3.71637	4.21307	4.79145
6	0.60501	1.17653	1.77264	2.32844	2.69937	3.52653	3.99806	4.70621	5.21023	5.92285
7	0.67156	1.33718	2.06510	2.68137	3.37250	4.08325	4.59868	5.28970	5.68041	6.71609
8	0.77738	1.59459	2.37590	3.07648	3.97328	4.76221	5.51199	6.24676	6.88373	7.73975
9	0.89141	1.81656	2.73473	3.53477	4.52929	5.43241	6.11571	6.90847	7.70339	8.71727
10	0.96730	1.94660	2.86635	3.83680	4.84561	5.81150	6.59416	7.56269	8.53889	9.65559
11	1.05584	2.10227	3.04452	4.13463	5.09460	6.11894	7.05376	8.31609	9.21628	10.43767
12	1.17354	2.30339	3.46212	4.61817	5.73675	6.78097	7.70448	9.18892	10.32705	11.66637
13	1.26104	2.47283	3.76706	4.80500	6.18625	7.52116	8.40981	9.80049	10.93617	12.36163
14	1.41796	2.77027	4.10865	5.47875	6.99844	8.36697	9.39986	10.69014	11.89762	13.56628
15	1.48955	2.88482	4.41565	5.75452	7.29600	8.69688	10.00848	11.42808	12.89246	14.61294
16	1.56690	3.08389	4.62376	6.09902	7.72918	9.15705	10.48019	12.25510	13.83367	15.64943
17	1.63248	3.30911	4.89233	6.38719	8.11058	9.86606	11.17831	12.78792	14.32659	16.36220
18	1.69362	3.34275	5.02338	6.59661	8.72433	10.31872	11.52457	13.32304	14.81895	16.72230
19	1.85217	3.64453	5.47919	7.06749	8.98972	10.85403	12.32868	14.29130	15.95459	18.27638
20	1.90134	3.81191	5.69919	7.44971	9.45703	11.29123	12.89046	14.84867	16.53118	18.77898

Table No. 77

S.MAN IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(60)+CONSTANT(40))+INDEPENDENT TIME
CONSTANT P=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.99946	0.99941	0.99936	0.99932	0.99926	0.99921	0.99917	0.99912	0.99908	0.99902
2	0.89934	0.79994	0.70782	0.62054	0.53716	0.46264	0.40700	0.33170	0.27149	0.20846
3	0.80866	0.63471	0.45823	0.31555	0.18342	0.08939	0.03599	-0.00000	-0.00000	-0.00000
4	0.72292	0.45127	0.22325	0.06986	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
5	0.64132	0.30406	0.06170	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
6	0.51960	0.12471	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
7	0.44683	0.04424	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
8	0.35698	0.00251	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
9	0.24581	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
10	0.18763	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
11	0.11630	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
12	0.05130	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
13	0.01751	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
14	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
15	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
16	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
17	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
18	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
19	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
20	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000

Table No. 78

The Goodness of fit test.
Constant Running Time.
Service Time:
Variable Time(60)+Constant(40)+Independent Time.
Single Serviceman.
Test No. 1
Keeping the ratio R(Service Time/Running Time) constant and increasing the number of machines from 1 to 20.

No.	Ratio R	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	0.1	0.02622
2	0.2	0.06855
3	0.3	0.09889
4	0.4	0.21268
5	0.5	0.13250
6	0.6	0.14350
7	0.7	0.43732
8	0.8	0.30565
9	0.9	0.40983
10	1.0	0.15999

For 19 degrees of freedom, the 5% level of significance is $P(30.144 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 30.144$. Hence, for the 5% level of significance, χ^2=1,2,...10 are not significant.

Test No. 2
Keeping machines constant and increasing the ratio R.

No.	No. of Machines.	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	1	0.00501
2	2	0.02908
3	3	0.04134
4	4	0.01929
5	5	0.06961
6	6	0.03060
7	7	0.07567
8	8	0.02261
9	9	0.03236
10	10	0.07855
11	11	0.20833
12	12	0.11009
13	13	0.16111
14	14	0.04783
15	15	0.05804
16	16	0.08290
17	17	0.14023
18	18	0.32282
19	19	0.18019
20	20	0.27957

For 9 degrees of freedom, the 5% level of significance is $P(16.919 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 19.675$. Hence, for the 5% level of significance, χ^2=1,2,...20 are not significant.

Table No. 79

THE PERCENTAGE DIFFERENCES ARE

N/P	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1	-1.26	-1.34	-1.44	-2.43	-1.21	-1.01	-2.05	-1.80	-2.41	-1.93
2	0.02	-0.00	0.27	1.03	2.20	3.21	2.73	4.58	5.65	8.78
3	0.76	1.47	2.52	4.72	9.70	2.18	-4.07	-4.92	-5.65	-3.73
4	0.64	2.85	7.65	1.80	-0.80	-1.49	-4.16	-2.74	-2.17	-1.17
5	0.64	3.73	-0.28	-4.39	-1.49	-5.15	-6.14	-6.85	-6.07	-3.79
6	1.91	8.30	-1.56	-2.94	-3.23	-1.78	-4.53	-1.58	-3.06	-0.74
7	1.35	-1.71	-1.66	-4.14	-3.45	-2.49	-5.98	-5.07	-6.10	-3.38
8	2.74	-0.25	-0.96	-3.71	-0.39	-0.40	-1.07	-1.78	-3.68	-2.42
9	2.94	0.88	1.38	-1.60	1.00	1.09	-2.33	-3.33	-4.06	-2.16
10	4.48	-2.58	-4.33	-3.81	-2.67	-2.59	-5.12	-4.65	-4.16	-2.32
11	5.56	-4.42	-7.58	-5.71	-6.90	-6.67	-7.63	-4.56	-5.83	-3.86
12	1.58	-3.98	-3.61	-3.40	-3.83	-5.11	-7.42	-3.22	-3.14	-1.35
13	-2.11	-4.82	-3.15	-7.17	-4.20	-2.76	-6.62	-4.60	-5.19	-3.76
14	0.90	-0.95	-1.86	-1.64	0.71	0.78	-2.98	-3.25	-4.09	-1.37
15	-1.01	-3.70	-1.53	-3.53	-1.93	-2.37	-3.48	-3.35	-2.87	-0.69
16	-2.33	-3.56	-3.28	-4.09	-2.53	-3.54	-5.15	-2.72	-2.16	-0.14
17	-4.17	-2.48	-3.64	-5.41	-3.67	-2.10	-4.68	-4.94	-4.50	-1.58
18	-6.06	-6.93	-6.51	-7.68	-2.06	-3.21	-7.09	-5.76	-6.58	-4.86
19	-2.61	-3.84	-3.35	-6.24	-4.32	-3.46	-5.74	-4.12	-4.58	-1.34
20	-4.98	-4.43	-4.45	-6.05	-4.30	-4.50	-6.27	-5.24	-5.94	-3.55

THE MEAN PERCENTAGE DIFFERENCE IS -2.39252

THE STD. DEVIATION IS 3.15370

VARIABLE(60)+CONSTANT(40)+INDEPENDENT TIME

Table No. 80

CYCLE TIME FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(40)+CONSTANT(60))+INDEPENDENT TIME
CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	1.08968	1.18714	1.28372	1.37048	1.48148	1.56166	1.66200	1.76492	1.85276	1.96255
2	1.09967	1.19750	1.29670	1.39637	1.50769	1.61576	1.70766	1.83404	1.95044	2.09654
3	1.10491	1.20685	1.31497	1.43073	1.58857	1.77598	1.98130	2.27156	2.54760	2.88973
4	1.10390	1.21512	1.36119	1.56794	1.97322	2.35082	2.68106	3.03365	3.47868	3.91003
5	1.10450	1.22027	1.45927	1.90582	2.42059	2.87190	3.26287	3.77955	4.23198	4.80983
6	1.10806	1.26700	1.77344	2.30848	2.87949	3.52654	4.02162	4.66171	5.18825	5.87689
7	1.11240	1.33841	2.04231	2.67831	3.39766	4.02207	4.58966	5.29258	5.93659	6.72978
8	1.11690	1.56476	2.39064	3.10053	3.90137	4.72604	5.41881	6.21263	6.90626	7.[illegible]2481
9	1.11994	1.77816	2.68039	3.49844	4.49594	5.31716	6.01128	6.88697	7.69255	8.70389
10	1.13414	1.95617	2.89866	3.83532	4.83134	5.79238	6.63363	7.65166	8.54974	9.65598
11	1.14187	2.09343	3.14206	4.11010	5.14286	6.23858	7.18136	8.33156	9.28028	10.48968
12	1.18632	2.32925	3.50753	4.59991	5.74403	6.82472	7.83999	9.11176	10.28313	11.63979
13	1.27029	2.50968	3.76491	4.85797	6.26570	7.43253	8.43482	9.78447	10.99207	12.40934
14	1.37536	2.73302	4.11601	5.44472	6.89559	8.27350	9.25758	10.71976	11.87936	13.51290
15	1.47436	2.91254	4.38838	5.68543	7.28992	8.73065	9.87630	11.50163	12.82855	14.55192
16	1.56338	3.07714	4.61662	6.09730	7.69650	9.17036	10.46427	12.17808	13.63964	15.55369
17	1.63882	3.28873	4.92516	6.43667	8.13720	9.87350	11.13994	12.90025	14.19833	16.32479
18	1.73982	3.40150	5.16949	6.67845	8.60932	10.27326	11.63362	13.50341	14.95259	16.90465
19	1.86186	3.63522	5.47506	7.16196	9.02422	10.79214	12.32572	14.26323	16.00213	18.24794
20	1.91634	3.80446	5.72585	7.44547	9.54194	11.47004	12.86435	14.94866	16.66077	18.86820

Table No. 81

MACHINE IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(40)+CONSTANT(60))+INDEPENDENT TIME
CONSTAN R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00044	0.00048	0.00252	0.00803	0.01486	0.02772	0.04145	0.06272	0.08780	0.12358
3	0.00637	0.01303	0.02302	0.04667	0.10333	0.19515	0.32135	0.51488	0.69815	0.92658
4	0.00774	0.02658	0.06797	0.18241	0.48042	0.76359	1.01093	1.32036	1.60895	1.93216
5	0.01000	0.03122	0.17131	0.52506	0.93648	1.29736	1.60991	2.02279	2.38452	2.84692
6	0.00984	0.07143	0.47826	0.92390	1.39923	1.93779	2.35034	2.88353	3.32210	3.89440
7	0.01682	0.14913	0.75063	1.29537	1.91114	2.44634	2.93300	3.53466	4.08679	4.76575
8	0.02091	0.36976	1.09172	1.71266	2.41285	3.13375	3.73957	4.43421	5.04054	5.75620
9	0.02261	0.58083	1.38235	2.10811	2.99519	3.72462	4.34121	5.11865	5.83419	6.73265
10	0.03805	0.76678	1.60853	2.45026	3.34619	4.21116	4.96754	5.88296	6.68866	7.68474
11	0.04585	0.90330	1.85562	2.73568	3.67380	4.66906	5.52551	6.57011	7.43239	8.53122
12	0.09005	1.13499	2.21374	3.21476	4.26281	5.25310	6.18333	7.34833	8.41955	9.66207
13	0.17329	1.31652	2.47433	3.48218	4.78142	5.85797	6.78181	8.02632	9.14024	10.44653
14	0.27752	1.53710	2.82065	4.06389	5.40040	6.67785	7.59051	8.94706	10.02363	11.53995
15	0.37643	1.71742	3.09357	4.30431	5.79892	7.14271	8.21228	9.72652	10.96375	12.57021
16	0.46569	1.88412	3.32623	4.71260	6.21093	7.59155	8.80310	10.40880	11.77816	13.57148
17	0.54208	2.09440	3.63368	5.05489	6.65478	8.28802	9.47863	11.13422	12.35471	14.35526
18	0.64340	2.21189	3.88020	5.49298	7.12671	8.69741	9.98154	11.74579	13.11354	14.95603
19	0.76405	2.44283	4.18491	5.78221	7.54489	9.21842	10.67027	12.50452	14.15127	16.27792
20	0.82054	2.61299	4.43690	6.07144	8.05859	9.88891	11.21260	13.18994	14.81566	16.91191

Table No. 82

SERVICE UTILIZATION FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(40)+CONSTANT(60))+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.09022	0.18773	0.28436	0.37116	0.48222	0.58245	0.66284	0.76581	0.85368	0.96353
2	0.19536	0.39524	0.58964	0.78207	0.98718	1.17770	1.33413	1.54447	1.72725	1.94801
3	0.29725	0.58306	0.87761	1.15432	1.45810	1.74515	1.98130	2.27156	2.54760	2.88973
4	0.38683	0.78661	1.17569	1.54527	1.97322	2.35082	2.68108	3.09365	3.47868	3.91003
5	0.47522	0.94830	1.44344	1.90582	2.42059	2.87190	3.26287	3.77955	4.23198	4.80983
6	0.59262	1.17725	1.77344	2.30848	2.87349	3.52654	4.02162	4.66171	5.18825	5.87689
7	0.67247	1.32963	2.04231	2.67831	3.39766	4.02207	4.58966	5.29258	5.93659	6.72938
8	0.77228	1.56476	2.39064	3.10053	3.90137	4.72604	5.41881	6.21263	6.90626	7.72481
9	0.88096	1.77616	2.68039	3.49844	4.49594	5.31716	6.01128	6.85697	7.69255	8.70389
10	0.96655	1.95617	2.89866	3.83532	4.83134	5.79238	6.63363	7.65166	8.54974	9.65598
11	1.06243	2.09343	3.14206	4.11610	5.14286	6.23858	7.18136	8.33156	9.28028	10.48988
12	1.16236	2.32925	3.50753	4.59991	5.74403	6.82472	7.83999	9.11176	10.28313	11.63979
13	1.26917	2.50968	3.76491	4.85797	6.26570	7.43253	8.43452	9.78447	10.99297	12.40934
14	1.37536	2.73302	4.11601	5.44472	6.89559	8.27350	9.25758	10.71976	11.87936	13.51290
15	1.47436	2.91254	4.38838	5.68543	7.28992	8.73065	9.87830	11.50163	12.82855	14.55192
16	1.56338	3.07714	4.61662	6.09730	7.69650	9.17036	10.46427	12.17808	13.63964	15.55369
17	1.63882	3.28873	4.92516	6.43667	8.13720	9.87350	11.13994	12.90025	14.19833	16.32479
18	1.73982	3.49150	5.16940	6.67645	8.60932	10.27326	11.63362	13.50341	14.95259	16.90465
19	1.86186	3.63522	5.47506	7.16196	9.02422	10.79214	12.32572	14.26323	16.00213	18.24794
20	1.91634	3.80446	5.72585	7.44547	9.54194	11.47004	12.86435	14.94866	16.66077	18.66820

Table No. 83

S.MAN IDLE FACTOR FOR A SINGLE SERVICEMEN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(40)+CONSTANT(60))+INDEPENDENT TIME
CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.99946	0.99941	0.99936	0.99931	0.99926	0.99921	0.99917	0.99912	0.99908	0.99902
2	0.90071	0.80226	0.70706	0.61629	0.52051	0.43806	0.37353	0.28957	0.22320	0.14853
3	0.80766	0.62376	0.43716	0.27641	0.13048	0.03083	-0.00000	-0.00000	-0.00000	-0.00000
4	0.71706	0.43452	0.18550	0.02267	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
5	0.62328	0.27197	0.01583	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
6	0.51545	0.08975	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
7	0.43943	0.00877	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
8	0.34462	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
9	0.23897	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
10	0.16759	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
11	0.07944	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
12	0.02396	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
13	0.00112	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
14	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
15	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
16	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
17	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
18	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
19	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
20	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000

Table No. 84

The Goodness of fit test.
Constant Running Time.
Service Time:
Variable Time(40)+Constant(60)+Independent Time.
Single Serviceman.
Test No. 1
Keeping the ratio R(Service Time/Running Time) constant and increasing the number of machines from 1 to 20.

No.	Ratio R	$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$
1	0.1	0.01513
2	0.2	0.05545
3	0.3	0.05992
4	0.4	0.16942
5	0.5	0.11150
6	0.6	0.12409
7	0.7	0.42302
8	0.8	0.25575
9	0.9	0.38249
10	1.0	0.12790

For 19 degrees of freedom, the 5% level of significance is $P(30.144 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 30.144$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 10$ are not significant.

Test No. 2
Keeping machines constant and increasing the ratio R.

No.	No. of Machines	$= \sum \frac{(o_i - e_i)^2}{e_i}$
1	1	0.00457
2	2	0.00670
3	3	0.03208
4	4	0.01835
5	5	0.05994
6	6	0.03061
7	7	0.07399
8	8	0.02749
9	9	0.04201
10	10	0.06425
11	11	0.14836
12	12	0.09359
13	13	0.14144
14	14	0.06242
15	15	0.07343
16	16	0.10303
17	17	0.13281
18	18	0.20812
19	19	0.17121
20	20	0.23026

For 9 degrees of freedom, the 5% level of significance is $P(16.919 < \chi^2 < \infty) = 0.05$ and the rejection region is $\chi^2 \geqslant 19.675$. Hence, for the 5% level of significance, $\chi^2 = 1, 2, \ldots 20$ are not significant.

Table No. 85

THE PERCENTAGE DIFFERENCES ARE

N/P	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1	-0.93	-1.05	-1.22	-2.07	-1.19	-1.09	-2.17	-1.87	-2.40	-1.77
2	-0.13	-0.22	-0.27	-0.14	0.49	0.95	0.42	1.85	2.61	4.77
3	0.35	0.53	1.09	2.11	5.80	-1.39	-5.67	-5.33	-5.59	-3.58
4	0.20	1.19	4.60	-2.14	-1.36	-2.02	-4.17	-3.19	-3.18	-2.00
5	0.20	1.59	-2.80	-4.73	-3.13	-4.15	-6.60	-5.26	-5.64	-3.42
6	0.47	5.45	-1.52	-3.77	-3.90	-1.83	-3.96	-2.51	-3.47	-1.51
7	0.81	-4.49	-2.75	-4.25	-2.73	-3.95	-5.96	-5.01	-5.20	-3.19
8	1.16	-2.27	-0.35	-2.95	-2.20	-1.15	-2.74	-2.32	-3.37	-2.61
9	1.38	-1.25	-0.64	-2.61	0.26	-1.06	-4.00	-3.63	-4.20	-2.31
10	2.61	-2.25	-3.25	-3.85	-2.96	-2.91	-4.55	-3.52	-4.04	-2.32
11	3.25	-4.83	-4.61	-6.27	-6.02	-4.85	-5.96	-4.38	-5.18	-3.78
12	-1.62	-2.90	-2.35	-3.78	-3.71	-4.50	-5.80	-4.03	-3.55	-1.58
13	-2.70	-3.40	-3.20	-6.15	-2.97	-3.90	-6.34	-4.75	-4.71	-2.99
14	-2.13	-2.28	-1.69	-2.26	-0.77	-0.58	-4.45	-2.99	-4.24	-1.76
15	-2.02	-2.78	-2.13	-4.69	-2.02	-1.99	-4.74	-2.73	-3.35	-1.11
16	-2.55	-3.68	-3.43	-4.12	-2.94	-3.40	-5.29	-3.33	-3.53	-0.75
17	-3.80	-3.03	-2.98	-4.68	-3.35	-2.02	-5.01	-3.50	-5.35	-1.81
18	-3.49	-5.32	-3.79	-3.73	-3.35	-3.63	-6.21	-4.49	-5.73	-3.82
19	-2.11	-4.69	-3.42	-4.98	-3.95	-4.01	-5.76	-4.30	-4.29	-1.49
20	-4.23	-4.61	-4.01	-6.10	-3.44	-2.99	-6.46	-4.60	-5.21	-3.09

THE MEAN PERCENTAGE DIFFERENCE IS -2.71721

THE STD. DEVIATION IS 2.27316

VARIABLE(40)+CONSTANT(60)+INDEPENDENT TIME

Table No. 86

CYCLE TIME FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(20)+CONSTANT(80))+INDEPENDENT TIME

CONSTANT R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/F	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	1.09257	1.19036	1.28731	1.37724	1.48370	1.58213	1.66134	1.76510	1.85433	1.96539
2	1.09749	1.19512	1.29297	1.38726	1.49077	1.58974	1.67336	1.78697	1.88982	2.02644
3	1.10084	1.19766	1.29914	1.39856	1.53099	1.74328	1.98110	2.09414	2.55103	2.89807
4	1.10107	1.20189	1.31760	1.54234	1.95251	2.34731	2.66362	3.07633	3.43516	3.88954
5	1.10087	1.20363	1.45016	1.91160	2.41560	2.88647	3.28536	3.80801	4.25516	4.82932
6	1.10242	1.22567	1.75422	2.29779	2.90291	3.50583	3.98006	4.61301	5.15726	5.83567
7	1.10475	1.35329	2.03526	2.68648	3.38624	4.05504	4.60292	5.32916	5.94296	6.74425
8	1.10498	1.56053	2.35667	3.05091	3.88151	4.69938	5.34627	6.17906	6.87528	7.72635
9	1.10839	1.75832	2.63490	3.47682	4.43918	5.26068	5.97414	6.69921	7.68905	8.70078
10	1.11350	1.95254	2.91472	3.80647	4.84669	5.80035	6.59940	7.64065	8.53508	9.65452
11	1.12000	2.11617	3.17560	4.15589	5.23137	6.34000	7.20092	8.34211	9.34063	10.55295
12	1.17362	2.33620	3.47332	4.56131	5.78246	6.91913	7.87261	9.11382	10.20002	11.60585
13	1.26679	2.50806	3.74069	4.93436	6.29061	7.47190	8.48823	9.81857	10.99258	12.46657
14	1.37610	2.72708	4.06561	5.39582	6.81929	8.12018	9.23153	10.67151	11.93584	13.48231
15	1.46653	2.90556	4.35213	5.73634	7.25029	8.66956	9.85547	11.40003	12.79363	14.48385
16	1.55784	3.07971	4.64317	6.09826	7.71144	9.21180	10.46690	12.13062	13.38042	15.45396
17	1.64780	3.27986	4.92412	6.42921	8.16371	9.81335	11.14080	12.87638	14.38834	16.30310
18	1.73692	3.44696	5.16277	6.83911	8.63837	10.29156	11.69259	13.54563	15.16692	17.06991
19	1.83687	3.64604	5.45340	7.34901	9.03939	10.87369	[illegible]	14.30893	15.98749	18.21232
20	1.93149	3.81914	5.73693	7.75891	9.56584	11.43051	12.98132	15.00586	16.79663	19.00125

Table No. 87

MACHINE IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(20)+CONSTANT(80))+INDEPENDENT TIME
CONSTAN R=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00005	0.00006	0.00077	0.00104	0.00305	0.00596	0.01055	0.01948	0.03206	0.05613
3	0.00342	0.00433	0.00829	0.01546	0.04643	0.16284	0.32122	0.52976	0.70094	0.93217
4	0.00443	0.00755	0.02569	0.15736	0.46467	0.76076	0.99780	1.30702	1.57594	1.91640
5	0.00527	0.01156	0.16061	0.52961	0.93256	1.30908	1.62861	2.04584	2.40332	2.86231
6	0.00494	0.03167	0.46228	0.91500	1.41894	1.92094	2.31586	2.84295	3.29618	3.86111
7	0.03841	0.16054	0.74462	1.30254	1.96179	2.47472	2.94399	3.56604	4.09185	4.77836
8	0.00870	0.36600	1.06221	1.66901	2.39533	3.11063	3.67639	4.40446	5.01320	5.75721
9	0.01189	0.56328	1.34182	2.08953	2.94453	3.67401	4.30772	5.12961	5.83083	6.72993
10	0.01701	0.75746	1.62283	2.42468	3.35999	4.21813	4.93670	5.87315	6.67746	7.68377
11	0.02351	0.92385	1.88631	2.77696	3.75366	4.76099	5.54308	6.57979	7.48692	8.58831
12	0.07672	1.14142	2.18316	3.17543	4.29811	5.33954	6.21302	7.35001	8.34489	9.63236
13	0.17000	1.31496	2.45194	3.55278	4.80418	5.89366	6.83114	8.05827	9.14118	10.50024
14	0.27834	1.53183	2.77378	4.00796	5.32692	6.53585	7.56722	8.90305	10.07602	11.51156
15	0.36310	1.71105	3.06096	4.35124	5.76321	7.08700	8.19277	9.63334	10.93212	12.50844
16	0.46083	1.88651	3.32282	4.71384	6.22526	7.63070	8.80642	10.36474	11.72297	13.47810
17	0.55122	2.08616	3.63253	5.04805	6.67955	8.23090	9.47936	11.11177	12.53377	14.33469
18	0.64069	2.25451	3.87384	5.45588	7.15392	8.71422	10.03646	11.78529	13.31509	15.13026
19	0.74043	2.45316	4.16420	5.83671	7.55887	9.29563	10.69938	12.54779	14.13689	16.24378
20	0.83502	2.62696	4.44748	6.27154	8.08164	9.85198	11.32410	13.24597	14.94586	17.03834

Table No. 88

SERVICE UTILIZATION FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)

SERVICE TIME(VARIABLE(20)+CONSTANT(80))+INDEPENDENT TIME

CONSTANT ρ=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/P	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.09311	0.19095	0.28795	0.37793	0.48444	0.56292	0.66217	0.76598	0.85526	0.96637
2	0.19596	0.39131	0.58568	0.77382	0.97693	1.16915	1.32731	1.53677	1.71742	1.94265
3	0.29388	0.58179	0.87447	1.15137	1.45596	1.74328	1.98110	2.09414	2.55103	2.89807
4	0.38674	0.77975	1.17026	1.54234	1.95251	2.34731	2.66362	3.07633	3.43516	3.88954
5	0.48077	0.96336	1.45016	1.91160	2.41560	2.86647	3.28536	3.80801	4.25516	4.82932
6	0.58820	1.16763	1.75422	2.29779	2.90291	3.50583	3.98036	4.61301	5.15726	5.83567
7	6.78265	1.35329	2.03526	2.68648	3.38624	4.05504	4.60282	5.32916	5.94296	6.74425
8	0.77465	1.56053	2.35667	3.05091	3.68151	4.69938	5.34627	6.17906	6.87528	7.72635
9	0.88062	1.75832	2.63490	3.47682	4.43918	5.26068	5.97414	6.89521	7.63905	8.70078
10	0.97043	1.95254	2.91472	3.80647	4.84669	5.80035	6.59940	7.64065	8.53598	9.65452
11	1.06751	2.11617	3.17560	4.15589	5.23137	6.34000	7.20092	8.34211	9.34063	10.55295
12	1.16980	2.33623	3.47332	4.56131	5.78246	6.91913	7.87261	9.11382	10.20002	11.60585
13	1.26649	2.53608	3.74069	4.93438	6.29061	7.47190	8.48823	9.81857	10.99258	12.46657
14	1.37610	2.72708	4.06561	5.39582	6.81929	8.12018	9.23153	10.67351	11.93584	13.48231
15	1.46653	2.90556	4.35213	5.73634	7.25029	8.66956	9.85547	11.40003	12.79369	14.48385
16	1.55784	3.07971	4.64317	6.09826	7.71144	9.21180	10.46690	12.13062	13.38042	15.45396
17	1.64780	3.27986	4.92412	6.42921	8.16371	9.81335	11.14080	12.87638	14.38834	16.30310
18	1.73692	3.44696	5.16277	6.83911	8.63837	10.29156	11.69259	13.54563	15.16692	17.08991
19	1.83687	3.64604	5.45340	7.34901	9.03939	10.87369	12.35647	14.30893	15.96749	18.21232
20	1.93149	3.81914	5.73693	7.75891	9.56584	11.43051	12.98132	15.00586	16.79663	19.00125

Table No. 89

S.MAN IDLE FACTOR FOR A SINGLE SERVICEMAN-(CONSTANT RUNNING TIME)
SERVICE TIME(VARIABLE(20)+CONSTANT(80))+INDEPENDENT TIME
CONSTANT F=(SERVICE TIME+INDEPENDENT TIME)/RUNNING TIME

N/F	0.10000	0.20000	0.30000	0.40000	0.50000	0.60000	0.70000	0.80000	0.90000	1.00000
1	0.99345	0.99940	0.99936	0.99931	0.99926	0.99921	0.99917	0.99912	0.99907	0.99902
2	0.90153	0.80381	0.70729	0.61343	0.51384	0.42060	0.34606	0.25020	0.17240	0.08379
3	0.80696	0.61587	0.42467	0.24718	0.07503	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
4	0.71232	0.42214	0.14734	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
5	0.62011	0.24126	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
6	0.51423	0.05804	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
7	0.42649	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
8	0.33333	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
9	0.22777	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
10	0.14307	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
11	0.05249	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
12	0.00383	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
13	0.00030	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
14	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
15	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
16	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
17	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
18	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
19	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
20	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000

Table No. 90

The Goodness of fit test.
Constant Running Time.
Service Time.
Variable Time(20)+Constant(80)+Independent Time.
Single Serviceman.
Test No. 1
Keeping the ratio R(Service Time/Running Time) constant and increasing the number of machines from 1 to 20.

No.	Ratio R	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	0.1	0.01411
2	0.2	0.04418
3	0.3	0.06468
4	0.4	0.12912
5	0.5	0.09110
6	0.6	0.10964
7	0.7	0.40299
8	0.8	0.28469
9	0.9	0.35713
10	1.0	0.10502

For 19 degrees of freedom, the 5% level of significance is $P(30.144<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2>30.144$. Hence, for the 5% level of significance, $\chi^2=1,2,...10$ are not significant.

Keeping machines constant and increasing the ratio R.

No.	No. of Machines.	$\chi^2=\sum\frac{(o_i-e_i)^2}{e_i}$
1	1	0.00393
2	2	0.00125
3	3	0.05941
4	4	0.02504
5	5	0.04949
6	6	0.03890
7	7	0.06425
8	8	0.04250
9	9	0.05011
10	10	0.06924
11	11	0.10693
12	12	0.09296
13	13	0.11812
14	14	0.07634
15	15	0.08923
16	16	0.12614
17	17	0.11912
18	18	0.16002
19	19	0.14732
20	20	0.16238

For 9 degrees of freedom, the 5% level of significance is $P(16.919<\chi^2<\infty)=0.05$ and the rejection region is $\chi^2>19.675$. Hence, for the 5% level of significance, $\chi^2=1,2,...20$ are not significant.

