A STUDY OF A CAFETERIA SYSTEM

USING DIGITAL SIMULATION

by

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CHAPTER 1

INTRODUCTION

Approximately one-fourth of the meals consumed in the United States are eaten away from home, and indications are that this number will increase. The importance of food services in commercial establishments, hospitals, industrial plants, feeding units, military services, schools and institutions have had an exciting yet show-developing history. Today's trend in large universities with expanding building programs and complex residence hall systems is toward centralization of food services. No single method of service is more universal to all segments of food service than cafeteria operation (Zipfel and Triplett, 1958). Due to increasing enrollment in schools and colleges, cafeteria food service systems in academic institutions are facing waiting line problems. Due to the rise in cost of labor and equipment the emphasis is on the effective utilization of food service equipment. The facilities and the service operations should be planned effectively so that the customers can be served efficiently, so as to return to work or classes on time. Therefore the cafeteria management faces the necessity of improving the efficiency and speed of cafeteria service, in addition to planning, for expansion of existing facilities or new facilities so as to answer the common demand by youth for speed, convenience and low cost.

1.1 DESCRIPTION OF THE CAFETERIA SYSTEM

A cafeteria system generally consists of a service and a dining area. The service area contains food items and checkout stations.

The dining area consists of a group of tables which provide eating facilities for the customers. A schematic diagram of a cafeteria system is shown in Fig. 1.

The customers enter in the service area, select their food items and join the shortest queue for checkout at checker and cashier stations. On completion of these operations the customers enter the dining area and sit in chairs to eat their food.

The function of the checker is to check the food items and hands over total food cost for the customer. The function of the cashier is to receive the payment and make change for the customer. In a cafeteria the checking and cashing may be separate operations or a combined operation depending upon the factors like number of arrivals and the service times. In the experimental model, checking and cashing are separate operations at noon time while for other periods of the day, it is a combined operation.

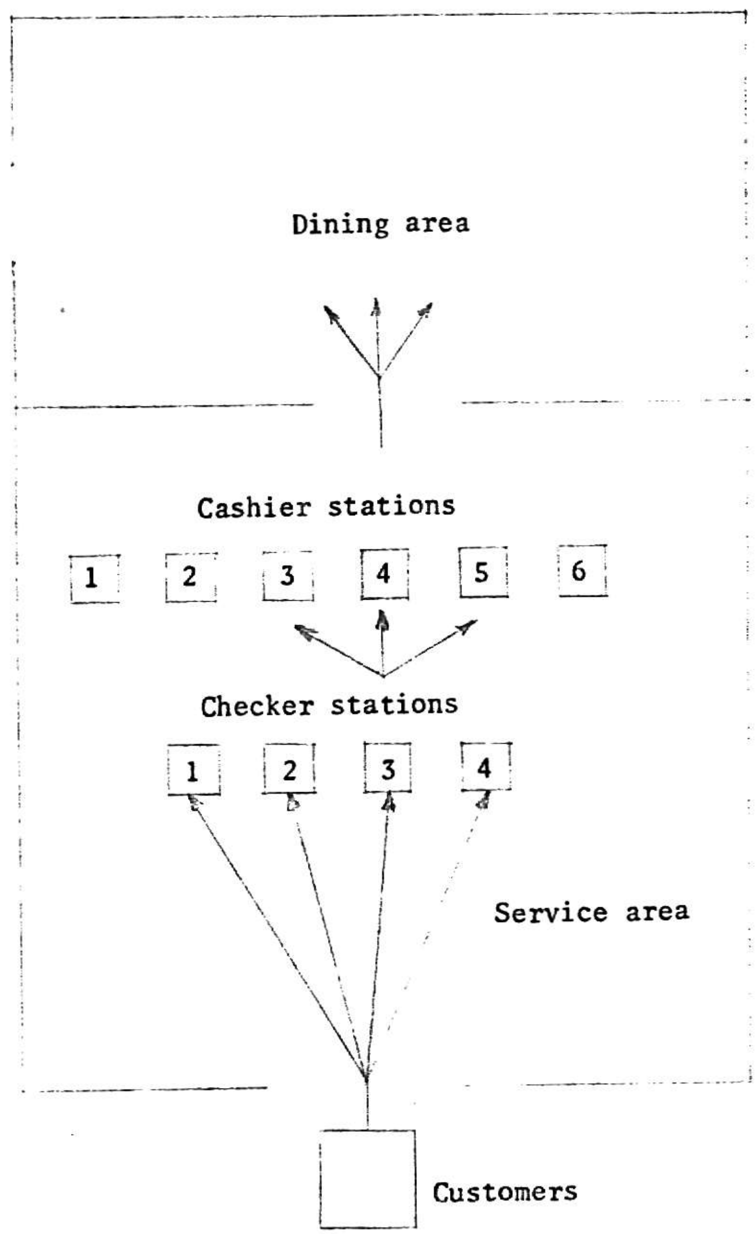

Fig. 1. Schematic diagram of a cafeteria system.

CHAPTER 2

LITERATURE REVIEW

In 1965 Fetter and Thompson [6] developed three simulation models which contained essential features of various subsystems of a hospital. This study was concerned with problems in the design and utilization of hospital facilities. Three subsystems studied were (1) the maternity suite, (2) an outpatient clinic, and (3) a surgical pavilion. The objective was to give hospital management the guiding lines that will forecast operating characteristics for alternative designs and, for a given number of facilities, the effect of adoption of alternative operating policies. The effect of change in admission rate, length of stay etc. were examined to guide the hospital management in its long-range planning.

Thompson and Fetter [21] simulated the activity of the maternity service under varying admission rate. They determined the relationship between size of hospital and percentage occupancy keeping the average length of stay and number of beds relative to demand constant for all runs. They observed a little difference in occupancy when admission rate is 4000 or more per year, but below that rate, the occupancy tends to rise significantly.

Lipton [16] developed a simulation model of a assenbly job shop to plan a new facility, so that management could know, for the next three years, the requirement of space and manpower they need, the most effective plant layout and whether an overhead conveyor system was to be used. To solve the above problems data were collected from an existing assembly job shop. It was found that the model developed underestimated the true situation. All the management objectives could not be realized but the results achieved were close to the actual situation which gave management useful and good information.

To illustrate the power of simulation, Skeith and Curry [19] solved the problem of machine maintenance work at the Sun Oil Company - DX Division. The problem was solved by using GPSS as the simulation language. The number of events which may occur in the system was limited to 40. Three models were simulated using FIFO (first in-first out), LIFO (last in-first out), and random principle and one repairman. A fourth model was simulated using the FIFO principle and two repairmen, a fifth model was simulated using the FIFO principle, two machine classes and one repairman. The five models gave a quick comparison about waiting time, repairmen utilization and average number of machines waiting using different repair policies.

Schiller and Lavin [18] undertook the problem of predicting the requirement of new facilities to meet contemplated changes in a company's business operation. The company wanted the consolidation of three warehouse facilities at one of the three locations. The problem was concerned with predicting new truck-dock facilities required to handle truck flow of the three different warehouses and considering the future openings of new stores. To analyze the problem, a complete survey of truck arrivals at the three warehouse locations were made for a seven-week period, from which arrival activity at the consolidated warehouse was determined. The next feature studied was truck servicing time. To simulate the docking operations, the interarrival times and service times were obtained by random selection from their respective frequency distribution curves. By varying specified number of service docks, the problem was simulated to give movement of trucks through the dock system, length of waiting queue and the amount of waiting time in the queue. The simulation was run for several days of docking operations to give average results of waiting time for each of the specified service docks. The simulation results were useful for management planning in regard to cost and policy information.

Edie [5] used probability theory to study the operation of collection of vehicular tolls for the Port Authority of New York. Before this study, the number of toll collectors provided for operating a toll plaza were determined on the basis of judgement and rule-of-thumb work standards. But to achieve savings in toll collection expenses and better service to the public, observations were made. Data collected was the number of vehicular arrivals in 30-second intervals, extent of the backup in each open toll lane and, toll transaction count at half-hourly intervals. By the application of probability theory the relation between traffic volume, number of toll booths and grade of service was determined. Then the system was established to tell in advance the number of toll booths required at any time of day.

Linder [15] described how a simulation model was used to find numerical relationships between the number of telephone lines and agents in an airline's telephone reservation office, volume of work-load and the specified grade of service. It took a 5 year sequence of research activities to relate standard of service and manpower requirements. The study helped in making models which were useful for making better decisions about the future. The most important part of this study was its emphasis on a technique for evaluating the costs of alternative strategies regarding customer service, instead of calculation of agent and line requirements. This technique provided office managers with a powerful management tool for manpower planning. The paper also described the work which is in progress to improve the method of forecasting telephone workload and to produce a fully automated system for budgeting and planning.

A study of real-time human decision-making was done by Bainbridge, Beishon, Hemming and Splaine [1] using a plant simulator. The simulated plant used in these experiments was a five-furnace electric and steel-melting shop. The operator's work was to control the electric power to the whole shop and was to maximize the steel output under given restrictions of energy consumption rate. The aim of the series of experiments was to develop a method for measuring the mental load on operators caused by process-control tasks. These measurements would be invaluable for manpower planning and for man-machine interface design.

The problem of peak hour operation in a bus terminal was solved by the Port of New York Authority operations research team [10] using traffic simulation and Monte Carlo methods. On working days between 5 and 6 P.M., about 20,000 New Jersey bound commuters entered the Port of New York Authority Bus Terminal in New York city and about 400 buses used to arrive in the terminal to load the commuters and then depart during this peak period of one hour. Due to traffic conditions buses arrival times deviated from their scheduled arrival times. Consequently when the bus arrived in the loading zone, its berth might be either vacant or occupied. If the berth was vacant on its arrival, the bus was denied entrance due to blocking conditions or if ahead of schedule, it was withheld to avoid creating a block. The optimum relationships of the length of waiting lines to the number of tandem berths on a single lane loading platform was useful for efficient design for any future construction of bus terminal. A limited number of days of peak hour operations were observed to find frequency distributions of bus arrivals and commuter passengers. The study pointed out that as the platform length increased more holding space per berth was required to maintain the same grade of service for passengers. Other problems were pointed out regarding optimum loading policy, dispatching systems and what sort of schedule was optimum for a given arrival behaviour and berth arrangements.

Of particular interest to this author is the usefulness of the simulation techniques as applied to food service systems. A few studies have been reported about food service systems. An interesting study of the design of cafeteria counters was made by M. Chartrand [3]. The study analyzed the causes of delay in service lines. The main objectives were to reduce waiting time and service time, while serving many customers from the counter. Delays were found to be generated by (1) poor service due to insufficient and untrained personnel; (2) poor layout at hot food, coffee, and check-out stations; (3) customers making selection of food; and (4) getting proper change. Arrival distribution, the number of checkout counters, service distribution and queue discipline were also examined. Among several useful principles considered was the arrangement of stations in parallel rather than in series. It was observed that service time may be reduced by eliminating multiple stops at counter stations; making it possible for customers to break out of line. It was noticed that self-service items should be placed parallel to the moving line, whereas service items should be placed at right angles to it. Various designs of the operation were studied and compared, but there is no evidence that actual studies had been conducted.

Kinckrehm [11] used the simulation technique to determine the effect of changes in layout or operating procedure on the time customers spend in a cafeteria line, the rate of flow of customers and the utilization of facilities. A single line cafeteria was selected for collection of data for this study. This study illustrated that a simulation technique may be used by food service management to determine the time the customer spends in the cafeteria service line and through changes in layout and operating characteristics, the best policy may be choosen. This analysis is also helpful for effective future planning.

Laudon [13] undertook study to develop a generalized cafeteria simulators. The main objectives were (1) to develop through the use of computer simulation, a generalized cafeteria model which could be used as an experimental tool in the optimization of an existing cafeteria system or for future design; (2) to provide a general and flexible cafeteria model which could be easily adapted to any specific cafeteria system; and (3) provide a measure of effectiveness to determine the estimated performance of the system at a reasonable cost.

CHAPTER 3

THE PROPOSED PROBLEM

3.1 PURPOSE OF THE STUDY

A queueing problem at the check out station in a cafeteria arises when either the service facilities stand idle or a customer has to wait in the line to be served. Increased investment in labor and service facilities, will involve high operating costs due to the idle time of the facilities. But on the other hand not providing enough service facilities will involve excessive waiting time to the customers [20]. Many customers don't object to a reasonable waiting time but will not tolerate a lengthy waiting period [17]. It is therefore desirable to obtain an optimum balance between the idle time of the facility and the customers waiting time, depending upon the system performance criterion used.

To determine whether proposed designs for future cafeteria system are effective and efficient, the management needs to evaluate the performance of the system at a reasonable expense. Due to practical and economical difficulties, it is not feasible to do experimentation in the actual cafeteria. So some technique needs to be used to determine the effect of arrival rate, service time and number of service stations on the time customers spend in the queue.

We begin our evaluation of the system by assuming certain performance levels for the checkout operation. We could provide one checkout station which may not be able to take care of the load of arrivals or we could provide so many checkout stations that no customer has to wait in the queue. But the latter policy becomes very expensive while the former policy is obviously undesirable. Therefore a compromising policy has to be adopted by employing a certain number of checkout stations. To achieve the objectives it was decided to use the following desired performance level for the checkout operation.

"No more than ten per cent of the customers wait in the queue for more than .75 minute".

Based upon the above performance level our purpose of the study is three fold:

1. To forecast the optimum number of checker and cashier service stations required in 1975 at Kansas State University union cafeteria.
2. To evaluate the number of operators required for service during different periods of the day.
3. To forecast the number of chairs needed in the dining area in 1975.

In order to obtain reasonable answers to these questions, it will be necessary to find the following statistics and relationships for the various configurations of the system investigated.

(a) The waiting time distribution of the customers in the queue - The customers wait in the queue before they are being served. The length of waiting-time of different customers is represented by a waiting time distribution.

(b) The service times distribution of the checkout operator - The service time is the length of time taken to serve an individual customer. In majority of cases it is assumed that service times of different customers are independent random variables, which can be represented by the service time distribution.

(c) The inter-arrival time distribution of the customers - The inter-arrival time is the time between arrivals, which is given by the inter-arrival distribution.

(d) The distribution of time between departures after the checkout operation - The elapsed time between customers departure after the checkout operation is called time between departures, which is given by the probability distribution.

(e) Average utilization of checkout operator which is given by the proportion of time the operator was busy.

$$\text{Average utilization} = \frac{\text{Total time performing service}}{\text{Total run time}}$$

3.2 SYSTEM DESCRIPTION:

COMPONENTS: Components are those entities of the system, which are independently defined and whose collective performance gives the output of the system [17]. There are many components we are studying in the cafeteria system: notably (1) the customer, (2) the service stations and (3) the waiting line at each station.

VARIABLES: These are the attributes of the system which have different values under different conditions of the system.

There are many variables in this system but we want to restrict ourselves and list the desired variables.

1. Mean time between arrivals
2. Time between departures
3. Waiting time in the queue
4. Mean service time
5. Number of checkout stations

PARAMETERS: There are those attributes of the cafeteria system, which do not change during the simulation run because of any change in the system during the simulation. The pertinent parameters of the cafeteria system are (1) distribution of time between successive arrivals, (2) service time distribution, (3) the number of checkout stations. We notice that the "number of checkout stations" is specified both as a variable as well as a parameter. This is so because the experimenter can control the number of service stations during any set of iterations of the simulation. Therefore the "number of service stations: is a parameter for each set of iterations of simulation, but it can be varied during the complete simulation.

3.3 ASSUMPTIONS

Following are the important assumptions considered to study the system.

1. All checkers, cashiers, and checker-cum-cashiers work at the same rate.
2. Enough space exists for the queue which may develop in front of each station.
3. The distributions of time between arrivals, and service times remain same throughout the period being studied.

4. Mean arrival rate is constant, regardless of the number of customers waiting in the queue (customers do not turn away when queue length is long).

5. Customers after joining the queue, do not shift to other queues.

6. Each customer will join the "Minimum" queue length, that is, the line with the least number of customers.

7. At the start of the simulation, the system is empty, that is, there is no customer in the system, nobody in the queue, and the facilities are idle.

8. The service time distribution of checker-cum-cashiers is same for models 1, 2, and 4.

9. All the checkers, cashiers, and checker-cum-cashiers are working at normal pace.

3.4 DATA FOR THE EXPERIMENT

It is necessary to collect data for the cafeteria system to determine:

(1) the probability distribution of interarrival times

(2) the service time distribution for each check-out operation

(3) the service time distribution at the tables i.e. occupancy time distribution in the chairs in the dining area. In other words, how long the customer stays in the dining area.

1. Inter-arrival Time Distribution: One of the basic parameters required to queueing or waiting line analysis is the mean arrival rate. The probability distribution of arrivals has

been observed to be Poisson in nature in most of the queueing problems. Detailed discussion is in [10,14,5]. So to study a cafeteria system, it is assumed that the number of customers arriving in the system per unit time has a Poisson distribution i.e. inter-arrival distribution is exponential.

Data was collected for five days (one work week) between period 7.30 A.M. to 4.00 P.M. to determine average interarrival rate. Number of arrivals at the checkout stations in the state room (snack side), and the cafeteria (main food service) were counted with the help of hand counter for each 15 minutes period. The number of arrivals on each side were added to give the total number of customers arriving for each period. These observations were taken during the summer semester. The following assumptions were made to determine the number of customers, who will use the cafeteria facilities at a future date say in 1975 as shown below.

(1) The customers using the cafeteria facilities are directly proportional to the number of students, staff and faculty at Kansas State University.

(2) The faculty and administrative staff also increases in the same ratio as the total enrollment in the university.

Fall semester 1968-69:

Total enrollment	= 12570
Faculty and staff (excluding students)	= 2700
Total	= 15270

Summer semester 1968-69:

Total enrollment	= 4209
Faculty and staff (excluding the students)	= 2141
Total	= 6350

Multiplying the observations by a factor of $\frac{15270}{6350} = 2.4$ will give the total customers who used the cafeteria services during Fall 1968-69. The above data were collected from the Office of Admissions and Records at Kansas State University.

Estimated number of customers in 1975:

Total enrollment in Fall 1968-69	= 12570
Faculty and staff	= 2700
Total	= 15270
Estimated enrollment [ ] in 1975	= 16000
Faculty and staff in 1975	$= \frac{16000}{12570} \times 2700 = 3420$
Total	= 19420
Ratio	$= \frac{19420}{15270} = 1.27$
Total multiplication factor	$= 2.4 \times 1.27 = 3.06$

The observed arrivals were multiplied by the multiplication factor to forecast the approximate number of arrivals in 1975 during the given duration.

