A MODEL TO DETERMINE SERVICE FACILITY REQUIREMENTS

by

CHARLES ROBERT REDDEN
B.S. University of British Columbia, 1970

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN BUISNESS ADMINISTRATION

in the Faculty of

Commerce

We accept this thesis as conforming to the
required standard

UNIVERSITY OF BRITISH COLUMBIA

January, 1975

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Management Science

The University of British Columbia
Vancouver 8, Canada

Date Jan 31/75

ABSTRACT

Credit unions have difficulty in estimating the facility requirements which will enable them to provide adequate member service. Due to the recent growth in membership, most credit unions have had to enlarge their facility to one which would adequately accommodate the present membership as well as provide for expected future growth in operations. The high cost of expansion has made it necessary to accurately determine their facility requirements. B. C. Central Credit Union, a service centre which provides professional assistance to credit unions and co-operatives throughout British Columbia, was concerned with the solution of this problem and first looked to how other organizations tried to solve their facility planning problems.

A number of organizations have developed, or attempted to develop, facility planning models. Some have resulted in complete failure and have been abandoned. Others could not answer enough of the questions that credit union managers needed to know about their facility requirements.

The management of B. C. Central Credit Union decided to acquire the services of the author for the purpose of designing and implementing a facility planning model.

After a preliminary investigation of the problem and discussions with credit union managers, it was decided that a simulation model would be the most appropriate management tool to use.

The scope of the project was to develop and implement a simulation model to accurately determine present and future teller facility requirements (wickets and queuing area) which will enable a credit union to provide adequate member service.

The teller facility is simulated under varying conditions to determine the required number of wickets and queuing area for a given credit union.

It is shown that the model is sensitive to the approximation of the teller service time distribution and the method of data collection on member arrivals. A credit union's teller facility requirements as well as the level of service are shown to be very dependent on the operating policy to regulate the number of wickets which are available.

At present, two credit unions have benefited considerably from the simulation model. In both cases, the management of the credit union had decided to build a new enlarged facility because the existing credit union could not adequately accommodate its members. The simulation model showed that only a change in the facility layout was required. The credit unions reversed their decision to build a new facility and simply changed the layout. Both are presently operating effectively with the new layout and have avoided the expense of a new building.

Table of Contents

Table of Contents

1. BACKGROUND

Due to recent growth in membership most credit unions have had a significant increase in the demand made on their facility. This increase in the demand has forced many credit unions to enlarge their facility. The high cost of expansion has made it necessary to accurately determine the facility requirements and the continuing growth rate has made it necessary to project the future requirements for the different operations in order to assure that the facility will be adequate for at least 3 - 5 years.

2. SCOPE

The purpose of this paper is to develop a simulation model to accurately determine present and future teller facility requirements (wickets and queuing area) which will enable the credit union to provide adequate member service.

3. DATA COLLECTION

Data from 3 major credit unions* was collected so that the queuing discipline, service process and arrival pattern could be adequately described within the model.

* Richmond Savings Credit Union, Prince George & District Credit Union, and Campbell River District Credit Union.

3. DATA COLLECTION (continued)

The environment of the credit union which the simulation model is concerned with is described in Figure 1.

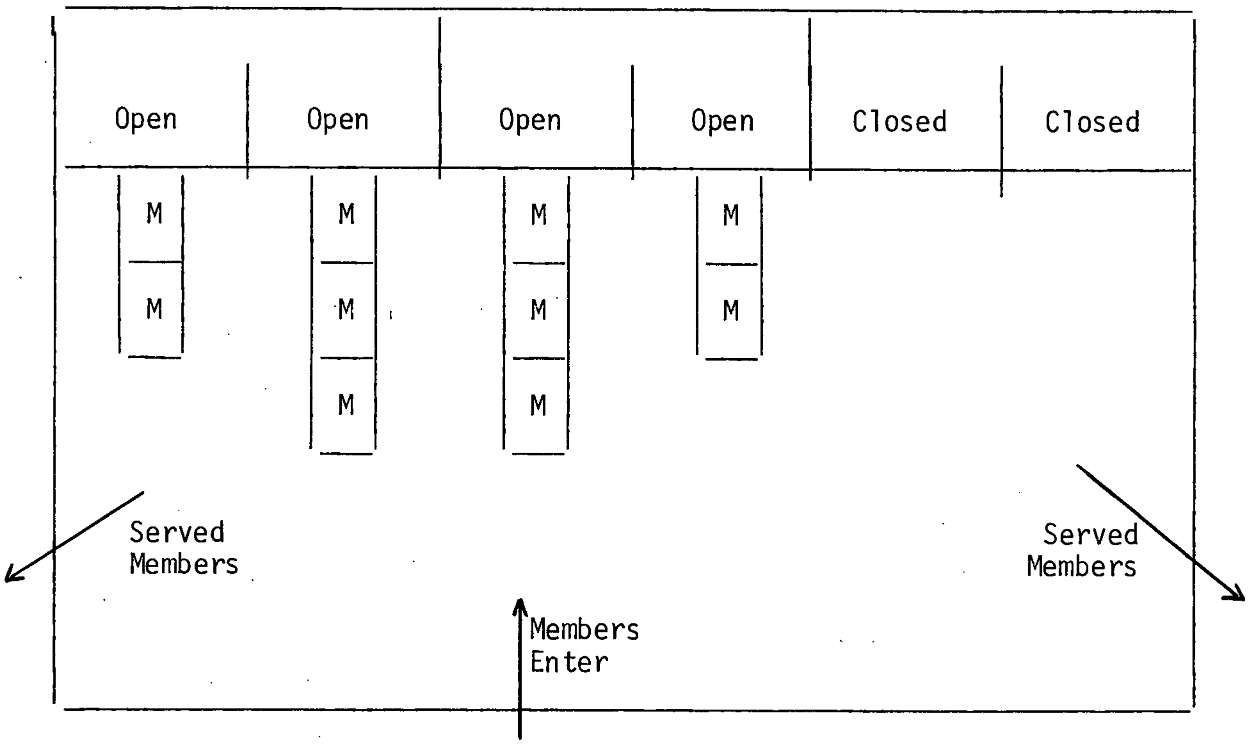


Figure 1

As shown in figure 1, members enter the system and join one of several queues. Service is performed in a FIFO discipline and then the member leaves the system. The number of available wickets depends on the present demand being made on the teller facility.

3. DATA COLLECTION (continued)

3.1 The queuing discipline

In the three credit unions* the multiple queuing discipline was used. However, from observing the real life situation, the FIFO operating characteristic is effectively maintained with respect to the total number of members waiting for service, since members tend to jockey for position between the several queues. Since the capacity of the queuing area is determined by the number of members waiting for service, the FIFO queuing discipline is used in the simulation model.

3.2 The service process

In those credit unions, tellers perform only simple services (e.g. cash withdrawals, deposits). When a member requires other types of service (e.g. general information about his account, traveller's cheques) he is serviced by other personnel.

The service time is the time required by a teller to serve an individual member. Since the service times vary stochastically, it is

*Richmond Savings Credit Union, Prince George & District Credit Union and Campbell River District Credit Union.

3.2 The service process (continued)

necessary to describe them by a probabilty distribution. Before estimating this distribution, it was necessary to make two assumptions. The first assumption is that all tellers have the same service rate distribution with equal means. The second assumption is that the distribution of service rates and the mean is not significantly different within or between days.