Table No. 91

THE PERCENTAGE DIFFERENCES ARE

N/P	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1	-0.67	-0.70	-0.95	-1.59	-1.04	-1.06	-2.21	-1.86	-2.32	-1.63
2	-0.27	-0.42	-0.56	-0.93	-0.64	-0.67	-1.60	-0.76	-0.58	1.27
3	-0.02	-0.23	-0.13	-0.16	1.96	-3.21	-5.66	*2.73	-5.46	-3.30
4	-0.06	0.09	1.25	-3.73	-2.40	-2.17	-4.79	-3.73	-4.39	-2.52
5	-0.13	0.20	-3.41	-4.44	-3.33	-3.67	-5.95	-4.55	-5.13	-3.03
6	-0.04	2.01	-2.59	-4.22	-3.12	-2.41	-4.96	-3.53	-4.05	-2.20
7	0.11	-3.43	-3.08	-3.96	-3.06	-3.16	-5.69	-4.36	-5.10	-2.97
8	0.08	-2.54	-1.76	-4.51	-2.69	-1.71	-4.05	-2.85	-3.80	-2.59
9	0.33	-2.35	-2.32	-3.21	-1.00	-2.11	-4.59	-3.46	-4.24	-2.35
10	0.74	-2.38	-2.71	-4.57	-2.65	-2.77	-5.04	-3.66	-4.29	-2.33
11	1.27	-3.79	-3.60	-5.23	-4.41	-3.30	-5.71	-4.26	-4.56	-2.80
12	-2.67	-2.61	-3.30	-4.59	-3.07	-3.17	-5.40	-4.01	-4.33	-1.86
13	-2.97	-3.46	-3.83	-4.67	-2.59	-3.39	-5.75	-4.42	-4.70	-2.54
14	-2.07	-2.50	-2.89	-3.14	-1.87	-2.42	-4.72	-3.42	-3.78	-1.96
15	-2.54	-3.01	-2.94	-3.24	-2.55	-2.68	-4.96	-3.59	-3.61	-1.57
16	-2.89	-3.60	-2.87	-4.10	-2.76	-2.97	-5.27	-3.71	-5.36	-1.39
17	-3.27	-3.34	-3.01	-4.79	-3.03	-2.62	-5.00	-3.68	-4.09	-1.94
18	-3.65	-4.03	-3.92	-4.28	-3.02	-3.46	-5.74	-4.19	-4.38	-2.77
19	-3.42	-3.80	-3.81	-2.50	-3.79	-3.28	-5.53	-4.00	-4.38	-1.69
20	-3.47	-4.24	-3.82	-2.15	-3.20	-3.32	-5.61	-4.24	-4.43	-2.40

THE MEAN PERCENTAGE DIFFERENCE IS -2.98627

THE STD. DEVIATION IS 1.76498

VARIABLE(20)+CONSTANT(80)+INDEPENDENT TIME

Table No. 92

Percentage of Walking Time.

Service Constant	Single row	Single row New Position	Two rows	Four rows
0.01	0.570	0.351	0.314	0.215
0.02	0.529	0.365	0.298	0.204
0.03	0.494	0.368	0.273	0.192
0.04	0.459	0.370	0.250	0.177
0.05	0.414	0.364	0.225	0.160
0.06	0.372	0.342	0.202	0.150
0.07	0.322	0.310	0.179	0.129
0.08	0.283	0.275	0.162	0.115
0.09	0.258	0.254	0.141	0.104
0.10	0.239	0.237	0.128	0.096
0.20	0.122	0.111	0.064	0.046
0.30	0.074	0.074	0.040	0.030

No. of servicemen. 1

No. of Machines. 20

Table No. 93

Percentage of Walking Time.

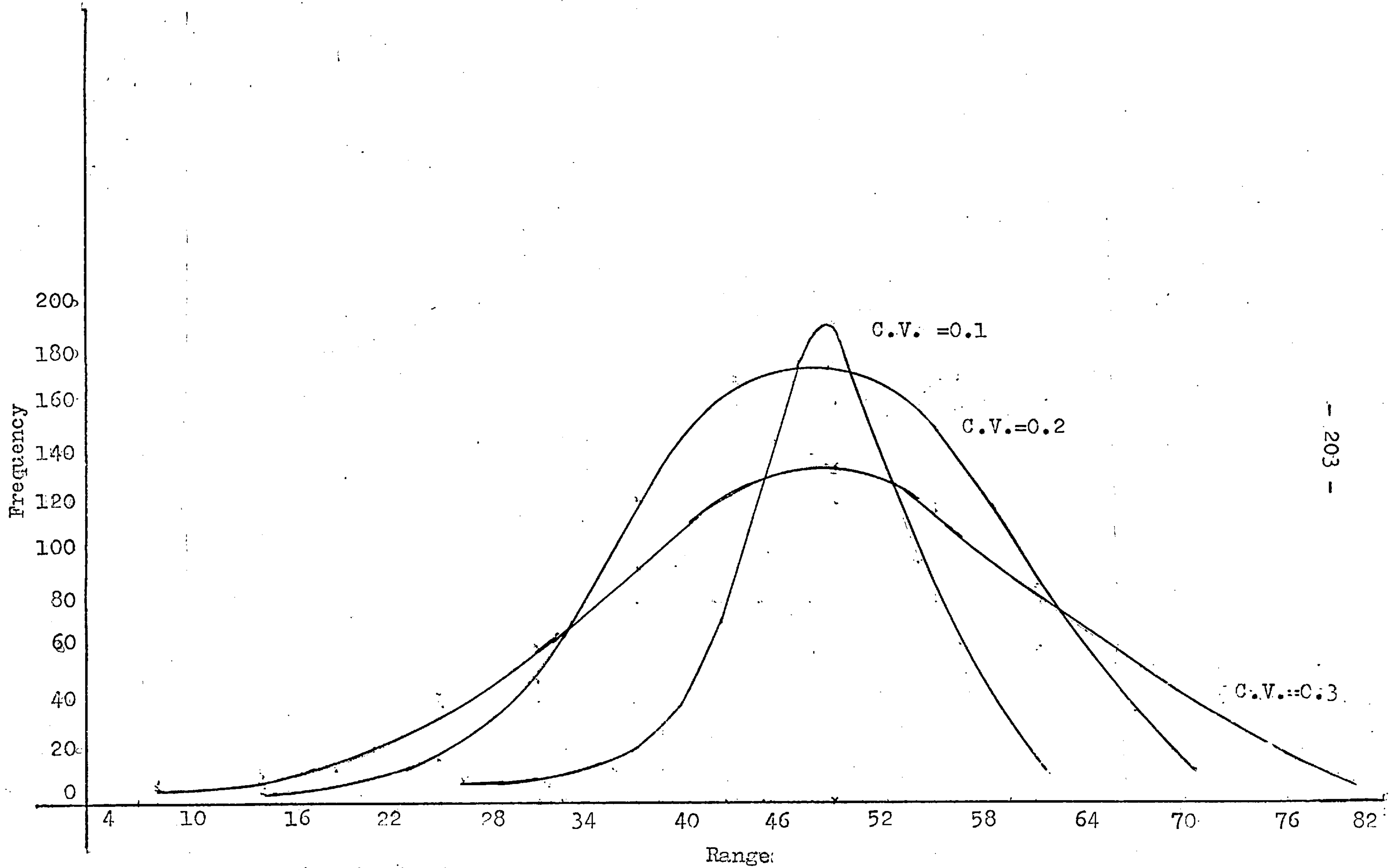
Service Constant	Single row	Single row New Position	Two rows	Four rows
0.01	1.155	0.618	0.610	0.358
0.02	1.089	0.651	0.564	0.345
0.03	1.012	0.689	0.522	0.322
0.04	0.890	0.672	0.468	0.282
0.05	0.769	0.670	0.403	0.255
0.06	0.676	0.637	0.360	0.225
0.07	0.591	0.580	0.315	0.197
0.08	0.509	0.507	0.276	0.173
0.09	0.474	0.473	0.251	0.153
0.10	0.417	0.416	0.220	0.139
0.20	0.201	0.201	0.106	0.067
0.30	0.141	0.141	0.070	0.044

No. of servicemen. 2

No. of Machines. 40

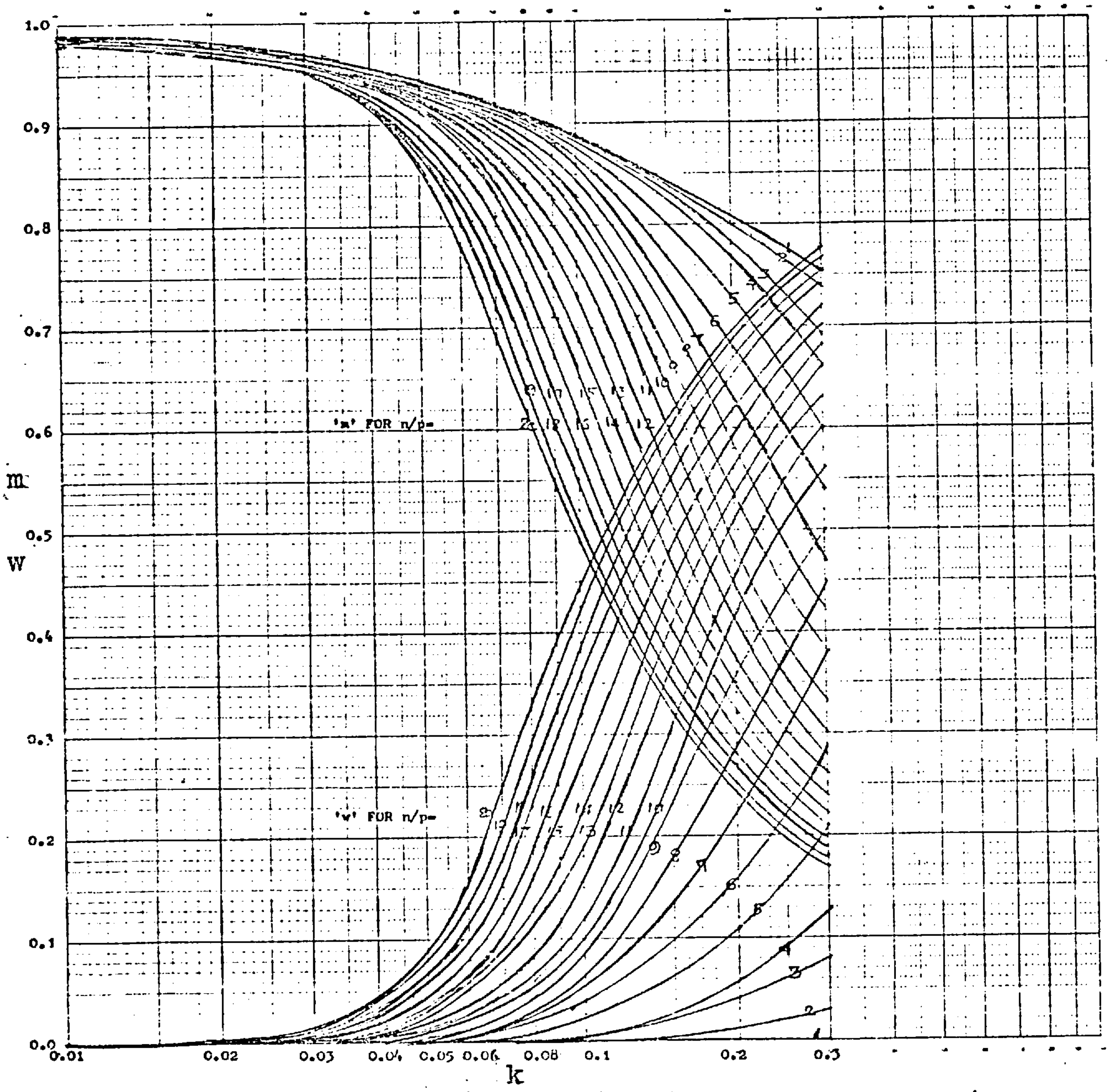
APPENDIX II

MODEL NO.	GRAPHS AND CHARTS
1 - 2	Figs. 1 - 13
3	Figs. 14 - 24
Optimum work force charts	Figs. 25 - 26
4 - 6	Figs. 27 - 35
9 - 16	Figs. 36 - 39

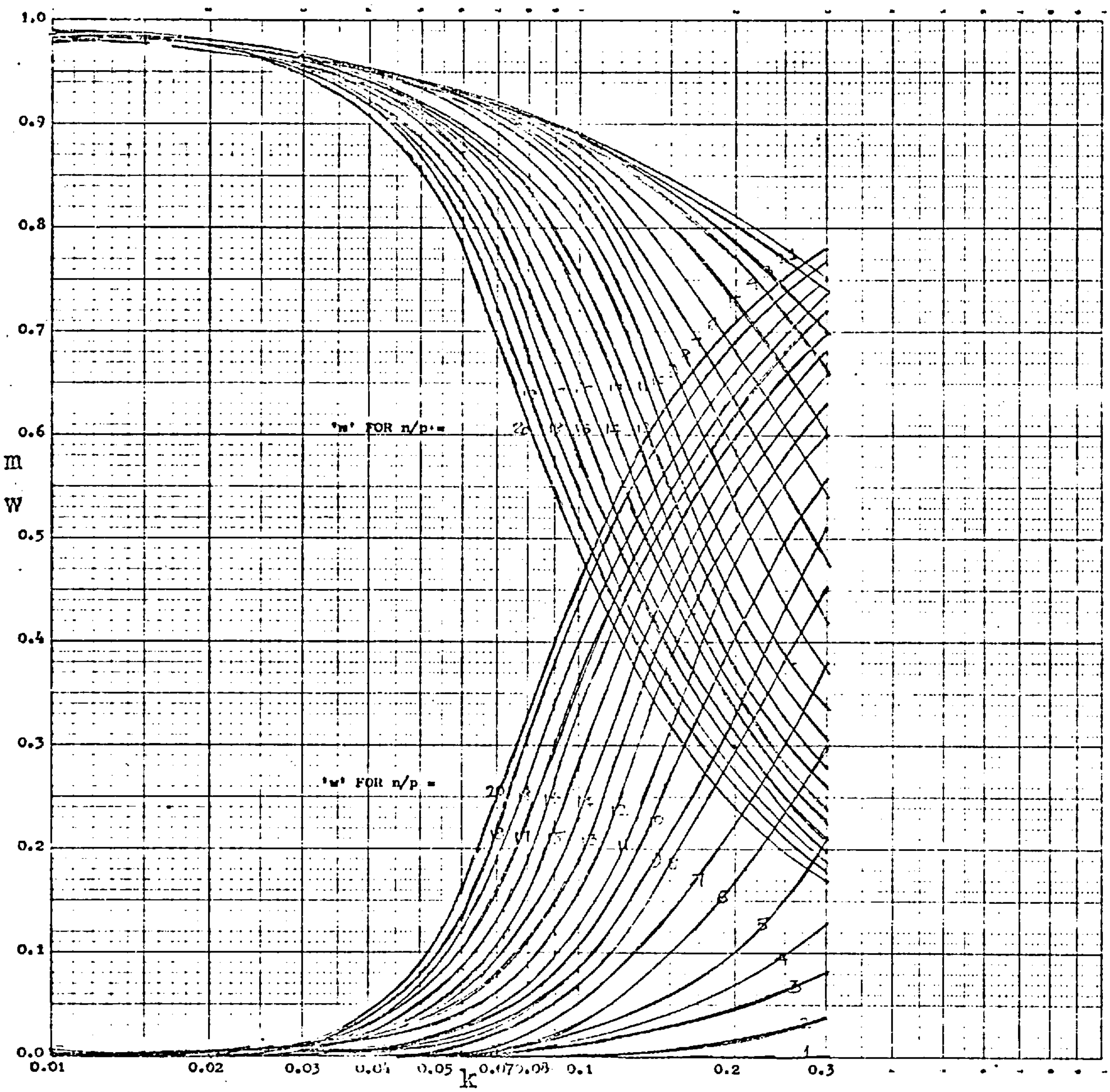


Normal Service Distribution Curves

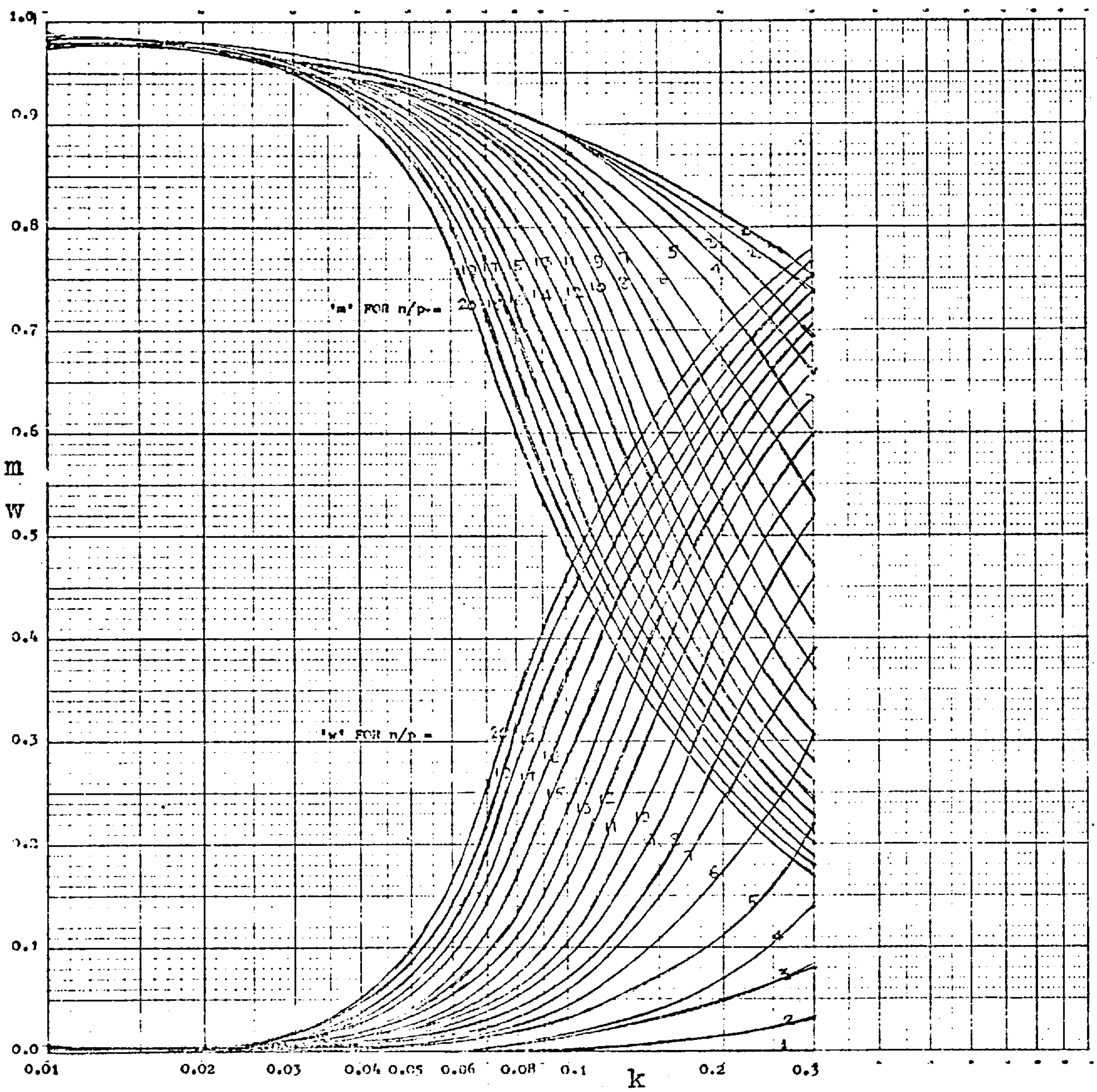
Fig. No. 1



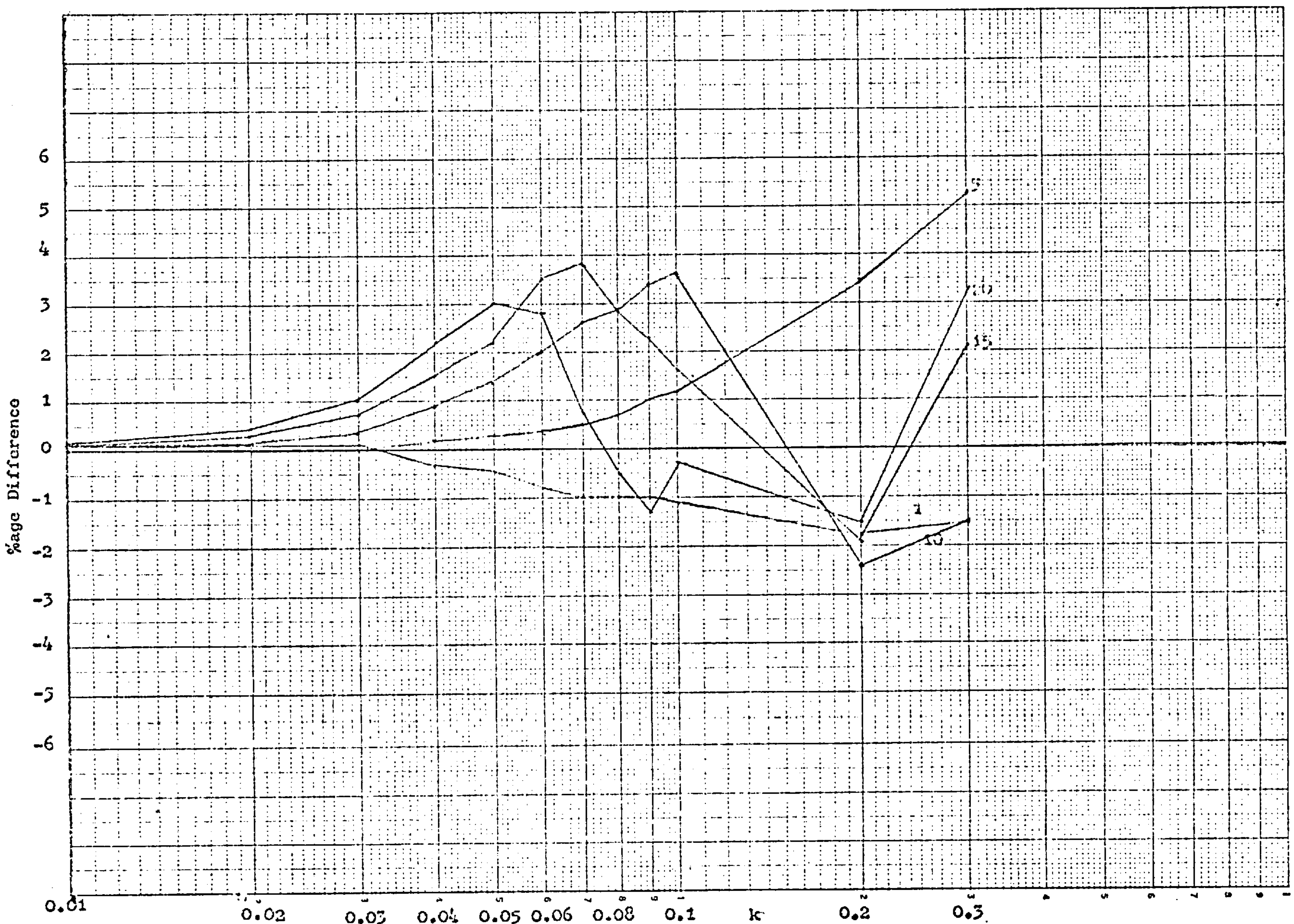
Curves for m and w for a single operator.
Coefficient of Variation 0.1
Fig. No. 2



Curves for m and w for a single operator
Coefficient of Variation 0.2
Fig. No. 3

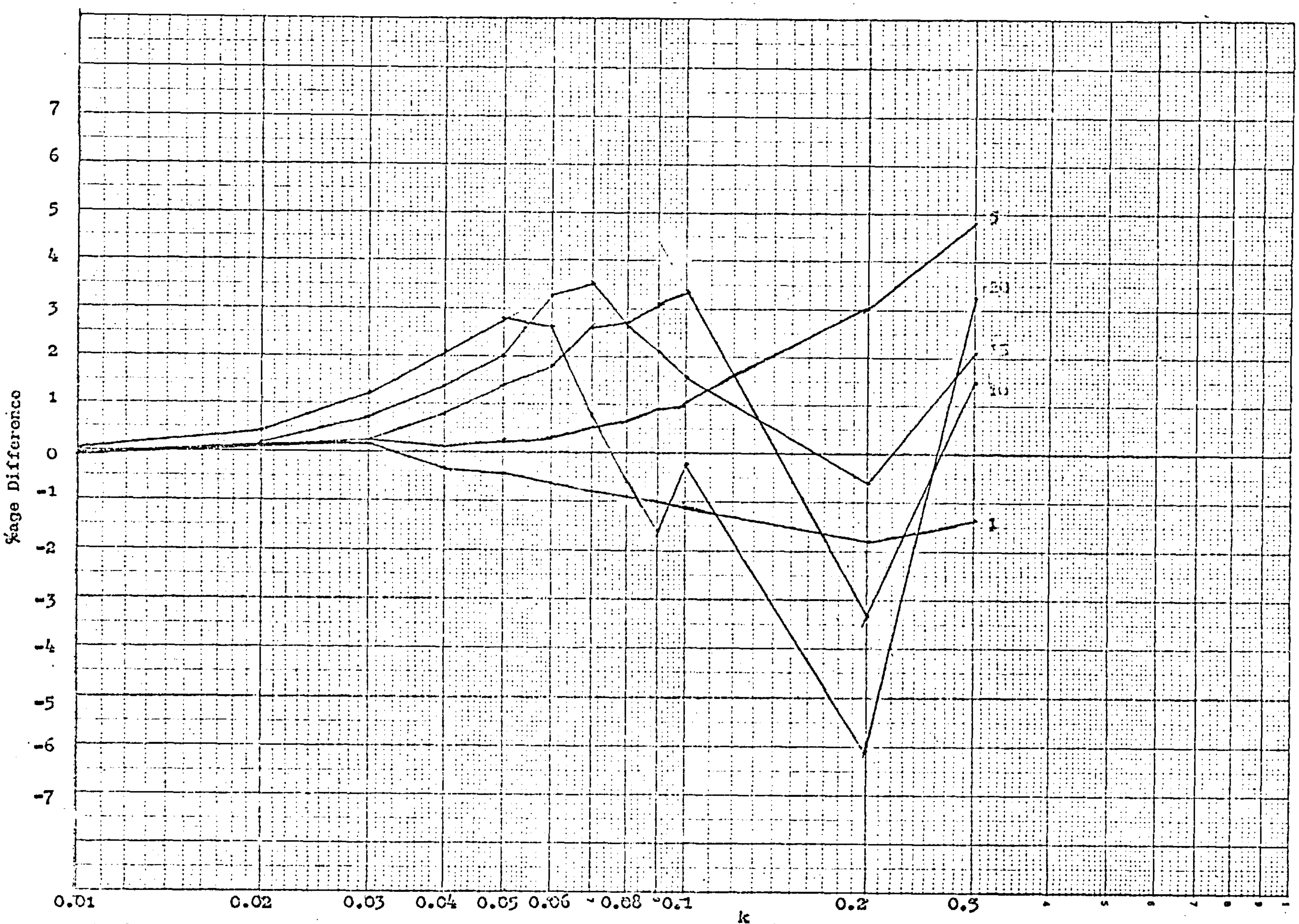


Curves for m and w for a single operator
Coefficient of Variation 0.3
Fig. No. 4



C.V. 0.1
Single Operator.