The variation of arrivals into the system was observed as shown in Fig. 2. The figure shows the average number of arrivals during each 15 minutes period of the day. To take into consideration the variation of the system loading, it was felt desireable to divide the whole day arrival pattern into four periods, which will give

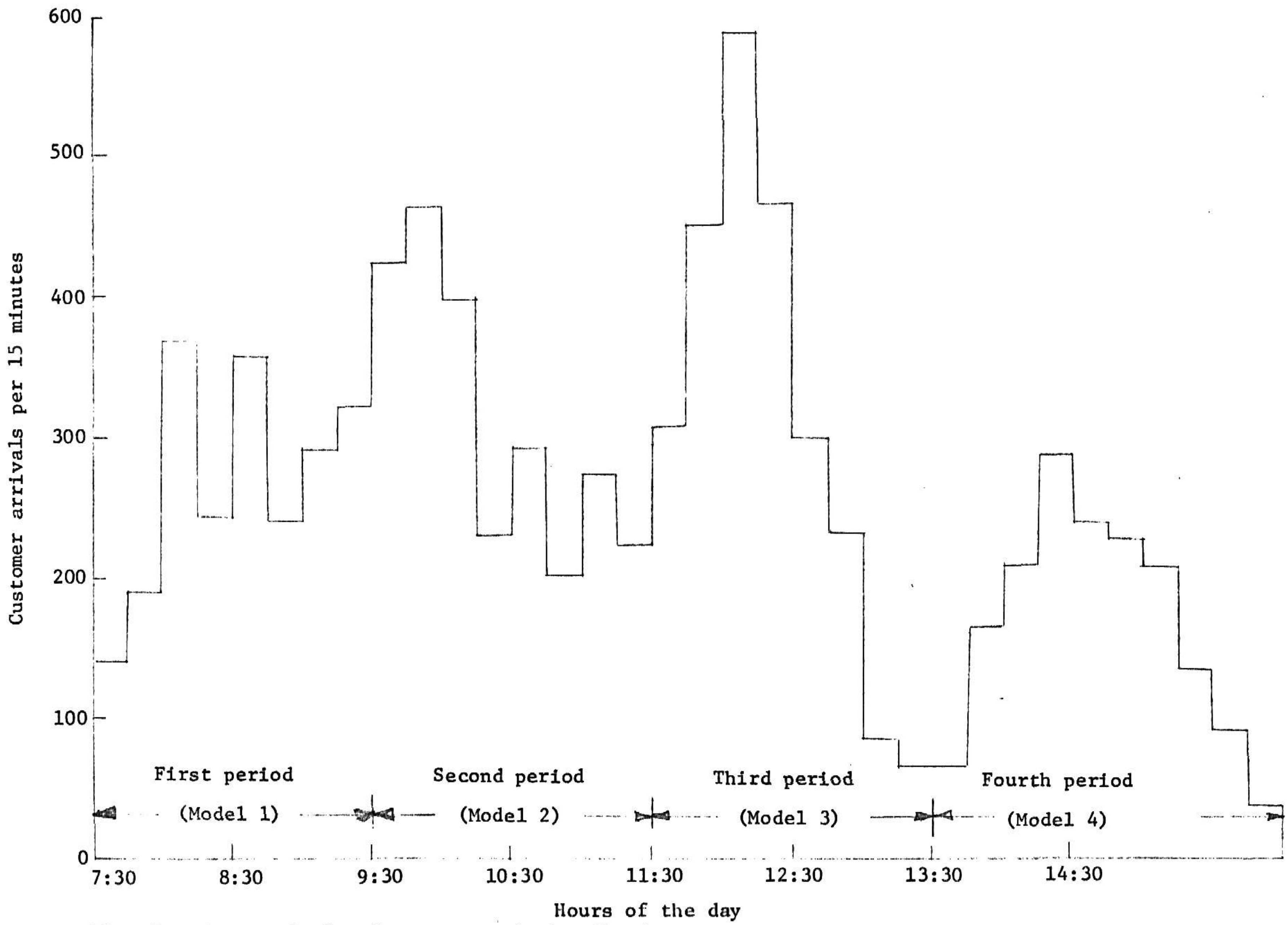

Fig. 2. Mean arrivals of customers during the day.

four distributions of arrivals each having a different mean. In this study, the first three periods are of 2 hours duration and a fourth period of 2 1/2 hours duration.

Table 1 shows mean arrivals during each period of the day. λ represents the average number of customers arriving in the system during each duration. The mean inter-arrival time ($\bar{T}$) is determined for each period or model by the following equation.

$$\bar{T} = \frac{\text{duration}}{\lambda}$$

Service Time Distribution: the other significant parameter in the queueing problem is service time. Four service time distributions for four different operations are being considered as follows:

(1) the service time distribution of the checker

(2) the service time distribution of the cashier

(3) the service time distribution of the checker-cum-cashier (when operations of checker and cashier are combined)

(4) the service time distribution at the chairs in the dining area.

The service time distributions of checker and cashier are used in simulating model 3, when both the operations are separate, while the service time distribution of checker-cum-cashier is used in simulating models 1, 2 and 4, when both the operations are combined. The design and analysis of the system is done on the basis of the existing system.

The service time is obtained using a stop watch calibrated in one hundredth of a minute. The service time

TABLE 1

Table 1. Mean inter-arrival time ($\bar{T}$) for each model

Model no.	Period of day	Duration in seconds	λ	$\bar{T}$ in secs
1	7:30 - 9:30	900	268	3.36
2	9:30 - 11:30	900	315	2.86
3	11:30 - 13:30	900	311	2.90
4	13:30 - 16:00	900	167	5.39

$$\bar{T} = \frac{\text{duration}}{\lambda}$$

of a customer was taken as the duration of time, when a customer started getting attention or service and until the service is finished. The service time at the chair or occupancy of the chair is the difference of time the customer arrives at the chair and leaves the chair.

To determine the service time distributions, data were collected for four operations as discussed above. The number of observations to be made for each operation was calculated by using the following procedure adopted by the Maytag Company as mentioned in Barnes [2].

(1) Take ten good readings.

(2) Determine the range R, which is the high value minus the low value.

(3) Determine the mean $\bar{X}$,

(4) Determine $R/\bar{X}$.

(5) From table, determine the number of readings required for 95% confidence level and ±5% precision. A final check was made to determine whether enough observations had been made, it was found that the observations recorded for each service time distribution was within the 95% confidence interval and usually between ±4% to ±6% precision.

Distribution curves were made out from the collected data and Chi-square tests of goodness of fit were performed to check the statistical conformity of the observed probability distributions of the services. A good fit at a .05 significance level was obtained. The service time distribution of the checker is found to be normally distributed with a mean equal to .15 minute and standard deviation is .047 minute.

The service time distribution of the cashier is found to be normal with mean equal to .21 minute and standard deviation .07 minute. The service time distribution of the checker-cum-cashier is also normally distributed with mean .15 minute and standard deviation .043 minute.

The service distribution at chairs is found to be a normal distribution with mean being 32.5 minutes and standard deviation 17 minutes.

CHAPTER 4

DESIGN OF THE SIMULATION MODEL

This type of problem is known mathematically as a queueing problem. The analytical techniques are available to solve simple queueing models, while for a complex queueing model, the analytical techniques may not be available. Consequently, simulation has been found to be a valuable and useful tool in analyzing systems in which a waiting line problem is to be studied.

According to Mize and Cox [17], simulation is, "the process of conducting experiments on a model of a system in lieu of either (1) direct experimentation with the system itself, or (2) direct analytical solution of some problem associated with the system". A carefully constructed, simulation model is the duplication of environment in which observations can be made under controlled conditions. A simulation model represents the actions and interactions of the components of the system under varying conditions. Simulation technique appears to offer opportunity for observing the estimated performance of the cafeteria system. Although simulation techniques should usually be used when all other techniques have been examined and found wanting, simulation has certain characteristics which are preferable to other techniques. With simulation, time can be expanded or compressed to furnish observations in any desired degree of detail.

4.1 COMPUTER PROGRAM

The logical model and data need to be translated into a computer program. The computer model can be written in any of the simulation languages such as GASP II, GPSS or Simscript. To simplify the programming, GPSS (General Purpose Simulation System) was chosen as the easiest to apply to the cafeteria problem. The cafeteria model can be modified readily once written in GPSS. In GPSS, statements are written in terms of block commands.

Most simulated studies are concerned with systems whose events are time-ordered. The computer program should be able to move the model through simulated time, causing events to occur according to desired order and proper time interval. The timing problem in digital simulation models arises from the fact that, while the components of the real system function simultaneously, the components of the simulated system function sequentially, because a digital computer executes its instructions one at a time [4].

Two basic time-flow mechanisms are available to represent the flow of time in a simulation model: the uniform-increment method and the variable-increment method. In the uniform-increment method the program up dates the status of the system being simulated once for each time increment, changing the status of the parts of the system according to the events taking place in the system. The time increment method can be assumed to represent as long or short a period of real world time as desired. In the variable-increment method, the change of status of the system occur at irregular intervals according to the size of interval between events.

The choice of the two time-flow mechanism depends upon the nature of the processes in the system being studied and upon the way the model was formulated. The uniform-increment method is preferred for the systems where events occur at regular intervals of time. To simulate the cafeteria system, the variable increment method was adopted to move the system through time. The controlling factor in the cafeteria system is the time between successive arrivals.

The various models in the system can be described by using block diagrams or flow diagrams. They consists of a series of blocks, each of which represents some step in the action of the system. The block diagrams for various models are shown in Appendix A.

The GPSS / 360 program consists of a set of simple entities, which are divided into four classes: dynamic, equipment, statistical, and operational.

The dynamic entities in the GPSS/360 are called "transactions". These represent the units of traffic in the system, such as customers in the problem. These transactions can be "created" and "destroyed" as desired during the simulation run. A number of "parameters" are associated with each transaction whose values are assigned by the experimenter to represent characteristics of the transaction. For example a transaction representing a customer might carry in a parameter the queue number which the transaction will join for service.

The equipment entities represent elements of the system which are acted upon by "transactions". These entities include "facilities", and "storages". A facility can give service to one transaction at a time. A storage can handle several transactions simultaneously. The checker or cashier station represents a facility, and the pool of chairs in the dining area represents the storage in the proposed problem.

Two types of statistical entities are called, "queues" and "tables" which are provided to measure the system behaviour. The queue entity keeps a record of the transactions being delayed at one or more points in the system, and maintains a record of the average number of transactions being delayed in the queue and the length of delay for each transaction. A table may be used to collect any desired frequency distribution. Each table has an argument, and the specified number of intervals into which the values of the argument can fall.

The operational entities are called "blocks". The blocks provide the logic of a system and command the transactions what to do next and where to go. These four classes of entities constitute the language of GPSS/360.

4.2 PROGRAM DESCRIPTION

The computer programs for various models in the system are shown in Appendix B. The computer program contains a number of blocks. The first block in Fig. 23 is a GENERATE block which creates transactions (customers) which enter into the system. Field A of the GENERATE block specifies the average or mean time between originations. This mean may be modified by specifying either a spread or a function as a modifier in field B. The function FN1 in the GENERATE block indicates that the mean inter-arrival time of $\frac{1}{100}$ minute is modified by a function arbitarily called function 1. This computes the time between arrivals which is a random number whose distribution is 1 times the distribution defined by function 1. The basic time increment is set to be $\frac{1}{100}$ minute i.e. 1 unit of simulated time is equivalent to

$\frac{1}{100}$ minute in the real time scale.

When a transaction passes through the SELECT block which contains "MIN" in column 14, it (transaction) will "select" the queue which has minimum number of customers in it (the queue) for service. The index number of the queue which the transaction will join is referenced by the value of transaction parameter specified in field A of the SELECT block. The transaction parameter is 12 as specified in field A of the SELECT block. Fields B and C of the SELECTMIN block specify the lower and upper limits of the queue to be selected by the transactions. If there are two or more queues with the same minimum number of transactions (customers), the transaction will "select" the first minimum queue out of all the minimum queues.

The QUEUE block indicates that the transaction enters that queue for service (checker station), whose index number is given by the value of transaction parameter 12. A QUEUE block immediately passes the transaction through the block if the next block can be entered. Otherwise a QUEUE block holds the transaction until the next block can be entered. A QUEUE block is incorporated in the simulation models for the purpose of gathering statistics or transactions which are delayed by a number of reasons.

The next block in the model is a SEIZE block. The transaction can enter in this block only, if the facility (checker station), whose index number is given by the value of transaction parameter 12, is unoccupied. In the simulated model, the facilities are the checker stations. When a transaction is able to enter a SEIZE block, it immediately goes to next sequential block without any time delay. The next block in the model is a DEPART block, which specifies the queue number in field A and the number of transactions to be removed from the queue in field B. A 1 or blank in the B field means, one transaction is removed from the queue. The DEPART block removes one transaction from the contents of the queue; the index number of the queue is given by transaction parameter 12. The SEIZE block and DEPART block allow the transaction to engage the facility (checker station) and leave the queue whenever the facility is unoccupied. These two blocks do not cause any delay to the transaction for any amount of simulated time.

The ADVANCE block indicates that the transaction is delayed in the block equal to its service time. The transactions (customers) are served in each queue according to FIFO (first-in first-out) principle.

The symbol FN2 specifies that the function, arbitrarly designated function 2 is to be used as modifier. Delay time in the block will consequently be a random quantity whose distribution is 1 times the distribution specified by function 2. The transactions are delayed for a finite time in the ADVANCE block.

After the transaction has spent time in the ADVANCE block, it then enters the RELEASE block. This releases the facility (checker station) whose index number is given by the value of transaction parameter 12, and also makes it possible for transactions (customers) waiting in the queue (if any) or arriving at a later date to take over the facility. After the checking operation is over, the transaction again joins the minimum queue for service at the cashier station. The transaction then seizes the facility, departs from the queue, is delayed in the ADVANCE block and releases the facility as discussed before.

The transaction finally joins the queue if any, to enter the "storage". The "storage" is defined as the pool of chairs in the dining area in this problem. The ENTER block and LEAVE block are used when the transactions enter and leave the storage. The storage capacity is defined in field A of the storage card, which represents the number of chairs in the pool. Other blocks are incorporated in the program to define the various operations as discussed above.

To gather certain statistics of the system the TABULATE block is incorporated in the program. Field A of the TABULATE block signifies the number of the TABLE in which statistics are to be gathered. The type of statistics to be tabulated is defined on a separate TABLE defination card. The TABULATE block with 1 in field A in Fig. 23 points out to the program that inter-arrival times of the transactions are to be gathered in Table number 1. The time between departures of the transactions are gathered in table 2 by using TABULATE block.

To determine the waiting time distribution and the service time distribution, "MARK" block is used along with "TABULATE" block. Each transaction in the block diagram possesses a transit time. To compute the transit time the program marks each transaction with the clock time (MARK TIME) at which the transaction enters the system. Then transit time at any point in the system is computed as clock time minus MARK TIME. The MARK block is incorporated so that the transit time of the transaction is reset to zero after the transaction has been in the system for some time. Field A of the MARK block specifies the parameter number n. The transaction which passes through the MARK block will have the absolute clock time stored in parameter n. So parameter transit time (MPn) of the transaction is determined as follows:

$$\text{MPn} = \begin{array}{l}\text{Parameter}\\ \text{Transit}\\ \text{Time}\end{array} = \begin{array}{l}\text{Current absolute}\\ \text{clock time}\end{array} - \begin{array}{l}\text{Value of Parameter n of}\\ \text{the transaction}\end{array}$$

The waiting times distribution of the transactions (customers) in the queues at the checker stations is determined by using MARK 3 and TABULATE 3 blocks, whose values are entered in table 3. The service times distribution of the transactions at the checker stations is determined by incorporating MARK 6 and TABULATE 5 blocks whose values are entered in table 5. The waiting times and service times distributions of the transactions at the cashier stations are determined by incorporating other TABULATE and MARK blocks in the model.

Finally, the transaction enters the TERMINATE block, where it is destroyed to remove it from the computer memory. A simulation time is controlled by using GENERATE block and TERMINATE block. TERMINATE block has 1 in field A. All other TERMINATE blocks in the program have blank fields A. The START card signifies that all input data has been received and the program may proceed. Field A of START card specifies the number of terminations to be executed before the simulation run stops. The final print out at the end of the run may be suppressed by using "NP" in field B of the START card. A blank field B means, a final printout is required. Field C of the START card signifies a "snap interval" after which a normal statistical printout occurs. The run termination count (KA) in field A of the START card defines the length of the simulation as = RUN TIME = KA x m (GENERATE block mean time).

To keep the events in the correct time sequence, the GPSS/360 program simulates a clock which is recording the time that has been reached in the model of the real system. The time shown by this clock at any instant is described as "absolute clock time". Another clock which can be addressed by the user is called the "relative clock time". The RESET card in the model is used to set all the numerical attributes to the queues, facilities, storage, and blocks equal to zero. The RESET card removes those attributes which are collected at the start of the simulation run and then collects statistics after the steady state conditions are reached. This card also sets the relative clock time to zero.

The function of the CLEAR card is to set both the relative clock time and the absolute clock time to zero. The seeds of the eight random number generators are not reset. All the transactions in the model are destroyed. The numerical attributes to the queues, facilities, storage, and blocks are set to zero as in the RESET card. The second iteration is made after CLEAR card is inserted. The SIMULATE card indicates that the model is to be run if no serious errors are found. If there is no SIMULATE card in the model, the job will terminate after the assembly phase. For each model two iterations are made for each run.

4.3 COMPUTER MODEL VALIDATION

A computer simulation model is considered valid if the results obtained from the simulated model are close to the results that would be obtained by the real-world system the computer model is supposed to represent. Data obtained from the simulation of the cafeteria system for 2 hours were analyzed and compared with observed data as shown in Table . The results indicate extremely small differences between observed and simulated data. Analysis of the difference between simulated and observed mean service time for each facility was made using the t test [6]. No significant differences were found between the observed and the simulated mean service time for each facility.

Observed and simulated service times at each facility are plotted in Figures 3 through 5. The cumulative frequency distributions of the service time for the observed and simulated data seem to be in agreement.

TABLE 2

Comparision of observed data with simulated data using mean service time of each facility.