The data was collected during a continuous period of the operating day when the system was moderately busy (all wickets open and 1 - 3 members waiting at each wicket). The main reason for collecting data during this period was to insure that an accurate estimate of the set-up time was included (i.e. that interval when the teller has finished servicing the member but not his transaction).

An extensive amount of data was collected from Richmond Savings Credit Union. It was thought that if a large amount of data was collected, not only would the distribution function be accurately described, but tests could be applied to determine whether a theoretical distribution could provide a statistically "good fit" to the empirical distribution.

It was hypothesized that the distribution of service times could be approximated by a theoretical distribution (e.g. exponential distribution). A statistical test (1) of a sample of 375 service times was performed to determine the "goodness of fit" of the test data to 7

3.2 The service process (continued)

theoretical distributions. (See Table 1.)

Table 1

GOODNESS OF FIT TESTS FOR SERVICE RATES

DISTRIBUTION	X^2	X Prob
Normal	164.0	0.00
Poisson	Very large	Very small
Binomial	Very large	Very small
Negative Binomial	Very large	Very small
Gamma	41.0	0.00
Lognormal	15.5	0.21
Exponential	122.0	0.00

Table 1 shows that the service rates cannot be approximated by any of the above common theoretical distributions. For this reason, the service process is described in the simulation model by an estimate of the empirical distribution.

3.3 The arrival pattern

From direct observation, it was apparent that the member arrival rate varied within and between days. It is difficult to accurately des-

3.3 The arrival pattern (continued)

cribe the arrival pattern for any given day because the member arrival rate during the day is dependent on many factors not controlled by the credit union. For this reason, in order to simulate the arrival pattern for a given day and to simulate the expected variation in the arrival rate for similar such operating days the following data collection strategy was used.

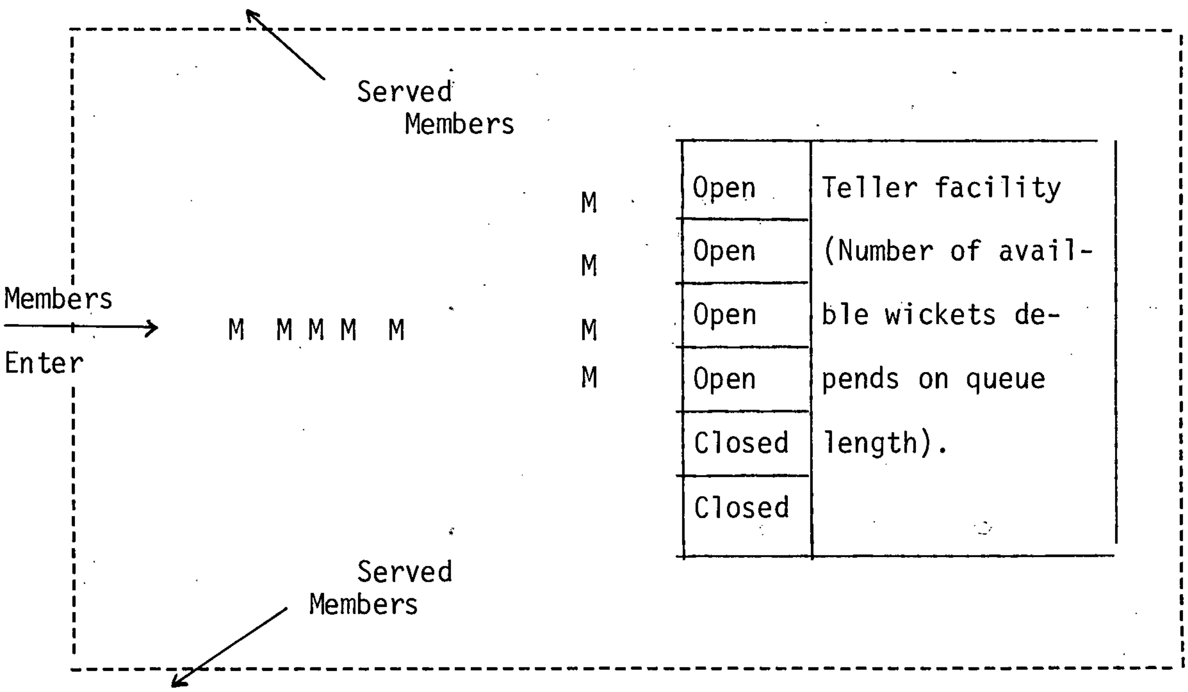
Data was collected on member arrivals by recording the number of members that enter the credit union to use the teller facility during each 15 minute period of operating day. The time dependent arrivals input to the simulation would then be this recorded frequency distribution which would represent the expected number of arrivals for the corresponding time period. Since the credit union has no direct control over the interarrival rates within such a short interval they were assumed to be completely random. More formally, it is assumed that the time of the next arrival is independent of the previous arrival, and the probability of arrival in an interval Δt is proportional to t . Thus, to a given interval the inter-arrival rates were assumed to be exponentially distributed about the recorded mean.

4. METHOD

4.1 Basic Structure

A computer model, programmed in the simulation language GPSSV, was developed to simulate the behavior of the above system (for a complete documentation, see Appendix 2).
The queuing system which the model had to describe is seen below.

Figure 1 - Queuing System



As shown in Figure 1, members enter the system and join a single queue. Service is performed in a FIFO discipline and then the member leaves the system. The number of available wickets depends on the present demand being made on the teller facility. In the above

4.1 Basic Structure (Continued)

system, the maximum number of wickets which could be made available is 6.

4.2 Model Input and Output

4.2.1 Model Input

To determine the facility requirements for a given credit union, the following information is input to the simulation model:

(i) The level of service the manager wishes to provide his members (which is defined in terms of the distribution of waiting time and the distribution of queue length).

(ii) The distribution of teller service times and the member arrival distribution from a maximum (peak) load condition.

(iii) Any physical contraints (e.g. area or the maximum number of wickets).

4.2.2 Model Output

The facility requirements can then be determined by evaluating the following output from the simulation:

(i) Frequency distribution of the member waiting time.

(ii) Frequency distribution of the number of members waiting in the system.

(iii) Frequency distribution of the queue length per available wicket.

4.2.2 Model Output (Continued)

(iv) Frequency distribution of the number of wickets utilized.

(v) Histogram of the average number of tellers utilized as a function of the time of day.

(vi) Histogram of the average number of members waiting per available wicket as a function of the time of day.

(vii) Histogram of the average number of member arrivals as a function of the time of day.

4.3 Method of Projection

It is important to estimate the teller facility requirements for a specified level of growth, so that the credit union can be prepared for the expected increase in demand. This model does not forecast when a certain level of growth will occur, but rather it shows the effect the increased demand will have on the future teller facility requirements.

Since there is no information available on the previous arrival rates the future peak loan conditions are approximated by increasing the mean arrival rate for each interval. For example, in order to estimate the facility requirements for a 40% increase in the demand, the mean arrival rate for each 15 minute interval would be increased by 40%. Since the arrival rates are assumed to be exponentially distributed, increasing the mean arrival rate for each interval will

4.3 Method of Projection (Continued)

automatically increase the corresponding variance of each interval by the appropriate amount.

5. SERVICE POLICY

5.1 Introduction

For a given queuing discipline, service process and arrival pattern, the two major factors which affect the member service and teller utilization are:

(i) The operating policy to regulate the number of wickets which are available for service (i.e. opening/closing wickets). This policy would be used to maintain an adequate balance between the level of service to the members and the teller utilization (since when a teller's wicket is closed she is free to perform other duties).

(ii) The physical limitations of the credit union in terms of the number of wickets and queuing area available.