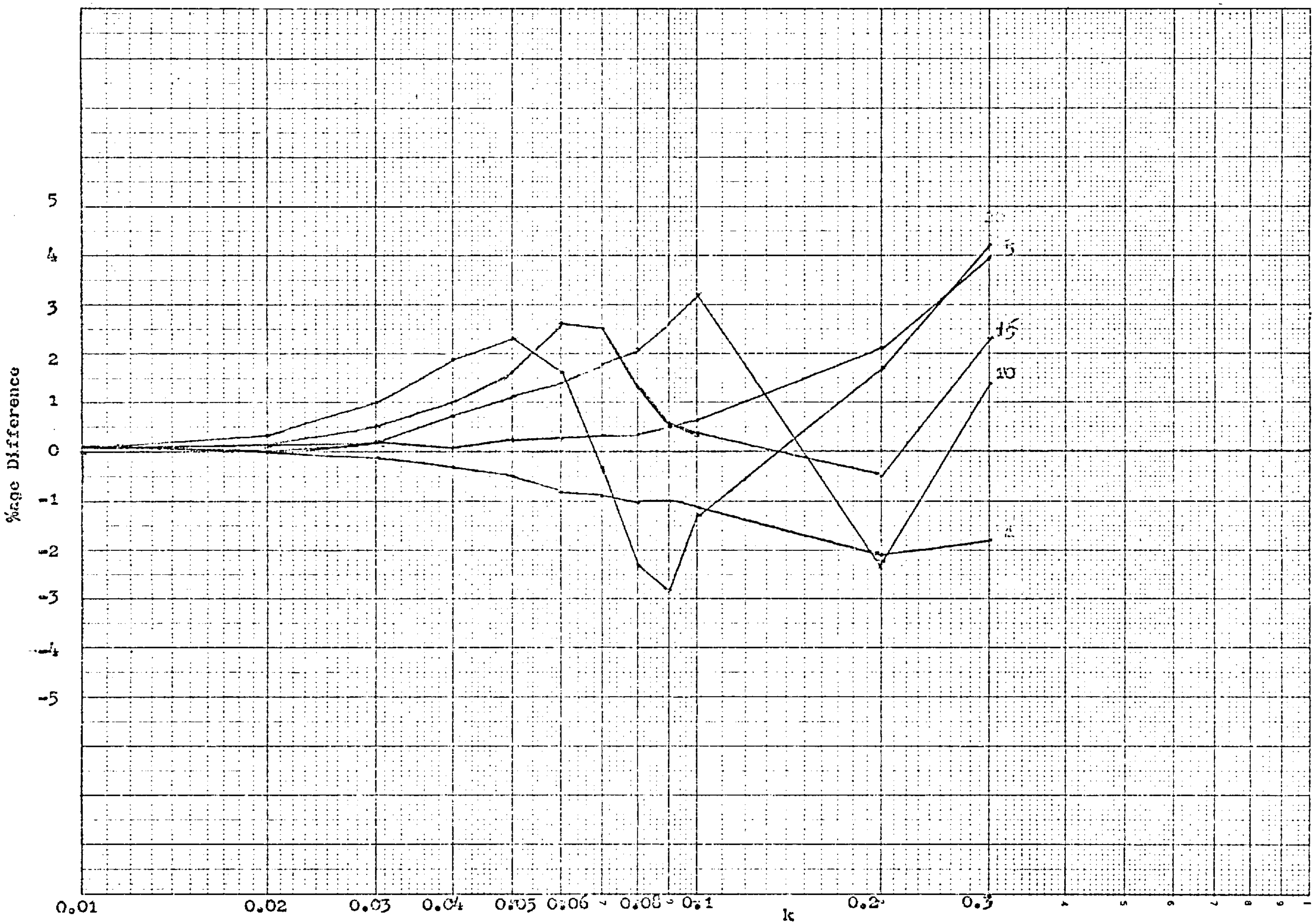
Fig. No. 5



C.V. 0.2

Single Operator

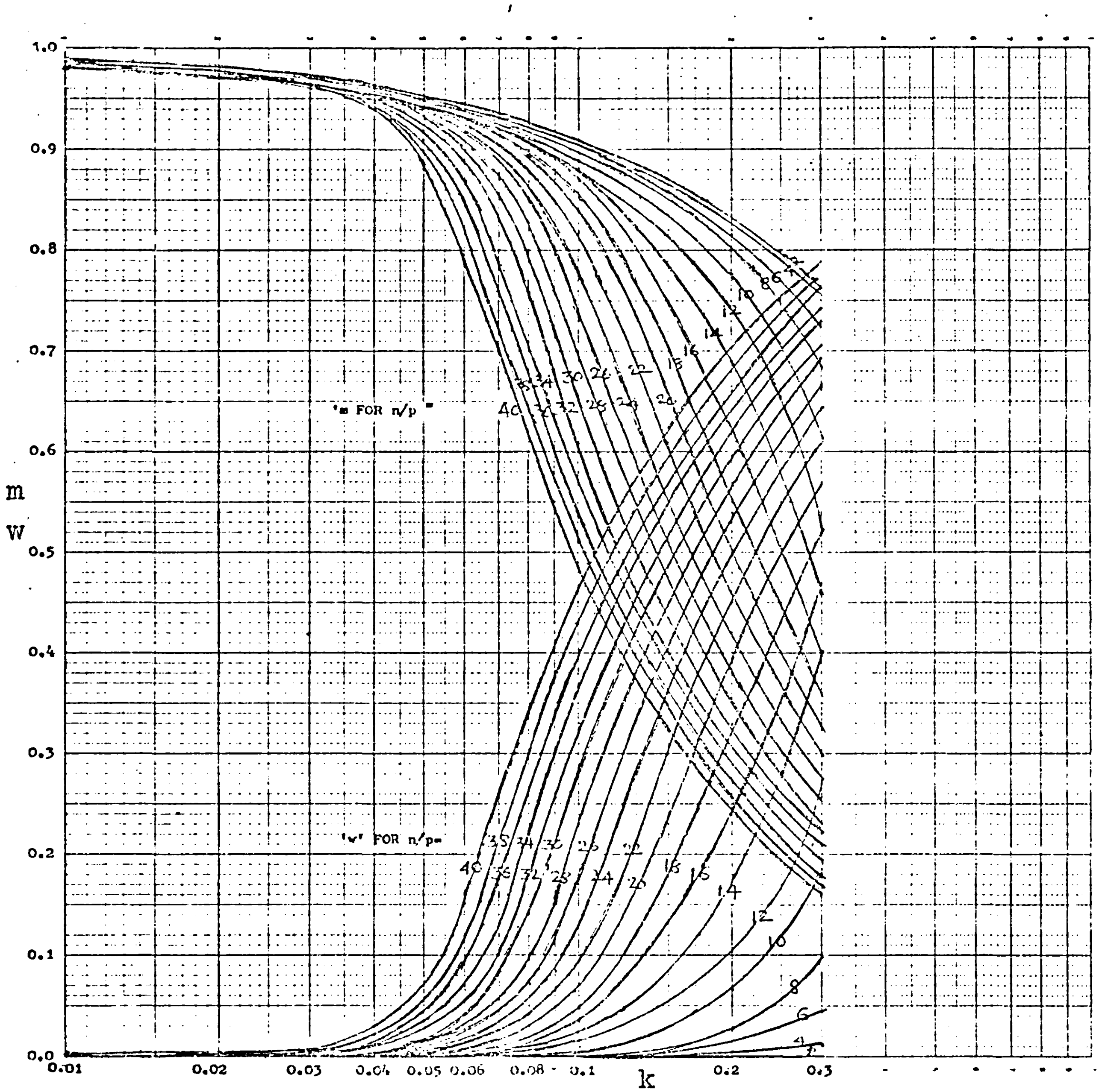
Fig. No. 6



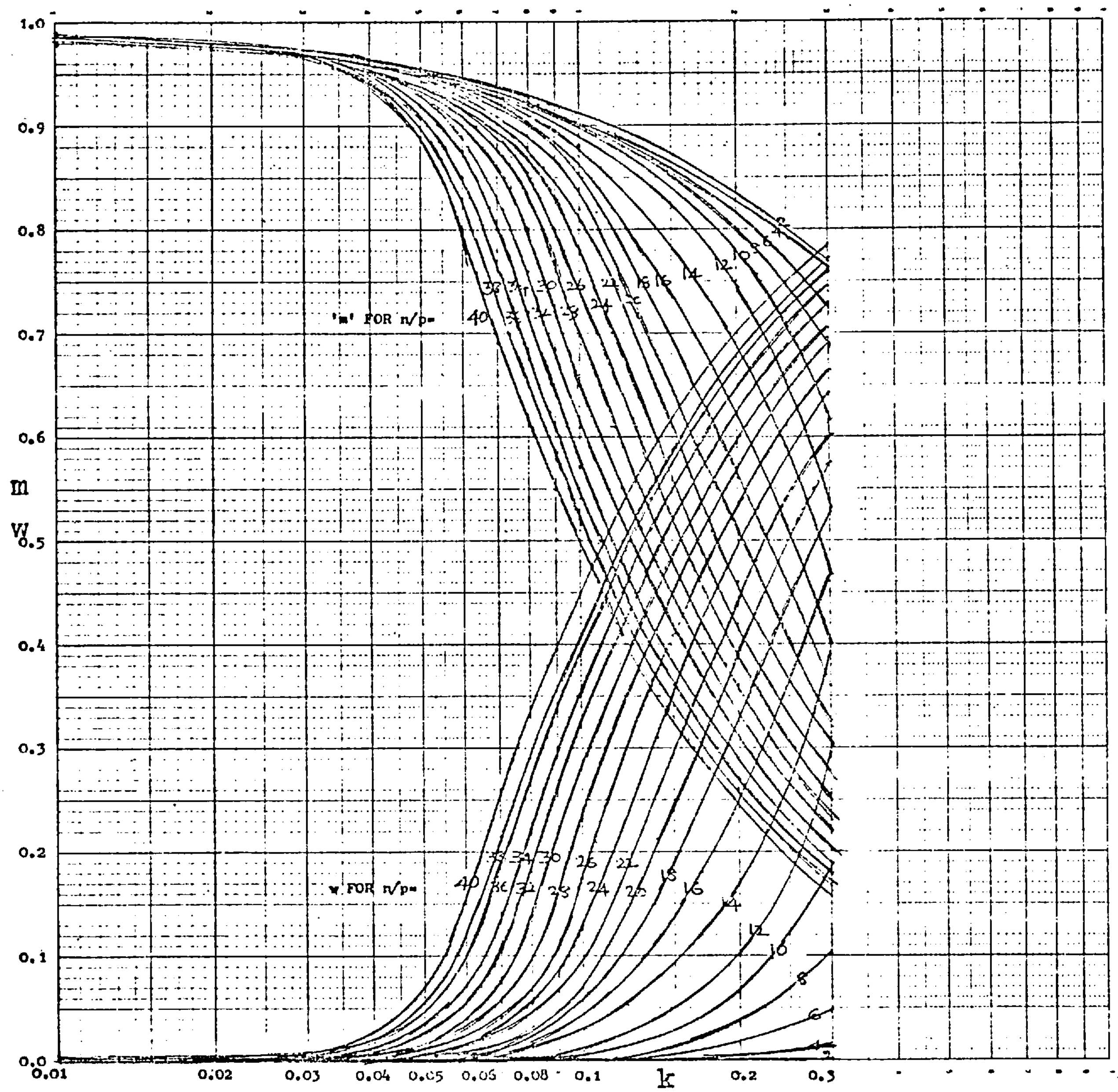
C.V. 0.3

Single Operator

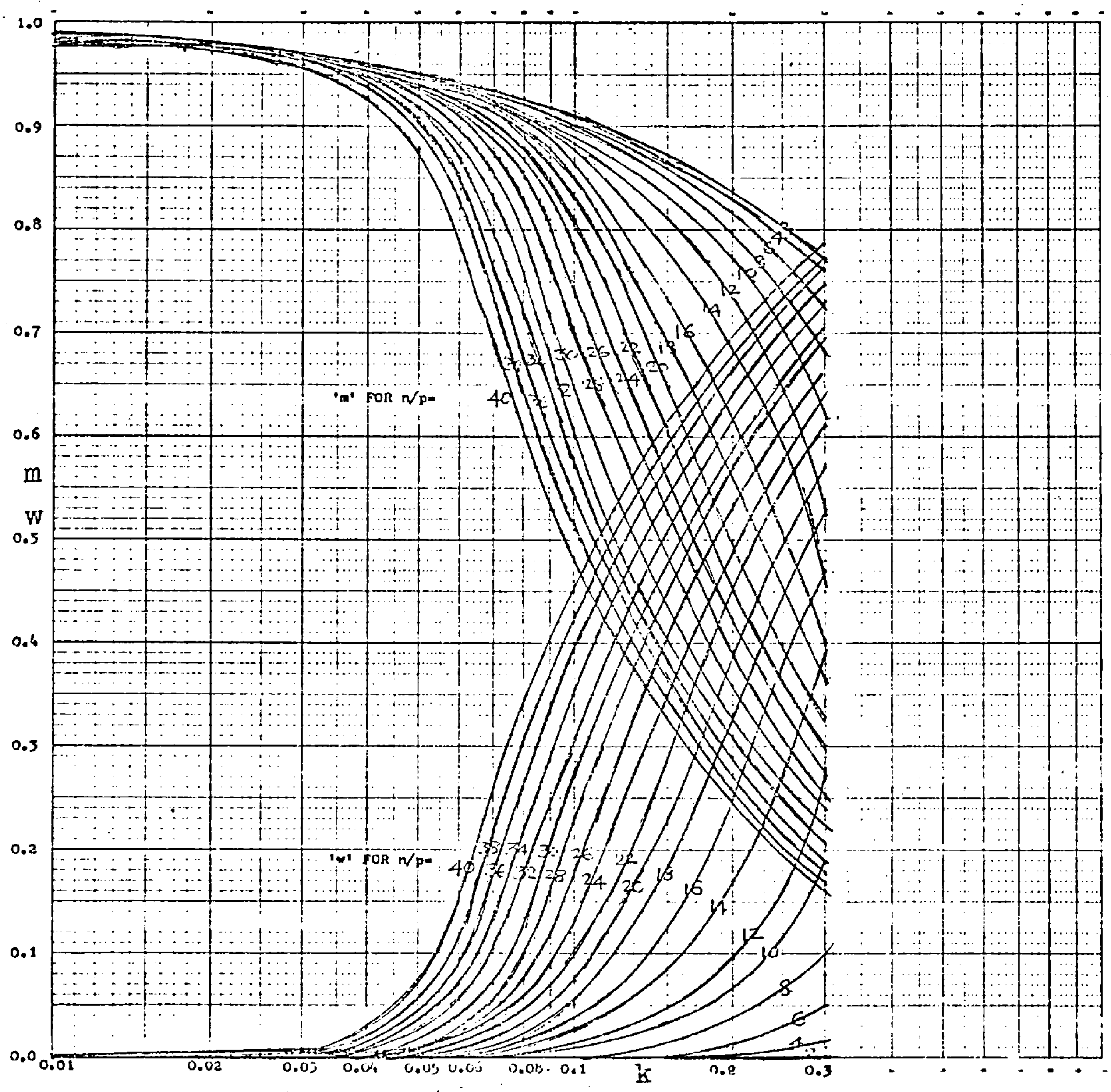
Fig. No. 7



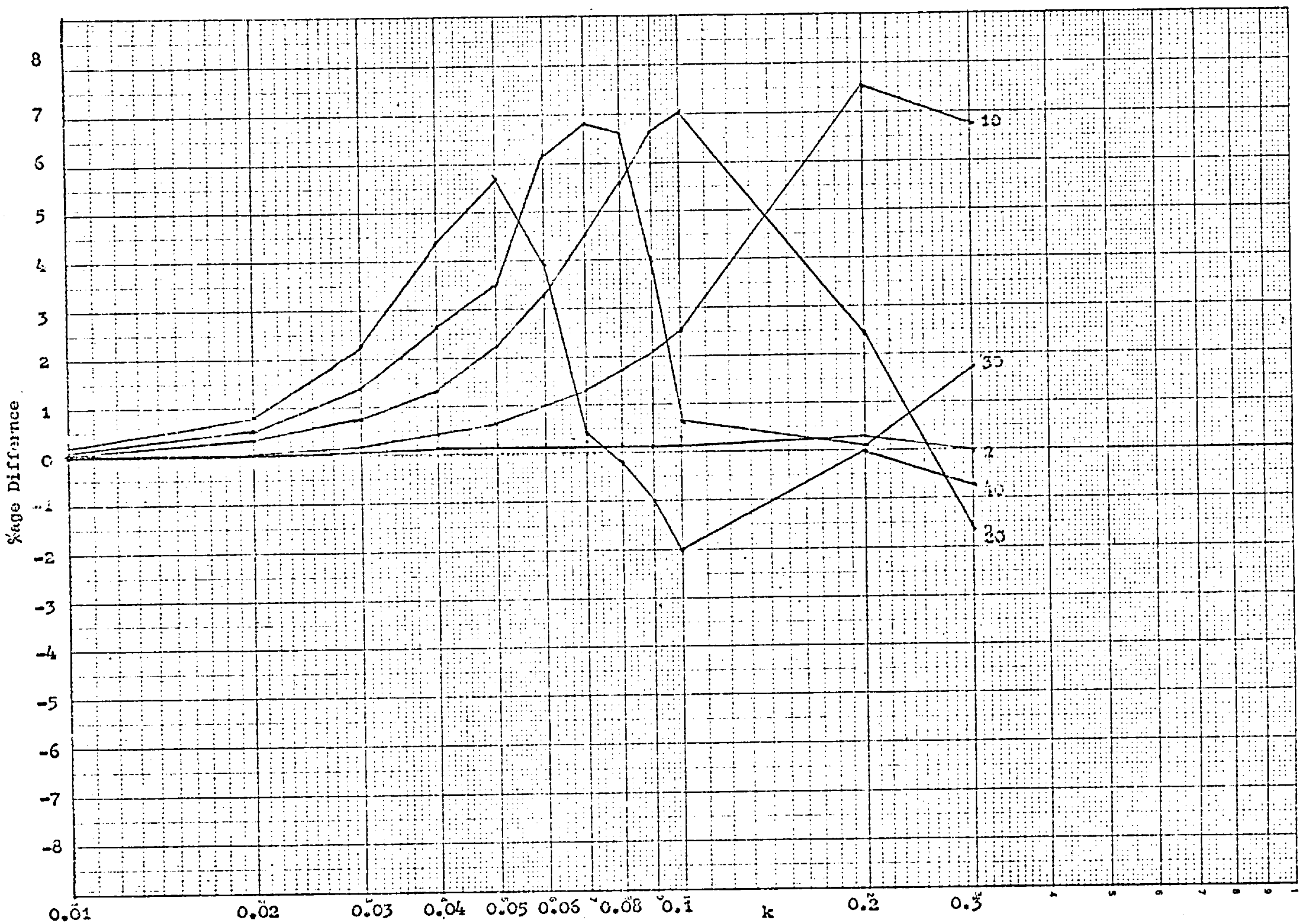
Curves of m and w for two operators
Coefficient of Variation 0.1
Fig. No. 8



Curves of m and w for two operators.
Coefficient of Variation 0.2
Fig. No. 9



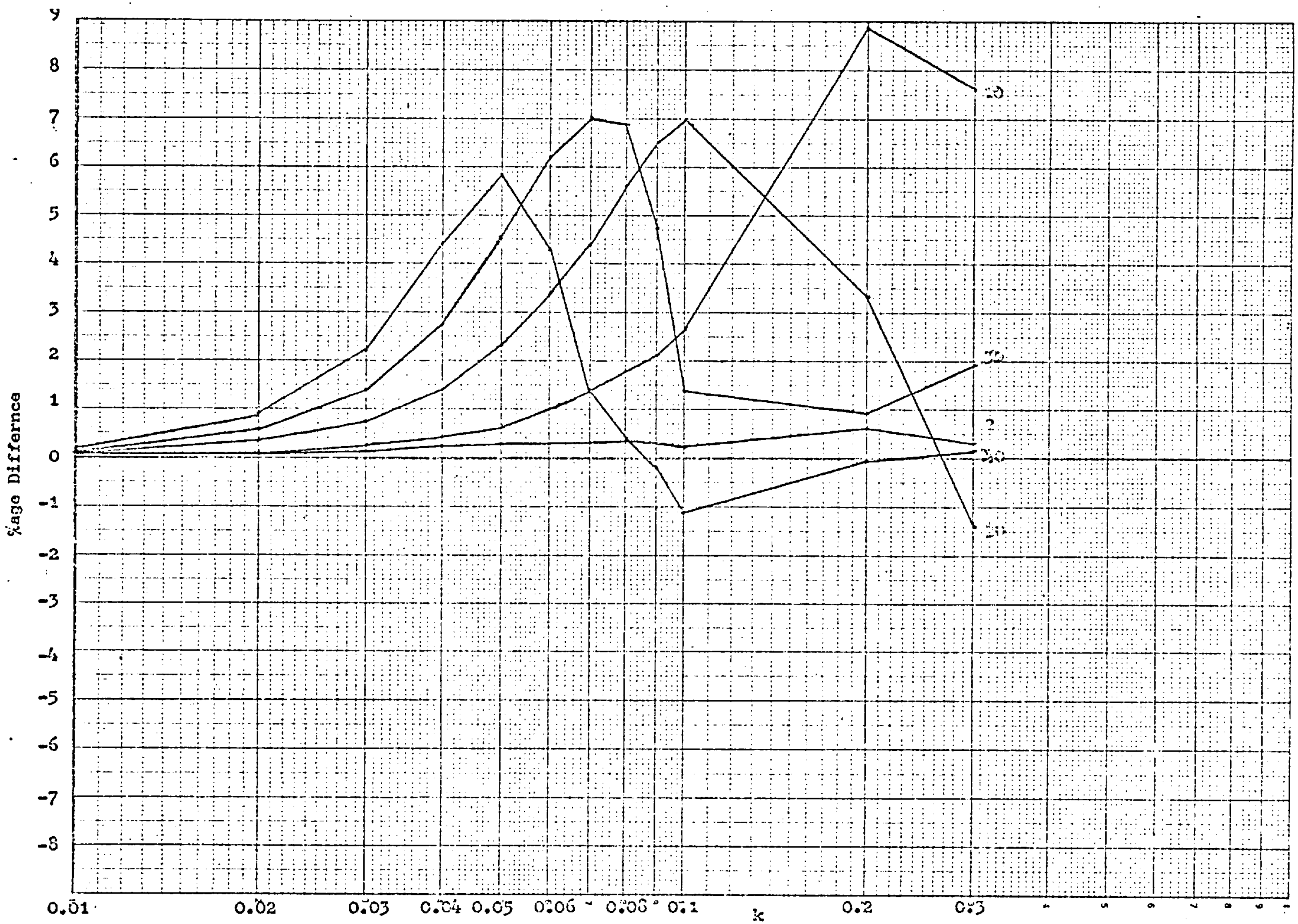
Curves for m and w for two operators.
Coefficient of Variation 0.3
Fig. No. 10