Facility	Observed data		Simulated data		Statistical analysis	Degrees of freedom
	Mean service time (min)	Std. dev. of the mean (min)	Mean service time (min)	Std. dev. of the mean (min)	t distribution	
Checker-cum-cashier	0.150	0.047	.146	.043	+0.65	2302
Checker	0.150	0.043	0.146	0.043	+0.80	2829
Cashier	0.209	0.070	0.207	0.070	+0.33	2811

From table t critical ($\alpha < .05$) = 1.98

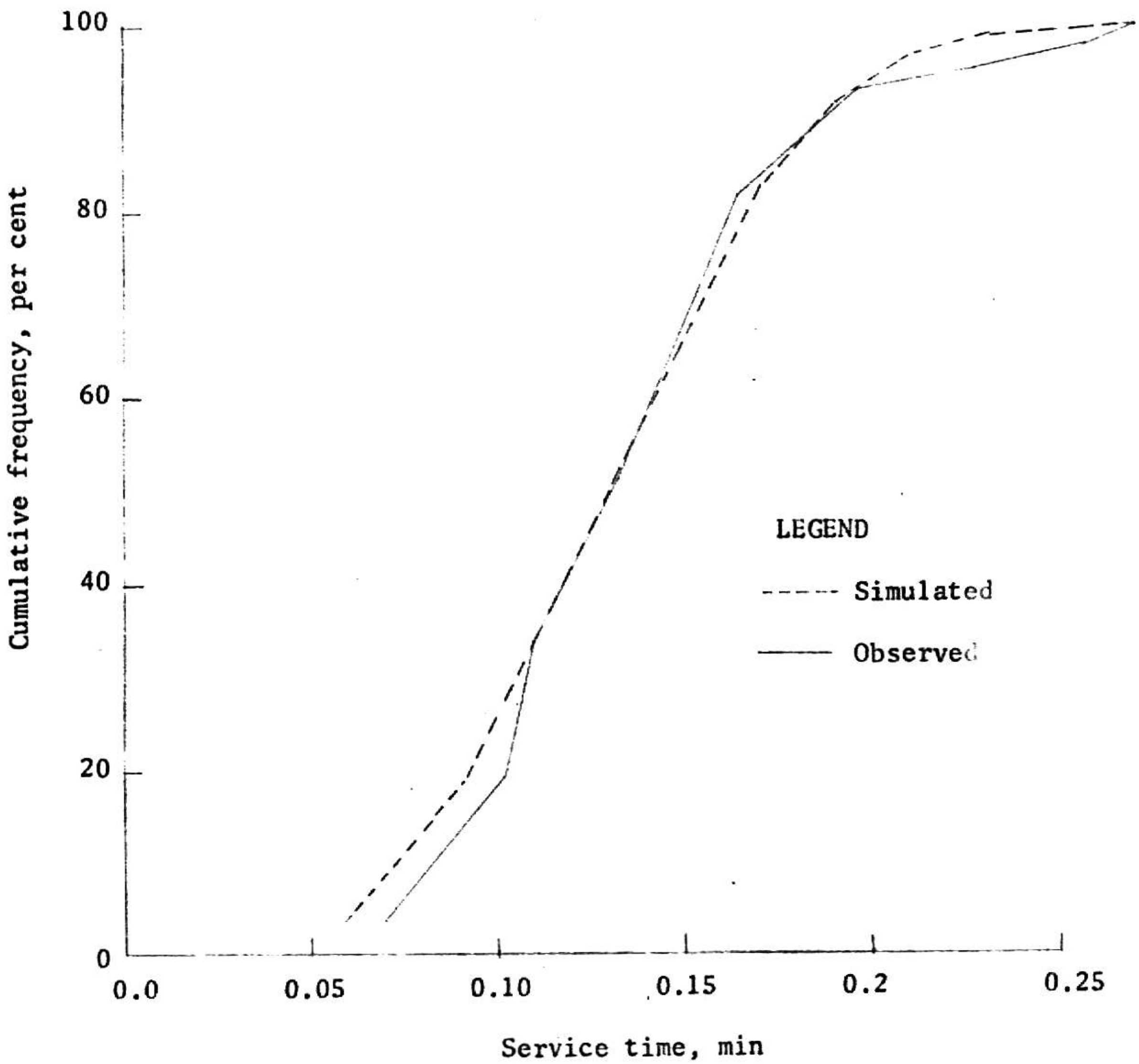

Fig. 3. Cumulative frequency distribution of service time at checker station.

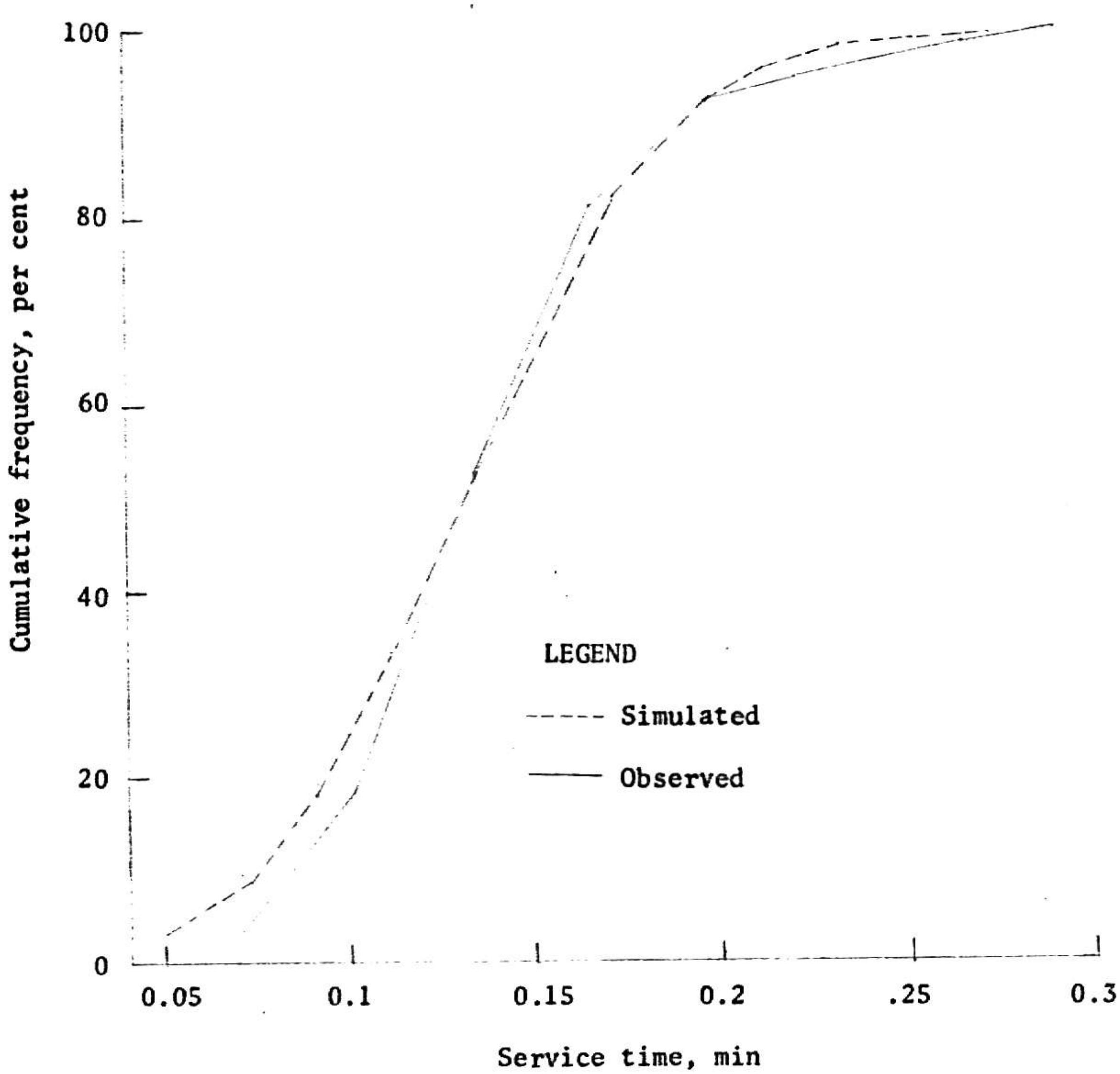

Fig. 4. Cumulative frequency distribution of service time at checker-cum-cashier station.

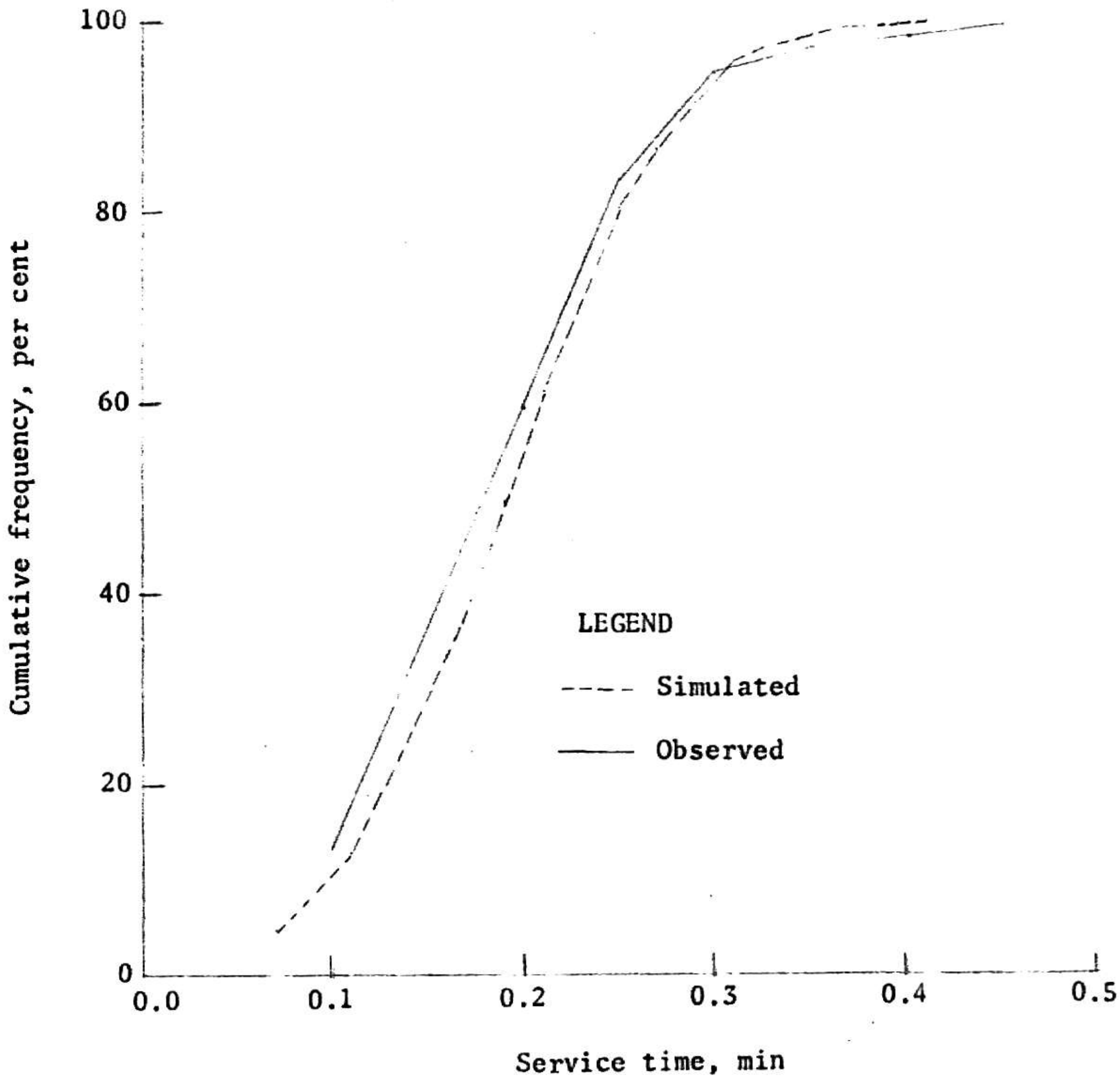

Fig. 5. Cumulative frequency distribution of service time at cashier station.

CHAPTER 5

THE ANALYSIS OF SIMULATION RESULTS

This chapter deals with the simulation results obtained for four models. The determination of the steady state conditions for each model are discussed. Each model was simulated for different runs having two iterations in each run. The typical simulation output for models 2 (9:30 - 11:30 A.M.), and 3 (11:30 - 1:30 P.M.) of the first iteration of a run are given in Appendix C. The results of all the simulation runs pertaining to each model are discussed separately.

5.1 STEADY STATE

A simulation model requires several cycles to warm up to their normal operating characteristics. In the cafeteria model, the normal operating conditions are not attained until a number of customers have entered the cafeteria. To study the normal operating conditions of the system, it is desirable to collect statistics after the steady state conditions are attained. Two alternatives are open: (1) the simulation run may be long enough so that the error caused by including the transient-period data is small or (2) after the steady state conditions are attained the transient-period data are discarded with a RESET card which leaves the transactions (customers) in the system, after which the simulator can be run further to collect the steady state data only. Unfortunately no analytical techniques are available to determine the steady state

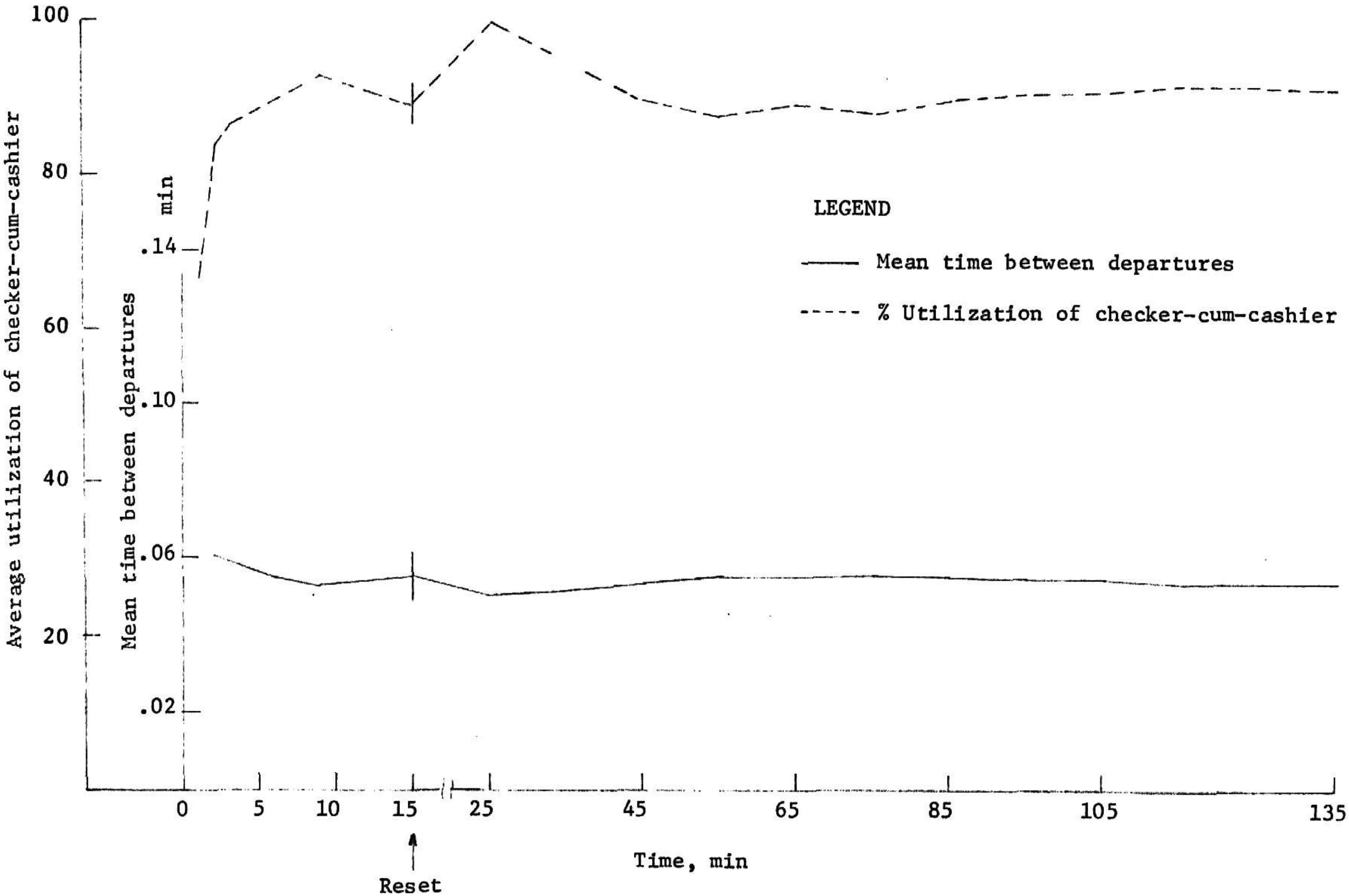

Fig. 6. The mean time between departures, and per cent utilization of checker-cum-cashier: Model 1

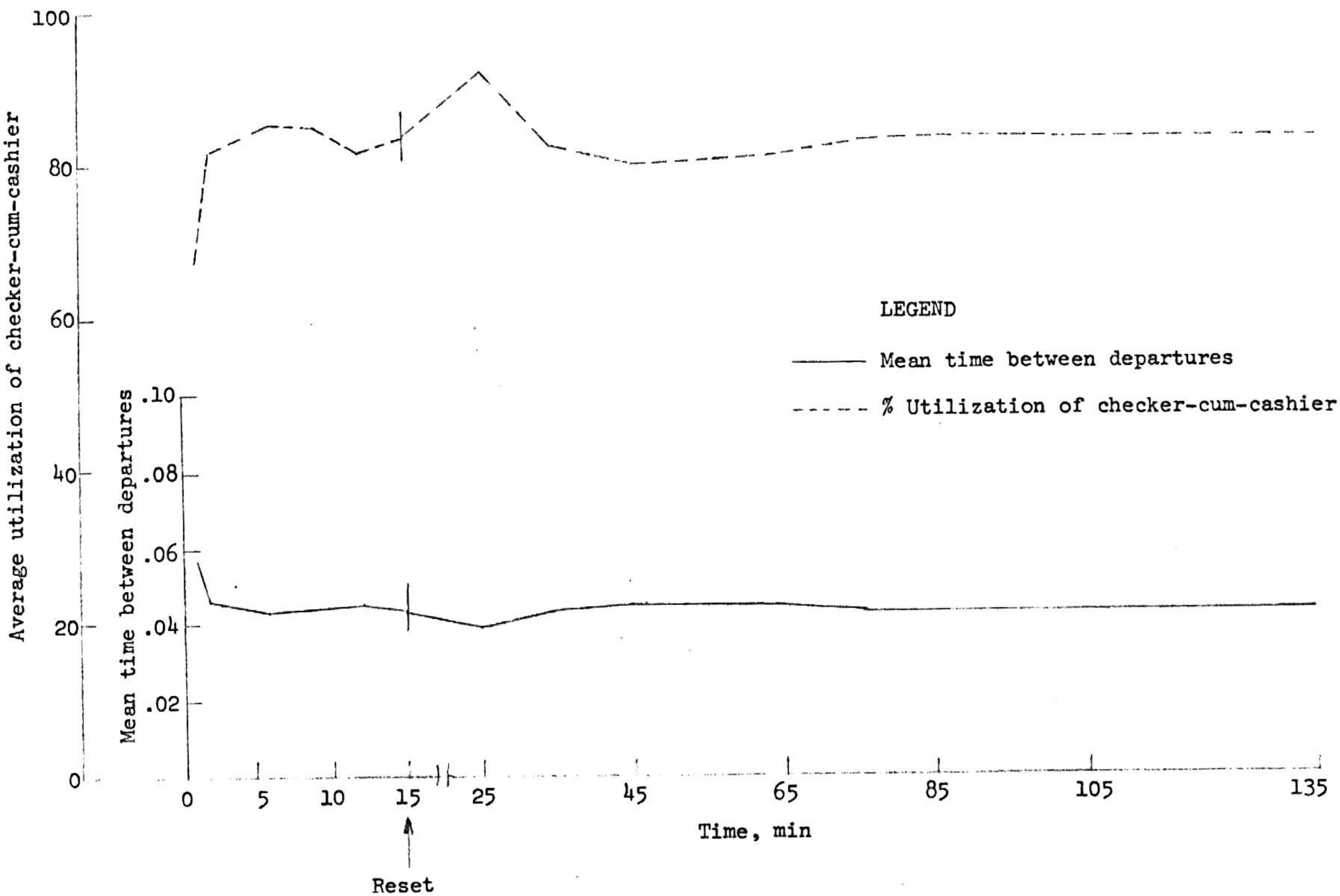

Fig. 7. The mean time between departures, and per cent utilization of checker-cum-cashier: Model 2.