Since the main purpose of this model is to define the facility requirements for a credit union that intends to change its physical limitation (i.e. expand), the existing physical constraints are not normally part of the model input. The service policy is then one of the major concerns which must be well defined and input to the model before the system behavior can be accurately described.

5.2 Policy Development

The operating policy of the model should either reflect existing operating policy by management, or improve on their policy, yet be simple enough for management to implement into their operations.
In general, the desired balance between teller utilization and level of service to the member differs between credit managers. For this reason, the policy utilized by the simulation must be flexible enough to adapt to the different credit union manager's requirements. (e.g. one manager may tolerate only very small queues, while another may not concern himself with the size of the queue).
The policy could either be formulated in terms of waiting time or queue length. Since the policy should be easy for management to implement into their own credit union, a policy formulated in terms of queue length is more practical.

5.3 Policy Formulation

Let the following notation be used to formulate the service policy:

Parameters

(1) (Y_1, Y_2) = range of acceptable queue length/available wicket

(2) (S_1, S_2) = minimum, maximum number of wickets which can be made available.

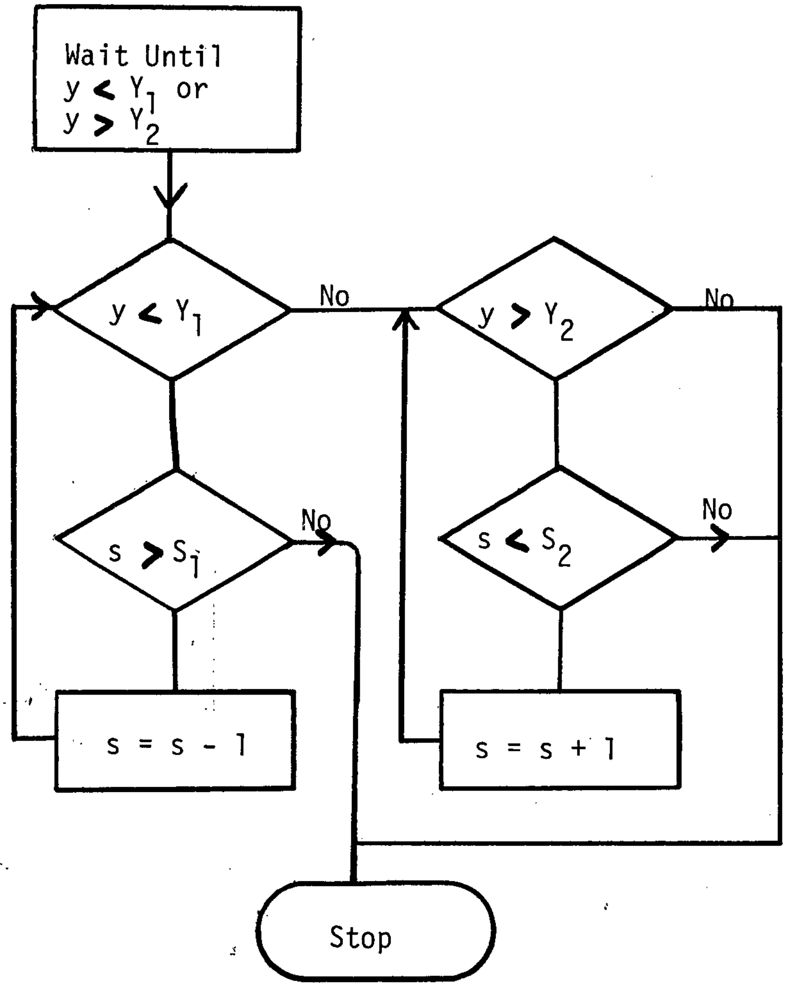
5.3 Policy Formulation (Continued)

Variables

(1) y = queue length/available wicket

(2) s = number of available wickets

Policy to increase/decrease the number of wickets.



6. COMPUTER PROGRAM

The simulation was formulated in the programming language GPSSV. This language is especially suitable for handling queuing problems and appeared most suitable for the problem in question. (For a complete documentation, see Appendix 2.)

Model Statistics

Statements - 680 lines

Core required - 15000 bytes

GPSS Entity option - B

Compile time - .09 minutes

CPU time - 6.37 minutes on IBM 360/67

Page printed - 40

7. STEADY STATE AND SENSITIVITY ANALYSIS

7.1 Introduction

In order to test for the sensitivity to parameter changes and determine when steady state conditions occur it was necessary to input some test data. Since a large volume of data had been collected on the arrival rate distribution, it was decided to select the test data which represented one full operating day and contained a high degree

7.1 Introduction (Continued)

of variation between adjacent time periods. The arrival rate distribution was then transformed to represent the arrival rate from a large credit union with a high degree of variablility in the member arrival rate, This was accomplished by increasing the mean arrival rate for each interval by 50%. Thus the data on arrival rates would represent a large credit union (where in particular the facility requirements are more difficult to determine), with a high degree of variation in the arrival rate.

It was assumed that if the model performed well under these conditions then it would perform at least as well under more normal circumstances.

7.2 Steady State Analysis

7.2.1 General

Before steady state conditions could be determined, it was necessary to gather information on the statistics of interest. The following sequence describes the method:

1) simulate the data for one complete cycle
2) record the values of the necessary statistics
3a)if the predetermined number of cycles have been run - stop
3b)otherwise destroy all cumulative statistics and return to step 1 with a different point in the random number* stream.

* The GPSSV compiler uses a multiplicative congruential method for generating random numbers with a period equal to $2^{31} - 1$.

7.2.1 General (Continued)

Since the simulation used a policy decision which attempted to maintain an adequate balance between teller utilization and level of service to the members it was evident that the distribution of waiting time and queue length would be significantly skewed in an upward direction. However, it was hypothesized that distribution of the statistics of interest (average waiting time, average queue length per available wicket) could be closely approximated by a normal distribution.

A statistical analysis (1) of a sample of 100 of each of the above statistics was performed to determine the "goodness of fit" of the test data to hypothetical distributions. (See Table 2.)

Table 2

Goodness of Fit Tests for Sample Statistics

	STATISTIC					
DISTRIBUTION	AVERAGE WAITING TIME		AVERAGE QUEUE LENGTH		MAXIMUM QUEUE LENGTH	
	X^2	Prob	X^2	Prob	X^2	Prob
Normal	3.76	0.81	3.98	0.86	4.87	0.77
Poisson	34.83	0.00	13.44	0.10	43.34	0.00
Binomial	87.02	0.00	62.34	0.00	89.29	0.00
Negative Binomial	5.81	0.67	1.36	0.99	10.24	0.18
Gamma	7.76	0.35	1.71	0.97	4.68	0.70
Lognormal	6.49	0.48	1.34	0.99	5.37	0.61
Exponential	Very Large	Very Small	Very Large	Very Small	Very Large	Very Small

7.2.1 General (Continued)

As shown in Table 2, the three distributions of the sample statistics provided a statistically good fit to the normal distribution. Therefore, statistical testing on the three values involving normality assumptions could be used.