C.V. 0.1

Two Operators

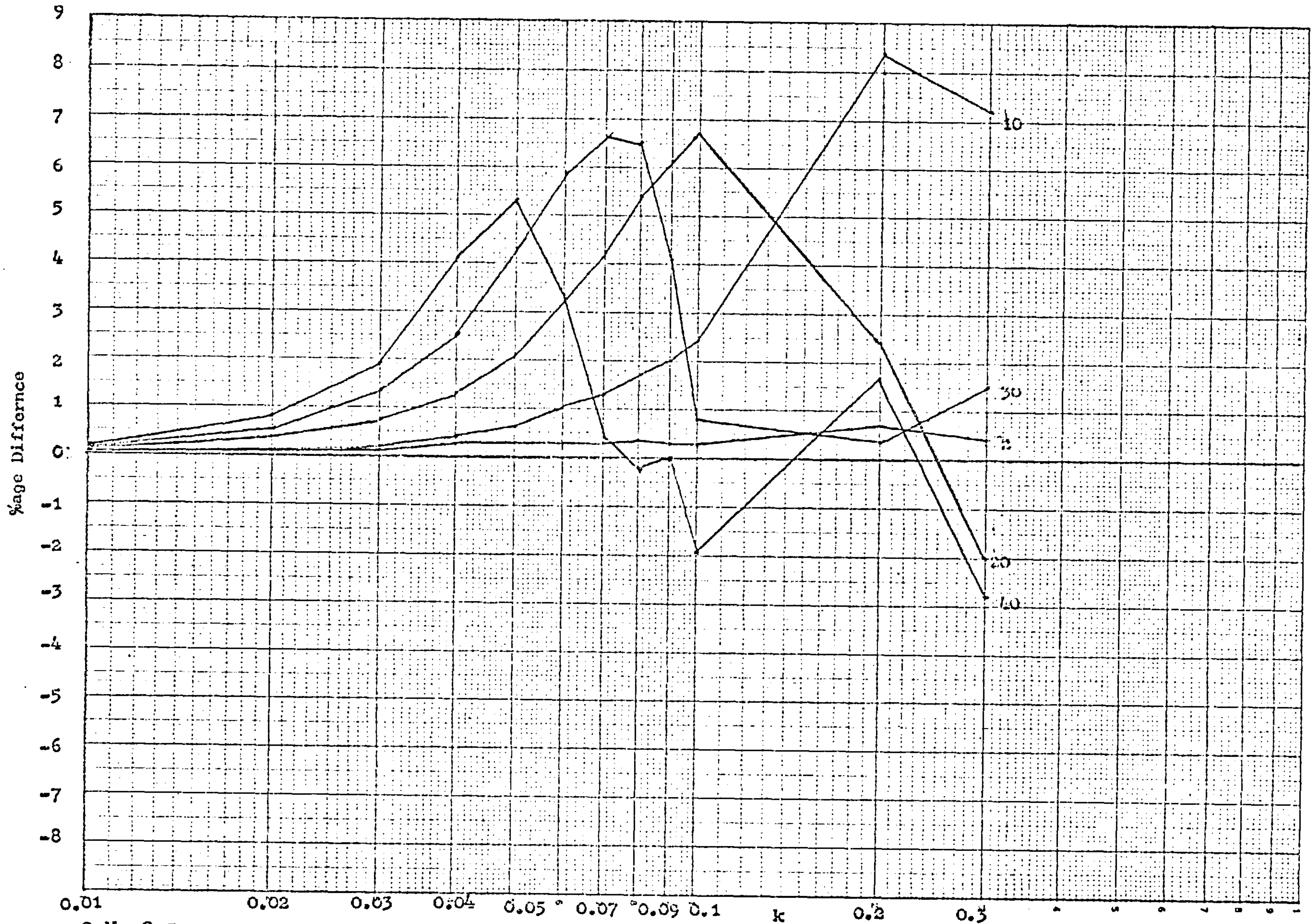
Fig. No. 11



C.V. 0.2

Two Operators

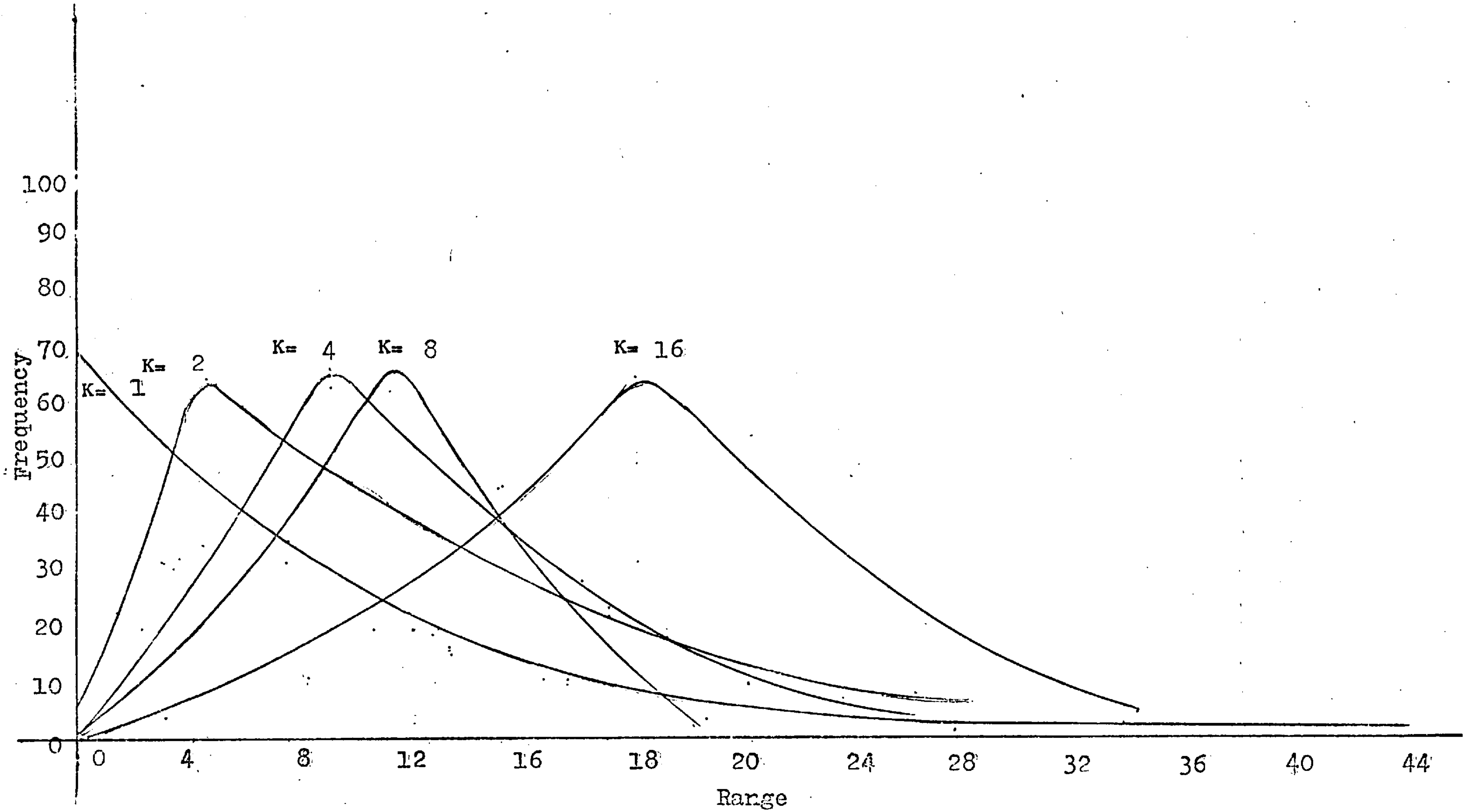
Fig. No. 12



C.V, 0.3

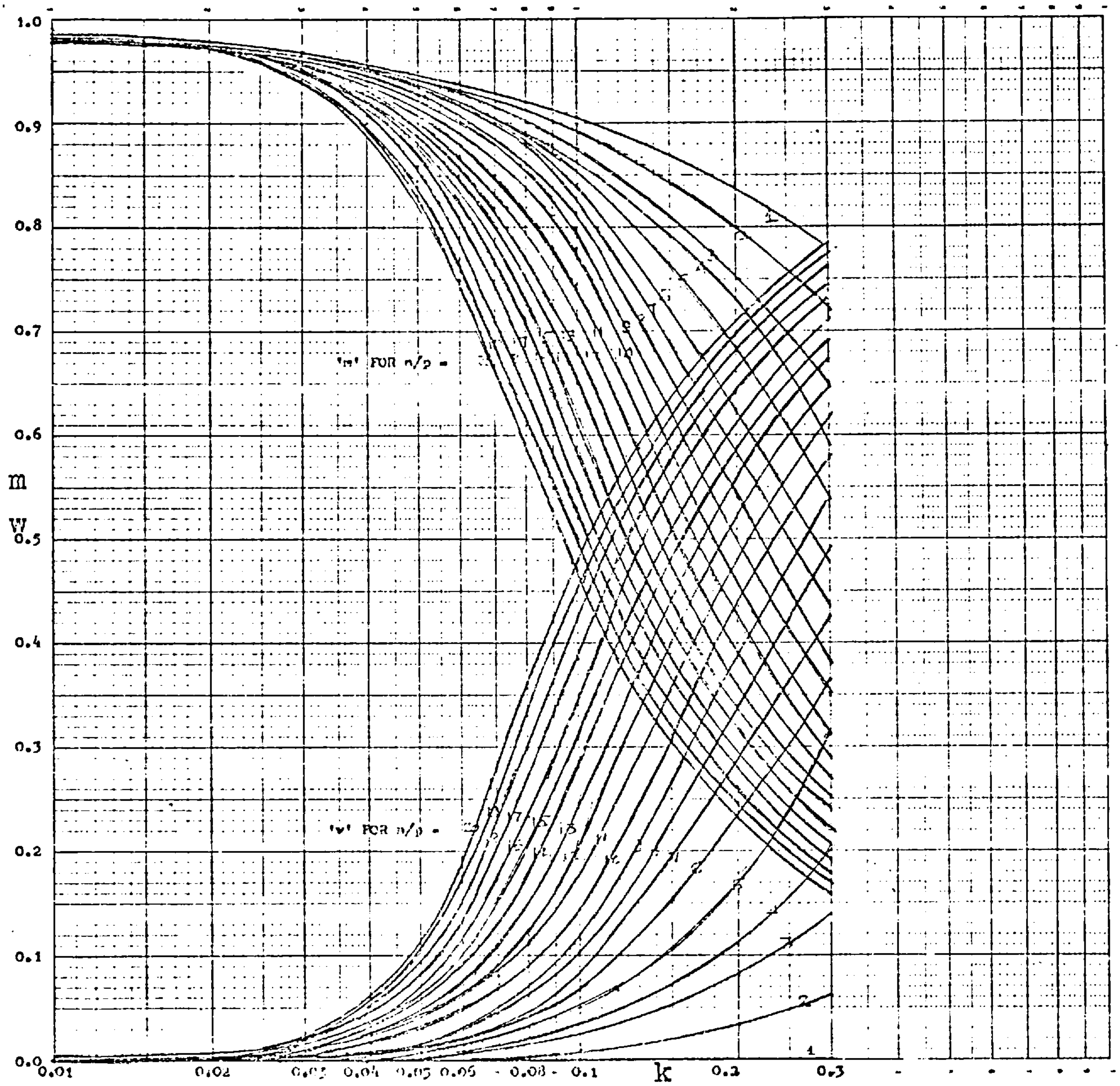
Two Operators

Fig. No. 13



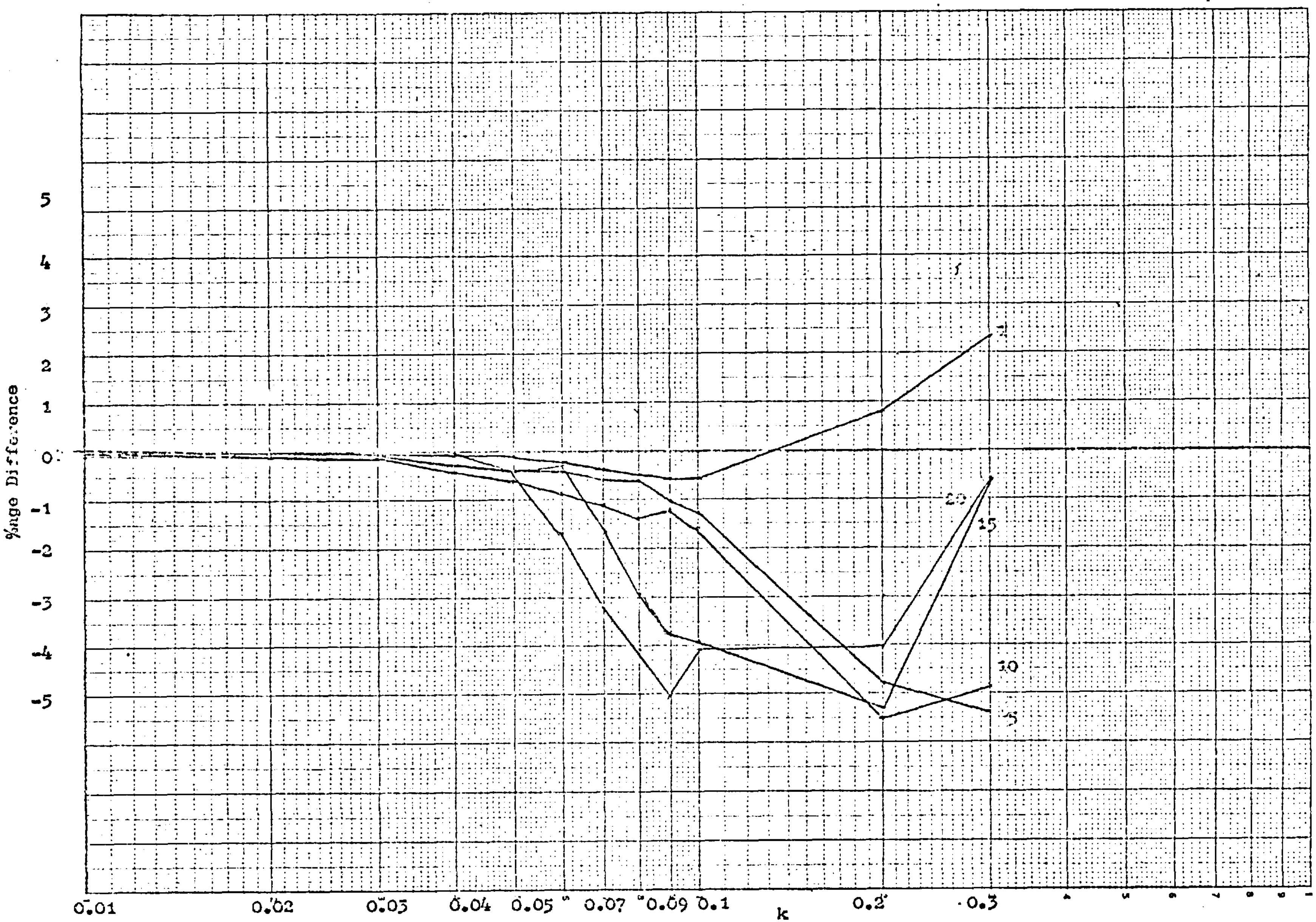
Erlang Service Distribution Curves

Fig. No. 14



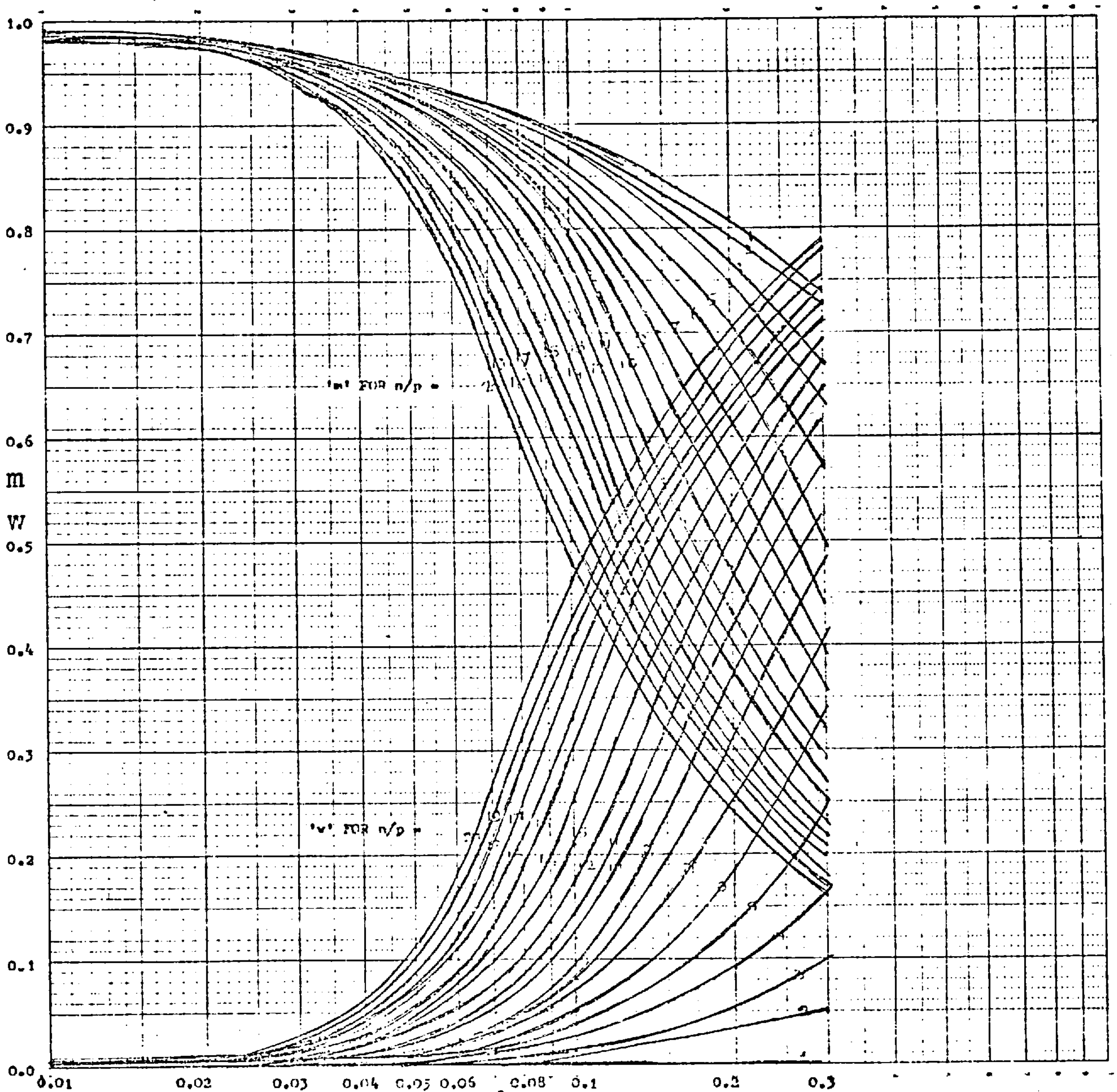
Curves for m and w for a single operator.
No. of phases 1

Fig. No. 15



No. of phases 1

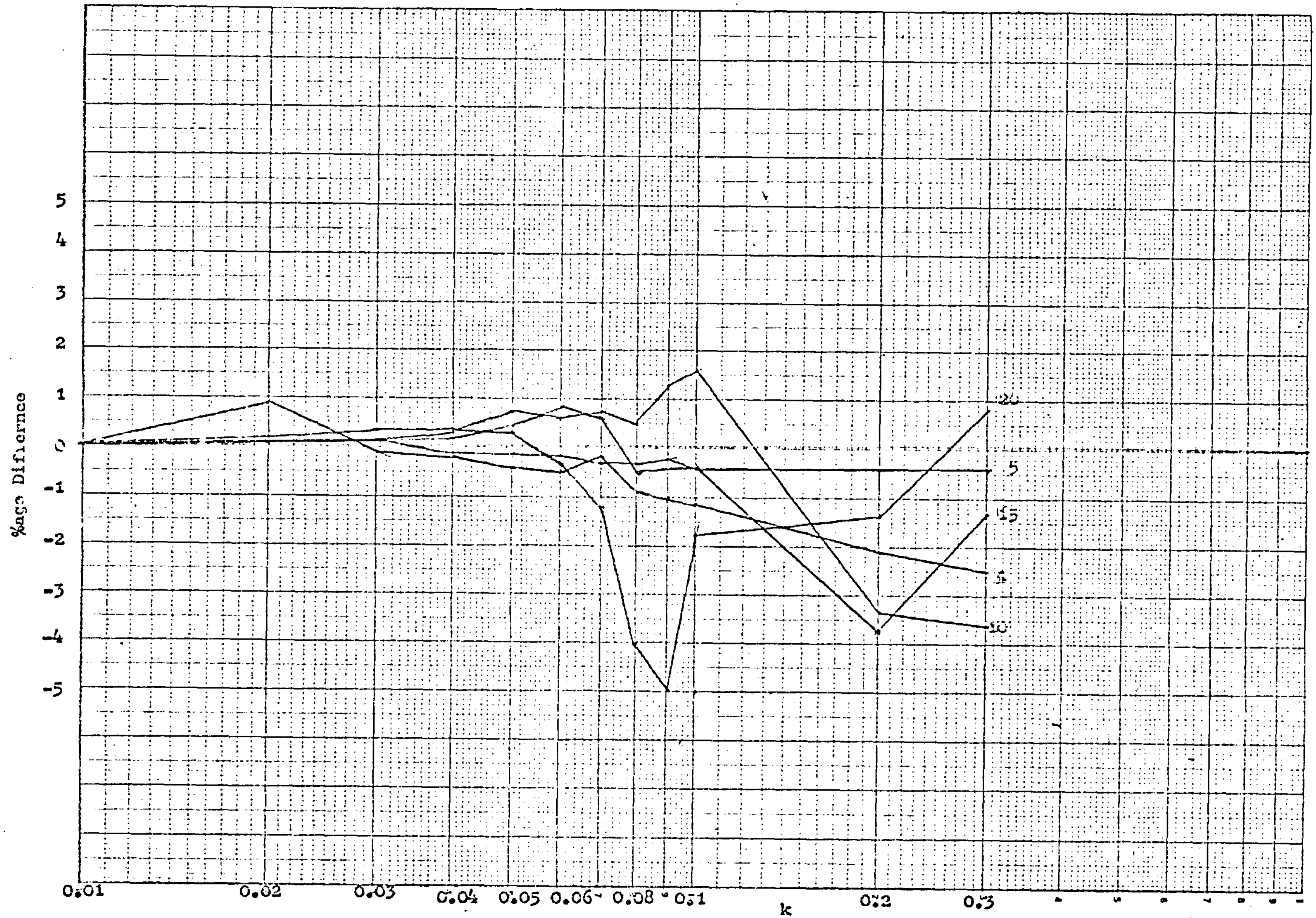
Fig. No. 16



Curves for m and w for a single operator.

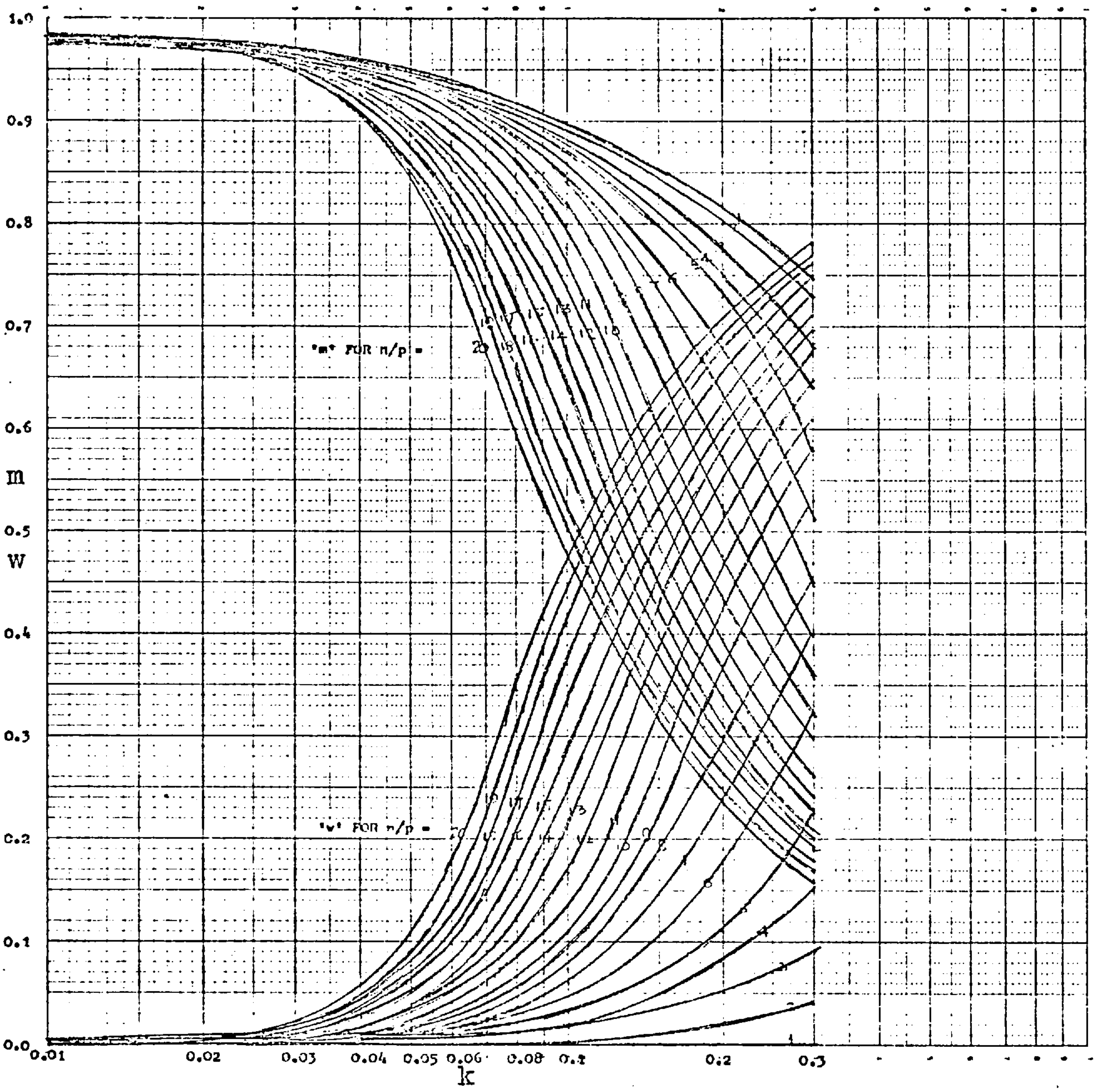
No. of phases 2

Fig. No. 17



No. of phases 2

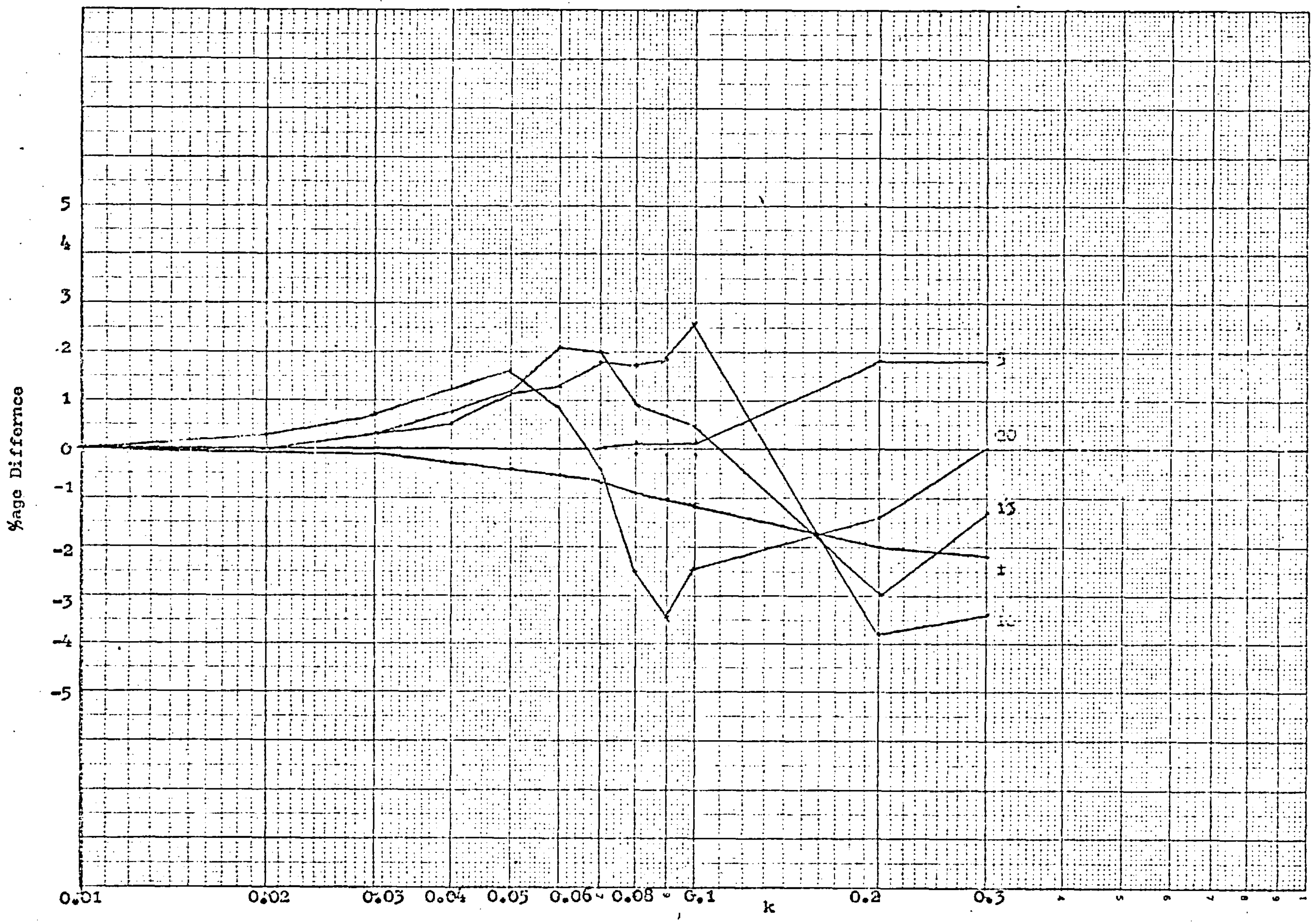
Fig. No. 18



Curves for m and w for a single operator.

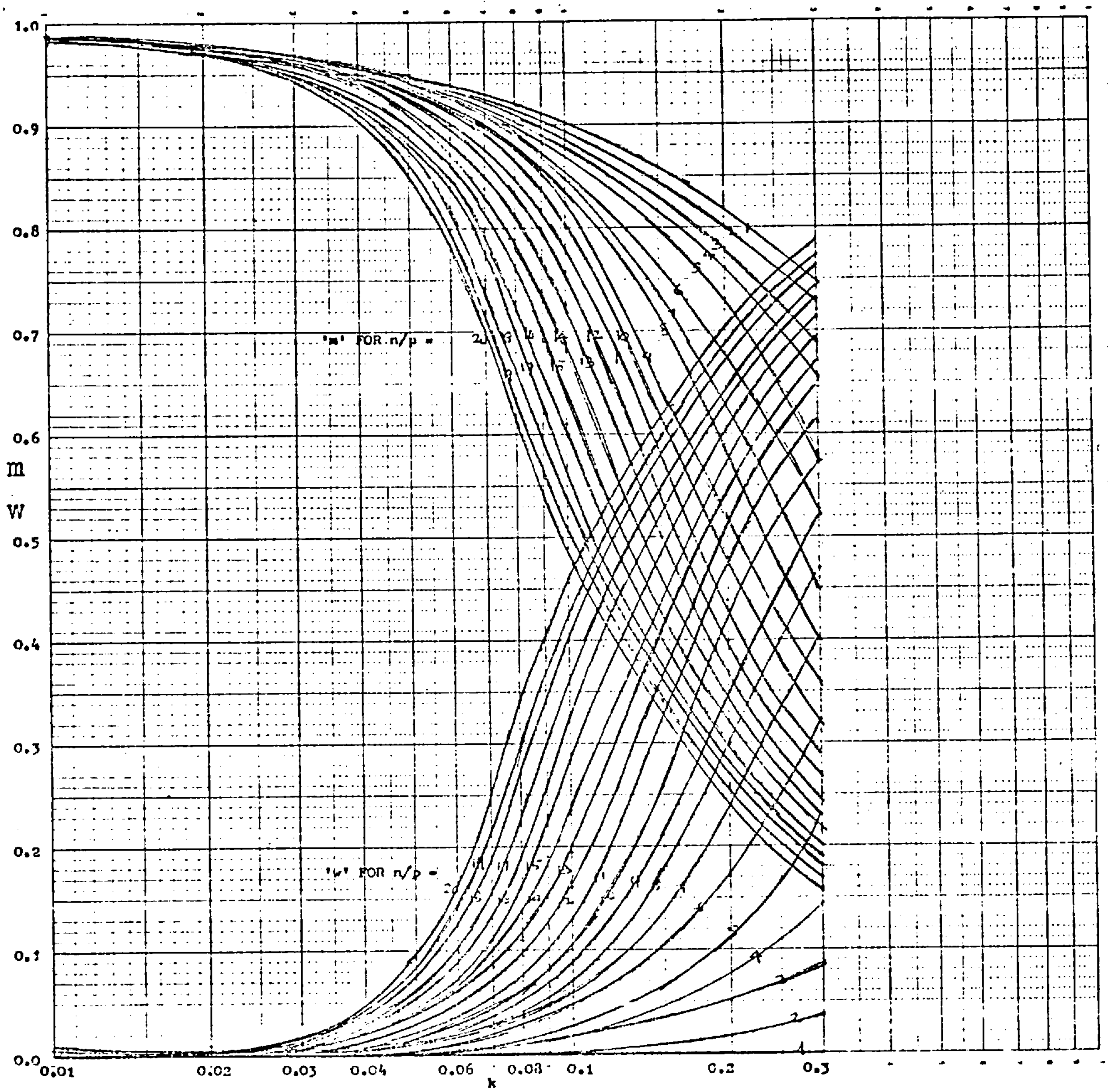
No. of phases 4

Fig. No. 19



No. of phases 4

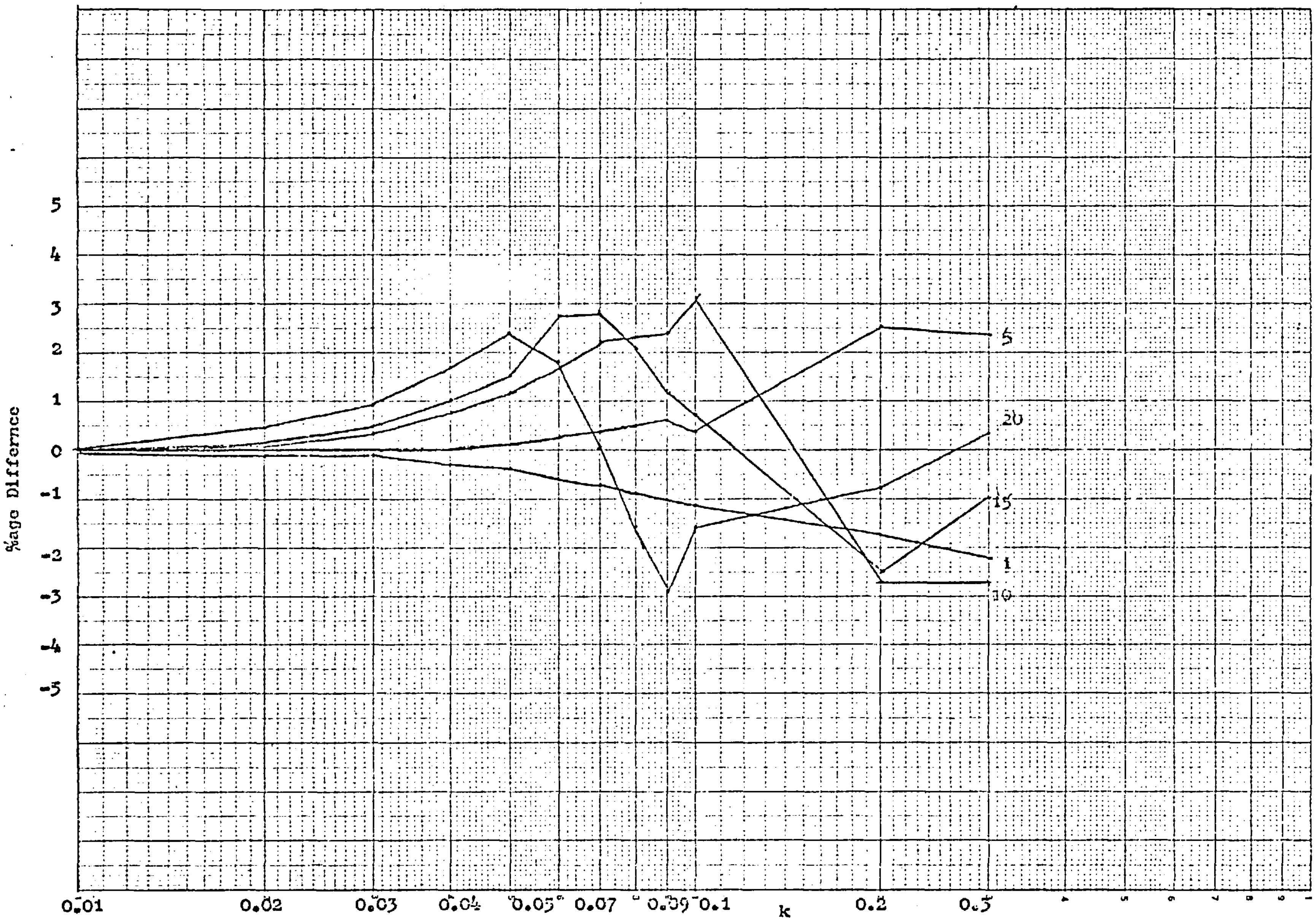
Fig. No, 20



Curves for m and w for a single operator.