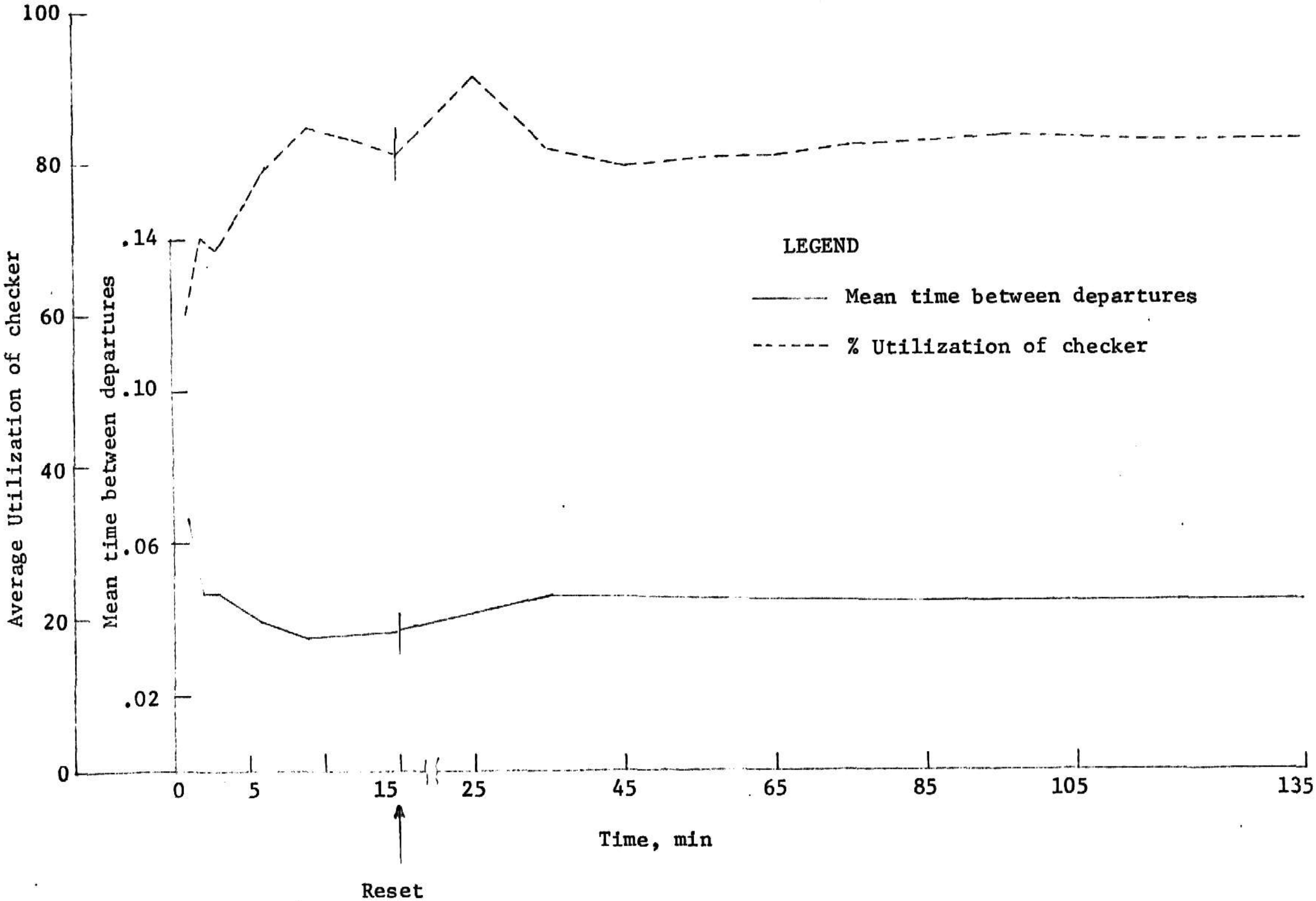

Fig. 8. The mean time departures, and per cent utilization of checker: Model 3.

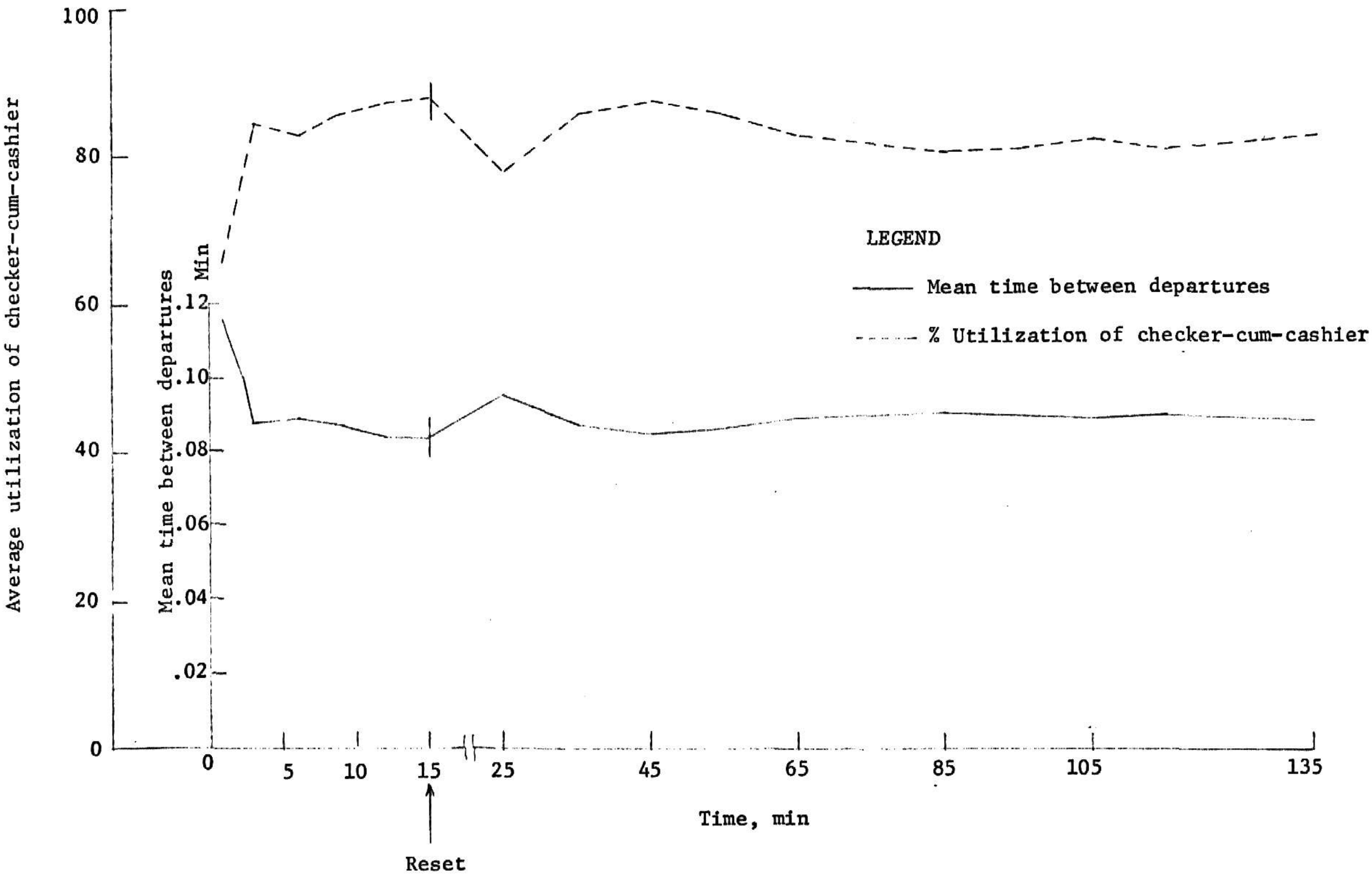

Fig. 9. The mean time between departures, and per cent utilization of checker-cum-cashier: Model 4.

condition beforehand. So to determine the steady state condition of a model, the best way is to experiment with the model itself. The criterion used in the determination of the steady state conditions are the mean time between departures, and the per cent utilization of the checkout operators.

The determination of the steady state for each model is given in Figures 6 through 9. It is seen that the mean time between departures and per cent utilization of checkout operators reach the steady state condition at 15 minutes of simulation for each model.

5.2 DETERMINATION OF NUMBER OF CHECKER AND CASHIER STATIONS

As discussed in chapter 3, increasing the number of checkout stations will involve high costs due to a high percentage of idle time at the stations. But on the other hand, by not providing enough checkout stations, the customers will have to wait too long. To obtain a compromise between two conflicting interests, the activity of the cafeteria system was simulated under varying numbers of checker and cashier stations keeping the inter-arrival time distribution and the service time distributions of the checkout operators constant for all runs.

The checker and cashier stations were designed for third period (11:30 - 1:30 P.M.) of the day only, as the checkout load is more than in any other period of the day. The checkout load depends upon the arrival rate and service times of the checkout operators. The service times of the operators in model 3 is more than in any other model. For each number of checker stations, the distribution of waiting times of the customers, maximum queue length and per cent of idle checker time were determined. The simulation results are shown in Table 3. Figure 10 shows the distributions of waiting times of the customers when the model was simulated using 4 and 5 checker stations.

It is concluded that 4 checker stations are needed for the busiest time periods of the day which satisfy the criterion of desired performance level as shown by results in Table 4. The most surporising result is the larger differences in system performance by using 3 or 4 checker stations. The results indicate that by designing for 3 checker stations, 100% of the customers wait more than 0.75 minute, while with 4 checker stations only 0.2% of the customers wait more than 0.75 minute. It is doubtful that the food service management realizes the drastic difference in system performance an additional service station can make. Figure 11 shows that as the number of checker stations increases, the mean waiting time of the customers decreases while per cent idle time of the checker station increases.

To determine the number of cashier stations for the third period, the distribution of waiting times of the customers, maximum queue length and per cent of idle cashier time were determined for each number of cashier stations. The results of the simulation runs are contained in Table 5. The clear relationship between the number of cashier stations, the mean waiting time of the customers, and the per cent idle cashiers time is plotted in Fig. 12. It would seem

Table 3

Effect of number of checker stations on the mean waiting time of the customers, per cent utilization of checkers, and the maximum queue length for model 3.

Number of checker stations	Iteration number	Waiting time (seconds)				% Utilization		% Idle time	Maximum queue length
		Iteration		Mean	Std. dev.	Iteration average	Average		
		Mean	Std. dev.						
3	1	425.34	203.4	425.34	203.4	100.0	100.0	0.0	104
4	1	8.62	7.47	7.96	6.86	82.9	81.6	18.4	6
	2	7.29	6.10			80.4			5
5	1	5.58	4.65	5.44	4.46	66.3	65.3	34.7	3
	2	5.31	4.24			64.3			3
6	1	5.08	4.11	5.04	4.04	55.1	54.5	45.5	2
	2	5.00	3.97			53.8			2
8	1	4.94	3.99	4.93	3.94	41.4	40.9	59.1	2
	2	4.92	3.90			40.3			1

Table 4

Effect of number of service stations on the per cent of customers waiting more than .75 minute.

Number of service stations	Per cent of customers waiting more than 0.75 minute				
	Model 1	Model 2	Model 3		Model 4
			Checker	Cashier	
1	-	-	-	-	100.0
2	100.0	-	-	-	3.8
3	7.8	100.0	100.0	-	0.0
4	0.0	0.3	0.2	100.0	0.0
5	0.0	0.0	0.0	12.1	0.0
6	0.0	0.0	0.0	0.0	-
7	0.0	0.0	0.0	0.0	-
8	-	0.0	0.0	0.0	-

Table 5

Effect of number of cashier stations on the mean waiting time of the customers, per cent utilization of cashiers, and the maximum queue length for model 3.

Number of cashier stations	Iteration number	Waiting time (seconds)				% Utilization		% Idle time	Maximum queue length
		Iteration		Mean	Std. dev.	Iteration average	Average		
		Mean	Std. dev.						
4				-	-		-	-	-
5	1	22.77	17.20	18.46	14.71	93.9	92.3	7.7	6
	2	14.07	9.86			90.7			5
6	1	8.43	5.60	8.29	5.56	78.2	76.9	23.1	6
	2	8.14	5.52			75.6			5
7	1	8.21	5.53	8.08	5.53	67.0	65.9	34.1	6
	2	7.96	5.53			64.8			5
9	1	8.15	5.53	8.07	5.51	52.21	48.7	51.3	6
	2	7.99	5.49			50.4			5

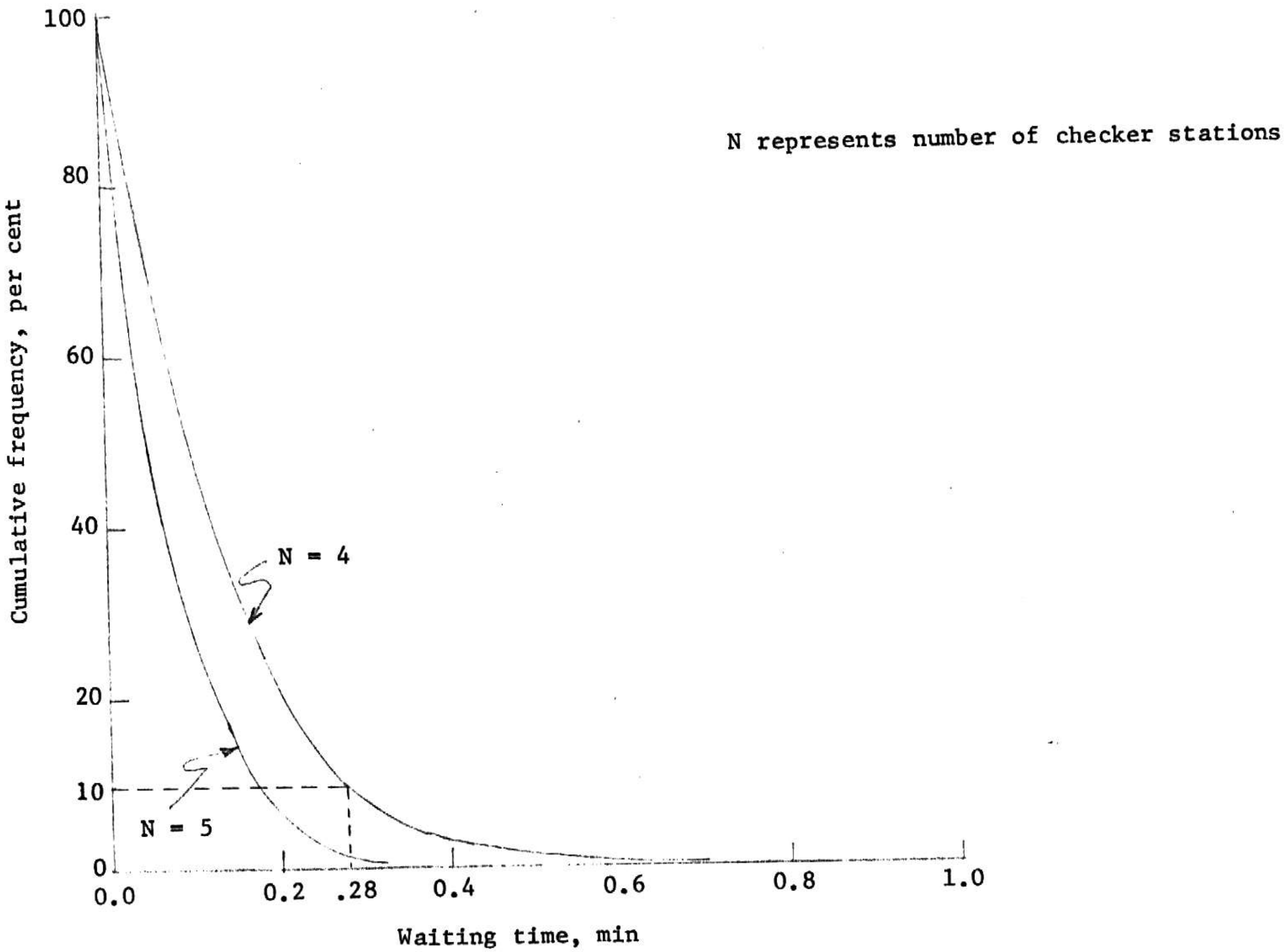

Fig. 10. Distributions of waiting times of customers at checker station: Model 3

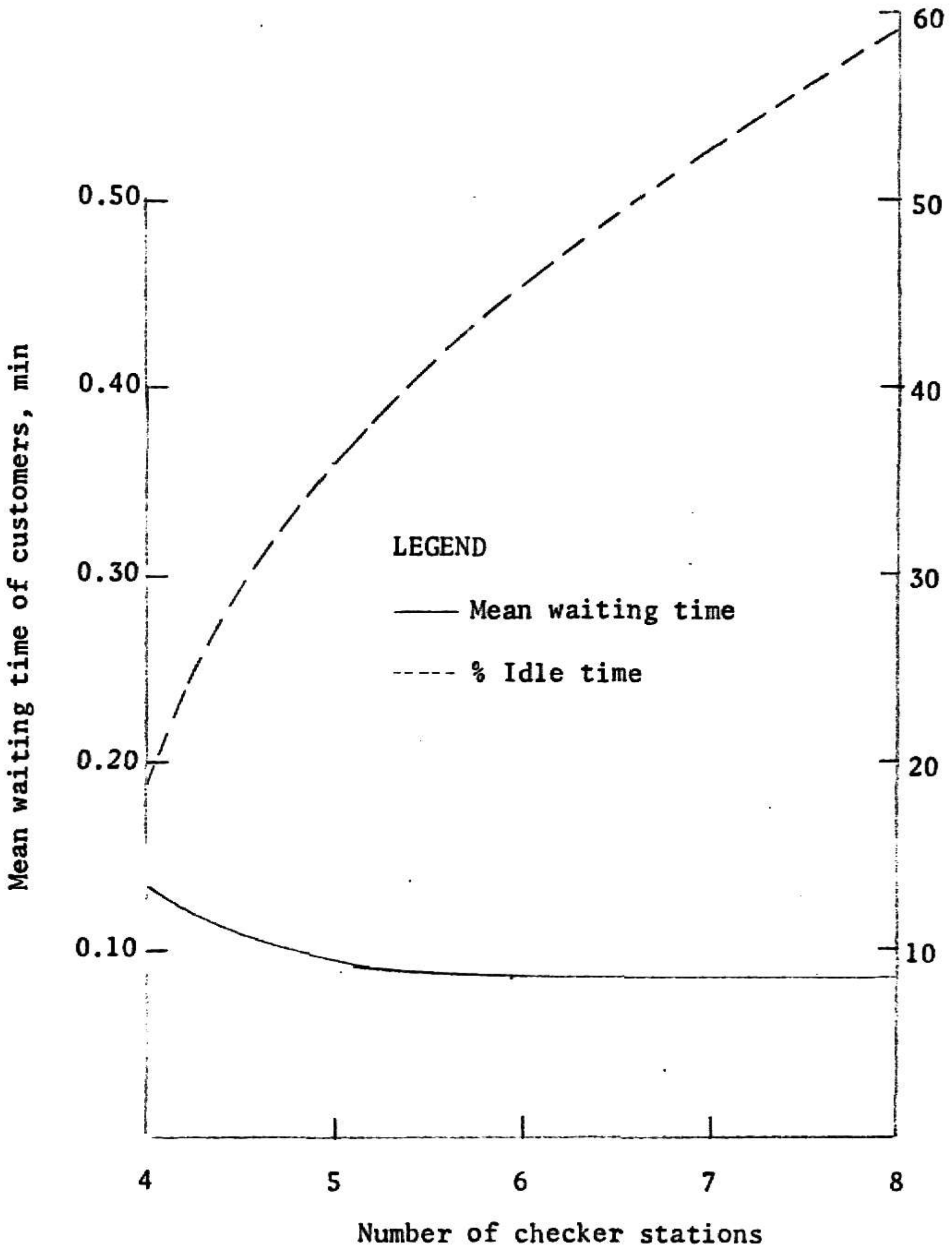

Fig. 11. Design curves for various numbers of checker stations: Model 3.

that there is little difference in the average waiting time of the customers when the number of cashier stations is 6 or more than 6, but less than 6 the average waiting time of the customers tends to rise significantly.