7.2.2 Run Length to Determine the Number of Wickets Required

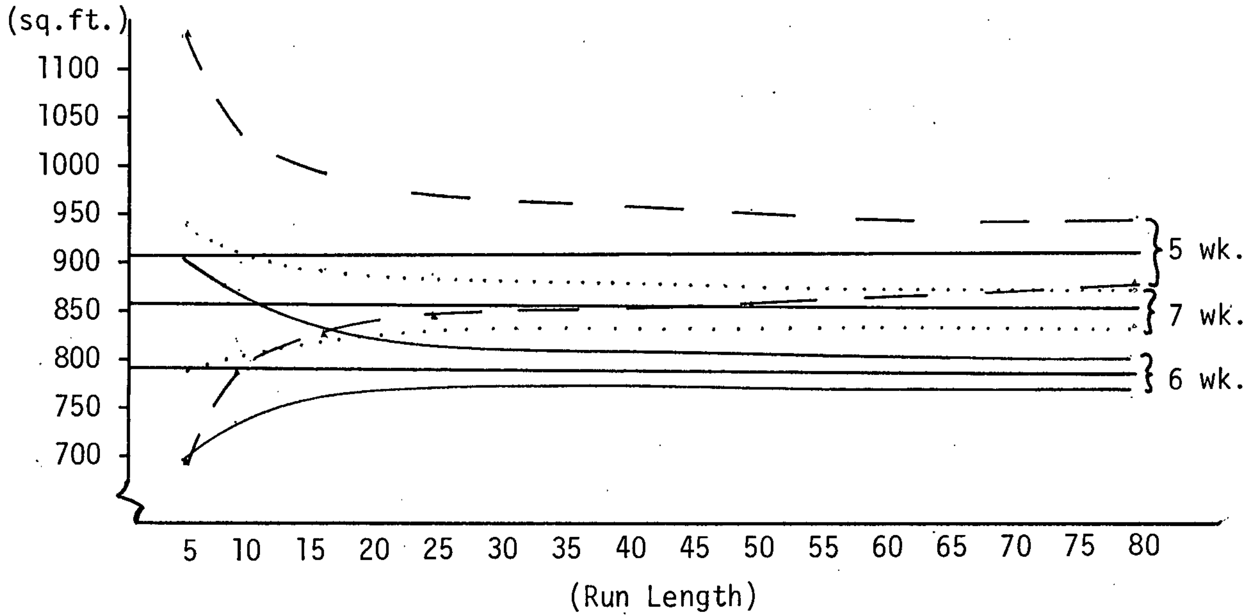
For the simulation to aid in defining the teller facility requirements for a given policy, it is essential to have reliable information on the area requirements as well as the level of service. Since the area requirements and the level of service are both dependent on the maximum number of available wickets S2, the area requirements and level of service for each case can be objectively compared.
One of the major problems of simulation experiments is determining the length of the simulation run. In this simulation model, the computing cost of simulating a run of length one (equivalent to one operating day) is $1.50. Therefore, if this model is to be of practical use, the run length must be kept to a minimum. It is of interest to observe the estimates of the queuing are required for different S2 as the length of the simulation increases. This will serve to answer two major questions:

1) What is the run length required to determine the number of wickets which will minimize the area required?
2) What is the run length required to determine the minimum area required?

7.2.2 <u>Run Length to Determine the Number of Wickets Required</u> (Cont.)

Figure 2 shows the relationship between the run length and the estimation of the area required for the teller facility as a function of the maximum number of available wickets. The number of wickets determines the width of the teller facility and the maximum queue length per available wicket determines the depth. Additional wickets reduce the maximum queue length, and thus the required depth of the teller facility. However, each additional wicket also increases the required width by a fixed amount*. Therefore, it is possible to minimize the total area required for the teller facility.

Figure 2 The Relationship Between the Area Required and Run Length



* The dimensions of a teller's wicket are 5½ ft. x 7½ ft.

7.2.2 Run Length to Determine the Number of Wickets Required (Cont.)

It would appear from Figure 2, that a minimum run length of 20 days simlation is required in order to determine the number of wickets which will minimize the area required and run length of 30 is required to determine the minimum area required.

7.2.3 Run Length Required to Estimate the Level of Service

It was of interest to determine the effect of run length on the estimate of the level of service. A confidence interval for the mean waiting time in the queue was determined for the different S2. Since the normality assumptions were satisfied, a confidence interval for the different means could be instructed (See figure 3), from the assumption that:

$$\text{Prob}\left(\mu_i - t_{\alpha,\nu_i}\sigma_{\bar{x}_i} \leq \bar{x}_i \leq \mu_i + t_{\alpha,\nu_i}\sigma_{\bar{x}_i}\right) \geq 1-\alpha$$

where $\bar{x}_i = \sum_{j=1}^{n_i} \frac{x_j}{n_i}$ = sample mean

$\mu_i \approx \hat{\mu}_i = \sum_{j=1}^{N_i} \frac{x_j}{N_i}$ = population mean

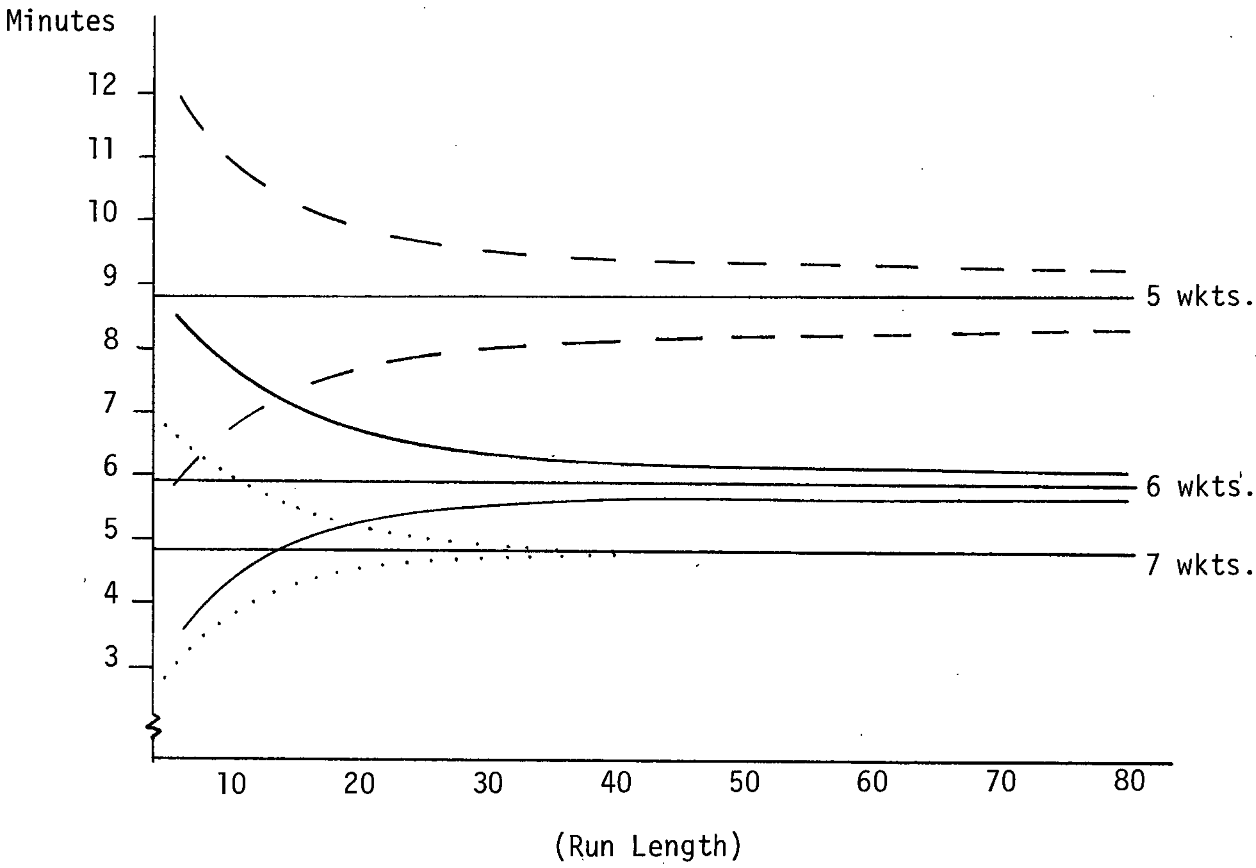
$\sigma_i^2 = \hat{\sigma}_i^2 = \sum_{j=1}^{N_i} \frac{(x_i - \hat{\mu}_i)^2}{N_i - 1}$ = population variance

$\sigma_{\bar{x}_i}^2 \approx \frac{\hat{\sigma}_i^2}{n_i}$ = sample variance of the mean

$\nu_i = n_i - 1$ = degrees of freedom

A 95% confidence interval was constructed for the average waiting time as a function of the run length of the simulation. Figure 3 shows confidence intervals when S2 = 5, 6, and 7 wickets.