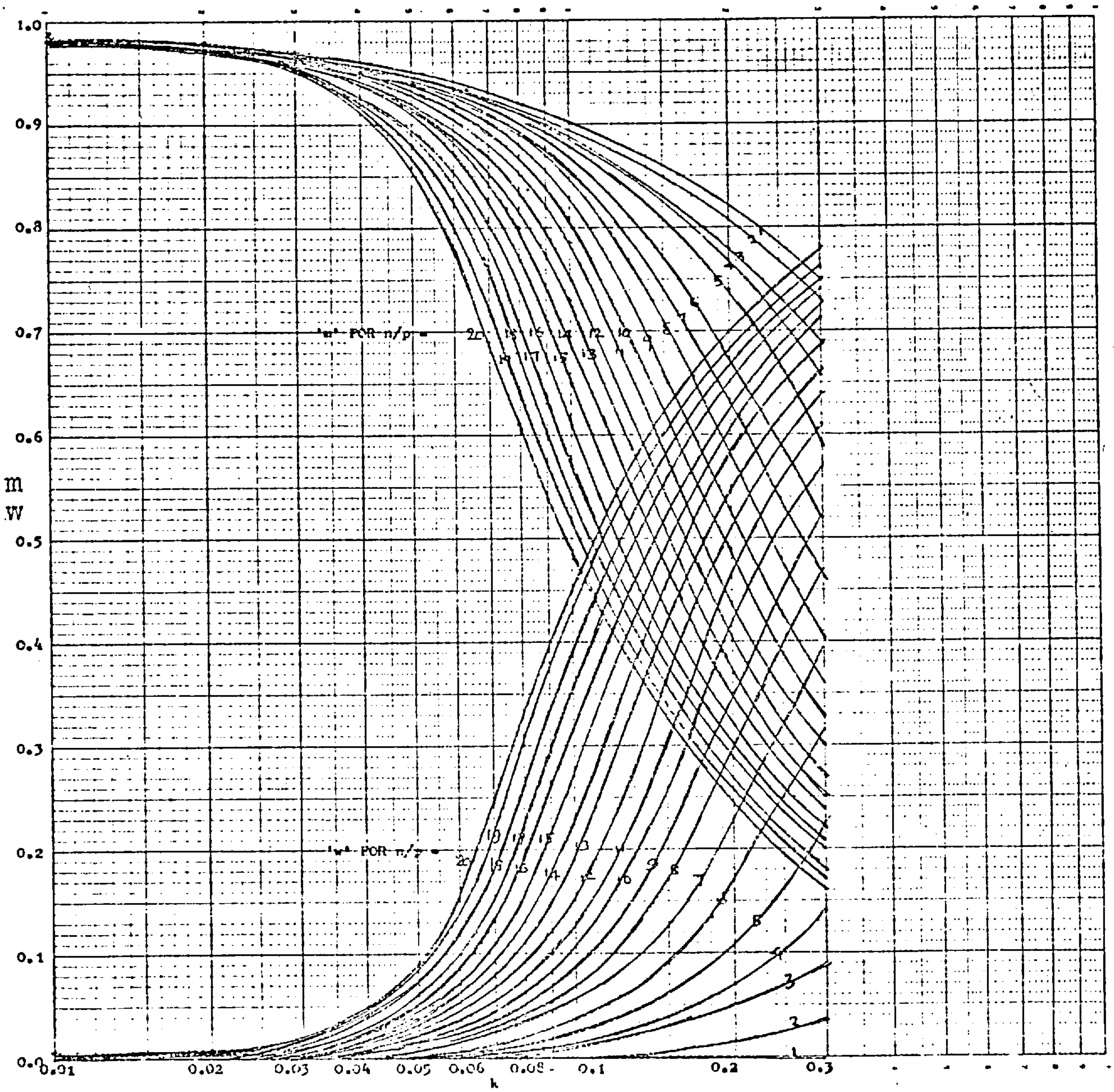
No. of phases 8

Fig. No.21



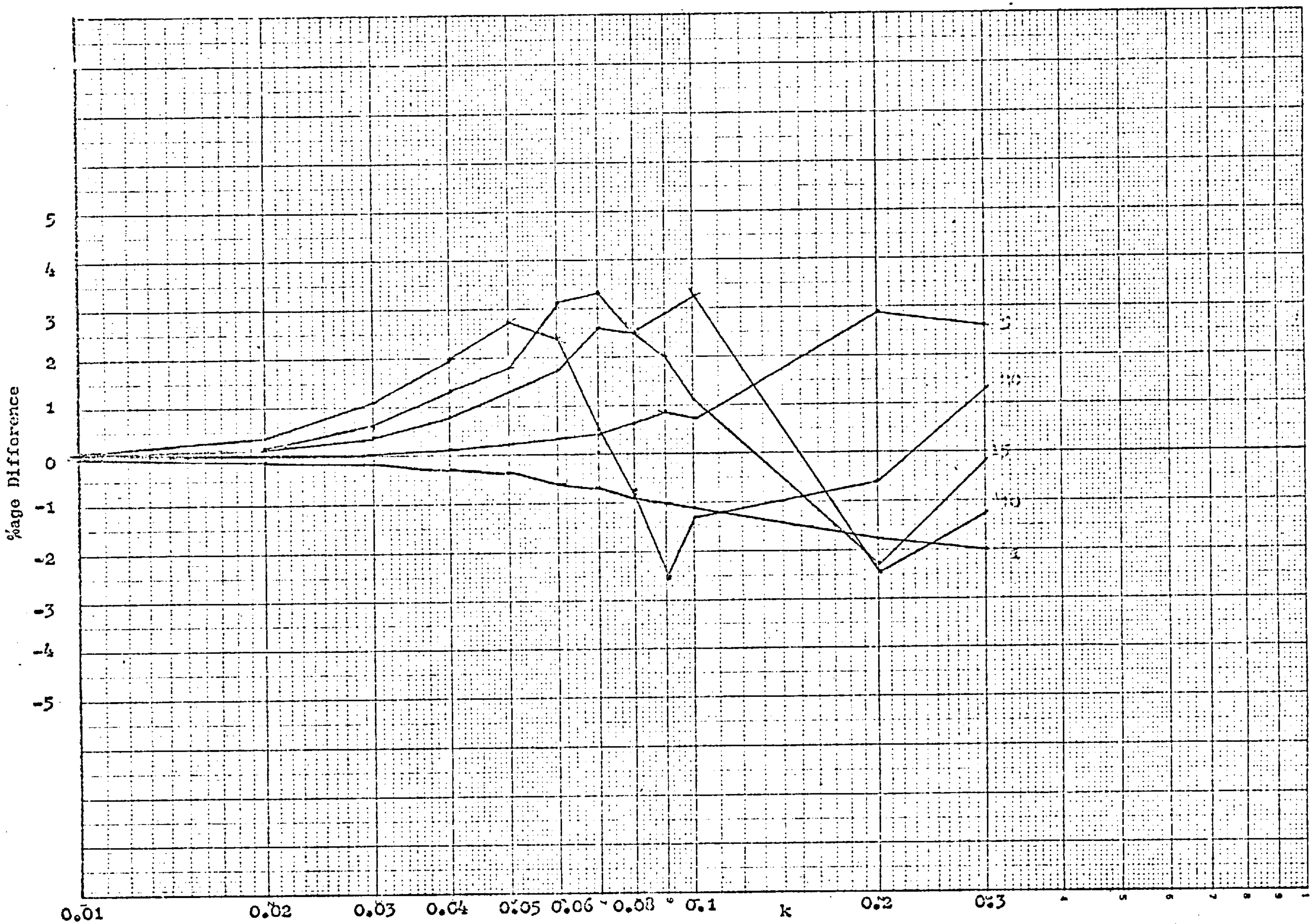
No. of phases 8

Fig, No. 22



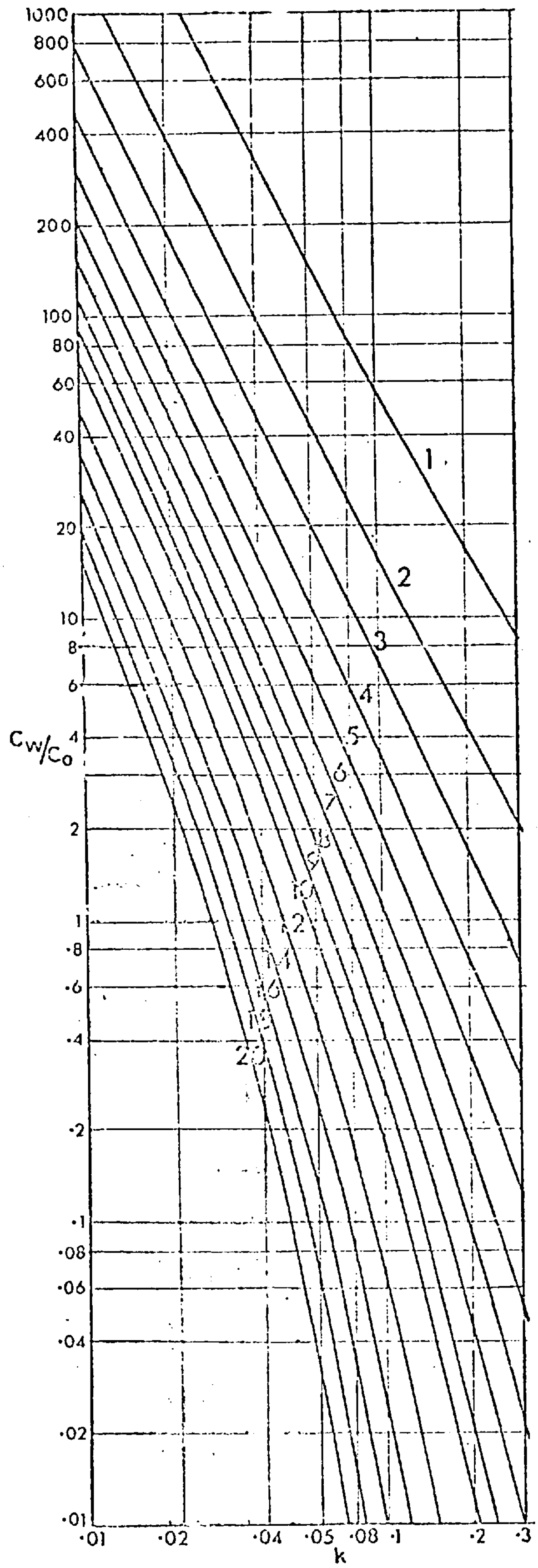
Curves for m and w for a single operator.
No. of phases 16

Fig. No. 23



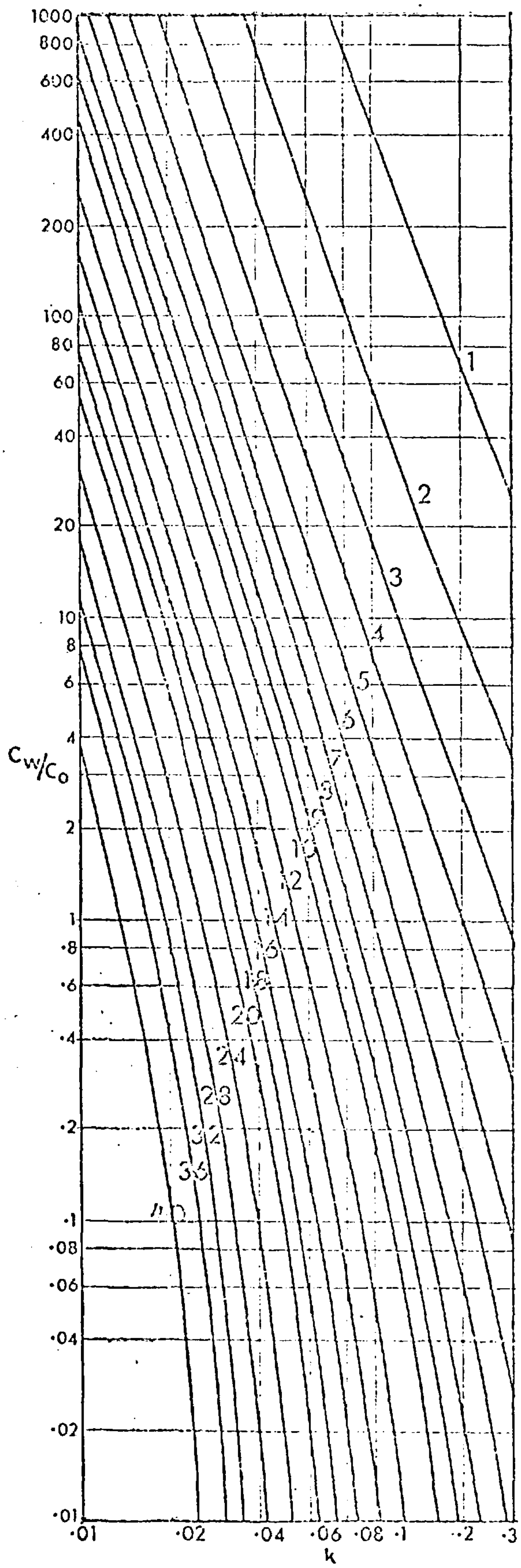
No. of phases 16

Fig. No. 24



Optimum workforce chart for a single operator.

Fig. No. 25



Optimum workforce chart for two operators.

Fig. No. 26

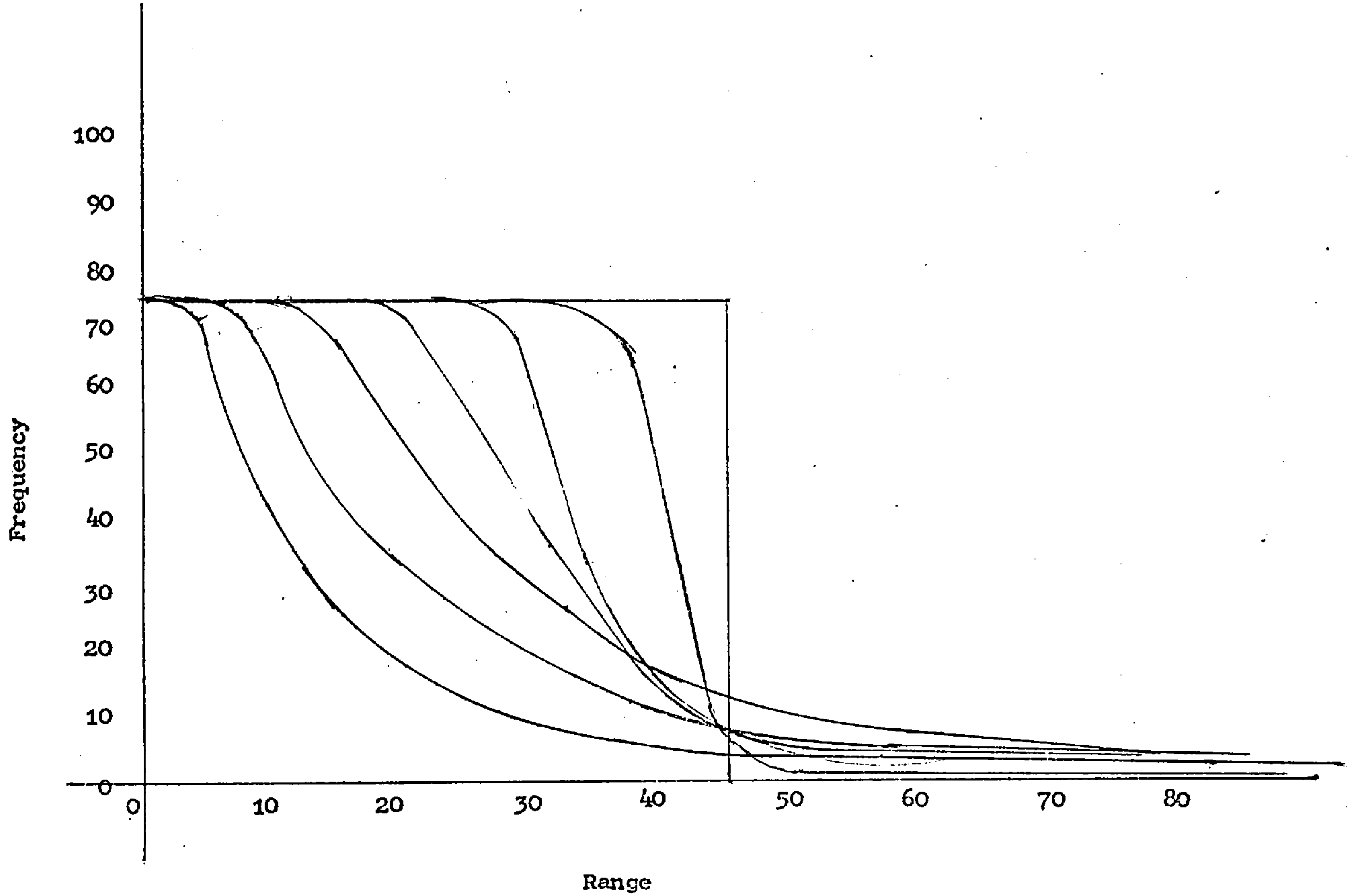
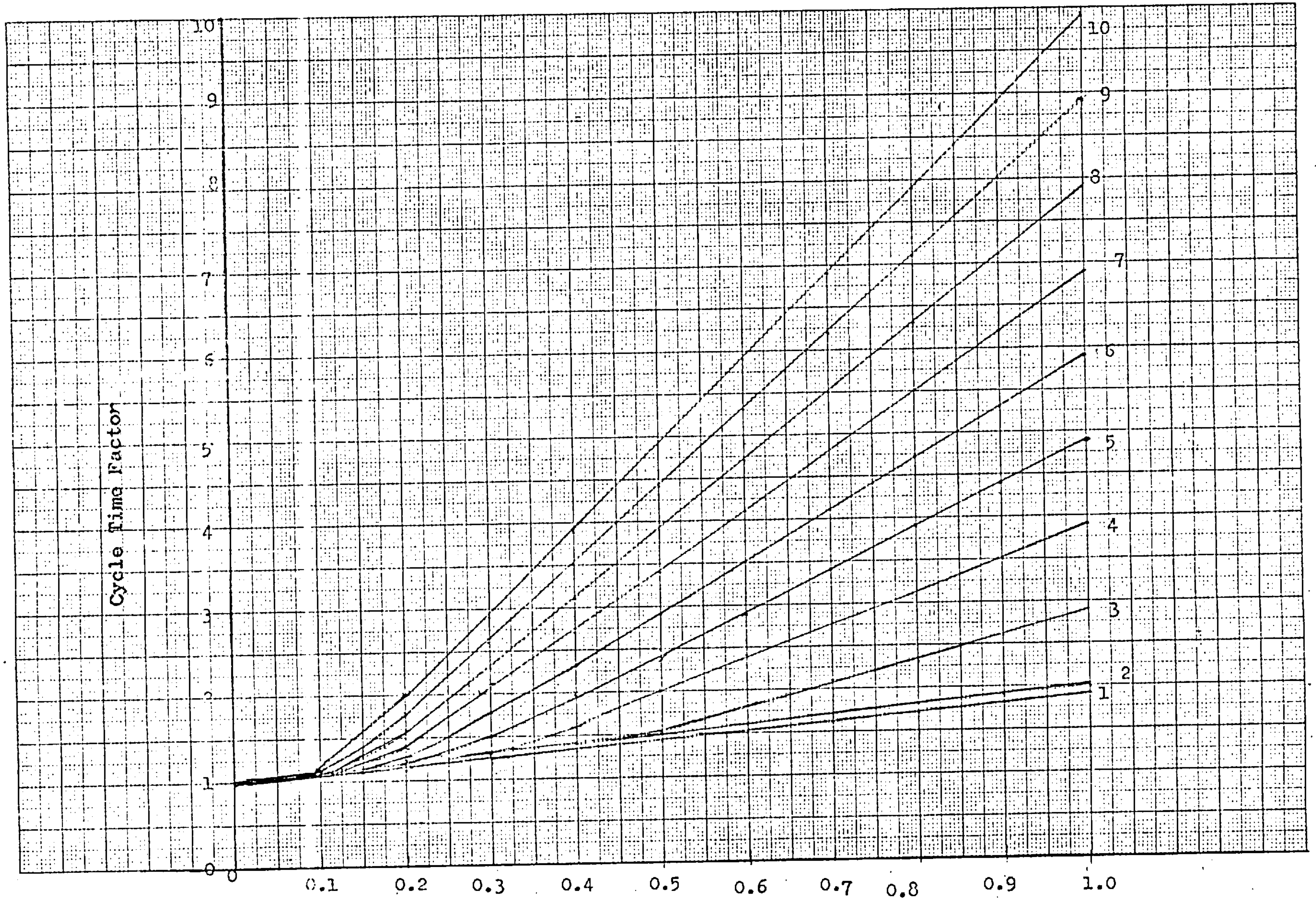


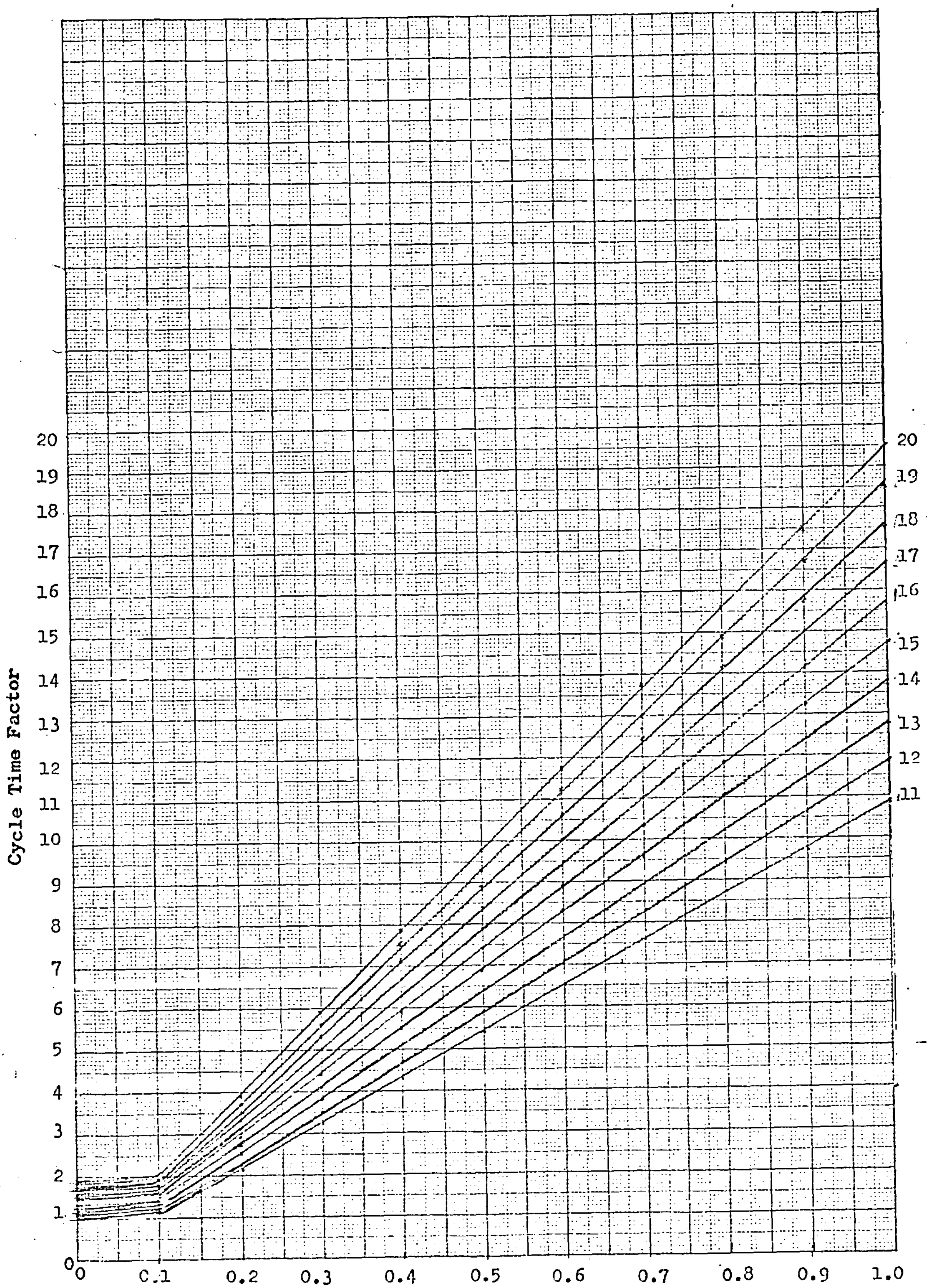
Fig. No. 27
Service time distribution curves for Semi-automatic machines



Ratio R

Deterministic Case
Single Operator
1 to 10 Machines

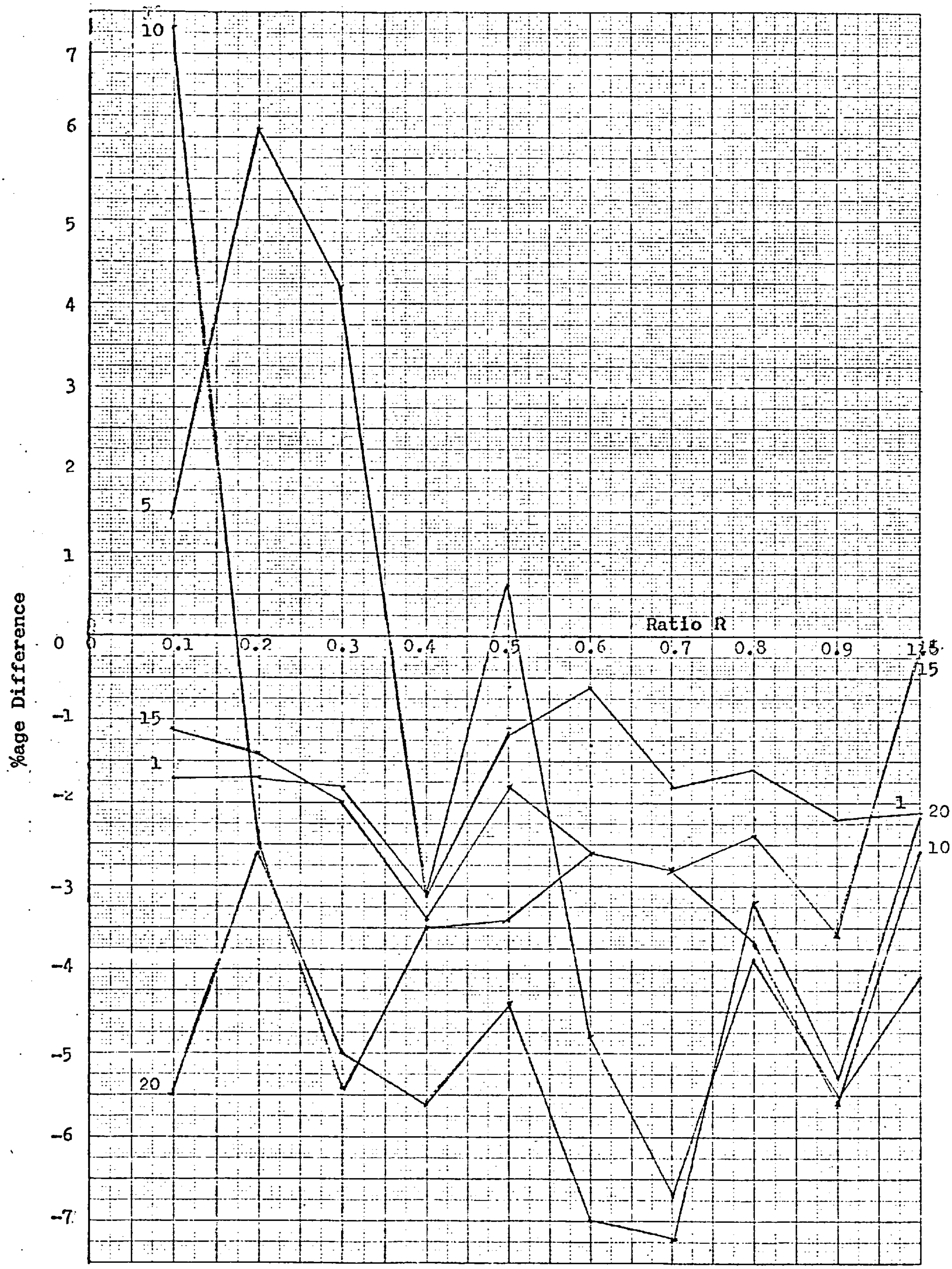
Fig. No. 28



Deterministic Case
Single Operator
11 to 20 Machines

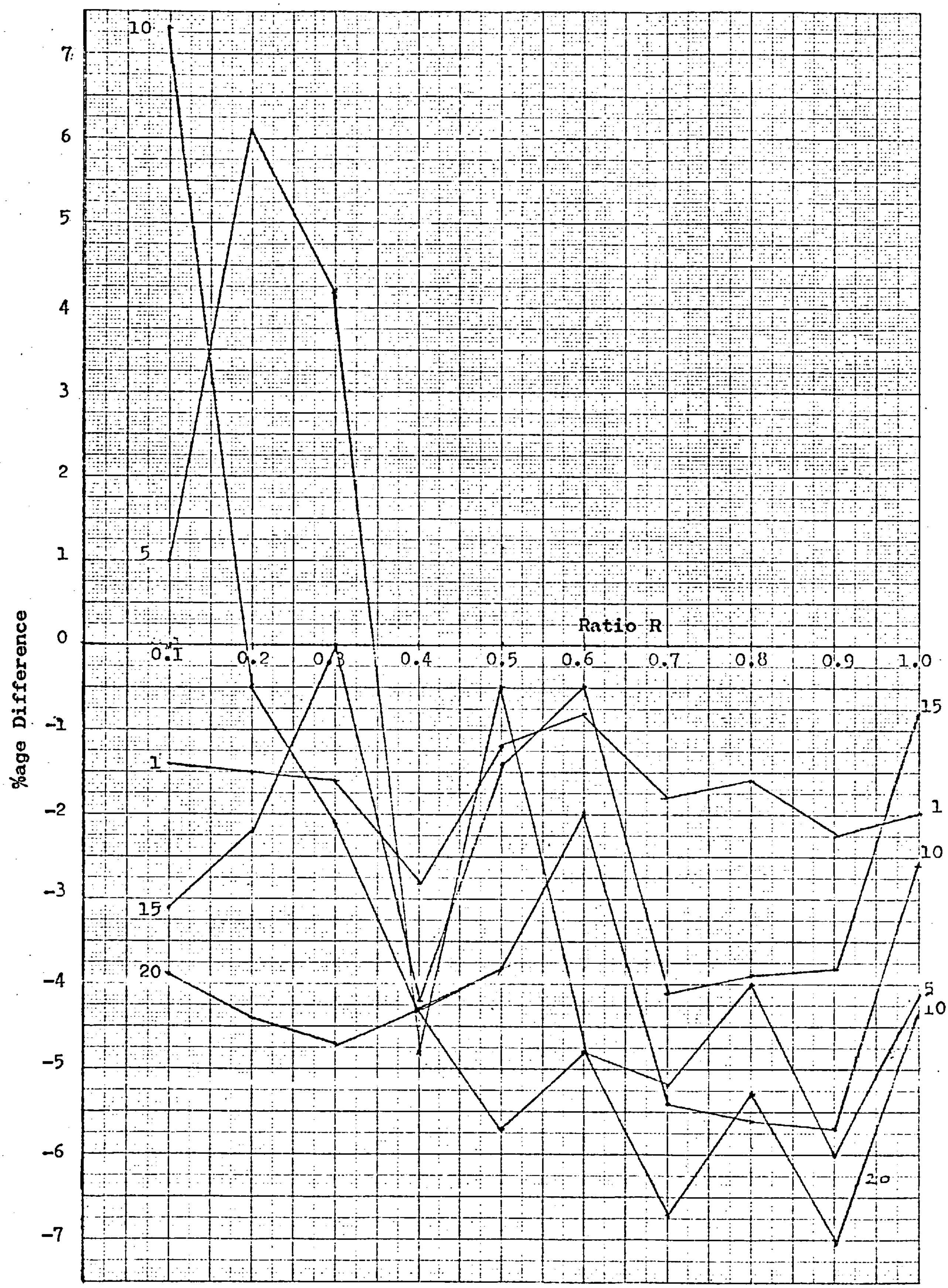
Ratio R

Fig. No. 29



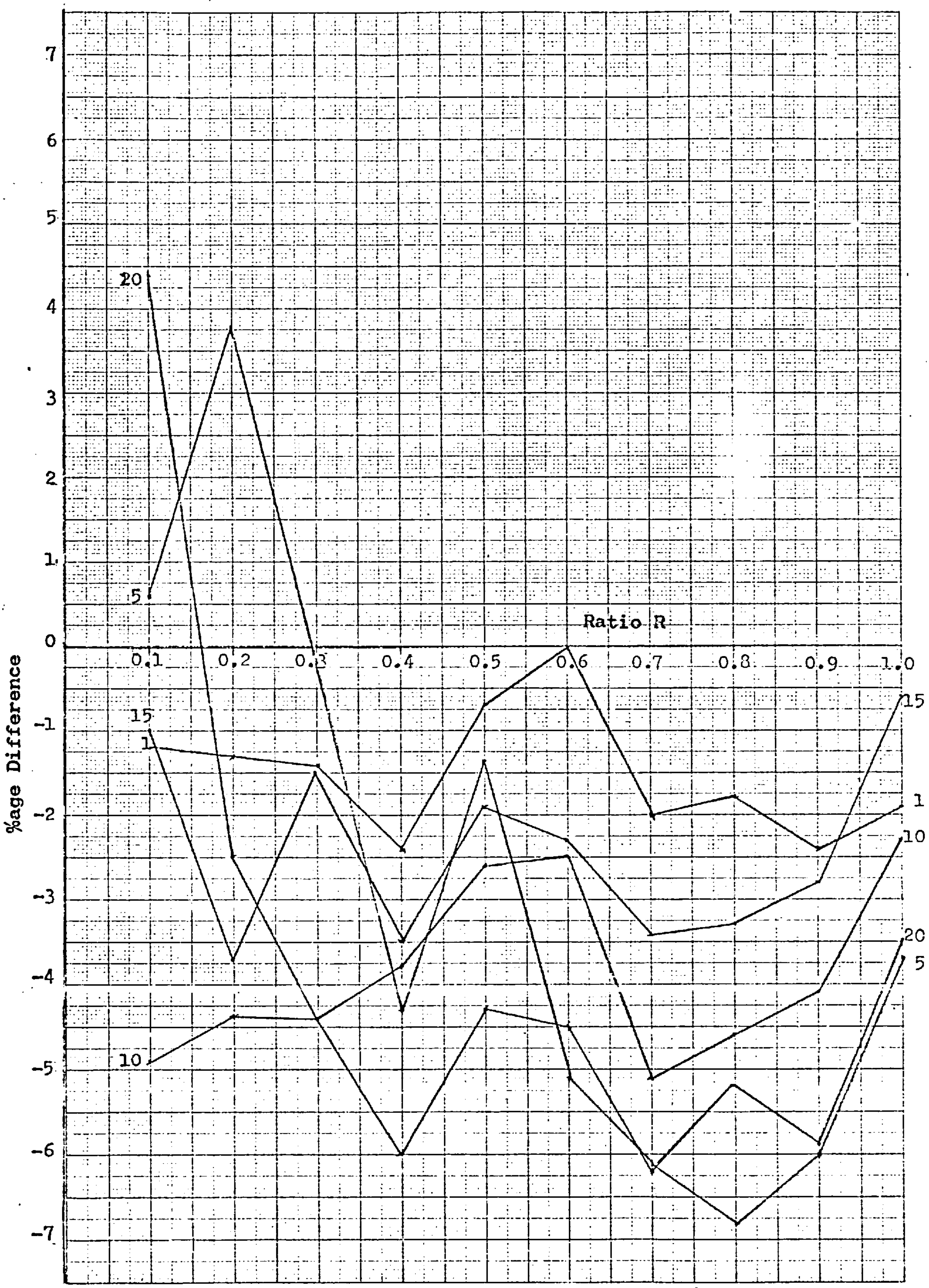
Variable(100)+Constant(0)+Independent Time