The waiting time distributions of the customers by using either 5 or 6 cashier stations are given in Fig. 13. By using 5 cashier stations, 12.1% of the customers wait more than 0.75 minute while by using 6 cashier stations no customer waits more than 0.75 minute. So the 'optimal' number of cashier stations required for the cafeteria system in 1975, satisfying the criterion of performance level is 6. It can be realized from the results in Table 4, the drastic difference in system performance an additional cashier station can make from 4 to 5 cashier stations.

To determine the 'optimal' number of checker-cum-cashiers for models 1, 2, and 4, the statistics of the waiting time distribution, maximum queue length, and the per cent utilization of the checker-cum-cashiers were collected under varying numbers of checkers-cum-cashiers. The relationships between the number of checker-cum-cashiers, the mean waiting time of the customers, and the per cent of idle checker-cum-cashiers time were plotted for each model as shown in Figures 14 through 16. The waiting time distributions for different numbers of checker-cum-cashiers were plotted as shown in Figures 17 through 19. The simulation results for each model are shown in Tables 6 through 8, keeping the other two system parameters i.e. the inter-arrival time distribution and the service time distribution of the checker-cum-cashier constant for all runs. The 'optimal'

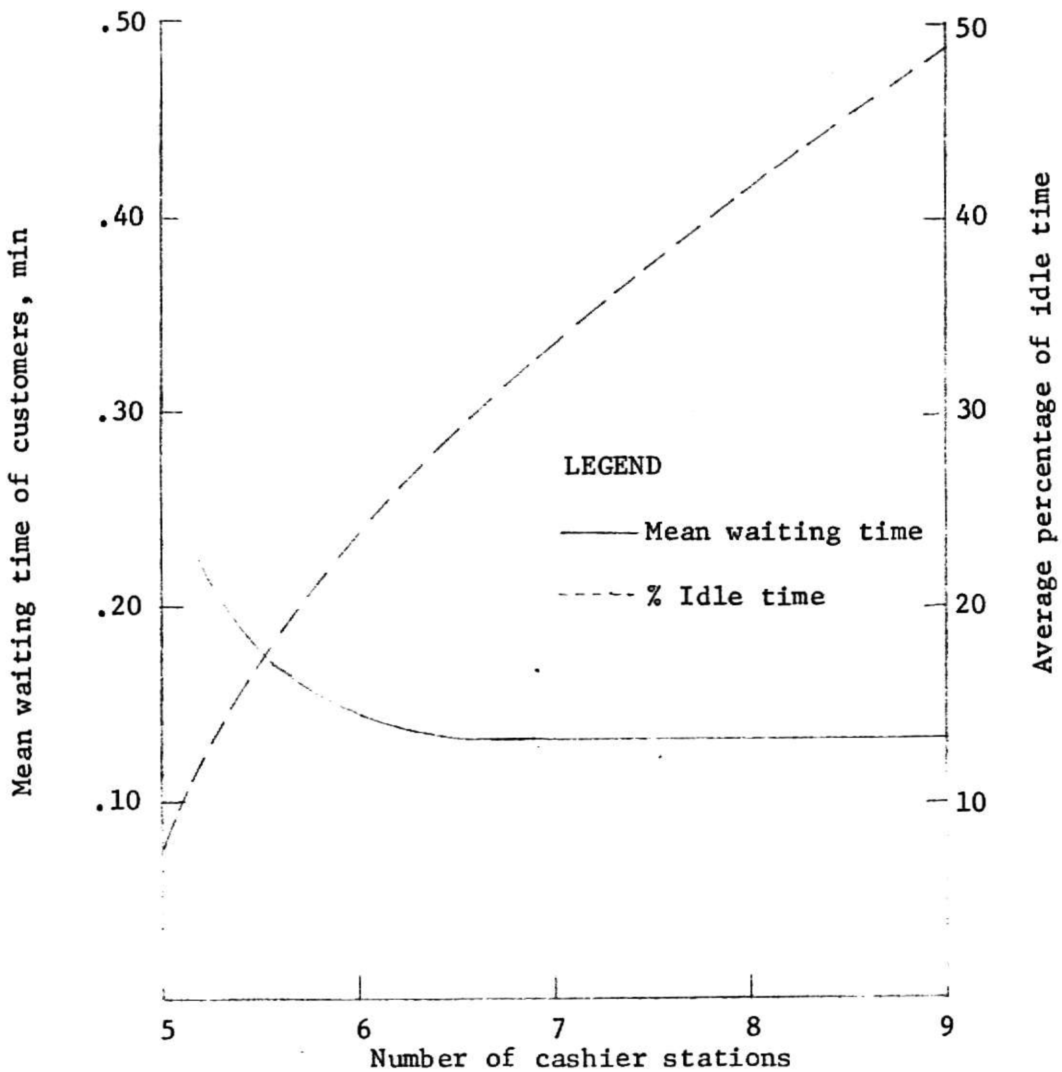

Fig. 12. Design curves for various values of cashier stations: Model 3.

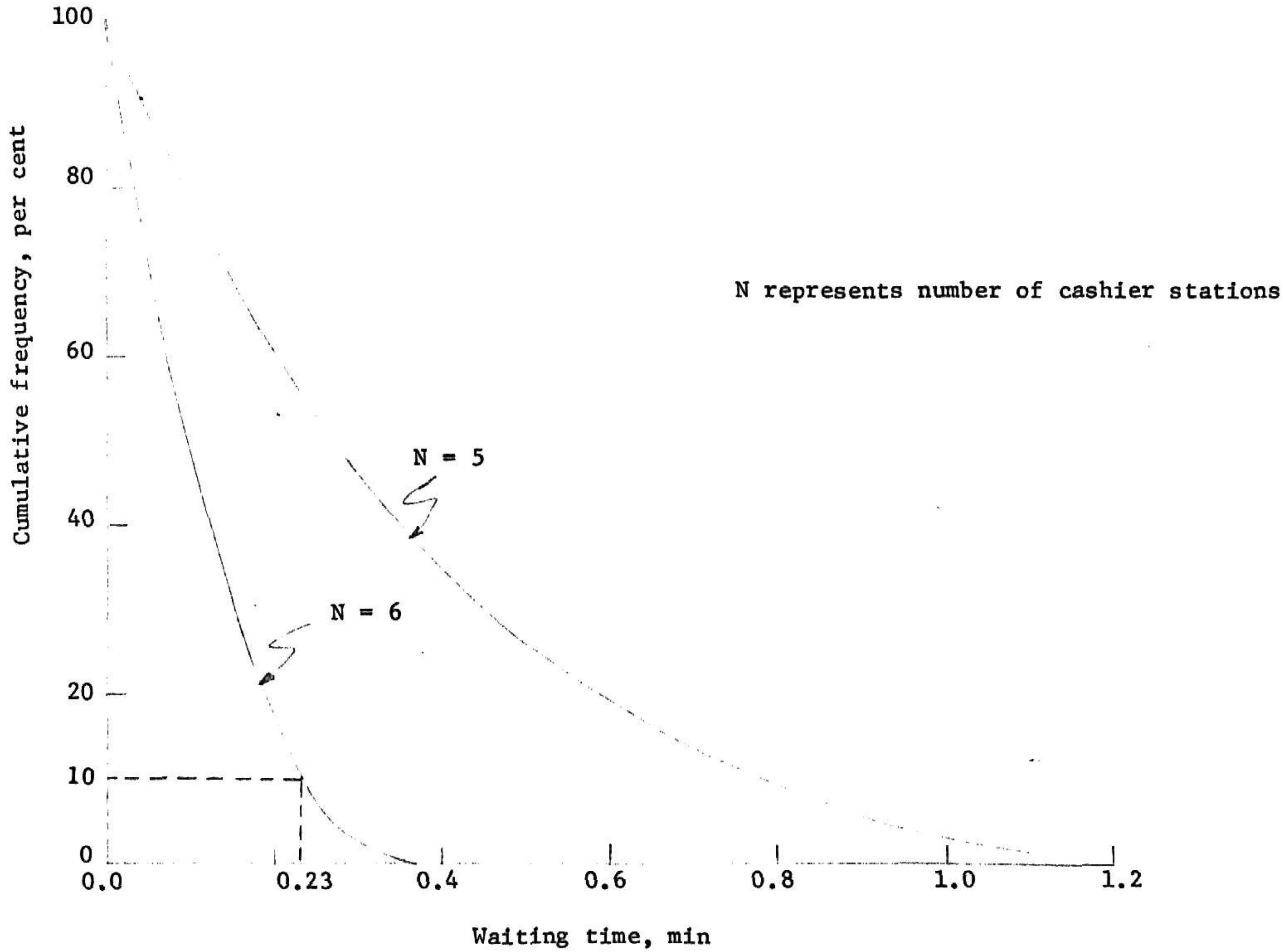

Fig. 13. Distributions of waiting times of customers at cashier stations: Model 3

number of checker-cum-cashiers for each model which satisfies the criterion of performance level are determined from the simulation results as given in Table 4. The optimal numbers are:

(a) For model 1: 3 checker-cum-cashiers

(b) For model 2: 4 checker-cum-cashiers

(c) For model 4: 2 checker-cum-cashiers

To determine the number of chairs required for the cafeteria in 1975, the system was first simulated for 120 minutes for the second period (9:30 - 11:30 A.M.) when the mean arrival load is maximum as shown in Table 1. The program worked, and it was found that about 800 chairs will be sufficient. But later it was felt that taking a period of 2 hours would considerably lower the mean of the arrival rate. Then the model was simulated for peak period of 60 minutes (11:30 - 12:30 P.M.) as shown in Fig. 2. But the program stopped due to error 599 - Which means the limits of GPSS/360 COMMON core exceeded. The REALLOCATE card was used to increase the COMMON core, which helped to run the program further to a certain extent. But the program again stopped due to error 599.

5.3 THE EFFECT OF VARIATION IN SERVICE TIME DISTRIBUTION FOR CHECKOUT OPERATION:

The service time distribution of model 1 was varied keeping the numbers of checker-cum-cashiers and the inter-arrival time distribution of the customers constant for all runs. The simulation results for various values of mean and standard deviation of the service time are shown in Table 9. The results indicate that the mean waiting time

Table 6

Effect of number of checker-cum-cashiers on the mean waiting time of the customers, per cent utilization, of checker-cum-cashiers, and the maximum queue length for model 1.

Number of checker-cum-cashiers	Iteration number	Waiting time (seconds)				% Utilization		% Idle time	Maximum queue length
		Iteration		Mean	Std. dev.	Iteration average	Average		
		Mean	Std. dev.						
2				-	-		-	-	
3	1	18.56	15.60	15.73	13.73	90.6	90.0	10.0	9
	2	12.92	10.87			89.3			7
4	1	5.84	5.27	5.66	5.02	67.8	67.4	32.6	4
	2	5.49	4.76			67.0			3
5	1	4.96	4.23	4.83	4.10	54.2	53.9	46.1	1
	2	4.71	3.96			53.6			1
6	1	4.77	4.08	4.68	3.96	38.7	38.5	61.5	1
	2	4.59	3.84			38.3			1

Table 7

Effect of number of checker-cum-cashiers in the mean waiting time of the customers, per cent utilization of checker-cum cashiers, and the maximum queue length for model 2.

Number of checker-cum-cashiers	Iteration number	Waiting time (seconds)				% Utilization		% Idle time	Maximum queue length
		Iteration							
		Mean	Std. dev.	Mean	Std. dev.	Iteration average	Average		
3	1	267.96	169.80	267.96	169.80	99.8	99.8	0.2	73
4	1	8.98	7.84	8.17	7.12	83.8	82.2	17.8	6
	2	7.35	6.19			80.6			5
5	1	5.61	4.61	5.45	4.43	67.0	65.7	34.3	3
	2	5.28	4.24			64.4			3
7	1	4.99	3.99	3.96	3.96	47.9	47.0	53.0	2
	2	4.85	3.92			46.0			2
8	1	4.96	3.97	3.94	3.94	42.0	41.0	58.9	2
	2	4.84	3.91			40.2			2

Table 8

Effect of the number of checker-cum-cashiers on the mean waiting time of the customers, per cent utilization of checker-cum-cashiers, and the maximum queue length for model 4.

Number of checker-cum-cashiers	Iteration number	Waiting time (seconds)				% Utilization		% Idle time	Maximum queue length
		Iteration		Mean	Std. dev.	Iteration average	Average		
		Mean	Std. dev.						
1		-	-	-	-	-	-	-	-
2	1	14.25	14.77	14.39	14.88	83.3	84.5	15.5	11
	2	14.52	15.00			85.6			10
3	1	4.78	4.86	4.83	4.89	55.7	56.4	43.6	4
	2	4.87	4.92			57.1			4
4	1	4.04	4.00	4.07	4.01	41.7	42.2	57.8	2
	2	4.10	4.02			42.8			2
5	1	3.97	3.90	3.98	3.91	33.4	33.8	66.2	1
	2	3.99	3.92			34.2			2