7.2.2 Run Length required to Estimate the Level of Service (Cont.)



It would appear from Figure 3, that a simulation of run length equal to 20 is sufficient for estimating the level of service.

7.3 Sensitivity Analysis

7.3.1 General

It was essential to measure the effect of parameter changes to the service policy, the method of estimating the distribution of service times

7.3.1 General (Continued)

and the method of estimating the arrival rates on the system behavior. After the effects were evaluated for a full range of reasonable conditions, the decision maker could then select that set of parameter values which best suited his definition of an adequate level of service, as well as determining the method of estimating the above distribution. The evaluations were performed with the identical random number stream in order to achieve the above.

7.3.2 Parameter Changes to the Service Policy

(i) S = The number of available wickets.

There is some argument as to the minimum number of wickets (S1), which should be available at all times. Clearly, there must be at least one wicket open but apparently not more than 2 wickets. Consequently, the values of S1 = 1 and S1 = 2 were included in the analysis. The maximum number of available wickets (S2) is a physical constraint rather than a parameter for the service policy. From other analysis (See Appendix 1), the value of S2 = 7 is certainly the maximum number of wickets that this particular credit union requires. Table 3 shows that the distribution of waiting is generally insensitive to the above values of S1. If the upper portion of the distribution (the 95 - 99 percentiles) are compared for any fixed Y2, then the differences are very slight. Table 4 shows that the distribution of queue length corresponding to the 99 percentile is not sensitive to the value of S1.

7.3.2 <u>Parameter Changes to the Service Policy</u> (Continued)

Table 3

The relationship between the distribution of waiting time in the queue and decision policy.

X = Waiting Time In Queue (Minutes)	S1 = Minimum Number of Wickets: 1				S1 = Minimum Number of Wickets: 2			
	Y2 = Policy to Increase Tellers				Y2 = Policy to Increase Tellers			
	2	3	4	5	2	3	4	5
≤ 2	44.0	23.5	16.9	13.0	46.7	28.0	21.1	18.3
≤ 4	87.0	59.5	39.2	29.2	86.9	61.3	41.2	34.0
≤ 6	95.7	88.9	69.8	50.9	95.7	89.5	69.9	54.2
≤ 8	98.2	96.2	90.5	76.4	98.0	96.4	90.5	77.1
≤10	99.5	98.5	96.5	92.7	99.3	98.4	96.4	92.6
≤12	99.9	99.5	98.6	97.0	99.8	99.5	98.6	97.3
≤14	100	99.9	99.6	98.8	100	99.9	99.6	99.1
≤16	100	100	99.9	99.7	100	100	99.9	99.8
≤18	100	100	100	100	100	100	100	100
≤20	100	100	100	100	100	100	100	100

All values inside the array are cumulative percentages for the corresponding column.

Table 3 shows the relationship between the distribution of waiting time in the queue and the decision policy. The shaded area represents that region of major concern to credit union management. That is, their interpretation of the maximum waiting time in the queue. (95 - 99 percentile).

7.3.2 Parameter changes to the Service Policy (Continued)

Table 4

The relationship between the distribution of queue length per available wicket and decision policy.

Y = Queue Length Per Wicket (Members)	S1 = Minimum Number of Tellers							
	1				2			
	Y2 = Policy to Increase Tellers				Y2 = Policy to Increase Tellers			
	2	3	4	5	2	3	4	5
≤ 1	4.6	3.3	2.6	2.2	9.6	7.3	6.0	5.3
≤ 2	38.9	21.7	17.0	13.7	44.5	28.8	22.2	19.6
≤ 3	85.5	55.0	37.2	29.1	86.7	58.9	42.0	36.7
≤ 4	96.0	89.4	64.7	48.5	96.3	90.4	66.9	53.7
≤ 5	98.7	86.7	91.1	72.7	98.9	97.1	92.0	74.5
≤ 6	99.8	99.1	97.4	92.9	99.8	99.2	97.7	93.7
≤ 7	99.9	99.8	99.4	98.2	100	99.9	99.5	98.8
≤ 8	99.9	99.9	99.9	99.7	100	100	99.9	99.8
≤ 9	100	100	99.9	99.9	100	100	100	100
≤ 10	100	100	100	100	100	100	100	100
≤ 11	100	100	100	100	100	100	100	100
≤ 12	100	100	100	100	100	100	100	100

All values inside the array are cumulative percentages for the corresponding column.

Table 4 above shows the relationship between the distribution of queue length per available wicket and decision policy. The underlined values represent that region of major concern to credit union management (i.e.

7.3.2 Parameter Changes to the Service Policy (Continued)

the 99 percentile).

When analysing the distribution of queue length, the sensitivity analysis of the decision policy by varying the policy parameters serves a different purpose from the analysis of the distribution of waiting time. Whereas the distribution of waiting time is considered a measure of the level of service given to members, the distribution of queue length is also a measure of the system requirements in terms of the queuing area required.
The queuing area required is generally defined to be that area which will adequately accommodate 99% of the members. Since the multi-queue discipline is practised and in general the queuing area is rectangular in shape, a system designed to accommodate a maximum queue/available wicket of 10 members will require twice the queuing area that a system designed to serve a maximum queue/available wicket of 5 members.

(ii) Y = The acceptable queue length/available wicket

The minimum acceptable queue length (Y1) of one appears, in general, to be agreed upon. That is, a wicket is closed if the teller is idle. The maximum acceptable queue length (Y2) appears to differ considerably among management. In order to accommodate most styles of management the values of Y2 = 2, 3, 4, and 5 were included in the analysis.

7.3.2 Parameter Changes to the Service Policy (Continued)

Tables 3 and 4 show the sensitivity of the distribution of waiting time and queue length to the above values of Y2. Since the mean service time is approximately 2.2 minutes, it is not surprising that for increasing values of Y2 the distributions would shift upwards in this manner.

7.3.3 The Distribution of Service Times

It was of interest to examine the difference between the statistics on the level of service and the estimated requirements when the service rate distribution was approximated by the expotential distribution vs the empirical distribution. (See Table 5.)

Table 5

The sensitivity of service rate distribution on the statistical output.