Fig. No. 30



Variable(80)+Constant(20)-Independent Time

Fig. No. 31



Variable(60)+Constant(40)+Independent Time

Fig. No. 32

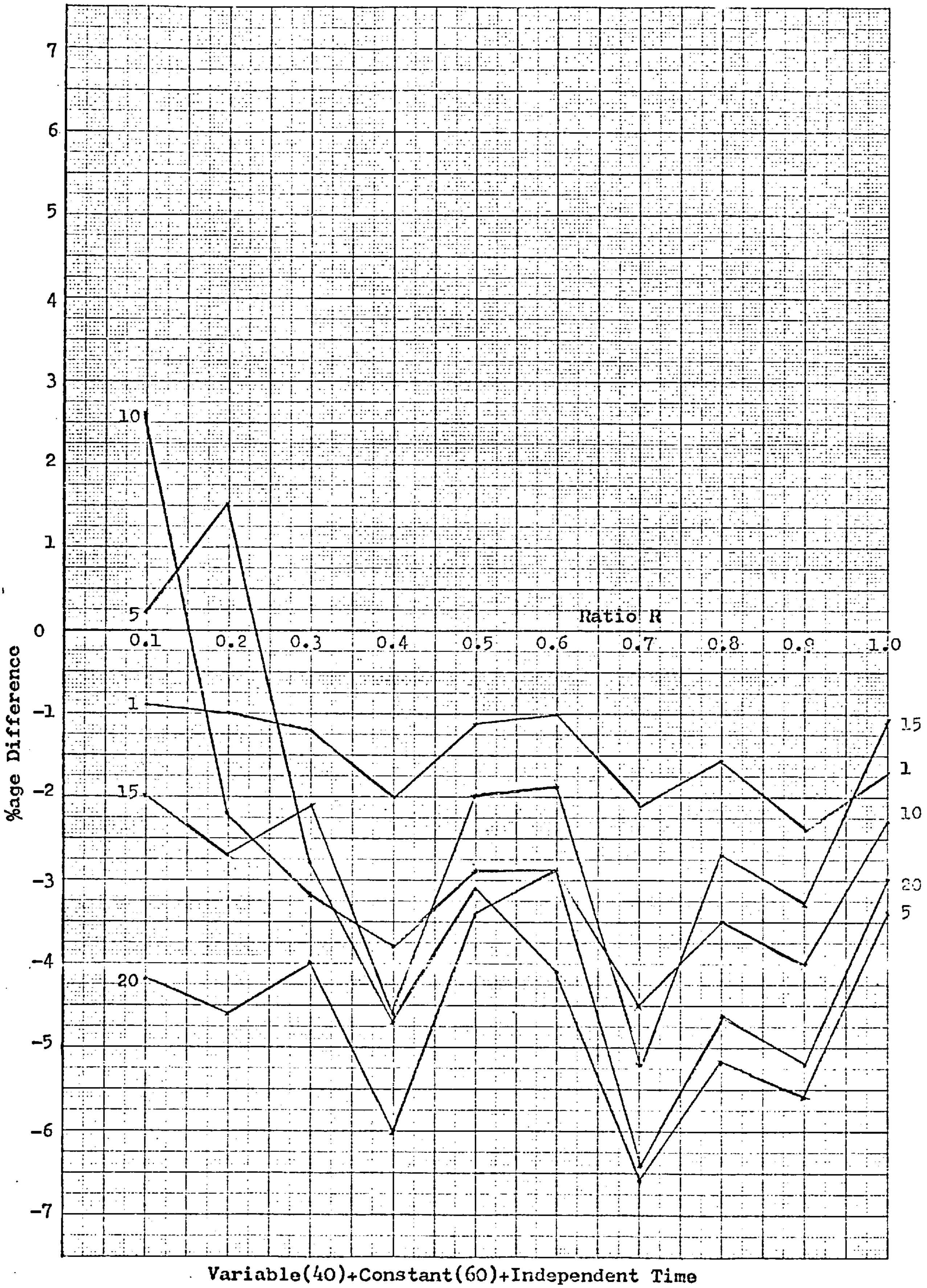

7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
%age Difference
Ratio R
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
10
5
1
15
20
15
1
10
20
5
Variable(40)+Constant(60)+Independent Time

Fig. No. 33

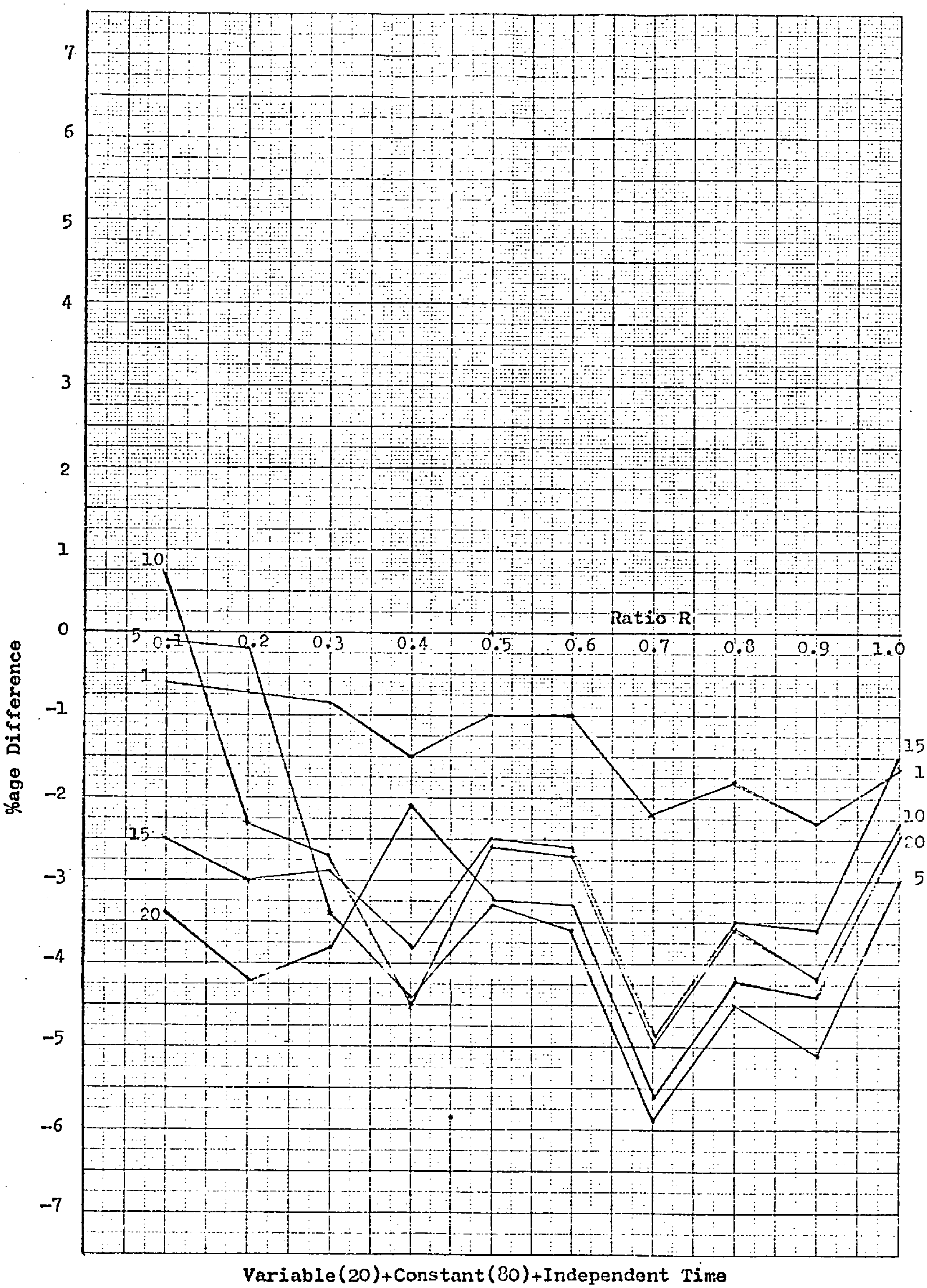

%age Difference
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
Ratio R
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
10
5
1
15
20
15
1
10
20
5
Variable(20)+Constant(80)+Independent Time

Fig. No. 34

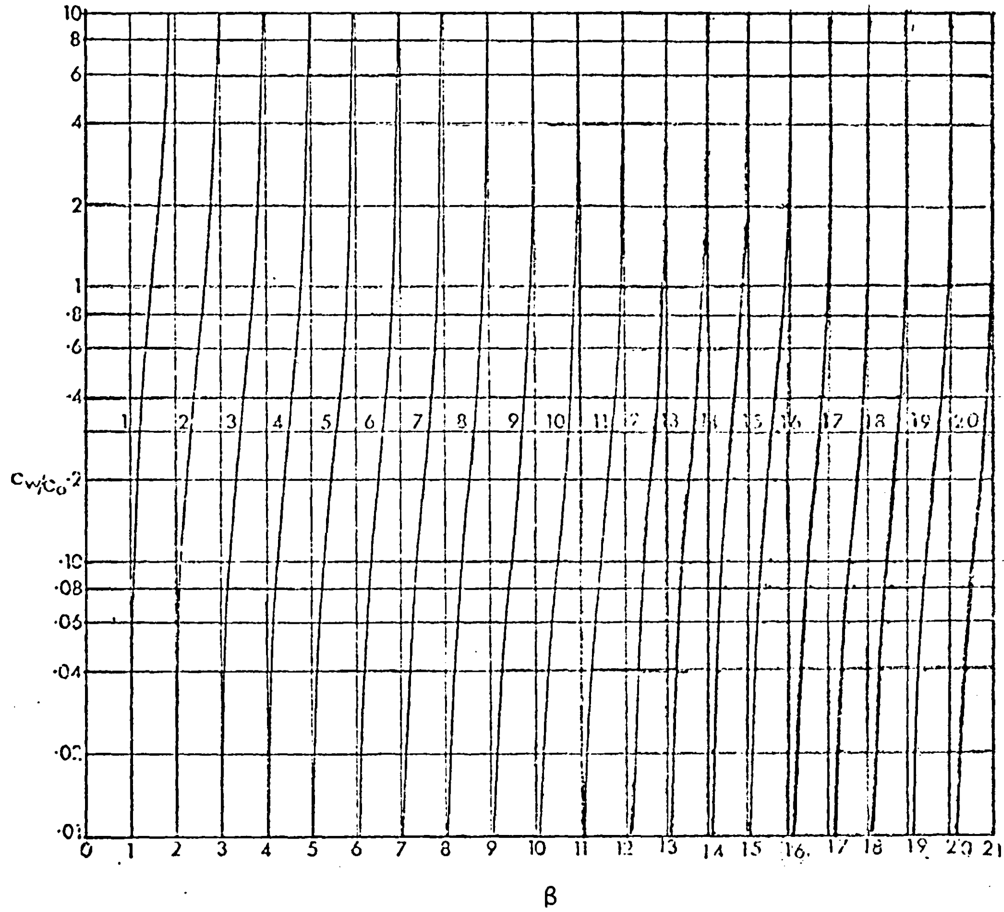
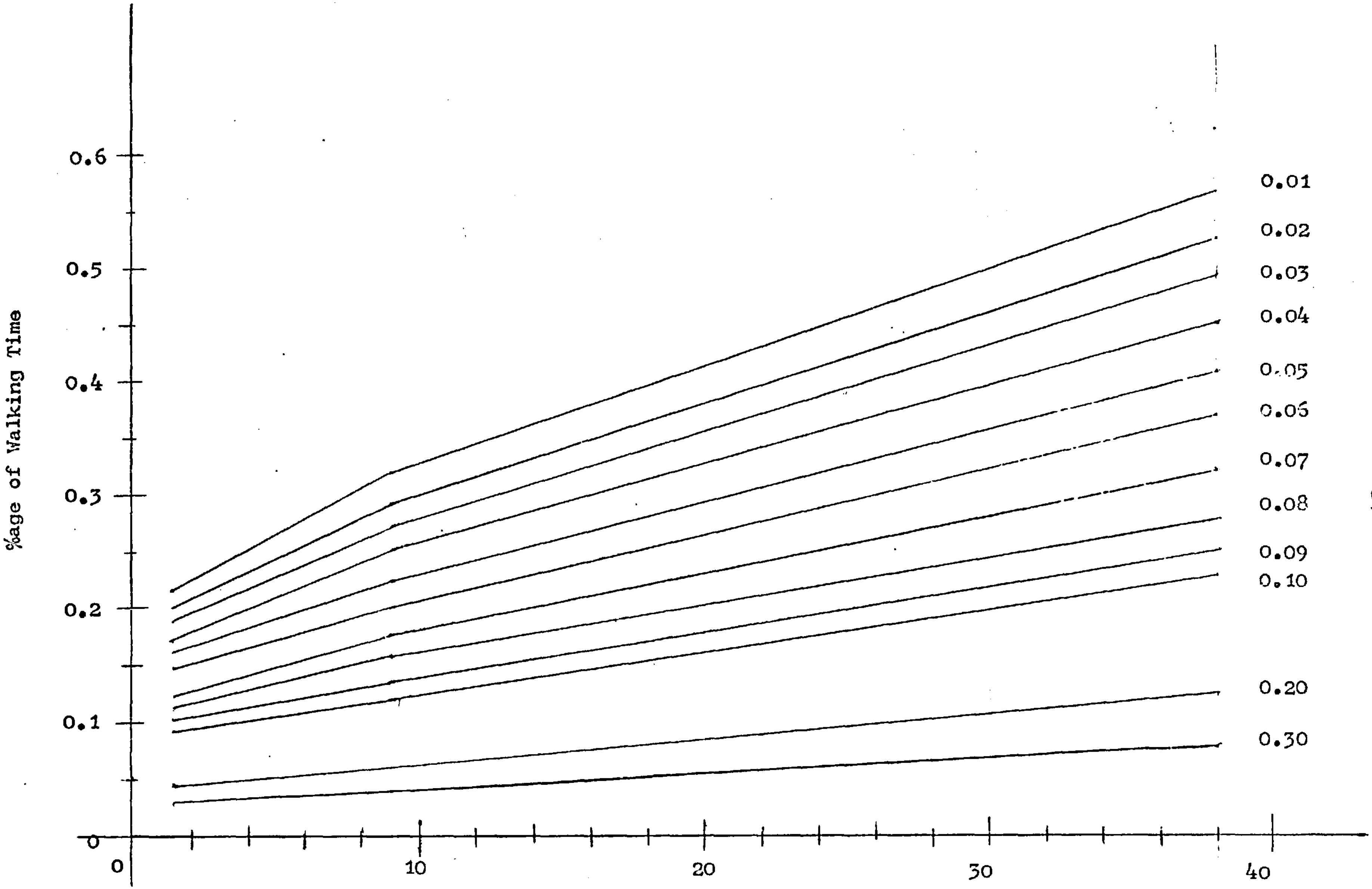


Chart for determining the optimum number of machines to a single operator.(deterministic case).

Fig. No. 35



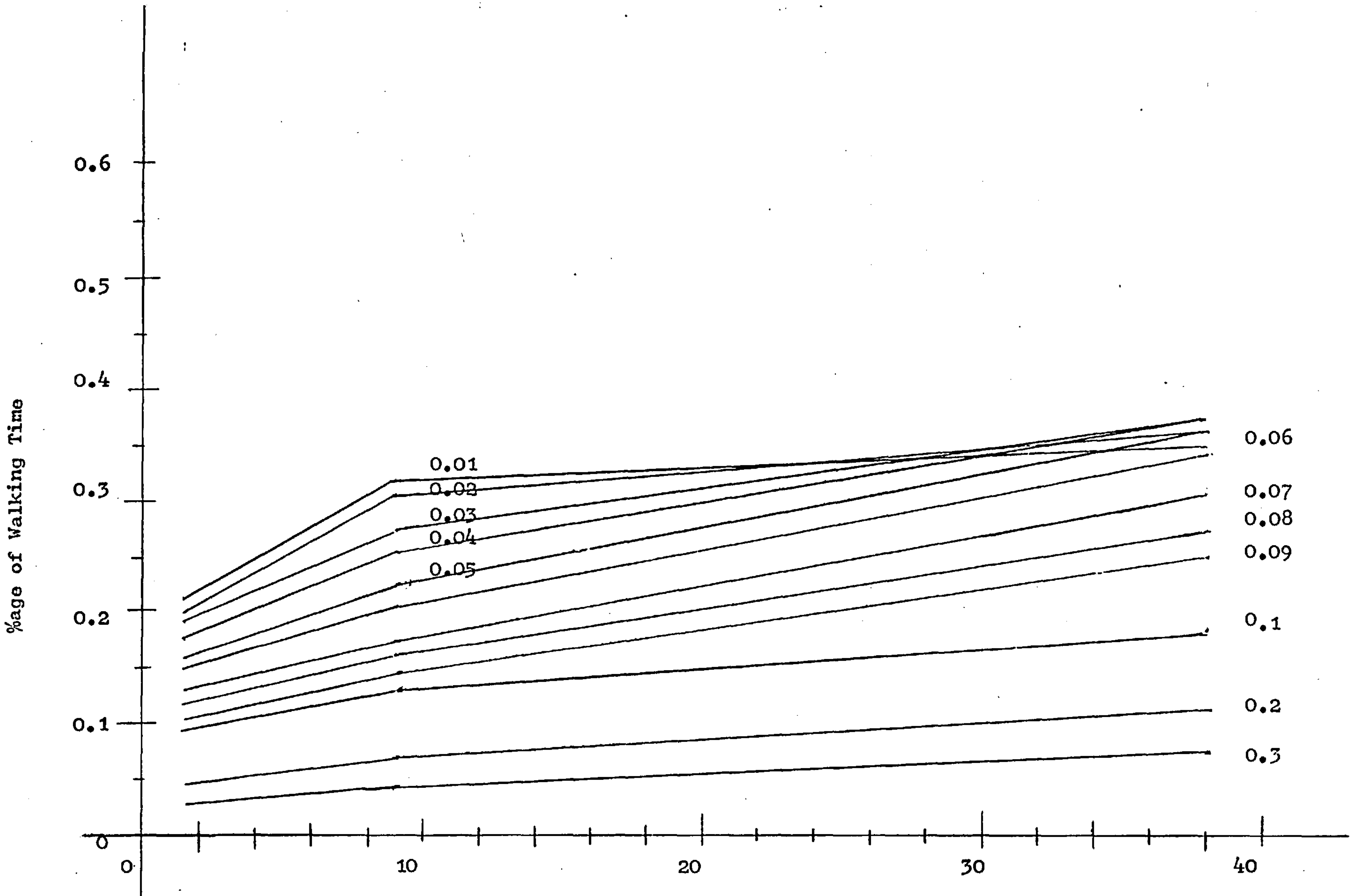
Models.9, 11 and 12

No. of Machines 20

Single Operator

RATIO LENGTH/BREADTH

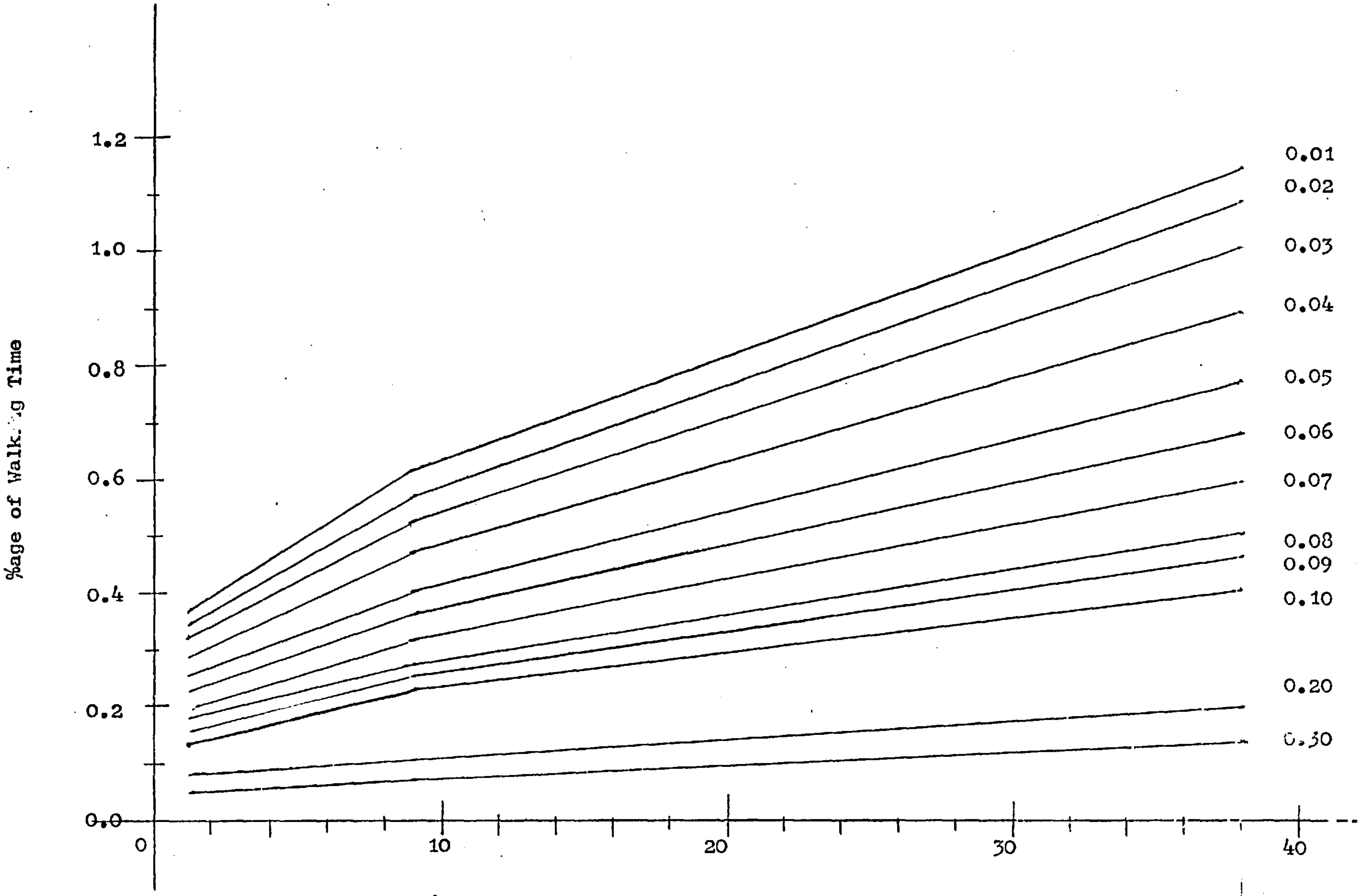
Fig. No. 36



Models. 10,11 and 12
No. of Machines 20
Single Operator.

RATIO LENGTH/BREADTH

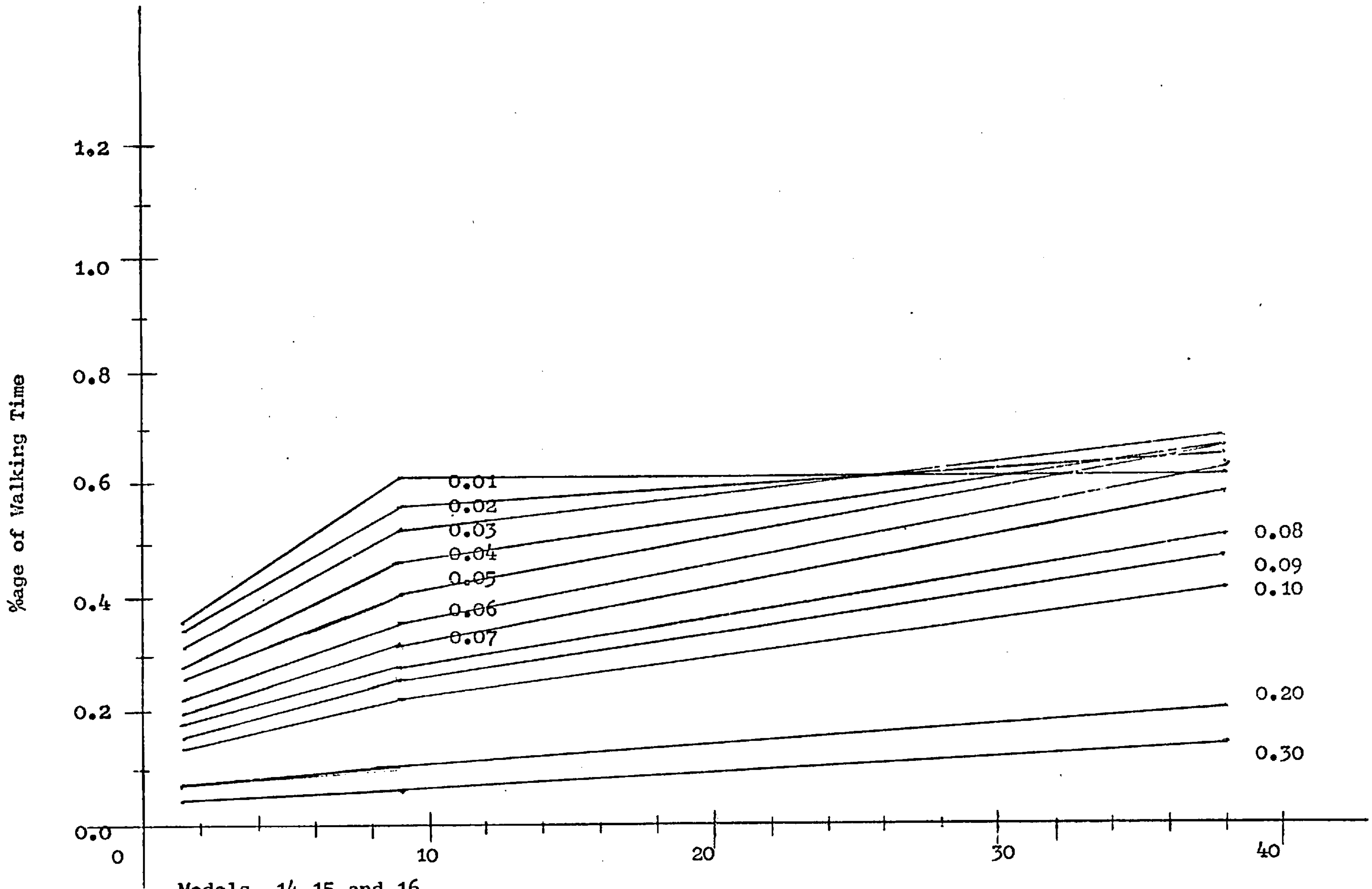
Fig. No. 37



Models. 13.15 and 16
No. of Machines 40
Two Operators

RATIO LENGTH/BREADTH

Fig. No. 38



Models. 14,15 and 16
No. of Machines 40
Two Opeators.

RATIO LENGTH/BREADTH

Fig. No. 39

APPENDIX III

The following relates to cost analysis models assumed in the text. The derivation of these formulae is to be found in King (20,21), from which source they have been taken.

1. Semi-Automatic Machines

Let n = number of machines assigned to operator

a = combined activity time (loading and unloading)

b = independent activity time - operator (cleaning, inspection and walking to next machine, etc.)

t = running time of the machine

i_o = idle time per cycle - operator

i_m = idle time per cycle - machine

C_o = cost per unit time of an operator

C_m = cost per unit time of a working machine

C_w = cost per unit time of an idle machine

$$\text{Cycle time} = \frac{a + t + i_m}{\text{machine}} + \frac{(a + b)n + i_o}{\text{operator}}$$

For a machine to be fully utilised

$$i_m = 0$$

$$\therefore \quad \tau = a + t = (a + b)n + i_o$$

Cost per unit time = $C_o + n\,C_m$, hence cost per product unit

$$= \frac{C_o + n\,C_m}{n/\tau} = \left(\frac{C_c}{n} + C_m\right)(a + t) \qquad \text{(III.1)}$$

For the operator to be fully utilised

$i_o = 0$

$\therefore \quad \tau = (a + b)n = a + t + i_m$

Cost per unit time

$$= C_o + \frac{n\{(a + t)C_m + i_m C_w\}}{\tau}$$

hence cost per product unit

$$= \frac{\dfrac{C_o + \{(a + t)C_w + (a + b)n\ C_w - (a + t)C_w\}}{(a + b)}}{n/\tau}$$

$$= (a + b)(C_o + n\ C_w) + (a + t)(C_m - C_w) \qquad \text{(III.2)}$$

For both machines and operator to be fully utilised

$i_m = i_o = 0$

$\therefore \quad \tau = (a + t) = (a + b)n$

and hence

$$n = \frac{a + t}{a + b}$$

Let $\beta = \dfrac{a + t}{a + b}$

From equations (III.1) and (III.2), the cost per product unit is a minimum for $n = \beta$. From (III.1) and (III.2) n_o is the optimum number of machines to assign to the operator providing:

$$\left(\frac{C_o}{n_o} + C_m\right)(a + t) < (a + b)\{C_o + (n_o + 1)C_w\}$$

$$+ (a + t)(C_m - C_w)$$

$$= C_o\left\{\frac{a + t}{n_o} - (a + b)\right\} < C_w\{(a + b)(n_o + 1)$$

$$- (a + t)\}$$ cont.

$$= \frac{C_w}{C_o} > \frac{\beta - n_o}{n_o(n_o - 1 - \beta)} \qquad \text{(III.3)}$$

Let Φ be the limiting value of the cost ratio.