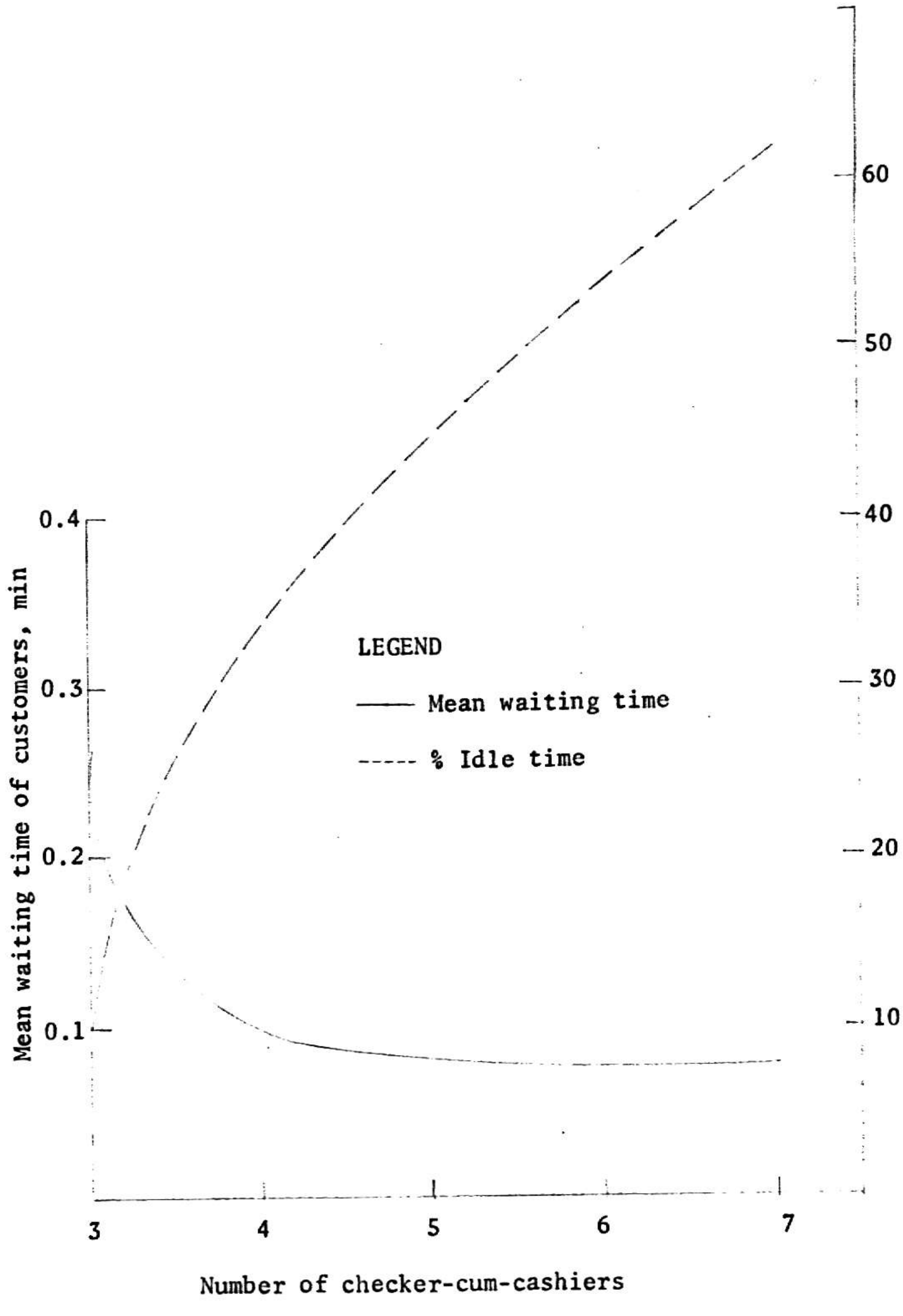

Fig. 14. Design curves for various numbers of checker-cum-cashiers: Model 1

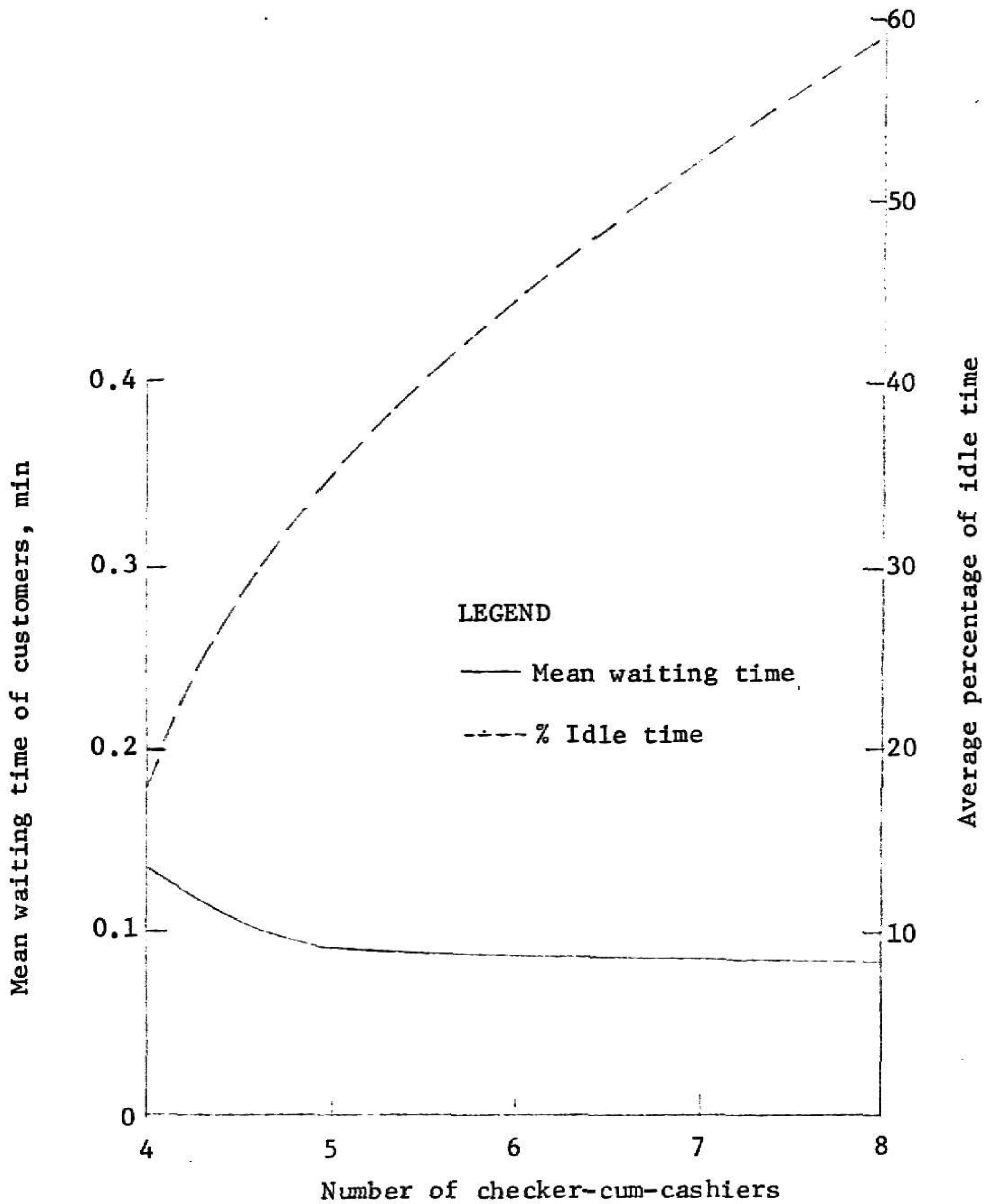

Fig. 15. Design curves for various numbers of checker-cum-cashiers: Model 2

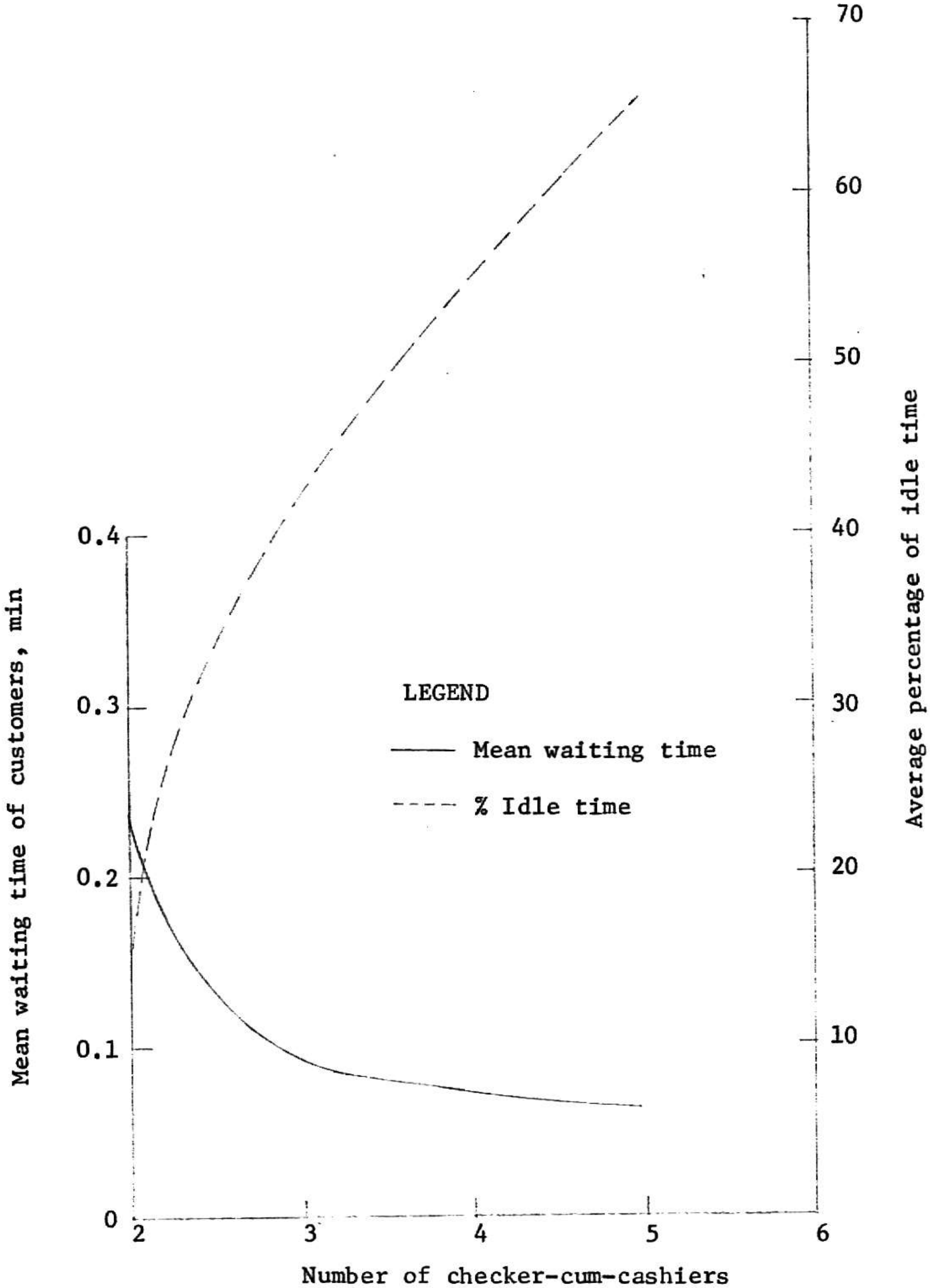

Fig. 16. Design curves for various numbers of checker-cum-cashiers: Model 4

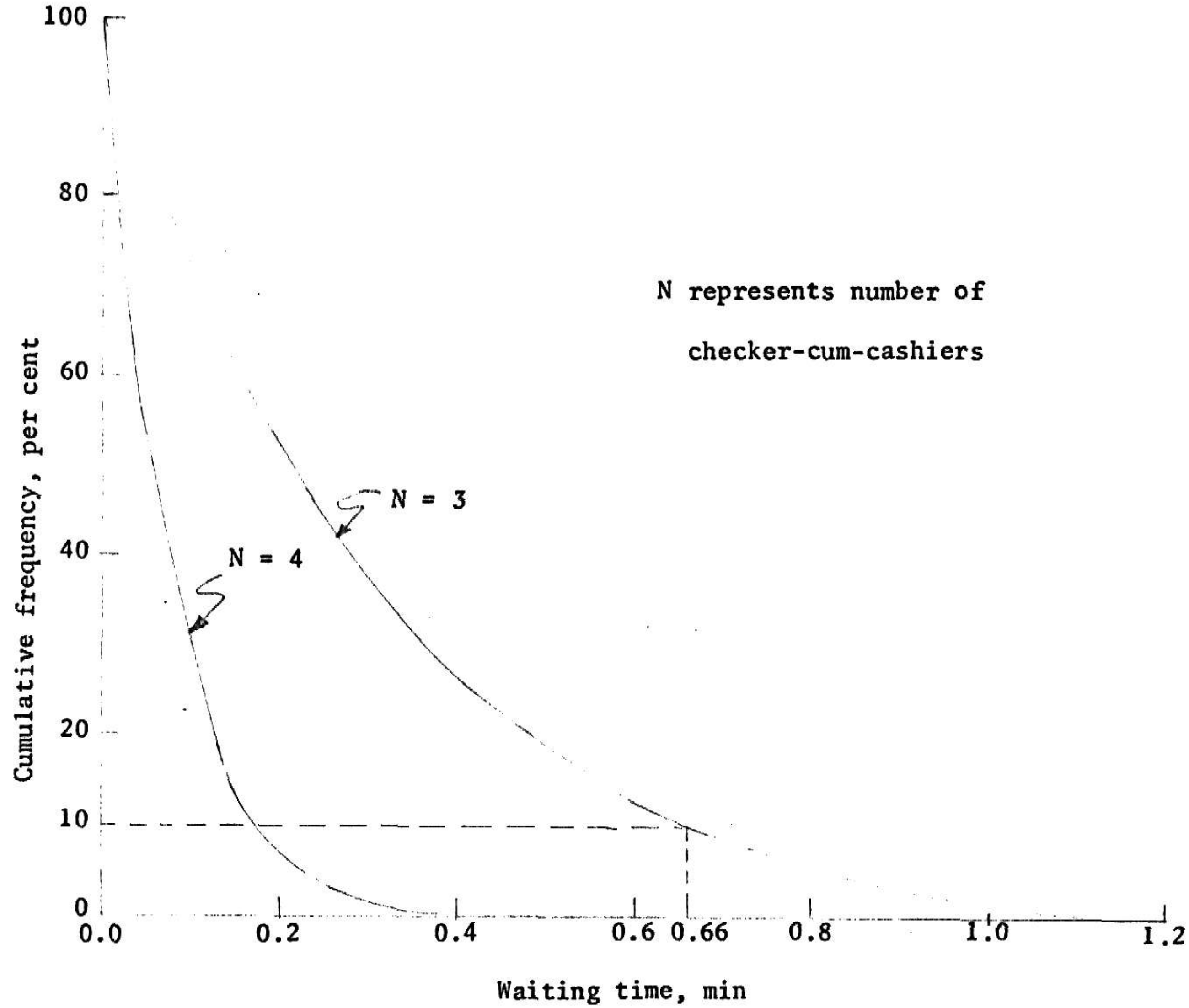

Fig. 17 Distributions of waiting times of customers at checking-cum-cashing operation: Model 1

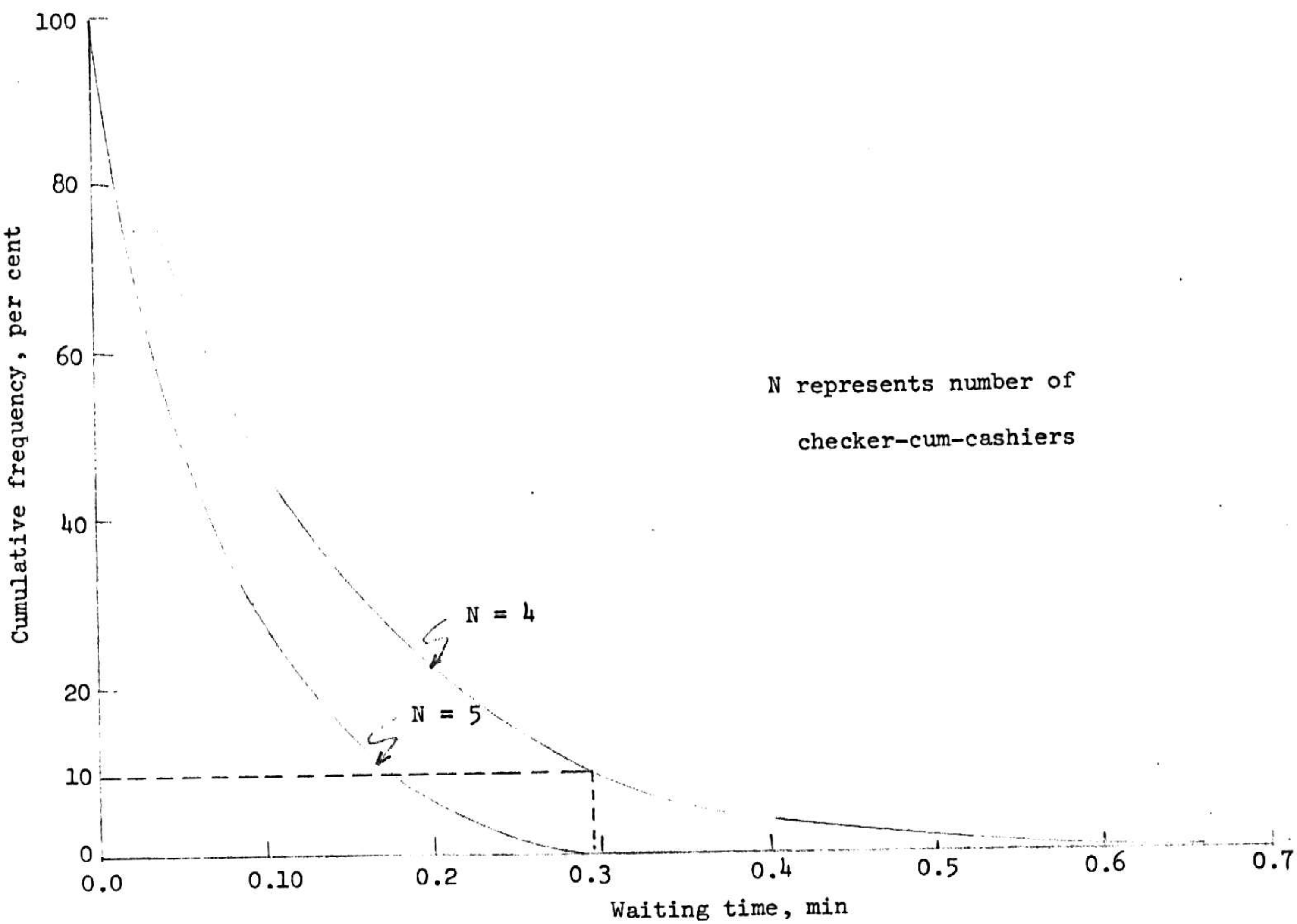

Fig. 18. Distributions of waiting times of customers at checking-cum-cashing operation: Model 2

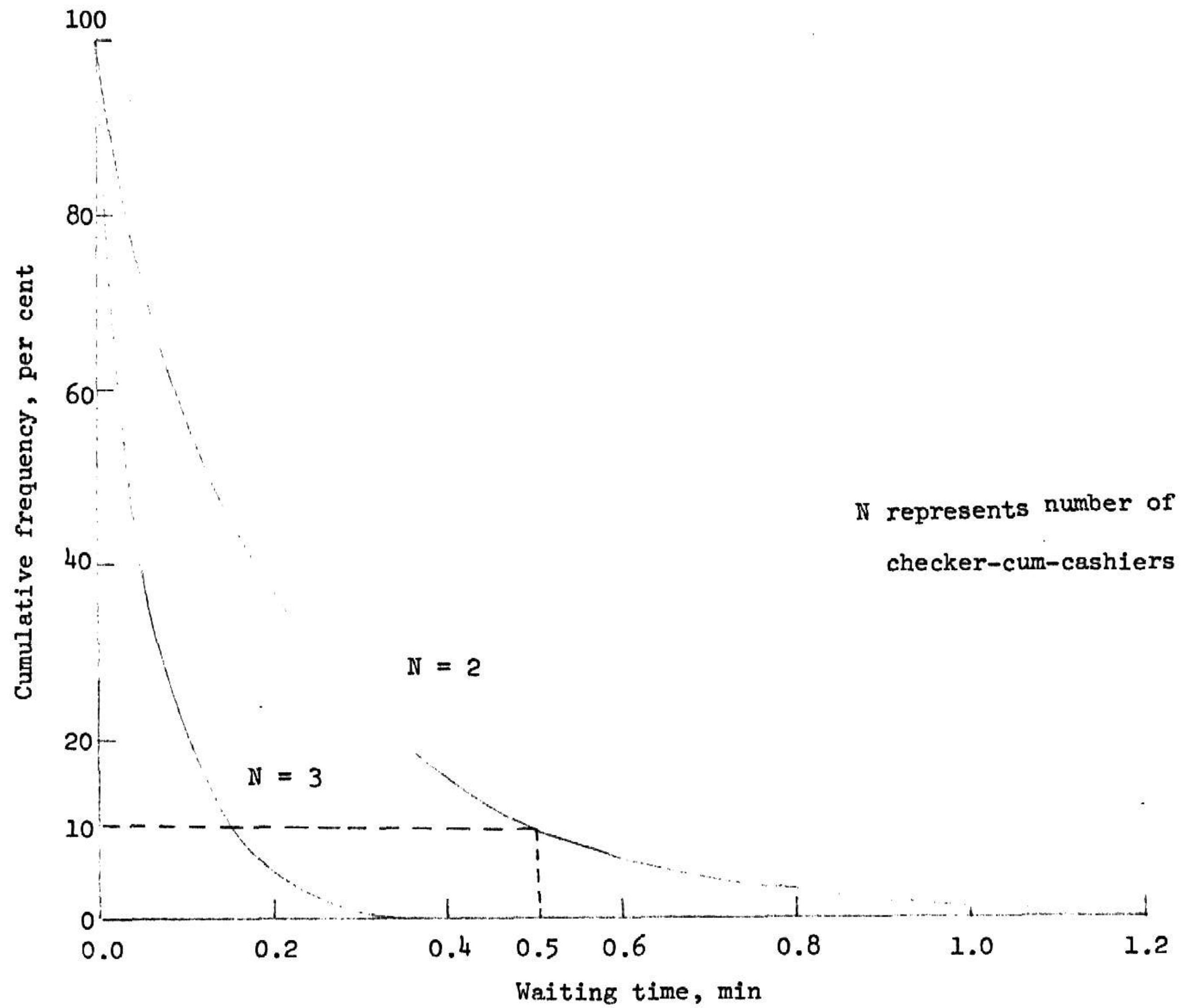

Fig. 19. Distributions of waiting times of customers at checking-cum-cashing operation: Model 4

of the customers increases sharply with an increase in the service time. Conversely by a little decrease in the service time of the checkout operation, the mean waiting time of the customers can be reduced considerably. With an increase by 20% of mean and standard deviation of the service time distribution (From 8.10 and 2.54 to 9.90 and 3.11 seconds), an increase of 71.3 percent of customers (From 0.2 to 71.5) who wait more than 0.75 minute is obtained as given by results of iteration no. 1.