Distribution	Statistic: Level of Service — Average Waiting Time (Min.)	Statistic: Level of Service — Average Queue Length (Members)	Statistic: Level of Service — Maximum Queue Length (Members)	Area Requirements (sq.ft.)
Empirical	5.86	4.02	9.6	1125
Exponential	5.04	3.79	9.6	1125

7.3.3 The Distribution of Service Times (Continued)

Table 5 shows that the exponential distribution tends to underestimate the average waiting time in the queue and to a lesser degree the average queue length per available wicket. This is caused because the variance for the exponential distribution is less than the variance of the empirical distribution. However, there is no difference in the maximum queue length per available wicket (and hence the estimated area requirements). This indicates that these statistics are primarily a function of operational policy and not on the distribution of the service rates.

It should be noted in some environments where the tellers perform other time consuming duties (e.g. providing general information about the members account, issuing travellers cheques, etc.) the variance of the teller service rates would be much greater. The exponential distribution would then underestimate the average waiting time to a much greater degree.

7.3.4 The Distribution of Arrival Rates

The system behavior with respect to waiting time in the queue and queue length during the operating day is clearly a function of the variability* of the arrival rate distribution.

* For example see Hillier and Lieberman, p. 301.

7.3.4 The Distribution of Arrival Rates (Continued)

This model assumes that for short enough intervals the arrival rate can be considered exponentially distributed about the mean. In this manner the arrival rate distribution can be considered as exponentially distributed with the mean varying over time. In order to estimate the effect of the interval length on the output of the simulation, it was decided to simulate the data under identical conditions. (e.g. the same random number stream) with one exception. That is the estimated average waiting time, queue length and area requirements for the teller facility were compared for different interval lengths. (See Table 6.)

Table 6

The sensitivity of the estimates of area requirements and the level of service to the interval length between successive data collections on member arrivals.

Interval Length (Minutes)	Area Requirements (sq.ft.)	Level of Service		
		Average Waiting Time (Minutes)	Average Queue Length (Members)	Maximum Queue Length (Members)
15	880	5.86	4.02	9.6
30	790	5.40	3.74	8.2
45	710	4.80	3.49	7.0
60	700	4.90	3.54	6.8
75	620	4.55	3.38	5.6

7.3.4 The Distribution of Arrival Rates (Continued)

Table 6 shows that both the required area estimates and the level of service estimates are sensitive to the method of estimating the distribution of member arrivals. The longer intervals (and thus fewer of them) reduce the natural variation of the time dependent arrivals. This causes an averaging effect (smoothing the peaks and troughs) of the queue length which would result in understating the area requirements, as well as overestimating the level of service.

8. VERIFICATION

In order to verify the simulation model in a practical situation, the present and future teller facility requirements were determined for Campbell River and District Credit Union. (See Appendix 1.)

The management of Campbell River and District Credit Union had originally decided to build a new enlarged facility because the existing credit union could not adequately accommodate its members. The simulation model showed that only a change in the facility layout was required. Management reversed its decision to build a new facility and simply changed the layout. The credit union is presently operating effectively with the new layout and has avoided the expense of a new building.

9. CONCLUSIONS

9.1 Model Usage

9.1.1 Model Input

The sensitivity analysis shows that the model is sensitive to both the distribution of service times and the distribution of arrival rates. Since the service process could not be approximated by a theoretical distribution an estimate of the empirical distribution should be used. Also, since the arrival rates were found to be time dependent, the interval length between successive data collection should be approximately 15 minutes.

9.2 Steady State

The steady state analysis shows that a simulation run of 30 cycles is required to ensure steady state conditions.

9.3 Model Service Policy

The sensitivity analysis shows that the model is sensitive to the parameter values of the service policy. The manager of a given credit union should first be consulted in order to determine the service policy which he utilizes. These parameter values (range of acceptable queue length/available wicket and the minimum/maximum number of

9. CONCLUSIONS (Continued)

9.3 Model Service Policy (Continued)

wickets which can be made available) can then be input to the model in order to reflect the real world behavior.

10. RECOMMENDATIONS

10.1 Implementation

Credit unions or banks which have a large enough operation (minimum teller facility of 4 wickets) should make use of the simulation model whenever they are considering expanding their present facility. The model should be used to accurately determine present and future teller facility requirements, the level of member service to the provided and the necessary input required to determine a teller schedule.

10.2 Extensions

This simulation model could be extended to provide further insight into the queuing process and assist the credit union or bank managers in their evaluation of alternative policies. Improvements could be made reducing the number of assumptions made by the model and testing their validity.

10.2 Extensions (Continued)

Further development could include:

10.2.1 Estimate the significant differences between the following queue disciplines:

(i) Single Line
(ii) Quick Line

By utilizing a quick line (a queue designated for those members with simple transactions such as deposit or withdrawal) the credit union manager is utilizing a form of priority where the members requiring minimal service are processed sooner than other members. The simulation could evaluate the effectiveness of this queue discipline and determine the optimal number of quick lines for any given credit union.

10.2.2 Determine the effect of changing the time required by a teller to serve a member on the number of tellers and wickets required. The distribution of teller service rates may be significantly effected by:

- improving facility layout
- redefinition of teller activities.

10.2.3 Adapt the model to other contexts

For credit unions and banks, the model could also be used to determine the number of loan officers and loan offices required. The number of checkout stations and the queuing area required in supermarkets, liquor stores and airline booking offices could also be determined by the model with very minor changes.

11. SUMMARY

The simulation model as developed in this paper has been used in three credit unions and has provided the information necessary to accurately determine present and future teller facility requirements which will enable the credit union to provide adequate member service. Although the internal complexities of the simulation model are not well understood by credit union managers, its capability to accurately determine their present and future service facility requirements is known to many. It is expected during 1975 that at least five additional credit unions will make use of and benefit from the simulation model.

REFERENCES

1. FREQ University of British Columbia Computing Centre, 1973.

2. Gordon, Geoffry: System Simulation (New Jersey, Prentice-Hall Inc., 1969).

3. GPSS/360 Introductory User's Manual (IBM Corp., Form No. H20-0304).

4. GPSS/360 User's Manual (IBM Corp., Form No. H20-0326).

5. Hillier, F.S., Lieberman, G.J.: Introduction to Operations Research (San Francisco, Holden Day, Inc., 1972).

7. Naylor, Thomas H., Joseph L. Balintfy, Donald S. Burdich and Kong Chu: Computer Simulation Techniques (New York, John Wiley and Sons, Inc., 1966).

APPENDICES

Appendix 1	A Sample Computer Printout
Appendix 2	Model Documentation
Appendix 3	Other Facility Planning Models
Appendix 4	A Case Study

APPENDIX 1

A SAMPLE COMPUTER PRINTOUT

RELATIVE CLOCK 4608449 ABSOLUTE CLOCK 4608449

BLOCK COUNTS

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
1	0	0	11	0	14298	21	0	14298	31	0	14298	41	0	1536
2	0	14298	12	0	51117	22	0	14298	32	0	14298	42	0	1536
3	0	14298	13	0	51117	23	0	14298	33	0	512	43	0	1536
4	0	14298	14	0	51117	24	0	14298	34	0	512	44	0	1536
5	0	14298	15	0	19479	25	0	14298	35	0	512	45	0	1536
6	0	14298	16	0	14298	26	0	14298	36	0	512	46	0	1536
7	0	14298	17	0	14298	27	0	14298	37	0	512	47	0	1536
8	0	14298	18	0	14298	28	0	14298	38	0	512	48	0	1536
9	0	14298	19	0	14298	29	0	14298	39	0	512	49	0	1536
10	0	14298	20	0	14298	30	0	14298	40	0	1536	50	0	1536