Then

$$\Phi = \frac{\beta - n_o}{n_o(n_o + 1 - \beta)} \qquad \text{(III.4)}$$

2. Automatic Machines

Let

m = machine running time per time unit

s = service time per time unit

w = waiting time per time unit

where m + s + w = 1 (unit of time)

C_m = the cost per unit time of a machine in the working state

C_s = the cost per unit time of a machine in the being serviced state

C_w = the cost per unit time of a machine in the waiting for service state

C = the cost per unit time of a serviceman

n = the number of automatic machines

p = the size of the workforce engaged solely in servicing the automatic machines

γ = the rate of production of a working machine

then the average total cost per automatic machine per unit time

$$= \frac{pC}{n} = m\,C_m + s\,C_s + w\,C_w$$

Total cost per product unit C is given by

$$= (\frac{pC}{n} + m\ C_m + s\ C_s + w\ C_w)m$$

$$= \frac{C(\frac{p}{n} + \frac{w\ C_w}{C})}{m\ \gamma} + \frac{(C_m + k\ C_s)}{\gamma} \qquad \text{(III.5)}$$

Determine $p = p_o$, the optimum size of the servicing work force to be assigned to the n automatic machines to minimise C, as given by equation (III.5). For $p = p_o$, the total cost per product unit is

$$C_{p_o} = \frac{C(\frac{p_o}{n} + w_{p_o} \cdot \frac{C_w}{C})}{m_{p_o} \cdot \gamma} + \frac{C_m + k\ C_s}{\gamma} \qquad \text{(III.6)}$$

For $p = p_p + 1$, the total cost per product unit is

$$C_{p_o+1} = \frac{C(\frac{p_o+1}{n} + w_{p_o+1} \cdot \frac{C_w}{C})}{m_{p_o+1} \cdot \gamma} + \frac{C_m + k\ C_s}{\gamma} \qquad \text{(III.7)}$$

From equations (III.6) and (III.7), p_o and not p_o+1 is the optimum number of servicemen for n machines if

$$C_{p_o+1} > C_{p_o}$$

or
$$\frac{\frac{p_o+1}{n} + w_{p_o+1} \cdot \frac{C_w}{C}}{m_{p_o+1}} - \frac{\frac{p_o}{n} + w_{p_o} \cdot \frac{C_w}{C}}{m_{p_o}} > 0$$

$\therefore$
$$\frac{m_{p_o} \cdot (p_o+1)}{n} + (w_{p_o+1} \cdot m_{p_o} - w_{p_o} \cdot m_{p_o+1}) \cdot \frac{C_w}{C}$$

$$- \frac{m_{p_o+1} \cdot p_o}{n} > 0 \qquad \text{(III.8)}$$

Since $m + s + w = 1$

$w = 1 - m(1 + k)$ as $s = mk$

Then, substituting for

$$w_{p_o} = 1 - m_{p_o}.(1 + k)$$

$w_{p_o+1} = 1 - m_{p_o+1}(1 + k)$ in equation (III.8)

gives

$$\frac{C_w}{C} = \frac{m_{p_o}}{n(m_{p_o+1} - m_{p_o})} - \frac{p_o}{n}$$

Thus, if Ω is called the limiting value of the cost ratio C_w/C, then

$$\Omega = \frac{m_{p_o}}{n(m_{p_o+1} - m_{p_o})} - \frac{p_o}{n} \qquad \text{(III.9)}$$

APPENDIX IV

THE SIMULATION PROGRAMMES

Programme No.	Title
	Users Instructions for Programmes I,II and III
I	Normal service time distribution - single operator programme.
II	Normal service time distribution - two operators programme.
III	Erlang service time distribution - single operator programme.
	Users Instructions for Programme IV
IV	Constant running time and variable time + constant time + independent time - single operator programme.
	Users Instructions for Programme V
V	Different means for arrival time and service time distribution programme.
	Users Instructions for Programme VI
VI	Inclusion of walking time programmes.
VII	Simon programme.

Users Instructions for Programmes I, II and III

The following data are required.

1) No. of machines in the system.

2) Mean of the distribution of machine breakdowns (negative Exponential)

3) Service time distribution.

   a) Mean and Standard deviation in the case of Normal distribition.

   b) Mean in the case of Negative Exponential distribution.

   c) Mean and No. of phases in the case of Erlang distribution.

4) Printing message times.

   Time at which the printing of messages like,

   A Machine Breaks At

   A Service Ends At

   Queue (Size of the queue)

   Frees (Free service man)

   will start.

5) Time allowed for running the simulation experiment.

6) Histogram Specifications:

   The histogram will have twelve zones: one below the value given by 'low bound', ten within consecutive zone widths above the low bound, and one above the highest zone width.

	Prog. No.I	Prog. No. II	Prog. No. III
	DO 15 J=I,I		
Card No.	2	2	2
	INTEGER BREAK(I)		
Card No.	12	17	11
	INTEGER CUST(I)		
Card No.	16	18	20
	CALL GROUP(BREAK,I,1)		
Card No.	22	27	26
	Specify I I-No. of machines in the system.		
	CALL HISTO (WAIT,LOWBOUND,ZONE WIDTH)		
Card No.	26	31	30
	CALL HISTO (SERV,LOWBOUND,ZONE WIDTH)		
Card No.	27	--	--
	CALL HISTO (SERVA,LOWBOUND,ZONE WIDTH)		
Card No.	--	32	--
	CALL HISTO (SERVB,LOWBOUND,ZONE WIDTH)		
Card No.	--	33	--
	Specify low bound and zone width(see Instruction6)		
	NN = NEGEXP(MEAN,1)		
Card No.	34,49	41,64	38,56
	MEAN-Specify mean: Breakdown between machines.		
	IF(CLOCK-TPRINT)80,80,90		
Card No.	38	45	42
	TPRINT-Specify the time units from which the messages will start printing(see Instruction3)		
	IF(CLOCK-STIME)11,40,40		
Card No.	42	48	45
	STIME-Specify Simulation time.		

	NN = RNORM(MEAN,STD.DEVIATION,3)		
Card No	57	73	--
	Specify MEAN and STD.DEVIATION of the Normal service time distribution.		
	NN = ERLANG(NO. OF PHASES,MEAN,7)		
Card No	--	--	61
	Specify No. of phases and Mean of the Erlang service time distribution.		

Sample out-put for Programme II is shown below(it is same for the programmes I and III except, instead of two service time distribution histograms there will be one).

```
TIMES SET INDEXED 1

A SERVICE ENDS AT    *1000
QUEUE          0
FREES          1


                    DISTRIBUTION OF WAIT-TIMES


HISTOGRAM NO    1     3284 ENTRIES
RANGES           0  20  40  60  80 100 120 140 160 180 200
FREQ         54.916.776.524.376.225.163. 93. 73. 35. 23. 26.
MINIMUM          0 MAXIMUM  353.00
MEAN    43.92 ESTIMATE OF POPULATION DEVIATION    44.56


                    DISTRIBUTION OF SERVICE-TIMES-A


HISTOGRAM NO    2     1639 ENTRIES
RANGES           0  15  30  45  60  75  90 105 120 135 150
FREQ         37.542.354.256.165.139. 53. 40. 25. 16. 12. 27.
MINIMUM          0 MAXIMUM  359.00
MEAN    35.54 ESTIMATE OF POPULATION DEVIATION    35.61


                    DISTRIBUTION OF SERVICE-TIMES-B


HISTOGRAM NO    3     1645 ENTRIES
RANGES           0  15  30  45  60  75  90 105 120 135 150
FREQ         46.524.378.225.162.111. 63. 37. 38. 19. 11. 26.
MINIMUM          0 MAXIMUM  [illegible]
MEAN    35.66 ESTIMATE OF POPULATION DEVIATION    35.65
```

Machine utilization factor,

$$m = \frac{N \cdot S_t - T_W - T_S}{N \cdot S_t}$$

where N- Number of machines in the system.
S_t- Total simulated time.
T_W- Total waiting time.
T_S- Total service time.

PROGRAMME I

```
JOB(UMTSA05,J7,T180,SP0)
ATTACH(SIMON/UN=LIBRARY)
MNF(T,B=BIN)
SETCORE(INDEF)
MAP(PART)
LOAD(BIN,SIMON)
EXECUTE.
.
      PROGRAM TEST(INPUT,OUTPUT,TAPE2=INPUT,TAPE3=OUTPUT)
      DO 15 J=1,20
      WRITE(3,300)J
      CALL SIMUL(J)
  300 FORMAT(////,20X,'THE NUMBER OF MACHINES = ',I4)
   15 CONTINUE
      STOP
      END
      SUBROUTINE SIMUL(N)
      INTEGER QUEUE,SMEN(4),TIMEC(21),TIMEA(21)
      INTEGER SIZEQ,HEADQ,SAMPL
      INTEGER BREAK(20)
      REAL NEGEXP
      REAL RNORM
      INTEGER REPAR
      INTEGER CUST(20)
      INTEGER MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,CLOCK,TAILM
      EXTERNAL HEADQ,SAMPL                            /
      DIMENSION WAIT(19),SERV(19)
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
C     DEFINE ENTITIES, SETS AND HISTOGRAM, READ IN DISTRIBUTION
      CALL SIMON
      CALL GROUP(BREAK,20,1)
      CALL ENTIT(SMEN,2)
      CALL SET(QUEUE)
      CALL SET(REPAR)
      CALL HISTO(WAIT,10.,5.)
      CALL HISTO(SERV,4.,4.)
      CALL HELPI(LMN,QUEUE,REPAR)
      CLOCK=0
C*****INITIATE THE SIMULATION WITH ALL MACHINES WORKING*****
      LWORK=0
      LFREE=1
      SMEN(2)=LFREE
      DO 1 I=1,N
      NN=NEGEXP(1./1200.,1)
      CALL EVENT(BREAK(I),NN,I)
    1 CONTINUE
C*****A PHASE*****
   10 CALL FAZEA(K)
      IF(CLOCK-99800)80,80,90
   90 CALL HELPA(LMN,K)
      CALL HELPB(LMN)
   80 CONTINUE
      IF(CLOCK-100000)11,40,40
   11 GO TO(21,20),K
C*****B PHASE*****
C     A SERVICE HAS ENDED, RECORD THE TOTAL CUSTOMER WAITING TIME
   20 SMEN(2)=LFREE
      GAPS=CLOCK-SMEN(4)
      CALL ADDTO(SERV,GAPS)
```

```
      DELAY=CLOCK-CUST(STATE)
      CALL ADDTO(WAIT,DELAY)
      NN=NEGEXP(1./1200.,2)
      CALL EVENT(BREAK(STATE),NN,STATE)
      GO TO 30
   21 CALL ADDLA(STATE,QUEUE)
      CUST(STATE)=CLOCK
C*****C PHASE*****
C     TEST CONDITION FOR STARTING
   30 IF(SIZEO(QUEUE)*SMEN(2))10,10,31
   31 SMEN(2)=LWORK
      SMEN(4)=CLOCK
      NN=RNORM(24.,2.4,3)
      CALL EVENT(SMEN,NN,HEADO(QUEUE))
      SMEN(3)=HEADO(QUEUE)
      CALL BEHEA(QUEUE)
      GO TO 10
C     PRINT OUT FINAL RESULTS
   40 WRITE(3,104)
      CALL WRITE(WAIT,1)
  104 FORMAT(////,20X,'DISTRIBUTION OF WAIT-TIMES')
      WRITE(3,105)
      CALL WRITE(SERV,2)
  105 FORMAT(////,20X,'DISTRIBUTION OF SERVICE-TIMES')
      RETURN
      END
      REAL FUNCTION NEGEXP(Z,N)
      CALL RANDO(N,K)
      AK=K
      Y=AK/100.
      NEGEXP=(-1.0/Z)*ALOG(1.0-Y)
      RETURN
      END
      REAL FUNCTION RNORM(RMEAN,SD,N)
100   MARK=0
      CALL RANDO(N,K)
      AK=K
      Y=AK/100.
      IF(Y-0.5)1,2,2
1     Y=1.-Y
      MARK=1
    2 Y=(-2.0*ALOG(1.-Y+.00002))**.5
      X=Y-((2.30753+0.27061*Y)/(1.+.99229*Y+.04481*Y*Y))
      IF(MARK)4,4,3
3     X=-X
    4 RNORM=RMEAN+X*SD
      IF(RNORM)100,5,5
5     RETURN
      END

 300
 2
A MACHINE BREAKS AT
A SERVICE ENDS AT
QUEUE    REPAR
```

PROGRAMME II

```
JOB(UMTSA05,J1)
PASSWORD(NAGACHA)
COPYCF(INPUT,DUM)
QUEUE(DUM=INPUT)

JOB(UMTSA05,J7,T60,LC=3000,SP5)
PASSWORD(NAGACHA)
ATTACH(SIMON/UN=LIBRARY)
MNF(B=BIN)
SETCORE(INDEF)
LOAD(BIN,SIMON)
EXECUTE(,LC=5670)

      PROGRAM TEST(INPUT,OUTPUT,TAPE2=INPUT,TAPE3=OUTPUT)
      DO 15 J=34,40,2
      WRITE(3,300)J
      CALL SIMUL(J)
  300 FORMAT(////,20X,'THE NUMBER OF MACHINES = ',I4)
   15 CONTINUE
      STOP
      END
      NO LIST
      SUBROUTINE SIMUL(N)
      INTEGER QUEUE
      INTEGER SMEN(2,4)
      INTEGER TIMEC(21)
      INTEGER TIMEA(21)
      INTEGER TIMEB(21)
      INTEGER SIZEO,HEADO,SAMPL
      INTEGER BREAK(40)
      INTEGER CUST(40)
      INTEGER FREES
      REAL NEGEXP
      REAL RNORM
      INTEGER MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,CLOCK,TAILM
      EXTERNAL HEADO,SAMPL
      DIMENSION WAIT(19),SERVA(19),SERVB(19)
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
C     DEFINE ENTITIES, SETS AND HISTOGRAM, READ IN DISTRIBUTION
      CALL SIMON
      CALL GROUP(BREAK,40,1)
      CALL GROUP(SMEN,2,2)
      CALL SET(QUEUE)
      CALL SET(FREES)
      CALL HISTO(WAIT,0.,20.)
      CALL HISTO(SERVA,5.,1.)
      CALL HISTO(SERVB,5.,1.)
      CALL HELPI(LMN,QUEUE,FREES)
      CLOCK=0
C*****INITIATE THE SIMULATION WITH ALL MACHINES WORKING*****
      LWORK=0
      SMEN(1,2)=SMEN(2,2)=LFREE=1
      CALL ADDLA(SMEN(1,1),FREES)
      CALL ADDLA(SMEN(2,1),FREES)
      DO 1 I=1,N
      NN=NEGEXP(1./60.,1)
      CALL EVENT(BREAK(I),NN,I)
    1 CONTINUE
```

```
C*****A PHASE*****
   10 CALL FAZEA(K)
      IF(CLOCK-9800)80,80,90
   90 CALL HELPA(LMN,K)
      CALL HELPB(LMN)
   80 IF(CLOCK-10000)11,40,40
   11 GO TO(21,20),K
C*****B PHASE*****
C     A SERVICE HAS ENDED, RECORD THE TOTAL CUSTOMER WAITING TIME
   20 CALL ADDLA(MEMBE,FREES)
      I=MEMNU(MEMBE)
      SMEN(I,2)=LFREE
      GAPS=CLOCK-SMEN(I,4)
      SMEN(I,4)=CLOCK
      GO TO(25,35),I
   25 CALL ADDTO(SERVA,GAPS)
      GO TO 45
C*****A MACHINE BREAKS DOWN*****
   21 CALL ADDLA(STATE,QUEUE)
      CUST(STATE)=CLOCK
      GO TO 30
   35 CALL ADDTO(SERVB,GAPS)
   45 DELAY=CLOCK-CUST(STATE)
      CALL ADDTO(WAIT,DELAY)
      NN=NEGEXP(1./60.,2)
      CALL EVENT(BREAK(STATE),NN,STATE)
C*****C PHASE*****
C     TEST CONDITION FOR STARTING
   30 IF(SIZEO(QUEUE)*SIZEO(FREES))10,10,31
   31 JIM=HEADO(FREES)
      CALL BEHEA(FREES)
      J=MEMNU(JIM)
      SMEN(J,2)=LWORK
      SMEN(J,4)=CLOCK
      GO TO(32,33)J
   32 NN=RNORM(12.,2.4,3)
      CALL EVENT(JIM,NN,HEADO(QUEUE))
      SMEN(J,3)=HEADO(QUEUE)
      GO TO 34
   33 NN=RNORM(12.,2.4,4)
      CALL EVENT(JIM,NN,HEADO(QUEUE))
      SMEN(J,3)=HEADO(QUEUE)
   34 CALL BEHEA(QUEUE)
      GO TO 10
C     PRINT OUT FINAL RESULTS
   40 WRITE(3,104)
      CALL WRITE(WAIT,1)
  104 FORMAT(////,20X,'DISTRIBUTION OF WAIT-TIMES')
      WRITE(3,105)
      CALL WRITE(SERVA,2)
  105 FORMAT(////,20X,'DISTRIBUTION OF SERVICE-TIMES-A')
      WRITE(3,106)
      CALL WRITE(SERVB,3)
  106 FORMAT(////,20X,'DISTRIBUTION OF SERVICE-TIMES-B')
      RETURN
      END
      REAL FUNCTION NEGEXP(Z,N)
      CALL RANDO(N,K)
      AK=K
```

```
      Y=AK/100.
      NEGEXP=(-1.0/Z)*ALOG(1.0-Y)
      RETURN
      END
      REAL FUNCTION RNORM(RMEAN,SD,N)
100   MARK=0
      CALL RANDO(N,K)
      AK=K
      Y=AK/100.
      IF(Y-0.5)1,2,2
1     Y=1.-Y
      MARK=1
    2 Y=(-2.0*ALOG(1.-Y+.00002))**.5
      X=Y-((2.30753+0.27061*Y)/(1.+.99229*Y+.04481*Y*Y))
      IF(MARK)4,4,3
3     X=-X
    4 RNORM=RMEAN+X*SD
      IF(RNORM)100,5,5
5     RETURN
      END

450
2
A MACHINE BREAKS AT
A SERVICE ENDS AT
QUEUE    FREES
```

PROGRAMME III

```
JOB(UMTSA05,J1).
PASSWORD(NAGACHA)
COPYCF(INPUT,DUM)
QUEUE(DUM=INPUT)
.
JOB(UMTSA05,J7,T180,LC1500,M7314,SP0)
PASSWORD(NAGACHA)
LIBFILE(SIMONC)
MNF(T,B=BIN)
SETCORE(INDEF)
MAP(PART)
LOAD(BIN,SIMONC)
EXECUTE.
.
      PROGRAM TEST(INPUT,OUTPUT,TAPE2=INPUT,TAPE3=OUTPUT)
      DO 15 J=1,20
      WRITE(3,300)J
      CALL SIMUL(J)
  300 FORMAT(////,20X,'THE NUMBER OF MACHINES = ',I4)
   15 CONTINUE
      STOP
      END
      SUBROUTINE SIMUL(N)
      INTEGER QUEUE,SMEN(4),TIMEC(21),TIMEA(21)
      INTEGER SIZEO,HEADO,SAMPL
      INTEGER BREAK(20)
      REAL NEGEXP
      REAL RNORM
      REAL ERLANG
      REAL SUM
      REAL F
      REAL FACTOR
      INTEGER REPAR
      INTEGER CUST(20)
      INTEGER MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,CLOCK,TAILM
      EXTERNAL HEADO,SAMPL
      DIMENSION WAIT(19),SERV(19)
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
C     DEFINE ENTITIES, SETS AND HISTOGRAM, READ IN DISTRIBUTION
      CALL SIMON
      CALL GROUP(BREAK,20,1)
      CALL ENTIT(SMEN,2)
      CALL SET(QUEUE)
      CALL SET(REPAR)
      CALL HISTO(WAIT,0.,5.)
      CALL HISTO(SERV,0.,5.)
      CALL HELPI(LMN,QUEUE,REPAR)
      CLOCK=0
C*****INITIATE THE SIMULATION WITH ALL MACHINES WORKING*****
      LWORK=0
      LFREE=1
      SMEN(2)=LFREE
      DO 1 I=1,N
      NN=NEGEXP(1./1200.,11)
      CALL EVENT(BREAK(I),NN,I)
    1 CONTINUE
C*****A PHASE*****
   10 CALL FAZEA(K)
      IF(CLOCK-99900)80,80,90
```

```
   90 CALL HELPA(LMN,K)
      CALL HELPB(LMN)
   80 IF(CLOCK-100000)11,40,40
   11 GO TO(21,20),K
C*****B PHASE*****
C     A SERVICE HAS ENDED, RECORD THE TOTAL CUSTOMER WAITING TIME
   20 SMEN(2)=LFREE
      GAPS=CLOCK-SMEN(4)
      CALL ADDTO(SERV,GAPS)
      GO TO 45
   21 CALL ADDLA(STATE,QUEUE)
      CUST(STATE)=CLOCK
      GO TO 30
   45 DELAY=CLOCK-CUST(STATE)
      CALL ADDTO(WAIT,DELAY)
      NN=NEGEXP(1./1200.,12)
      CALL EVENT(BREAK(STATE),NN,STATE)
C*****C PHASE*****
C     TEST CONDITION FOR STARTING
   30 IF(SIZEO(QUEUE)*SMEN(2))10,10,31
   31 SMEN(2)=LWORK
      SMEN(4)=CLOCK
      NN=ERLANG(1,360.,7)
      CALL EVENT(SMEN,NN,HEADO(QUEUE))
      SMEN(3)=HEADO(QUEUE)
      CALL BEHEA(QUEUE)
      GO TO 10
C     PRINT OUT FINAL RESULTS
   40 WRITE(3,104)
      CALL WRITE(WAIT,1)
  104 FORMAT(////,20X,'DISTRIBUTION OF WAIT-TIMES')
      WRITE(3,105)
      CALL WRITE(SERV,2)
  105 FORMAT(////,20X,'DISTRIBUTION OF SERVICE-TIMES')
      RETURN
      END
      REAL FUNCTION NEGEXP(Z,N)
      CALL RANDO(N,K)
      AK=K
      Y=AK/100.
      NEGEXP=(-1.0/Z)*ALOG(1.0-Y)
      RETURN
      END
      REAL FUNCTION ERLANG(KK,ERMEAN,N)
      EXTERNAL F,SUM,FACTOR
      FKK=FLOAT(KK)
      EPS=1.0E-6
      B=1./ERMEAN
      ERLAX=ALOG(100.0)/B
      ERLAXD=ERLAX/100.0
      CALL RANDO(N,K)
      AK=K
      Y=AK/100.0
      FO=F(Y,0.0,KK,B,N,SUM)
      DO 10 I=1,101
      Z=FLOAT(I-1)*ERLAXD
      FI=F(Y,Z,KK,B,N,SUM)
      IF(FO*FI)9,8,11
   11 IF(ABS(FI).LE.EPS) GO TO 8
```

```
      FO=FI
   10 CONTINUE
    9 ZO=Z-ERLAXD
      ERLAXD=ERLAXD/100.0
      FOO=F(Y,ZO,KK,B,N,SUM)
      DO 12 J=1,101
      Z=FLOAT(J-1)*ERLAXD+ZO
      FII=F(Y,Z,KK,B,N,SUM)
      IF(FII*FOO)8,8,13
   13 IF(ABS(FII).LE.EPS) GO TO 8
      FOO=FII
   12 CONTINUE
    8 EPLANG=Z
      RETURN
      END
      REAL FUNCTION SUM(Z,KK,B)
      EXTERNAL F,FACTOR
      SUM=0.0
      FKK=FLOAT(KK)
      DO 10 KI=1,KK
      SUM=SUM+((FKK*B*Z)**(KI-1))/FACTOR(KI-1)
   10 CONTINUE
      RETURN
      END
      REAL FUNCTION F(Y,Z,KK,B,N,SUM)
      EXTERNAL SUM,FACTOR
      FKK=FLOAT(KK)
      F=Y-1.0+EXP(-FKK*B*Z)*SUM(Z,KK,B,N)
      RETURN
      END
      REAL FUNCTION FACTOR(K)
      FACTOR=1.0
      IF(K.EQ.0.OR.K.EQ.1)RETURN
      DO 11 J=2,K
      FACTOR=FACTOR*FLOAT(J)
   11 CONTINUE
      RETURN
      END

300
2
A MACHINE BREAKS AT
A SERVICE ENDS AT
QUEUE    REPAR
```

Users Instructions for Programme IV

The following data are required.

1) No. of machines in the system.

2) Mean running time for the machines.

3) Mean of the service time distribution.

   (Variable time + constant time + independent time)

4) Time allowed for running the simulation experiment.

Input data.

Card No.	Particulars
2	DO 15 J=I, I
14	INTEGER MACHI (I)
15	INTEGER STOP (I)
30	CALL GROUP (MACHI,I,1)
	Specify I I-No. of machines in the system.
4	TIME=STIME
50	IF(CLOCK-STIME) 11,40,40
	Specify STIME STIME-Simulation time
24	DATA ITIME/IR/
	Specify IR IR-Mean running time of the machine
25	DATA ATIME/ST/
	Specify ST ST-Mean service time

The following results are given in the output.

CYLF-Cycle time factor
OPEF-Operator idle factor
BMER-Machine idle factor
SERF-Service factor

Calculation.

Multiply the factors by the running time of the machine to get the following.

Cycle time
Idle time of the machine
Idle time of the operator
Service time of the operator

```
      PROGRAM TEST(INPUT,OUTPUT,TAPE2=INPUT,TAPE3=OUTPUT)
      DO 15 J=1,20
      WRITE(3,300)J
      TIME=10000.
      CALL SIMUL(J,TIME)
  300 FORMAT(////,20X,'THE NUMBER OF MACHINES =',I4)
   15 CONTINUE
      STOP
      END

      SUBROUTINE SIMUL(N,TIME)
      INTEGER QUEUE
      INTEGER SMEN(1,5)
      INTEGER TIMEA(21)
      INTEGER MACHI(20)
      INTEGER STOP(20)
      INTEGER SIZEO,HEADO,SAMPL
      INTEGER FREES
      REAL NEGEXP
      REAL GAPS(3)
      INTEGER MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,CLOCK,TAILM
      EXTERNAL HEADO,SAMPL
      DIMENSION WAIT(19),SERVA(19)
      DIMENSION ATIME(1),ITIME(1)
      DATA ITIME/25/
      DATA ATIME/2./
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
C     DEFINE ENTITIES, SETS AND HISTOGRAM, READ IN DISTRIBUTION
      CALL SIMON
      JXXXX=2000*N+1
      Y=RANDY(JXXXX)
      CALL GROUP(MACHI,20,1)
      CALL GROUP(SMEN,1,2)
      CALL SET(QUEUE)
      CALL SET(FREES)
      CALL HISTO(WAIT,0.,30.)
      CALL HISTO(SERVA,0.,40.)
      CALL HELPI(LMN,QUEUE,FREES)
      CLOCK=0
      SMEN(1,2)=LFREE=1
      CALL ADDLA(SMEN(1,1),FREES)
      DO 1 I=1,N
      STOP(I)=0
    1 CALL ADDLA(I,QUEUE)
      NN=NEGEXP(1./ATIME(1),JXXXX)
      GO TO 30
C*****A PHASE*****
   10 NN=NEGEXP(1./ATIME(1),JXXXX)
      NN=NN+0

      NN=NN+5

      CALL FAZEA(K)
      I=STATE
   80 IF(CLOCK-10000)11,40,40
   11 GO TO (21,20),K
C*****B PHASE*****
   20 CALL ADDLA(MEMBE,FREES)
      I=MEMNU(MEMBE)
      IF(SIZEO(QUEUE).EQ.0)SMEN(I,5)=0
      SMEN(I,2)=LFREE
      GAPS(I)=FLOAT(CLOCK)-GAPS(I)
```

```
      CALL ADDTO(SERVA,GAPS)
      ITIMER=CLOCK
      I=STATE
      DELAY=CLOCK-STOP(I)
      CALL ADDTO(WAIT,DELAY)
      CALL EVENT(MACHI(STATE),ITIME(1),STATE)
      GO TO 30
   21 CALL ADDLA(I,QUEUE)
      STOP(I)=CLOCK
C*****C PHASE*****
C     TEST CONDITION FOR STARTING
   30 IF(SIZEO(QUEUE)*SIZEO(FREES))10,10,34
   34 JIM=HEADO(FREES)
      CALL BFHEA(FREES)
      J=MEMNU(JIM)
      SMEN(J.4)=CLOCK
      I=HEADO(QUEUE)
      CALL BFHEA(QUEUE)
      CALL EVENT(JIM,NN,I)
      GAPS(J)=CLOCK
      GO TO 30
   40 CONTINUE
C     PRINT OUT FINAL RESULTS
      WRITE(3,106)ITIMEB

  106 FORMAT(//10X,'THE LAST SERVICE FINISHED AT',5X,I10)
      BN=N
      AMAUT=1.-WAIT(16)/(TIME*BN)
      TOTU=SERVA(16)/TIME
      AIDU=1.-TOTU
      SEUT=SERVA(16)/(TIME*BN)
      WAUT=1.-AMAUT-SEUT
      SMEAN=SERVA(16)/SERVA(15)
      CYCLE=(WAIT(16)/WAIT(15))+FLOAT(ITIME(1))
      BMIO=CYCLE-FLOAT(ITIME(1))-(SERVA(16)/SERVA(15))
      BMIF=BMIO/FLOAT(ITIME(1))
      CYLF=CYCLE/FLOAT(ITIME(1))
      SERF=CYLF-BMIF-1.
      B=5.
      D=SERVA(16)-((SERVA(15)-BN)*B)
      A=D/SERVA(15)
      R=(A+FLOAT(ITIME(1)))/(A+B)
      AIO=CYCLE-BN*(A+B)
      OPEF=AIO/ITIME(1)

      T=BN*(A+B)
      W=T/ITIME(1)

      C=(SERVA(16)-((SERVA(15)-BN)*B))/SERVA(15)
      R=(C+ITIME(1))/(C+B)

      H=(R-BN)/(BN*(BN+1-R))

      WRITE(3,107)AMAUT,WAUT,SEUT,TOTU,AIDU,SMEAN,BMIF,OPEF,SERF,CYLF,A,
     ;T,W,C,D,R,H
  107 FORMAT(1H0,13(F9.5,1X))
      RETURN
      END
      REAL FUNCTION NEGEXP(Z,JXXXX)
      Y=RANDY(JXXXX)
      NEGEXP=(-1.0/Z)*ALOG(1.0-Y)
      RETURN
      END
  300
  2
A MACHINE BREAKS AT
A SERVICE ENDS AT
```

Users Instructions for Programme V

The following data are required.

1) Mean Arrival rate for the machines for each group.

2) Mean Service time for each group.

3) Other instructions: See page 248

Input data.