The results also indicate that, an increase in the service time of the checkout operation, has no significant effect on the mean time between departures. The average utilization of the checker-cum-cashiers also increases with an increase in the service time of the checker-cum-cashiers. The effects of variation in the service time are plotted in Fig. 20 for iteration 1.

5.4 THE EFFECT OF VARIATION IN ARRIVAL RATE OF CUSTOMERS

The Table 10 shows the simulation results under varying mean arrival rate or mean inter-arrival time of customers keeping the other system parameters constant for all runs. Figure 21 shows the influence of number of arrivals per minute, on per cent of the customers who wait more than 0.75 minute at the checkout operation. It is readily apparent that, with the same service time and number of checkers and cashiers, the per cent of customers waiting more than 0.75 minute will increase rapidly with an increase in the arrival rate. The results indicate that while 6 cashier stations are capable of handling the increased arrival rate (23.2 customers per minute), 4 checker stations, will soon reach the critical load after which the

Table 9

Effect of variation in service time of checker-cum-cashier on the mean waiting time of customers, time between departures, and per cent utilization of checker-cum-cashiers.

Service time (seconds)		Iteration number	Waiting time (seconds)		% Of the customers waiting more than 0.75 minute	Time between departures (seconds)		% Utilization
Mean	Std. dev.		Mean	Std. dev.		Mean	Std. dev.	average
		1	9.04	8.58	0.2	3.22	2.58	81.3
8.10	2.54							
		2	7.54	7.14	0.0	3.22	2.58	80.1
		1	18.56	15.60	7.7	3.23	2.46	90.6
9.00	2.83							
		2	12.92	10.87	1.3	3.22	2.46	89.3
		1	94.09	62.70	71.5	3.29	2.41	98.3
9.90	3.11							
		2	50.88	32.02	49.3	3.24	2.37	97.8

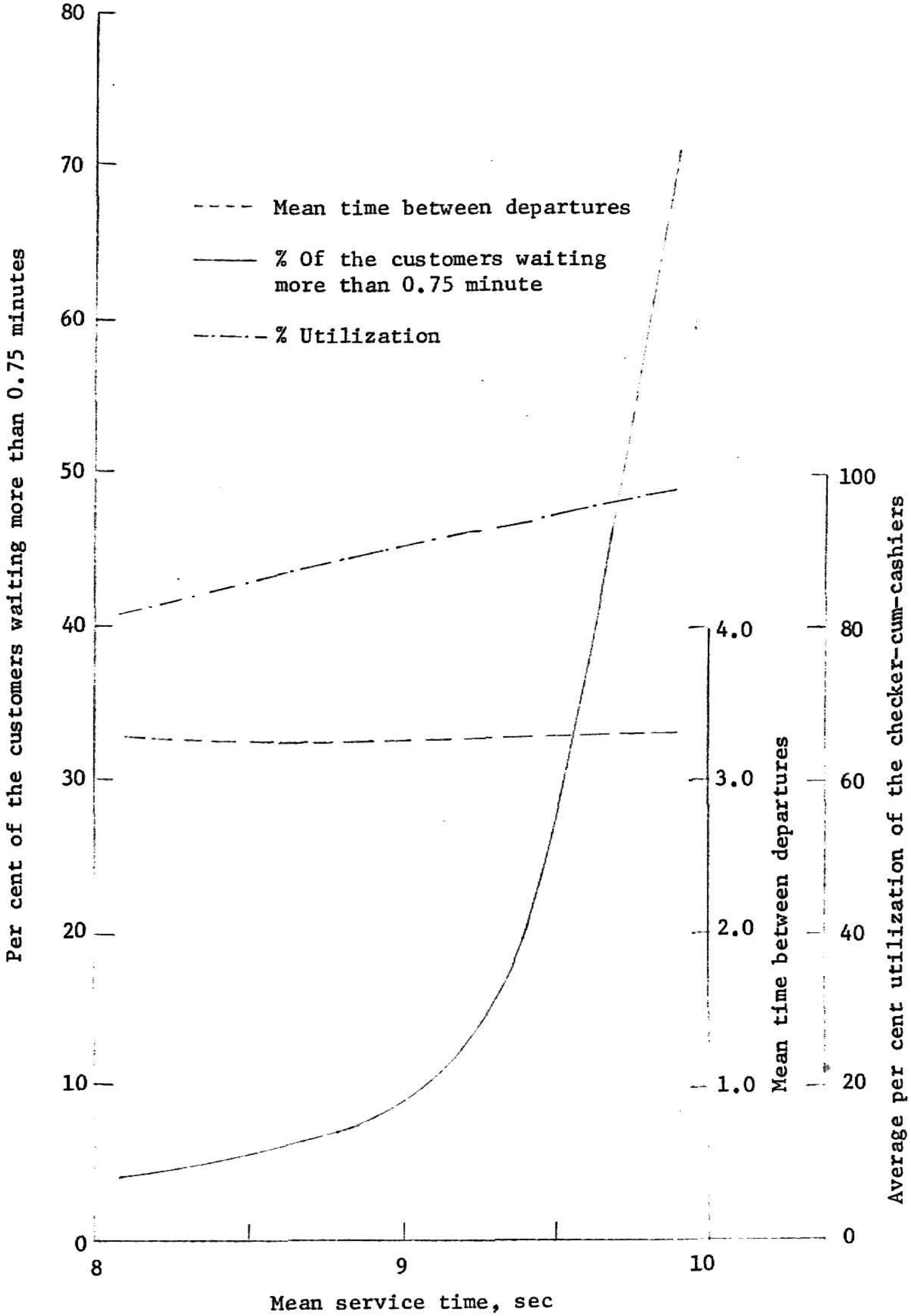

Fig. 20. Relationship between mean service time, per cent of the customers waiting more than 0.75 minute, per cent utilization and mean time between departures.

desired performance level will decrease sharply as shown in Fig. 21. An increase in 12.1% of arrival load (from 20.7 to 23.2 customers per minute) increases the per cent of the customers waiting more than 0.75 minute from 0.2 to 10.0 as shown in Table 10.

The results also show that at a mean arrival rate of 25 customers per minute, 81.7% of the customers wait more than 0.75 minute, but by introducing a constant arrival rate of 25 customers per minute, 4 checker stations are still capable of handling the increased load and no customer has to wait more than 0.75 minute. It could be concluded that if classes could be scheduled so as to strive for constant arrival rate, the efficiency and performance of the cafeteria system can be increased considerably.

The effect of arrival rate on the time between departures and per cent utilization of the checkers is also shown in the graph (Fig. 21). The time between departures decreases while per cent utilization of the checkers increases with an increase in the arrival rate.

Table 10

Effect of variation in mean arrival rate of customers on the mean waiting time of the customers, per cent of customers waiting more than 0.75 minute, time between departures, and per cent utilization of checkout stations

Mean arrival rate per minute (Poisson)	Iteration number	Waiting time (seconds) at				% of the customers waiting more than .75 minute		Time between departures		% Utilization	
		Checker stations		Cashier stations		checker stations	cashier stations				
		Mean	Std. dev.	Mean	Std. dev.			Mean	Std. dev.	Checker	Cashier
20.7	1	8.61	7.44	8.36	5.55	0.2	0.0	2.64	2.48	82.9	78.2
	2	7.29	6.10	8.14	5.52	0.0	0.0	2.68	2.34	80.4	75.6
21.8	1	10.50	8.98	8.32	5.46	.2	0.0	2.53	2.25	86.2	81.4
	2	8.94	8.23	8.52	5.61	.4	0.0	2.59	2.25	83.6	78.5
22.8	1	14.80	12.22	8.69	5.56	2.4	0.0	2.42	2.20	90.0	84.9
	2	12.40	10.61	8.74	5.60	1.7	0.0	2.44	2.11	88.8	83.5
23.2	1	20.62	16.45	8.83	5.39	10.0	0.0	2.35	2.11	92.7	87.6
	2	17.41	14.62	9.01	5.73	5.8	0.0	2.37	2.02	91.9	86.3
23.8	1	30.00	22.2	8.91	5.42	23.0	0.0	2.29	2.08	94.9	89.6
	2	23.20	18.4	9.12	5.89	16.2	0.0	2.31	2.01	93.9	88.2
25.0	1	101.4	51.66	9.06	5.46	81.7	0.0	2.19	1.92	99.3	93.8
25.0 (constant)	1	6.18	3.75	8.56	5.57	0.0	0.0	2.41	2.11	90.5	83.8

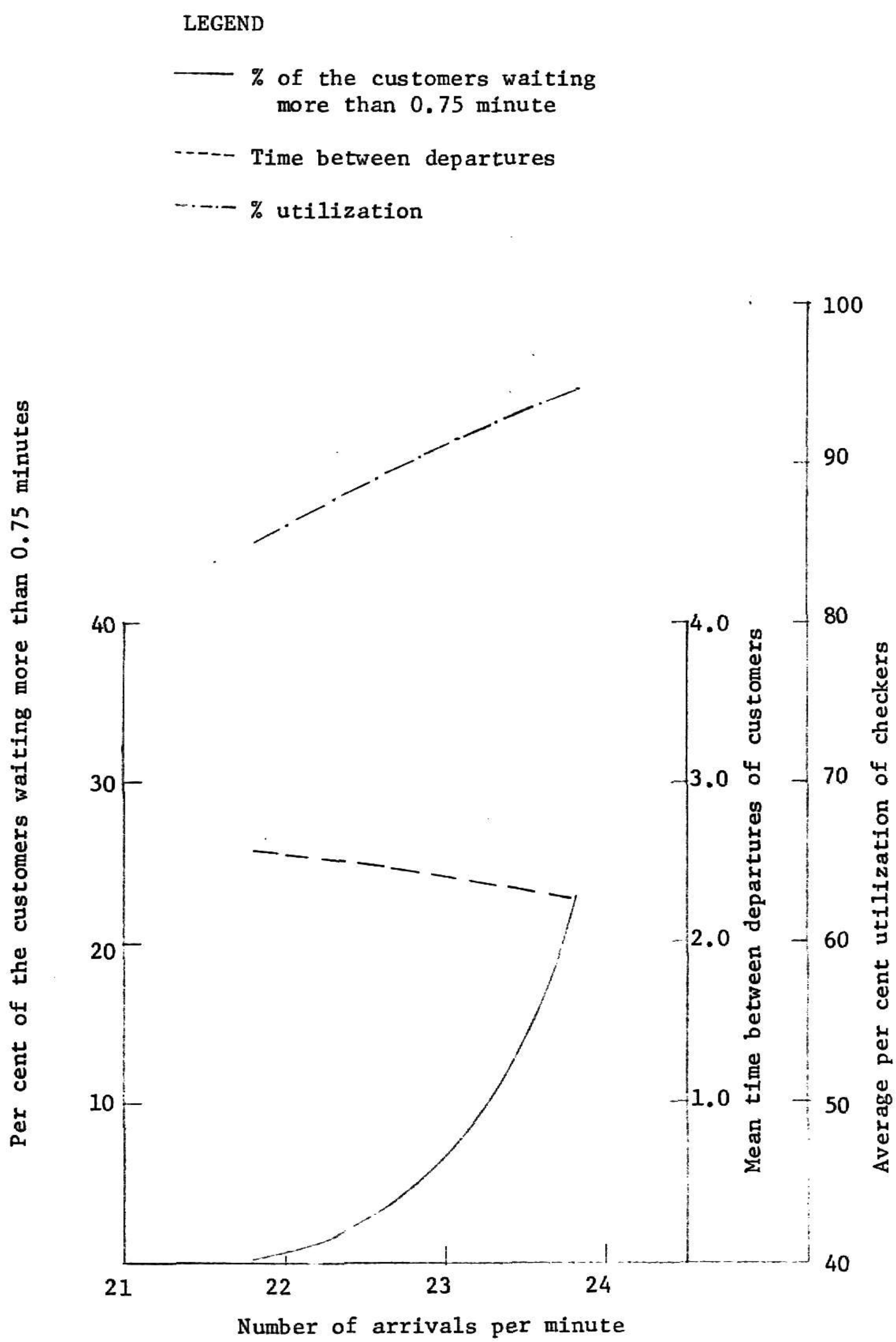

Fig. 21. Relationship between the number of arrivals, per cent of the customers waiting more than 0.75 minute, per cent utilization and mean time between departures.

CHAPTER 6

SUMMARY AND CONCLUSION

The purpose of this study was to develop a simulation model to be used as an experimental tool to determine the future design of service facilities for the checkout operations of a cafeteria food service system.

The cafeteria simulator developed was written in GPSS/360 language and a digital computer, the IBM 360, was used for the implementation of the simulation. Necessary data to manipulate the model was obtained by timing each checkout operation. The observed service times data were fitted with continuous probability distributions and both observed and theoretical frequency distributions were plotted. The arrival distribution was assumed as Poisson. To determine the mean arrival rate of customers during each period, the total number of customers arriving during each 15 minutes were counted for five days.

Two computer programs were written as given in Appendix B. In the first program the functions of checker and cashier are combined. This program was used to simulate models, 1, 2, and 4, when the checkout operation is combined. The second program was used to simulate model 3, when the checkout operation of checker and cashier is separate. Both the programs were simulated to determine the future design (1975) of the checkout stations and the requirements of checkout operators for each period. The criterion used in selecting the number of checkout stations or operators is that not more than 10% of the costomers wait for 0.75 minute in the queue. 4 checker stations and 6 cashier stations seems to be the best solution to take up the peak load period (11:30 - 1:30 P.M.). By incorporating variations in the service times of the checkout operations and the inter-arrival times of the customers, the effects on the desired performance level, mean waiting time, facility utilization, and time between departures were studied.

This study illustrated that the developement of the computer model of a cafeteria system can help the food service management for both future planning and operations of checkout facilities of a cafeteria system. The model could be simulated by introducing changes in the service time, and the inter-arrival time; and best plan and policy could be adopted.

APPENDIX A

BLOCK DIAGRAMS

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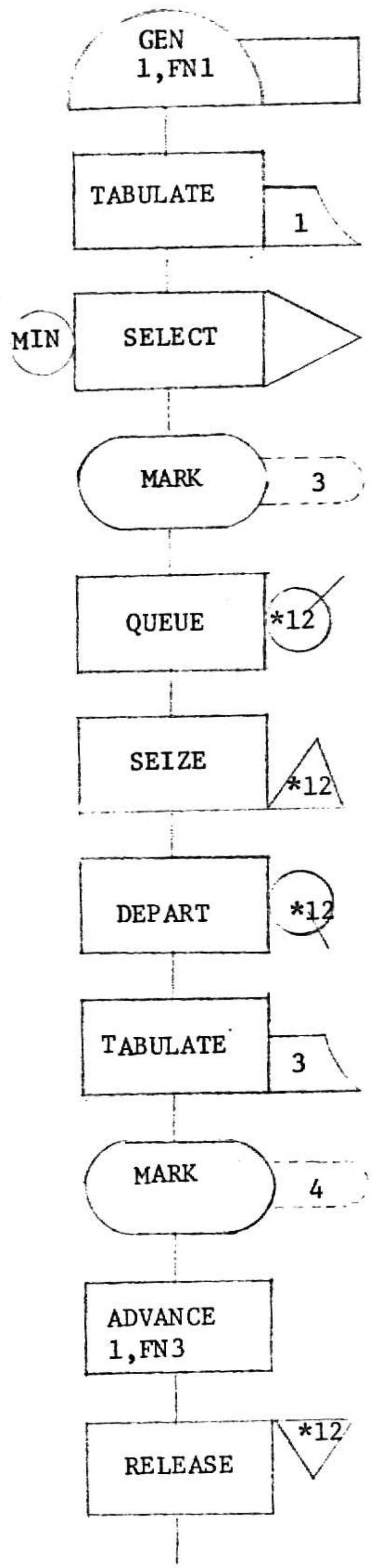


Models 1, 2, and 4

Fig. 22. Block diagram for cafeteria system

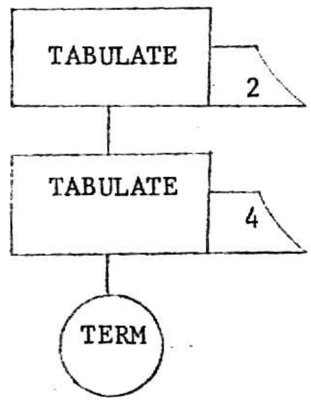
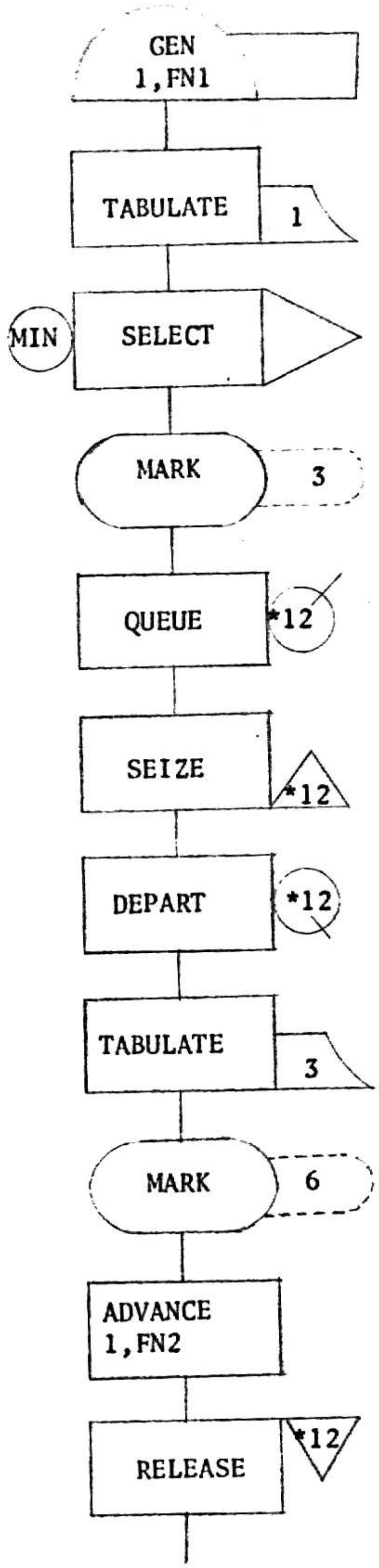


Fig. 22. Block diagram for cafeteria system (continued).