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
51	0	1536	61	0	283	71	0	277	81	0	16	91	0	1
52	0	2541	62	0	283	72	0	277	82	0	16			
53	0	2719	63	0	0	73	0	277	83	0	1			
54	0	2719	64	0	1312	74	0	277	84	0	1			
55	0	2469	65	0	904	75	0	1536	85	0	1			
56	0	2219	66	0	904	76	0	1536	86	0	449			
57	0	1005	67	0	753	77	0	16	87	0	449			
58	0	283	68	0	753	78	0	16	88	0	449			
59	0	283	69	0	284	79	0	16	89	0	449			
60	0	283	70	0	277	80	0	16	90	0	449			

```
*****************************************
*                                       *
*              FACILITIES               *
*                                       *
*****************************************
```

-AVERAGE UTILIZATION DURING-

FACILITY	NUMBER ENTRIES	AVERAGE TIME/TRAN	TOTAL TIME	AVAIL. TIME	UNAVAIL. TIME	CURRENT STATUS	PERCENT AVAILABILITY	TRANSACTION NUMBER SEIZING	TRANSACTION NUMBER PREEMPTING
1	817	1381.835	.244				100.0		
2	811	1364.333	.240				100.0		
3	1257	1312.171	.357				100.0		
4	1621	1344.725	.473				100.0		
5	2039	1338.685	.592				100.0		
6	2338	1373.045	.696				100.0		
7	2672	1313.712	.761				100.0		
8	2743	1336.001	.796				100.0		

```
*****************************************
*                                       *
*               STORAGES                *
*                                       *
*****************************************
```

-AVERAGE UTILIZATION DURING-

STORAGE	CAPACITY	AVERAGE CONTENTS	ENTRIES	AVERAGE TIME/UNIT	TOTAL TIME	AVAIL. TIME	UNAVAIL. TIME	CURRENT STATUS	PERCENT AVAILABILITY	CURRENT CONTENTS	MAXIMUM CONTENTS
1	9	7.719	14581	2439.721	.964				100.0	6	8

QUEUES

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS	$AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
1	77	15.338	14298		.0	4943.878	4943.878		
2	69	11.175	14298	888	6.2	3602.072	3840.599		

$AVERAGE TIME/TRANS = AVERAGE TIME/TRANS EXCLUDING ZERO ENTRIES

FULLWORD SAVEVALUES

NUMBER	CONTENTS	NUMBER	CONTENTS	NUMBER	CONTENTS	NUMBER	CONTENTS	NUMBER	CONTENTS	NUMBER	CONTENTS
1	192	2	192	3	192	4	80	5	80	6	80
7	120	8	120	9	120	10	96	11	96	12	96
13	80	14	80	15	80	16	120	17	120	18	120
19	88	20	88	21	88	22	104	23	104	24	104
25	98	26	88	27	89	28	72	29	72	30	72
31	48	32	48	33	45	34	120	35	120	36	120
37	112	39	112	39	112	40	96	41	96	42	96
43	56	44	56	45	55	46	72	47	72	48	72
49	80	50	80	51	80	52	48	53	48	54	48
55	40	56	40	57	40	58	208	59	208	60	208
61	136	62	136	63	136	64	120	65	120	66	120
67	160	68	160	69	160	70	240	71	240	72	240
73	304	74	304	75	304	76	176	77	176	78	176
79	200	80	200	81	200	82	200	83	200	84	200
85	112	66	112	87	112	88	120	89	120	90	120
91	8	92	8	93	8	94	8	95	8	96	8
152	1	153	5	154	1	155	11	156	7	158	5
159	6	160	1	161	7	162	6	163	1	164	6
165	4	167	5	169	7	169	1	170	8	171	6
172	1	173	5	174	5	175	1	176	6	177	5
179	5	180	4	182	3	183	2	184	1	185	2
186	6	188	11	189	10	190	1	191	8	192	6
193	1	194	4	195	1	197	1	198	3	200	5
201	6	202	1	203	4	204	2	206	1	207	1
208	1	209	4	210	10	211	1	212	18	213	16
214	1	215	10	216	8	218	5	219	6	220	1
221	13	222	15	223	2	224	28	225	34	226	3
227	43	228	39	229	2	230	37	231	34	232	2
233	34	234	31	235	1	236	26	237	18	239	8
240	5	241	1	242	3	243	1	303	2	304	1
305	5	306	5	308	3	309	3	310	1	311	4
312	4	313	1	314	4	315	3	317	3	319	3
319	1	320	4	321	4	322	1	323	3	324	3
325	1	326	4	327	4	329	4	330	3	332	2
333	2	334	1	335	2	336	3	339	6	339	6
341	5	342	4	343	1	344	3	345	1	347	1
348	2	350	4	351	4	352	1	353	5	354	3

356	2	357	1	359	1	360	3	361	1	362	6
363	7	365	5	366	4	368	2	369	3	371	4
372	5	373	1	374	7	375	7	376	1	377	10
378	11	379	1	380	12	381	11	382	1	383	11
384	10	385	1	386	9	387	8	389	5	390	3
391	1	392	2	393	1	451	3	452	2	453	3
454	4	455	5	456	5	457	5	458	4	459	4
460	4	461	4	462	4	463	4	464	4	465	4
466	4	467	4	468	4	469	4	470	4	471	4
472	4	473	4	474	4	475	4	476	4	477	4
478	4	479	4	480	4	481	3	482	3	483	3
484	3	485	2	486	3	487	3	488	4	489	4
490	5	491	5	492	5	493	5	494	4	495	4
496	3	497	3	498	2	499	2	500	3	501	3
502	3	503	3	504	3	505	3	506	2	507	2
508	2	509	2	510	3	511	5	512	6	513	7
514	7	515	7	516	7	517	7	518	6	519	6
520	6	521	6	522	6	523	7	524	7	525	8
526	8	527	8	528	8	529	8	530	6	531	6
532	8	533	8	534	8	535	9	536	8	537	6
538	8	539	7	540	6	541	6	542	5	543	3
544	2	545	2	546	2	601	2	602	1	603	1
604	24	606	599	609	4608000	610	1	611	1	614	36000
615	8	616	16	619	2	625	8				

```
****************************************
*                                      *
*          FULLWORD MATRICES           *
*                                      *
****************************************
```

FULLWORD MATRIX 1

ROW/COLUMN	1	2	3	4	5	6	7	8	9	10
1	24	10	15	12	10	15	11	13	11	9

ROWS 2-5, COLUMNS 1-10 ARE ZERO

ROW/COLUMN	11	12	13	14	15	16	17	18	19	20
1	6	15	14	12	7	9	10	6	5	26

ROWS 2-5, COLUMNS 11-20 ARE ZERO

ROW/COLUMN	21	22	23	24	25	26	27	28	29	30
1	17	15	20	30	38	22	25	25	14	15

ROWS 2-5, COLUMNS 21-30 ARE ZERO

ROW/COLUMN	31	32	33	34	35	36	37	38	39	40
1	1	1	24	0	0	0	0	0	0	0

ROWS 2-5, COLUMNS 31-40 ARE ZERO

ROWS 1-5, COLUMNS 41-50 ARE ZERO

```
**************************************
*                                    *
*               TABLES               *
*                                    *
**************************************
```