Card No.	Particulars
2	DO 15 J=J,I
14	INTEGER MACHI (I)
15	INTEGER STOP (I)
30	CALL GROUP (MACHI, I,1)
	Specify I
	I-No. of Machines in the system
34	CALL HISTO(WAIT,LOWBOUND,ZONE WIDTH)
35	CALL HISTO(SERVA,LOWBOUND,ZONE WIDTH)
36	CALL HISTO(SERVB,LOWBOUND,ZONE WIDTH)
	Specify Lowhound and Zone width
48	IF(CLOCK-TPRINT) 80,80,90
	Specify TPRINT (see page 249)
51	IF(CLOCK-STIME)11,40,40
	Specify STIME(see page249)

The output format is the same as given in the page 249

PROGRAMME V

```
JOB(UMTSA05,J1)
PASSWORD(NAGACHA).
LIBFILE(SIMONC)
MNF(T,B=BIN)
SETCORE(INDEF)
MAP(PART)
LOAD(BIN,SIMONC)
EXECUTE.
      PROGRAM TEST(INPUT,OUTPUT,TAPE2=INPUT,TAPE3=OUTPUT)
      DO15 J=6,6
      WRITE(3,300)J
      CALL SIMUL(J)
  300 FORMAT(////,20X,'THE NUMBER OF MACHINES =',I4)
   15 CONTINUE
      STOP
      END
      SUBROUTINE SIMUL(N)
      INTEGER QUEUE
      INTEGER SMEN(2,5)
      INTEGER TIMEA(21)
      INTEGER TIMEB(21)
      INTEGER MACHI(40)
      INTEGER STOP(40)
      INTEGER SIZEO,HEADO,SAMPL
      INTEGER FREES
      EXTERNAL HEADO,SAMPL
      REAL NEGEXP
      REAL GAPS(3)
      INTEGER MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,CLOCK,TAILM
      DIMENSION WAIT(19),SERVA(19),SERVB(19)
      DIMENSION ATIME(6),ITIME(6)
      DATA ITIME/1200,1200,1200,1200,1200,1200/
      DATA ATIME/12.,12.,24.,24.,36.,36./
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
C     DEFINE ENTITIES, SETS AND HISTOGRAM, READ IN DISTRIBUTION
      CALL SIMON
      JXXXX=2000*N+1
      Y=RANDY(JXXXX)
      CALL GROUP(MACHI,40,1)
      CALL GROUP(SMEN,2,2)
      CALL SET(QUEUE)
      CALL SET(FREES)
      CALL HISTO(WAIT,0.,200.)
      CALL HISTO(SERVA,50.,50.)
      CALL HISTO(SERVB,50.,50.)
      CALL HELPI(LMN,QUEUE,FREES)
      CLOCK=0
      SMEN(1,2)=SMEN(2,2)=LFREE=1
      CALL ADDLA(SMEN(1,1),FREES)
      CALL ADDLA(SMEN(2,1),FREES)
      DO 1 I=1,N
      STOP(I)=0
    1 CALL ADDLA(I,QUEUE)
      GO TO 30
C*****A PHASE*****
   10 CALL FAZEA(K)
      I=STATE
      IF(CLOCK-99999)80,80,90
```

```
   90 CALL HELPA(LMN,K)
      CALL HELPB(LMN)
   80 IF(CLOCK-100000)11,40,40
   11 GO TO (21,20),K
C*****B PHASE*****
   20 CALL ADDLA(MEMBE,FREES)
      I=MEMNU(MEMBE)
      IF(SIZEQ(QUEUE).EQ.0)SMEN(I,5)=0
      SMEN(I,2)=LFREE
      GAPS(I)=FLOAT(CLOCK)-GAPS(I)
      IF(I.EQ.1)CALL ADDTO(SERVA,GAPS(I))
      IF(I.EQ.2)CALL ADDTO(SERVB,GAPS(I))
      I=STATE
      DELAY=CLOCK-STOP(I)
      CALL ADDTO(WAIT,DELAY)
      CALL EVENT(MACHI(STATE),ITIME(I),STATE)
      GO TO 30
   21 CALL ADDLA(I,QUEUE)
      STOP(I)=CLOCK
C*****C PHASE*****
C     TEST CONDITION FOR STARTING
   30 IF(SIZEQ(QUEUE)*SIZEQ(FREES))10,10,34
   34 JIM=HEADQ(FREES)
      CALL BEHEA(FREES)
      J=MEMNU(JIM)
      SMEN(J,4)=CLOCK
      I=HEADQ(QUEUE)
      CALL BEHEA(QUEUE)
   35 NN=NEGEXP(1./ATIME(I),JXXXX)
      IF(NN.LT.INT(ATIME(I)*0.25)) GO TO 35
      CALL EVENT(JIM,NN,I)
      GAPS(J)=CLOCK
      GO TO 30
C     PRINT OUT FINAL RESULTS
   40 WRITE(3,104)
      CALL WRITE(WAIT,1)
  104 FORMAT(////,20X,'DISTRIBUTION OF WAIT-TIMES')
      WRITE(3,105)
      CALL WRITE(SERVA,2)
  105 FORMAT(////,20X,'DISTRIBUTION OF SERVICE-TIMES-A')
      WRITE(3,106)
      CALL WRITE(SERVB,3)
  106 FORMAT(////,20X,'DISTRIBUTION OF SERVICE-TIMES-B')
      RETURN
      END
      REAL FUNCTION NEGEXP(Z,JXXXX)
      Y=RANDY(JXXXX)
      NEGEXP=(-1.0/Z)*ALOG(1.0-Y)
      RETURN
      END

300
2
A MACHINE WAITING AT
A SERVICE ENDS AT
QUEUE    FREES
```

Users Instructions for Programme VI

The following data are required.

1) The walking time matrix has to be calculated for the given layout.

2) Other instructions are the same as given in the page 248

Input data.

Card No.	Particulars
2	DO 15 J=I,1
19	INTEGER BREAK(I)
20	INTEGER CUST (I)
35	CALL GROUP(BREAK,I,1)
	Specify I I-No. of Machines in the system.
24	DATA/ATIME/ Specify ATIME- Mean breakdown time of the machines
39 40 41	Histogram Specifications: See pages 248 and 249
44 to 81	Walking time matrix. (Calculations for each given layout)

The following outputs are given:

The output format is the same as that one given in page 249 . In addition to that the following walking time details are given:

SUMI - Total walking time between machines.

SUM2 - Total walking time between resting place and machines.

SUM - Total walking time (SUM1 + SUM2)

$$\%\text{age of Walking time} = \frac{\text{SUM}}{\text{Total operator's time.}} \times 100$$

```
      PROGRAM TEST(INPUT,OUTPUT,TAPE2=INPUT,TAPE3=OUTPUT)
      DO 15 J=40,1
      WRITE(3,300)J
      DO 15 K=1,12
      IF(K.LE.10)E1=1./(12.*FLOAT(K))
      IF(K.GT.10)E1=1./(120.*FLOAT(K-9))
      CALL SIMUL(J,E1)
  300 FORMAT(////,20X,'THE NUMBER OF MACHINES = ',I4)
   15 CONTINUE
      STOP
      END
      SUBROUTINE SIMUL(N,E1)
      INTEGER QUEUE
      INTEGER SMEN(2.5)
      INTEGER TIMEC(21)
      INTEGER TIMEA(21)
      INTEGER TIMEE(21)
      INTEGER SIZEC,HEADO,SAMPL
      INTEGER BREAK(40)
      INTEGER CUST(40)
      INTEGER FREES
      REAL NEGEXP
      REAL RNORM
      INTEGER MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,CLOCK,TAILM
      EXTERNAL HEADO,SAMPL
      DIMENSION WAIT(19),SERVA(19),SERVB(19)
      COMMON MIN,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      DIMENSION SUM1(2),SUM2(2),SUM(2)
      DIMENSION ATIME(1)
      DATA ATIME/1200./
      DIMENSION XX(40,40),XY(40)
C     DEFINE ENTITIES, SETS AND HISTOGRAM, READ IN DISTRIBUTION
      CALL SIMON
      JXXXX=2000*N+1
      Y=RANDY(JXXXX)
      CALL GROUP(BREAK,40,1)
      CALL GROUP(SMEN,2,2)
      CALL SET(QUEUE)
      CALL SET(FREES)
      CALL HISTO(WAIT,0.,20.)
      CALL HISTO(SERVA,0.,15.)
      CALL HISTO(SERVB,0.,15.)
      CALL HELPI(LMN,QUEUE,FREES)
      CLOCK=0
C*****INITIATE THE SIMULATION WITH ALL MACHINES WORKING*****
      DO 200 I=1,39
      L=I+1
      DO 300 J=L,40
      X=FLOAT(IABS(I-J)*2)
      IF(ABS(X-2.).GT.0.0001) X=X+2.
      XX(I,J)=X
  300 XX(J,I)=X
      XX(I,I)=0
  200 CONTINUE
      XX(40,40)=0
      F=1.
      X=41.
      F=0.
      DO 120 I=1,40
      XY(I)=X
      IF(F.LE.0.) GO TO 110
      IF(ABS(X-43.).LT.0.0001) GO TO 130
      X=X+2.
      GO TO 120
  130 F=0.
      GO TO 140
  110 IF(ABS(X-3.).LT.0.0001) GO TO 150
  140 X=X-2.
      GO TO 120
  150 F=1.
  120 CONTINUE
      DO 13 J=1,2
      SUM1(J)=0.0
   13 SUM2(J)=0.0
      SMEN(1,5)=0
      SMEN(2,5)=0
      LWORK=0
      SMEN(1,2)=SMEN(2,2)=LFREE=1
      CALL ADDLA(SMEN(1,1),FREES)
      CALL ADDLA(SMEN(2,1),FREES)
      DO 1 I=1,N
      NN=NEGEXP(1./ATIME(1),JXXXX)
      CALL EVENT(BREAK(I),NN,I)
    1 CONTINUE
C*****A PHASE*****
```

```
   10 CALL FAZEA(K)
      IF(CLOCK-99999)80,80,90
   90 CALL HELPA(LMN,K)
      CALL HELPB(LMN)
   80 IF(CLOCK-100000)11,40,40
   11 GO TO(21,20),K
C*****B PHASE*****
C     A SERVICE HAS ENDED, RECORD THE TOTAL CUSTOMER WAITING TIME
   20 CALL ADDLA(MEMBE,FREES)
      I=MEMNU(MEMBE)
      IF(SIZEO(QUEUE).EQ.0)SMEN(I,5)=0
      SMEN(I,2)=LFREE
      GAPS=CLOCK-SMEN(I,4)
      SMEN(I,4)=CLOCK
      IF(I.EQ.1)CALL ADDTO(SERVA,GAPS)
      IF(I.EQ.2)CALL ADDTO(SERVB,GAPS)
      GO TO 45
C*****A MACHINE BREAKS DOWN*****
   21 CALL ADDLA(STATE,QUEUE)
      CUST(STATE)=CLOCK
      GO TO 30
   45 DELAY=CLOCK-CUST(STATE)
      CALL ADDTO(WAIT,DELAY)
      NN=NEGEXP(1./ATIME(1),JXXXX)
      CALL EVENT(BREAK(STATE),NN,STATE)
C*****C PHASE*****
C     TEST CONDITION FOR STARTING
   30 IF(SIZEO(QUEUE)*SIZEO(FREES))10,10,34
   34 JIM=HEADO(FREES)
      CALL REHEA(FREES)
      J=MEMNU(JIM)
      K=HEADO(QUEUE)
      IF(SMEN(J,5))31,31,50
   50 SMEN(J,2)=LWORK
      SMEN(J,4)=CLOCK
      I=SMEN(I,5)
      T=XX(I,K)
      SUM1(J)=SUM1(J)+T
      GO TO 14
   31 SMEN(J,2)=LWORK
      SMEN(J,4)=CLOCK
      T=XY(K)
      SUM2(J)=SUM2(J)+T
   14 II=T
      SMEN(J,5)=K
      NN=NEGEXP(E1,JXXXX)
      IP=NN+II
      CALL EVENT(JIM,IP,HEADO(QUEUE))
      SMEN(J,3)=HEADO(QUEUE)
      CALL REHEA(QUEUE)
      GO TO 10
C     PRINT OUT FINAL RESULTS
   40 WRITE(3,104)
      CALL WRITE(WAIT,1)
  104 FORMAT(////,20X,'DISTRIBUTION OF WAIT-TIMES')
      WRITE(3,105)
      CALL WRITE(SERVA,2)
  105 FORMAT(////,20X,'DISTRIBUTION OF SERVICE-TIMES-A')
      WRITE(3,106)
      CALL WRITE(SERVB,3)
  106 FORMAT(////,20X,'DISTRIBUTION OF SERVICE-TIMES-B')
      SUM(1)=SUM1(1)+SUM2(1)
      SUM(2)=SUM1(2)+SUM2(2)
      TSUM=SUM(1)+SUM(2)
      WRITE(3,500)
  500 FORMAT(////,10X,'SUM',10X,'SUM1',10X,'SUM2')
      WRITE(3,501)(J,SUM(J),SUM1(J),SUM2(J),J=1,2)
  501 FORMAT(//' SMEN',I2,F7.0,6X,F7.0,7X,F7.0)
      WRITE(3,502)TSUM
  502 FORMAT(///10X,'TOTAL SUM',F9.0)
      RETURN
      END
      REAL FUNCTION NEGEXP(Z,JXXXX)
      Y=RANDY(JXXXX)
      NEGEXP=(-1.0/Z)*ALOG(1.0-Y)
      RETURN
      END

300
2
A MACHINE BREAKS AT
A SERVICE ENDS AT
QUEUE    FREES
```

PROGRAMME VII

```
      SUBROUTINE ADDFI(M,L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF(NIM)1060,1060,1061
 1060 K=1
      GO TO 1065
 1061 J=TAILM
      TAILM=MAST2(J)
      NIM=NIM-1
      MAST1(J)=M
      IF(MAST1(L))1062,1063,1064
 1062 K=3
 1065 CALL SLIP(1,K,L,M)
 1063 MAST2(J)=J
      MAST2(L)=J
      MAST1(L)=1
      RETURN
 1064 MAST1(L)=MAST1(L)+1
      K=MAST2(L)
      MAST2(J)=MAST2(K)
      MAST2(K)=J
      RETURN
      END
COMPILER SPACE


      SUBROUTINE ADDLA(M,L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF(NIM)1070,1070,1071
 1070 K=1
      GO TO 1075
 1071 J=TAILM
      TAILM=MAST2(J)
      NIM=NIM-1
      MAST1(J)=M
      IF(MAST1(L))1072,1073,1074
 1072 K=3
 1075 CALL SLIP(2,K,L,M)
 1073 MAST2(J)=J
      MAST2(L)=J
      MAST1(L)=1
      RETURN
 1074 MAST1(L)=MAST1(L)+1
      K=MAST2(L)
      MAST2(J)=MAST2(K)
      MAST2(K)=J
      MAST2(L)=J
      RETURN
      END
COMPILER SPACE


      SUBROUTINE ADDTO(D,V)
      DIMENSION D(19)
      DK=D(13)
      DO 2 J=1,11
      IF(DK-V)2,1,1
    1 D(J)=D(J)+1.
      GO TO 3
    2 DK=DK+D(14)
      D(12)=D(12)+1.
    3 D(15)=D(15)+1.
      D(16)=D(16)+V
      D(17)=D(17)+V*V
      IF(D(19)-V)5,5,4
    4 D(19)=V
    5 IF(V-D(18))7,7,6
    6 D(18)=V
    7 RETURN
      END
COMPILER SPACE
```

```
      SUBROUTINE BEHEA(L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF(MAST1(L))1032,1030,1031
 1030 J=2
      GO TO 1033
 1032 J=3
 1033 CALL SLIP(3,J,L,L)
 1031 K=MAST2(L)
      J=MAST2(K)
      MAST2(K)=MAST2(J)
      MAST2(J)=TAILM
      TAILM=J
      NIM=NIM+1
      MAST1(L)=MAST1(L)-1
      RETURN
      END
COMPILER SPACE

      SUBROUTINE BETAI(L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
       COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF(MAST1(L))1039,1040,1041
 1039 J=3
      GO TO 1043
 1040 J=2
 1043 CALL SLIP(4,J,L,L)
 1041 J=MAST2(L)
      K=J
      II=MAST1(L)-1
      MAST1(L)=II
      DO1042I=1,II
 1042 J=MAST2(J)
      MAST2(J)=MAST2(K)
      MAST2(L)=J
      MAST2(K)=TAILM
      TAILM=K
      NIM=NIM+1
      RETURN
      END
COMPILER SPACE

      INTEGER FUNCTION BOUND(K)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      BOUND=MAST2(K)
      RETURN
      END
COMPILER SPACE

      SUBROUTINE CLEAR(L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      K=MAST1(L)
      IF(K)373,204,4613
  373 CALL SLIP(5,3,L,L)
 4613 NIM=NIM+K
      K=MAST2(L)
      MAST1(L)=0
      M=MAST2(K)
      MAST2(K)=TAILM
      TAILM=M
  204 RETURN
      END
COMPILER SPACE

      SUBROUTINE DELET(M,IS)
```

```
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      L=IS
      J=MAST1(L)
      IF(J)1078,1084,1079
 1078 CALL SLIP(6,3,L,L)
 1079 MAST1(L)=J-1
      L=MAST2(L)
      DO 1080 II=1,J
      I=II
      K=MAST2(L)
      IF(MAST1(K)-M)1080,1081,1080
 1080 L=K
 1084 WRITE(3,100)IS
  100 FORMAT(' MISSING FROM SET',I4)
      L=M
      GO TO 1078
 1081 IF(I-J)1083,1082,1082
 1082 MAST2(IS)=L
 1083 MAST2(L)=MAST2(K)
      MAST2(K)=TAILM
      TAILM=K
      NIM=NIM+1
      RETURN
      END
COMPILER SPACE


      SUBROUTINE DISTR(IA,N)
      DIMENSION IA(21)
  100 FORMAT(21I3)
      READ(2,100)IA(21),(IA(I),I=1,20)
      IF(IA(21)-N)1201,1200,1201
 1201 WRITE(3,102)N,IA(21)
  102 FORMAT(' WRONG DATA NUMBER FOR DISTRIBUTION',I4,'; READ:',I4)
      CALL EXIT
 1200 RETURN
      END
COMPILER SPACE


      SUBROUTINE ENTIT(N,M)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF(2-NIM)1050,1051,1051
 1051 CALL SLIP(7,1,0,0)
 1050 N=TAILM
      NIM=NIM-2
      MAST1(N)=-1
      MAST1(N+1)=M
      TAILM=MAST2(N+1)
      IF(MAST2(1))100,100,101
  101 CONTINUE
      WRITE(3,1052)N,M
  100 CONTINUE
 1052 FORMAT(' ENTITY INDEXED',I4,' WITH REF NUMBER',I4/)
      RETURN
      END
COMPILER SPACE


      SUBROUTINE EVENT(I,J,NJK)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      MAST2(I)=NJK
      K=-J-CLOCK-1
      MAST1(I)=K
      L=MAST2(TAILM)
      MAST1(TAILM)=I
      NIS=MAST1(TIMES)
      IF(NIS*NIM)98,98,101
   98 IF(NIM)99,99,100
   99 WRITE(3,204)J
  204 FORMAT(5X,'SCHEDULED AT +',I5)
      CALL SLIP(8,1,1,I)
  100 MAST2(TAILM)=TAILM
```

```
      MAST2(TIMES)=TAILM
      GO TO 103
  101 IE=MAST2(TIMES)
      IP=MAST2(IE)
      DO1094 JC=1,NIS
      IEV=MAST1(IP)
      IF(K-MAST1(IEV))1092,1093,1095
 1093 IF(NAME-1)1092,1096,1092
 1096 IF(MAST1(I+1)-MAST1(IEV+1))1095,1092,1092
 1092 IE=IP
 1094 IP=MAST2(IP)
      MAST2(TIMES)=TAILM
 1095 MAST2(IE)=TAILM
      MAST2(TAILM)=IP
  103 TAILM=L
      NIM=NIM-1
      MAST1(TIMES)=NIS+1
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE FAZEA(K)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF(MAST1(TIMES))1090,1090,1091
 1090 CALL SLIP(9,2,1,0)
 1091 LAST=MAST2(TIMES)
      LEAD MAST2(LAST)
      MEMBE=MAST1(LEAD)
      K=MAST1(MEMBE+1)
      STATE=MAST2(MEMBE)
      MAST2(LAST)=MAST2(LEAD)
      MAST2(LEAD)=TAILM
      TAILM=LEAD
      NIM=NIM+1
      CLOCK=-1-MAST1(MEMBE)
      MAST1(TIMES)=MAST1(TIMES)-1
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE GROUP(IE,IN,IL)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      DIMENSION IE(1,1)
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      NIM=NIM-IN-IN
      IF(NIM)1150,1150,1151
 1150 CALL SLIP(10,1,0,0)
 1151 DO 1152 J=1,IN
      IE(J,1)=TAILM
      MAST1(TAILM)=-1
      NM=TAILM+1
      TAILM=NM+1
      MAST1(NM)=IL
 1152 MAST2(NM)=J
      IF(MAST2(1))100,100,101
  101 CONTINUE
      WRITE(3,1052)IE(1,1),IL,IN
  100 CONTINUE
 1052 FORMAT(' GROUP INDEXED',I4,' WITH REF NUMBER',I2,' AND',I4,'MEMBER
     +S'/)
      RETURN
      END
```

COMPILER SPACE

```
      INTEGER FUNCTION HEADO(L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF(MAST1(L))3,1,2
    1 K=2
      GO TO 4
    3 K=3
    4 CALL SLIP(11,K,L,L)
```

```
      2 K=MAST2(L)
        K=MAST2(K)
        HEADO=MAST1(K)
        RETURN
        END
COMPILER SPACE


        SUBROUTINE HELPA(IT,K)
        INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
       +CLOCK
        COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
        IF(IT)2,2,1
      1 JJ=IT+K*5-3
        JE=JJ+4
        WRITE(3,101)(MAST1(J),MAST2(J),J=JJ,JE),CLOCK
    101 FORMAT(1X,10A2,I5)
      2 RETURN
        END
COMPILER SPACE


        SUBROUTINE HELPB(IT)
        INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
       +CLOCK
        COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
        IF(IT)3,3,1
      1 MM=MAST2(IT)
        INSET=MAST1(IT+1)
        N=MAST1(IT)
        DO2 J=1,N
        JA=MM+2*J
        JB=INSET+J
      2 WRITE(3,100)MAST1(JA),MAST2(JA),MAST1(JA+1),MAST2(JA+1),MAST1(JB)
    100 FORMAT(1X,4A2,I5)
      3 RETURN
        END
COMPILER SPACE


        SUBROUTINE HELPI(IT,M,N)
        INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
       +CLOCK
        COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
        READ(2,100) I
    100 FORMAT(I2)
        IF(I)2,2,3
      2 IT=I
        RETURN
      3 IT=TAILM
        JJ=TAILM+2
        JK=TAILM+5*I+2*(N-M)+3
        MAST2(IT)=TAILM+5*I
        MAST1(IT)=N-M+1
        MAST1(IT+1)=M-1
        TAILM=JK+1
        NIM=NIM-TAILM+IT
        READ(2,101)(MAST1(J),MAST2(J),J=JJ,JK)
    101 FORMAT(10A2)
        RETURN
        END
COMPILER SPACE


        SUBROUTINE HISTO(D,B,W)
        DIMENSION D(19)
        DO1 J=1,18
      1 D(J)=0.
        D(13)=B
        D(14)=W
        D(19)=999999.
        RETURN
        END
COMPILER SPACE
```

```
      SUBROUTINE LISTS(L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      M=MAST1(L)
      WRITE(3,1020)L,M,CLOCK
 1020 FORMAT('0 THE CONTENTS OF SET NUMBER',I4,' WITH',I4,' MEMBERS AT',
     +I6/)
      IF(M)240,230,210
  240 CALL SLIP(15,3,L,_)
  210 N=MAST2(L)
      DO 220 J=1,M
      MEM=MAST1(N)
      WRITE(3,1030)J,MEM
 1030 FORMAT(I6,I8)
  220 N=MAST2(N)
  230 RETURN
      END
```

COMPILER SPACE

```
      INTEGER FUNCTION MEMNU(IE)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      MEMNU=MAST2(IE+1)
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE PRINT
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      WRITE(3,200)CLOCK,TAILM
  200 FORMAT('1CLOCK',I5,' TAILM',I5/)
      WRITE(3,101)(J,J=50,450,50)
  101 FORMAT(6X,'INDEX+ 0',9('  INDEX+',I3)//)
      M=10
      DO4 I=1,50
      IA=450+I
      IF(M-I)5,4,4
    5 M=M+10
      WRITE(3,102)
  102 FORMAT(1X)
    4 WRITE(3,100)I,(MAST1(K),MAST2(K),K=I,IA,50)
  100 FORMAT(I4,2(I7,I3),8(I7,I4))
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE RANDO(II,K)
      INTEGER NIM,TAILM,MAST1(500) ,MAST2(500) ,ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      I=II
      IF(I)7,5,8
    7 IF(I+10)9,10,10
    9 I=I+10
   10 I=-I
      ZZXZZ(I)=1100*I+1
    3 K=100.*RANDY(ZZXZZ(I))
      RETURN
    8 IF(I-11)3,2,2
    2 K=100.*(1.-RANDY(ZZXZZ(I-10)))
      RETURN
    5 READ(2,6)K
    6 FORMAT(I3)
      RETURN
      END
```

COMPILER SPACE

```
      FUNCTION RANDY(IX)
C     INTEGER SEED RANDOM NUMBER GENERATOR FOR CDC 6000 SERIES COMPUTERS
```

```
    1 IF(IX-1024-((IX-1024)/2)*2)2,3,4
    2 IX=-IX+2048
      GO TO 5
    3 IX=IX+1
    5 WRITE(3,100)IX
  100 FORMAT('*** SEED INCORRECT. RESET TO',I10)
      GO TO 1
    4 IX=IX*3125
      IX=IX-67108864*(IX/67108864)
      RANDY=IX/67108864.
      RETURN
      END
```

COMPILER SPACE

```
      INTEGER FUNCTION REFNU(IE)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      REFNU=MAST1(IE+1)
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE RESET(N,K)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      MAST1(N+1)=K
      RETURN
      END
```

COMPILER SPACE

```
      FUNCTION RNORM(RMEAN,SD,L)
      INTEGER MAST1(500),MAST2(500),ZZXZZ(10),TAILM
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ
  100 MARK=0
      Y=RANDY(ZZXZZ(L))
      IF(Y-0.5)1,2,2
  1   Y=1.-Y
      MARK=1
    2 Y=(-2.0*ALOG(1.-Y+.00002))**.5
      X=Y-((2.30753+0.27061*Y)/(1.+.99229*Y+.04481*Y*Y))
      IF(MARK)4,4,3
  3   X=-X
    4 RNORM=RMEAN+X*SD
      IF(RNORM)100,5,5
  5   RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE ROTAT(L,M)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      N=M
    4 IF(N)3,2,1
    3 N=MAST1(L)+N
      GO TO 4
    1 K=MAST2(L)
      DO 1020 J=1,N
 1020 K=MAST2(K)
      MAST2(L)=K
    2 RETURN
      END
```

COMPILER SPACE

```
      INTEGER FUNCTION SAMPL(IA,IN)
      DIMENSION IA(21)
      CALL RANDO(IN,M)
      DO 1110 I=4,20,2
```

```
      IF(M-IA(I))1111,1110,1110
 1110 CONTINUE
 1111 SAMPL=IA(I-3)+(M-IA(I-2))*(IA(I-1)-IA(I-3))/(IA(I)-IA(I-2))
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE SCAN(IS,IM,IL)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF(MAST1(TIMES))1090,1090,1091
 1090 CALL SLIP(12,2,1,0)
 1091 LAST=MAST2(TIMES)
      LEAD=MAST2(LAST)
      IM=MAST1(LEAD)
      IL=-1-MAST1(IM)
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE SET(L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF (NIM)1010,1010,1011
 1010 CALL SLIP(13,1,0,0)
 1011 L=TAILM
      TAILM=MAST2(L)
      NIM=NIM-1
      MAST1(L)=0
      IF(MAST2(1))100,100,101
  101 CONTINUE
      WRITE(3,105)L
  100 CONTINUE
  105 FORMAT(' SET INDEXED',I4/)
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE SETTI(N,M)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      CALL DELET(N,TIMES)
      NEWTI=M-CLOCK
      CALL EVENT(N,NEWTI,MAST2(N))
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE SIMON
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      INTEGER GNJAMES
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      DATA GNJAMES/1/
       GO TO (1,2),GNJAMES
    1 CALL REMARK(10HSIMON III.)
      GNJAMES=2
    2 READ(2,1002)I,MAST2(1)
 1002 FORMAT(I4,I1)
      IF(500-I)1003,1004,1004
 1003 I=500
 1004 DO 1001 J=2,I
 1001 MAST2(J)=J+1
      TIMES=1
      NAME=1
      MAST1(1)=0
      NIM=I-1
      TAILM=2
      WRITE(3,300)
  300 FORMAT(' TIMES SET INDEXED 1'/)
```

```
      DO 3 I=1,10
    3 ZZXZZ(I)=1100*I+1
      RETURN
      END
```

COMPILER SPACE

```
      INTEGER FUNCTION SIZEO(L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      SIZEO=MAST1(L)
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE SLIP(I,J,K,L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      DIMENSION A(15),N(15)
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      DATA A/4HADDF,4HADDL,4HBEHE,4HBETA,4HCLEA,4HDELE,4HENTI,4HEVEN,4HF
     +AZE,4HGROU,4HHEAD,4HSCAN,4HSET ,4HTAIL,4HLIST/
      DATA N/1HI,2*1HA,1HI,1HR,3*1HT,1HA,1HP,1HO,1HI,1H ,1HO,1HS/
      WRITE(3,100)
  100 FORMAT('0***** ERROR'/)
      GO TO(1,2,3,4),J
    1 WRITE(3,101)A(I),N(I),K,L
  101 FORMAT(' MASTER LIST EXHAUSTED BY CALL FROM ',A4,A1,' WITH SET NUM
     +BER',I4,' AND ENTITY',I4)
      GO TO 4
    2 WRITE(3,102)A(I),N(I),K
  102 FORMAT(' CALL FOR ',A4,A1,' OF EMPTY SET',I4)
      GO TO 4
    3 WRITE(3,103)A(I),N(I),K
  103 FORMAT(' ATTEMPT TO ',A4,A1,' MADE TO ENTITY ',I4)
    4 K=MAST1(MEMBE+1)
      WRITE(3,104)CLOCK,STATE,MEMBE,K
  104 FORMAT('0   CLOCK =',I5/4X,'STATE =',I5/4X,'MEMBE =',I5/4X,'REFNU
     +=',I5//'    * EXECUTION TERMINATED *')
      CALL EXIT
      END
```

COMPILER SPACE

```
      INTEGER FUNCTION TAILO(L)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      IF(MAST1(L))3,1,2
    1 K=2
      GO TO 4
    3 K=3
    4 CALL SLIP(14,K,L,L)
    2 K=MAST2(L)
      TAILO=MAST1(K)
      RETURN
      END
```

COMPILER SPACE

```
      INTEGER FUNCTION TIMEV(N)
      INTEGER NIM,TAILM,MAST1(500),MAST2(500),ZZXZZ(10),STATE,TIMES,
     +CLOCK
      COMMON NIM,TAILM ,MAST1,MAST2,ZZXZZ,STATE,NAME,TIMES,CLOCK,MEMBE
      TIMEV=-MAST1(N)-1
      RETURN
      END
```

COMPILER SPACE

```
      SUBROUTINE WRITE(D,IT)
      DIMENSION D(19),KK(11)
      DB=99999.99
```

```
      I=D(15)
      WRITE(3,100)IT,I
  100 FORMAT(//13H HISTOGRAM NO,I4,I8,8H ENTRIES)
      IF(I)1,1,2
    2 DO3 I=1,11
    3 KK(I)=D(13)+D(14)*FLOAT(I-1)
      WRITE(3,102)KK,(D(I),I=1,12)
  102 FORMAT(7H RANGES,I9,10I4,/11H FREQ        ,12F4.0)
         DA=D(16)/D(15)
      IF(D(15)-1.0)5,5,4
    4 CONTINUE
      DB=((D(17)/D(15))-DA*DA)
      DB=SQRT((DB*D(15))/(D(15)-1.))
    5 CONTINUE
      WRITE(3,103)D(19),D(18),DA,DB
  103 FORMAT(8H MINIMUM,F8.2,8H MAXIMUM,F8.2/5H MEAN,F8.2,33H ESTIMATE O
     1F POPULATION DEVIATION,F8.2)
    1 RETURN
      END

COMPILER SPACE
```