Model 3

Fig. 23. Block diagram for cafeteria system.

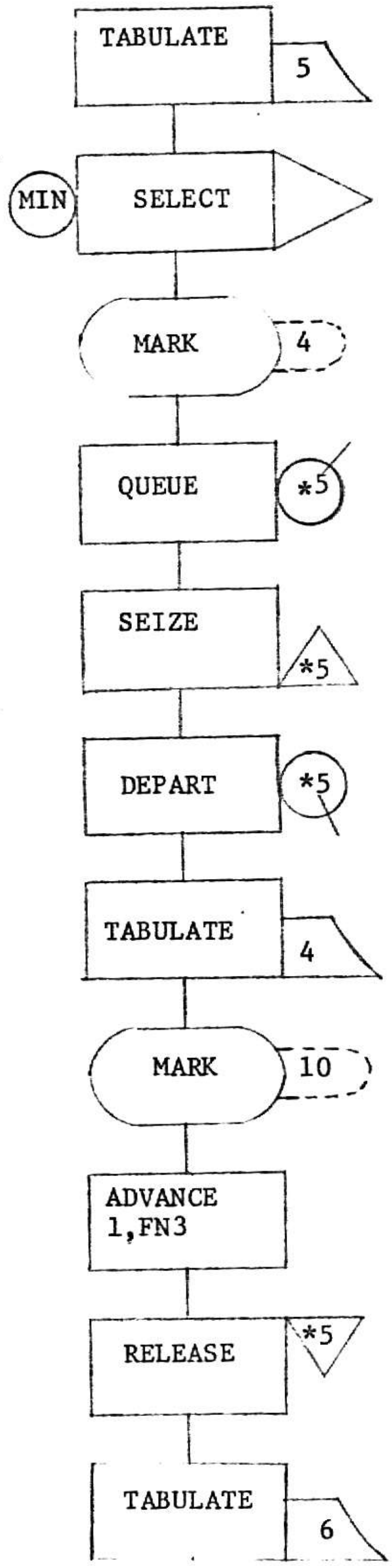


Fig. 23. Block diagram for cafeteria system (continued).

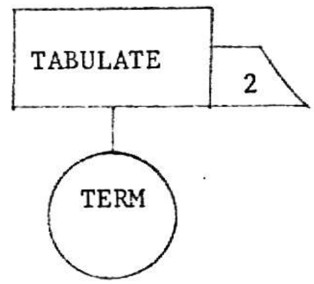


Fig. 23. Block diagram for cafeteria system (continued).

APPENDIX B

PROGRAM

```
      SIMULATE
*
*  PROGRAM FOR MODELS ONE-TWO AND FOUR
*
 1        TABLE       IA,0,2,25
 2        TABLE       IA,0,2,25
 3        TABLE       MP3,0,4,30
 4        TABLE       MP4,4,2,20
 1        FUNCTION    RN1,C24      INTERARRIVAL TIME DIST
.05,.244/.1,.502/.15,.775/.2,1.06/.25,1.37/.3,1.7/.35,2.05/.4,2.43
.45,2.85/.5,3.3/.6,4.37/.7,5.74/.75,6.61/.8,7.67/.85,9.04/.9,10.98
.95,14.29/.96,15.35/.97,16.72/.98,18.66/.99,21.96/.995,25.27
.998,29.64/.999,32.95
 3        FUNCTION    RN3,C22      SERVICE TIME DIST
.02,6.35/.03,6.97/.04,7.46/.05,7.91/.1,9.48/.15,10.52
.2,11.38/.3,12.45/.4,13.92/.5,15.0/.6,16.08
0.7,17.54/0.8,18.62/0.85,19.48/0.9,20.52/0.95,22.09/0.96,22.5
0.97,23.1/0.98,23.65/0.99,25.05/0.995,26.12/0.999,28.35
          GENERATE    1,FN1,,,,F    GENERATE CUSTOMERS FOR CAFETERIA
          TABULATE    1            RECORD INTERARRIVAL TIMES
          SELECTMIN   12,1,4,,Q    SELECT  SHORTEST QUEUE FOR SERVICE
          MARK        3
          QUEUE       *12          JOIN QUEUE FOR SERVICE
          SEIZE       *12          SEIZE FACILITY FOR SERVICE
          DEPART      *12          LEAVE SERVICE QUEUE
          TABULATE    3            RECORD WAITING TIMES
          MARK        4
          ADVANCE     1,FN3        GENERATE NORMAL SERVICE TIME
          RELEASE     *12          RELEASE SERVICE FACILITY
          TABULATE    2            RECORD TIME BETWEEN DEPARTURES
          TABULATE    4            RECORD SERVICE TIME DIST
          TERMINATE
          GENERATE    1
          TERMINATE   1
          START       1500,NP      RUN FOR 15 MINUTES NO PRINTOUT
          RESET
          START       12000        RUN FOR 2 HOURS
          CLEAR
          START       12000        RUN FOR 2 HOURS
          END
```

```
        SIMULATE
*
*   PROGRAM FOR MODEL THREE
*
 1      TABLE         IA,0,2,25
 2      TABLE         IA,0,2,25
 3      TABLE         MP3,0,4,30
 4      TABLE         MP4,0,4,30
 5      TABLE         MP6,6,2,20
 6      TABLE         MP10,6,2,20
 1      FUNCTION      RN1,C24      INTERARRIVAL TIME  DIST
.05,.247/.1,.507/.15,.783/.2,1.07/.25,1.38/.3,1.71/.35,2.07/.4,2.44
.45,2.8,/.5,3.34/.6,4.41/.7,5.8/.75,6.68/.8,7.75/.85,9.14/.9,11.09
.95,14.43/.96,15.51/.97,16.9/.98,18.85/.99,22.19/.995,25.53
.998,29.95/.999,33.29
 2      FUNCTION      RN2,C22      SERVICE TIME DIST-CHECKER
.02,6.35/.03,6.9/.04,7.46/.05,7.91
0.1,9.48/0.15,10.52/0.2,11.38/0.3,12.46/0.4,13.92/.5,15.0/.6,16.0
0.7,17.54/0.8,18.62/0.85,19.48/0.9,20.52/0.95,22.09/0.96,22.5
0.97,23.1/0.98,23.65/0.99,25.05/0.995,26.12/0.999,28.35
 3      FUNCTION      RN3,C21      SERVICE TIME DIST-CASHIER
.03,7.8/.04,8.7/.05,9.43/.1,11.97/.15,13.68/.2,15.1/.3,17.4
.4,19.25/.5,21.0/.6,22.75/.7,24.58/.8,26.9/.85,28.32/.9,30.
.95,32.56/.96,33.3/.97,34.2/.98,35.4/.99,37.4/.995,39.15/.9  ,4 .
        GENERATE      1,FN1,,,,,F   GENERATE CUSTOMERS FOR CAFETERIA
        TABULATE      1             RECORD INTERARRIVAL TIMES
        SELECTMIN     12,1,4,,Q     SELECTS SHORTEST QUEUE FOR SERVICE
        MARK          3
        QUEUE         *12           JOIN QUEUE FOR SERVICE
        SEIZE         *12           SEIZE CHECKER FOR SERVICE
        DEPART        *12           LEAVE SERVICE QUEUE
        TABULATE      3             RECORD WAITING TIMES
        MARK          6
        ADVANCE       1,FN2         GENERATE NORMAL SERVICE TIME
        RELEASE       *12           RELEASE SERVICE FACILITY
        TABULATE      5             RECORD SERVICE TIME DIST OF CHECKERS
        SELECTMIN     5,5,10,,Q     SELECT SHORTEST QUEUE FOR PAYMENT
        MARK          4
        QUEUE         *5            JOIN QUEUE FOR PAYMENT
        SEIZE         *5            SEIZE CASHIER FOR SERVICE
        DEPART        *5            LEAVE SERVICE QUEUE
        TABULATE      4             RECORD WAITING TIMES
        MARK          10
        ADVANCE       1,FN3         GENERATE NORMAL SERVICE TIME
        RELEASE       *5            RELEASE SERVICE FACILITY
        TABULATE      6             RECORD SERVICE TIME DIST OF CASHIERS
```

```
START      1500,NP    RUN FOR 15 MINUTES NO PRINTOUT
RESET
START      12CCO      RUN FOR 2 HCURS
CLEAR
START      12000      RUN FOR 2 HCURS
END
```

APPENDIX C

This appendix includes the simulation output of model 2 (for 4 checker-cum-cashiers), and model 3 (for 4 checkers and 6 cashiers).

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ACILITY	AVERAGE UTILIZATION	NUMBER ENTRIES
1	.988	814
2	.934	767
3	.814	676
4	.617	501

STATISTICS OF QUEUES

UEUE	MAXIMUM CONTENTS	TOTAL ENTRIES	AVERAGE TIME/TRANS
1	6	814	17.813
2	6	766	15.032
3	6	675	13.025
4	6	500	12.805

TABLE TO RECORD INTERARRIVAL TIMES

NTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
2753	4.359	4.[illegible]32

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0	556	20.19	20.1
2	721	26.18	46.3
4	489	17.76	64.1
6	328	11.91	76.0
8	239	8.68	84.7
10	131	4.75	89.5
12	81	2.94	92.4
14	83	3.01	95.4
16	40	1.45	96.9
18	27	.98	97.8
20	22	.79	98.6
22	12	.43	99.1
24	10	.36	99.4
26	4	.14	99.6
28	5	.18	99.8
30	3	.10	99.9
32	2	.07	100.0

EMAINING FREQUENCIES ARE ALL ZERO

TABLE TO RECORD TIME BETWEEN DEPARTURES

NTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
2757	4.352	3.585

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0	237	8.59	8.5
2	810	29.37	37.9
4	591	21.43	59.4
6	461	16.72	76.1
8	300	10.88	87.0
10	185	6.71	93.7
12	108	3.91	97.6
14	30	1.08	98.7
16	18	.65	99.3
18	4	.14	99.5
20	6	.21	99.7
22	3	.10	99.8
24	2	.07	99.9
26	0	.00	99.9
28	1	.03	99.9
30	1	.03	100.0

EMAINING FREQUENCIES ARE ALL ZERO

TABLE TO RECORD WAITING TIMES

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
2754	14.969	13.074

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0	394	14.30	14.3
4	179	6.49	20.8
8	304	11.03	31.8
12	468	16.99	48.8
16	437	15.86	64.7
20	310	11.25	75.9
24	190	6.89	82.8
28	134	4.86	87.7
32	89	3.23	90.9
36	71	2.57	93.5
40	42	1.52	95.0
44	32	1.16	96.2
48	29	1.05	97.2
52	15	.54	97.8
56	15	.54	98.3
60	14	.50	98.8
64	8	.29	99.1
68	4	.14	99.3
72	8	.29	99.6
76	4	.14	99.7
80	3	.10	99.8
84	3	.10	99.9
88	1	.03	100.0

REMAINING FREQUENCIES ARE ALL ZERO

TABLE TO RECORD SERVICE TIMES

NTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
2757	14.607	4.343

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
4	0	.00	.0
6	98	3.55	3.5
8	135	4.89	8.4
10	265	9.61	18.0
12	424	15.37	33.4
14	446	16.17	49.6
16	421	15.27	64.8
18	463	16.79	81.6
20	261	9.46	91.1
22	140	5.07	96.2
24	75	2.72	98.9
26	17	.61	99.5
28	12	.43	100.0

EMAINING FREQUENCIES ARE ALL ZERO

UTILIZATION OF CHECKERS

ACILITY	AVERAGE UTILIZATION	NUMBER ENTRIES
1	.988	812
2	.935	768
3	.803	656
4	.593	491

UTILIZATION OF CASHIERS

ACILITY	AVERAGE UTILIZATION	NUMBER ENTRIES
5	.997	565
6	.988	589
7	.938	548
8	.852	481
9	.609	355
10	.316	192

STATISTICS OF QUEUES

UEUE	MAXIMUM CONTENTS	TOTAL ENTRIES	AVERAGE TIME/TRANS
1	6	811	17.056
2	5	767	14.392
3	5	655	12.728
4	5	491	11.995
5	2	565	18.129
6	2	589	15.584
7	1	548	14.290
8	1	480	12.714
9	1	355	10.019
10	1	192	5.786

TABLE TO RECORD INTERARRIVAL TIMES

NTRIES IN TABLE		MEAN ARGUMENT	STANDARD DEVIATION
2723		4.461	4.878
UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0	544	19.97	19.9
2	723	26.55	46.5
4	468	17.18	63.7
6	327	12.00	75.7
8	237	8.70	84.4
10	127	4.66	89.0
12	83	3.04	92.1
14	90	3.30	95.4
16	37	1.35	96.8
18	30	1.10	97.9
20	19	.69	98.6
22	14	.51	99.1
24	8	.29	99.4
26	6	.22	99.6
28	5	.18	99.8
30	3	.11	99.9
32	0	.00	99.9
34	2	.07	100.0

EMAINING FREQUENCIES ARE ALL ZERO

TABLE TO RECORD TIME BETWEEN DEPARTURES

ITRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
2726	4.402	4.03[illegible]

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0	254	9.31	9.3
2	880	32.28	41.5
4	560	20.54	62.1
6	389	14.26	76.4
8	241	8.84	85.2
10	161	5.90	91.1
12	108	3.96	95.1
14	60	2.20	97.3
16	39	1.43	98.7
18	14	.51	99.2
20	3	.11	99.3
22	9	.33	99.7
24	2	.07	99.7
26	2	.07	99.8
28	1	.03	99.8
30	2	.07	99.9
32	0	.00	99.9
34	1	.03	100.0

EMAINING FREQUENCIES ARE ALL ZERO

TABLE TC RECORD WAITING TIMES AT CHECKER COUNTERS

NTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
2724	14.354	12.414

UPPER LIMIT	OBSERVED FRECUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0	412	15.12	15.1
4	186	6.82	21.9
8	313	11.49	33.4
12	445	16.33	49.7
16	438	16.07	65.6
20	333	12.22	78.0
24	162	5.94	84.0
28	125	4.58	88.6
32	92	3.37	91.9
36	66	2.42	94.4
40	41	1.50	95.9
44	34	1.24	97.1
48	18	.66	97.8
52	14	.51	98.3
56	11	.40	98.7
60	10	.36	99.1
64	5	.18	99.3
68	5	.18	99.4
72	7	.25	99.7
76	4	.14	99.8
80	2	.07	99.9
84	0	.00	99.9
88	1	.03	100.0

EMAINING FREQUENCIES ARE ALL ZERO

TABLE TO RECORD WAITING TIMES AT CASHIER COUNTERS

NTRIES IN TABLE	MEAN ARGUMENT		STANDARD DEVIATION
2726	13.940		9.253
UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0	411	15.07	15.0
4	140	5.13	20.2
8	257	9.42	29.6
12	353	12.94	42.5
16	441	16.17	58.7
20	429	15.73	74.5
24	341	12.50	87.0
28	203	7.44	94.4
32	105	3.85	98.3
36	32	1.17	99.4
40	12	.44	99.9
44	1	.03	99.9
48	0	.00	99.9
52	1	.03	100.0

EMAINING FREQUENCIES ARE ALL ZERO

TABLE TO RECORD SERVICE TIMES OF CHECKERS

NTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
2726	14.617	4.347

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
6	97	3.55	3.5
8	132	4.84	8.4
10	262	9.61	18.0
12	421	15.44	33.4
14	437	16.03	49.4
16	418	15.33	64.8
18	457	16.76	81.5
20	260	9.53	91.1
22	138	5.06	96.1
24	75	2.75	98.9
26	17	.62	99.5
28	12	.44	100.0

EMAINING FREQUENCIES ARE ALL ZERO

TABLE TO RECORD SERVICE TIMES OF CASHIERS

NTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
2726	20.690	7.007

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
6	0	.00	.0
8	139	5.09	5.0
10	84	3.08	8.1
12	130	4.76	12.9
14	181	6.63	19.5
16	214	7.85	27.4
18	280	10.27	37.7
20	320	11.73	49.4
22	304	11.15	60.6
24	264	9.68	70.2
26	265	9.72	80.0
28	175	6.41	86.4
30	136	4.98	91.4
32	103	3.77	95.1
34	56	2.05	97.2
36	42	1.54	98.7
38	14	.51	99.3
40	9	.33	99.6
42	10	.36	100.0

EMAINING FREQUENCIES ARE ALL ZERO

A STUDY OF A CAFETERIA SYSTEM
USING DIGITAL SIMULATION

by

VED PARKASH AGGARWAL

B.E. (Mechanical Engineering),

Punjab University, Punjab, India, 1963

AN ABSTRACT OF A MASTER'S THESIS

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requirements for the degree

MASTER OF SCIENCE

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KANSAS STATE UNIVERSITY

Manhattan, Kansas

1970

This thesis is concerned with the development of a computer model of cafeteria system used for the optimization of checkout stations for future designs. Necessary data consisting of service times for checkout operations were collected. A day of cafeteria operation was divided into four periods; each period representing a model. GPSS (General Purpose Simulation System) was used as a simulation language; which is efficient and easy to apply to the waiting line problem.

Models 1 (7:30 - 9:30 A.M.), 2 (9:30 - 11:30 A.M.) and 4 (1:30 - 4:00 P.M.) are simulated when both the operations of, checking and cashing are combined, and model 3 (11:30 - 1:30 P.M.) is simulated when both the operations are separate. Two iterations for each run were made under varying numbers of checkout stations keeping the service time and inter-arrival time parameters constant.

Variations in the service time distribution and inter-arrival distribution were incorporated to study the effects on the mean waiting time, desired performance level, utilization, and time between departures. It was determined that by using 4 checker stations and 6 cashier stations for the peak load period (11:30 - 1:30 P.M.), an additional arrival load of 12.1% can be accomodated. But after the critical load, any increase in arrival load will considerably lower the desired performance level.