TABLE 2

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
14298	59.574	41.750	851797.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	954	6.67	6.6	93.3	-.000	-1.426
5	382	2.67	9.3	90.6	.083	-1.307
10	468	3.27	12.6	87.3	.167	-1.187
15	494	3.45	16.0	83.9	.251	-1.067
20	469	3.28	19.3	80.6	.335	-.947
25	540	3.77	23.1	76.8	.419	-.828
30	541	3.78	26.9	73.0	.503	-.708
35	515	3.60	30.5	69.4	.587	-.585
40	583	4.07	34.5	65.4	.671	-.468
45	631	4.41	39.0	60.9	.755	-.349
50	724	5.06	44.0	55.9	.839	-.229
55	758	5.30	49.3	50.6	.923	-.109
60	720	5.03	54.4	45.5	1.007	.010
65	832	5.81	60.2	39.7	1.091	.129
70	824	5.76	65.9	34.0	1.174	.249
75	700	4.89	70.8	29.1	1.258	.369
80	611	4.27	75.1	24.8	1.342	.489
85	472	3.30	78.4	21.5	1.426	.608
90	335	2.34	80.8	19.1	1.510	.728
95	337	2.35	83.1	16.8	1.594	.848
100	273	1.90	85.0	14.9	1.678	.968
105	221	1.54	86.6	13.3	1.762	1.088
110	225	1.57	88.1	11.8	1.846	1.207
115	193	1.34	89.5	10.4	1.930	1.327
120	157	1.09	90.6	9.3	2.014	1.447
125	100	.69	91.3	8.6	2.098	1.567
130	153	1.07	92.4	7.5	2.182	1.686
135	120	.83	93.2	6.7	2.266	1.806
140	127	.89	94.1	5.8	2.349	1.926
145	102	.71	94.8	5.1	2.433	2.046
150	115	.80	95.6	4.3	2.517	2.165
155	103	.72	96.3	3.6	2.601	2.285
160	93	.65	97.0	2.9	2.685	2.405
165	111	.77	97.7	2.2	2.769	2.525
170	115	.80	98.6	1.3	2.853	2.644
175	97	.67	99.2	.7	2.937	2.764
180	49	.34	99.6	.3	3.021	2.884
185	35	.24	99.8	.1	3.105	3.004

190	15	.10	99.9	.0	3.189	3.123
195	4	.02	100.0	.0	3.273	3.243

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 3

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
1380	26.380	25.937	36405.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	364	26.37	26.3	73.6	-.000	-1.017
10	168	13.62	39.9	60.0	.379	-.631
20	171	12.39	52.3	47.6	.758	-.245
30	125	9.05	61.4	38.5	1.137	.139
40	97	7.02	68.4	31.5	1.516	.525
50	120	8.69	77.1	22.8	1.895	.910
60	122	8.84	86.0	13.9	2.274	1.296
70	103	7.46	93.4	6.5	2.653	1.681
80	58	4.20	97.6	2.3	3.032	2.067
90	21	1.52	99.2	.7	3.411	2.452
100	8	.57	99.7	.2	3.790	2.838
110	1	.07	99.8	.1	4.169	3.223
120	2	.14	100.0	.0	4.548	3.609

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 4

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
2423	43.028	25.375	104257.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	152	6.27	6.2	93.7	-.000	-1.695
10	148	6.10	12.3	87.6	.232	-1.301
20	219	9.03	21.4	78.5	.464	-.907
30	284	11.72	33.1	66.8	.697	-.513
40	291	12.00	45.1	54.8	.929	-.119
50	344	14.19	59.3	40.6	1.162	.274
60	339	13.99	73.3	26.6	1.394	.668
70	310	12.79	86.1	13.8	1.626	1.062
80	175	7.22	93.3	6.6	1.859	1.457
90	87	3.59	96.9	3.0	2.091	1.851
100	54	2.22	99.1	.8	2.324	2.245
110	14	.57	99.7	.2	2.556	2.639
120	4	.16	99.9	.0	2.788	3.033
130	2	.08	100.0	.0	3.021	3.427

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 5

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
3711	42.211	29.500	156647.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	318	8.56	8.5	91.4	-.000	-1.430
10	371	9.99	18.5	81.4	.236	-1.091
20	343	9.24	27.8	72.1	.473	-.752
30	389	10.48	38.2	61.7	.710	-.413

40	347	9.35	47.6	52.3	.947	-.074
50	404	10.88	58.5	41.4	1.184	.264
60	476	12.82	71.3	28.6	1.421	.602
70	488	13.15	84.5	15.4	1.658	.941
80	307	8.27	92.7	7.2	1.895	1.280
90	133	3.58	96.3	3.6	2.132	1.619
100	48	1.29	97.6	2.3	2.369	1.958
110	14	.37	98.0	1.9	2.605	2.297
120	17	.45	98.4	1.5	2.842	2.636
130	9	.24	98.7	1.2	3.079	2.975
140	18	.48	99.2	.7	3.316	3.314
150	8	.21	99.4	.5	3.553	3.653
160	14	.37	99.8	.1	3.790	3.992
170	7	.18	100.0	.0	4.027	4.331

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 6

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
565	61.495	20.937	34745.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-2.937
10	5	.88	.8	99.1	.162	-2.459
20	9	1.59	2.4	97.5	.325	-1.981
30	31	5.48	7.9	92.0	.487	-1.504
40	75	13.27	21.2	78.7	.650	-1.026
50	64	11.32	32.5	67.4	.813	-.549
60	60	10.61	43.1	56.8	.975	-.071
70	92	16.28	59.4	40.5	1.138	.406
80	93	17.34	76.8	23.1	1.300	.883
90	105	18.58	95.3	4.6	1.463	1.361
100	26	4.60	100.0	.0	1.626	1.839

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 7

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
640	31.282	24.000	20021.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	55	8.59	8.5	91.4	-.000	-1.303
10	77	12.03	20.6	79.3	.319	-.886
20	123	19.21	39.8	60.1	.639	-.470
30	117	18.28	58.1	41.8	.958	-.053
40	68	10.62	68.7	31.2	1.278	.363
50	68	10.62	79.3	20.6	1.598	.779
60	27	4.21	83.5	16.4	1.917	1.196
70	37	5.78	89.3	10.6	2.237	1.613
80	56	8.74	98.1	1.8	2.557	2.029
90	8	1.24	99.3	.6	2.876	2.446
100	4	.62	100.0	.0	3.196	2.863

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 8

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
5579	89.571	41.875	499722.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	65	1.16	1.1	98.8	-.000	-2.139
10	61	1.09	2.2	97.7	.111	-1.900
20	98	1.75	4.0	95.9	.223	-1.661
30	135	2.41	6.4	93.5	.334	-1.422
40	220	3.94	10.3	89.6	.446	-1.183
50	355	6.36	16.7	83.2	.558	-.945
60	454	8.13	24.8	75.1	.669	-.706
70	626	11.22	36.0	63.9	.781	-.467
80	617	11.05	47.1	52.8	.893	-.228
90	453	8.11	55.2	44.7	1.004	.010
100	470	8.42	63.7	36.2	1.116	.249
110	417	7.47	71.1	28.8	1.228	.487
120	327	5.86	77.0	22.9	1.339	.726
130	242	4.33	81.3	18.6	1.451	.965
140	229	4.10	85.4	14.5	1.562	1.204
150	209	3.74	89.2	10.7	1.674	1.443
160	182	3.26	92.4	7.5	1.786	1.681
170	219	3.92	96.4	3.5	1.897	1.920
180	146	2.61	99.0	.9	2.009	2.159
190	50	.89	99.9	.0	2.121	2.398
200	4	.07	100.0	.0	2.232	2.637

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 10

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
14293	16.232	15.503	232098.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	1404	9.81	9.8	90.1	-.000	-1.047
1	521	3.64	13.4	86.5	.061	-.982
2	510	3.56	17.0	82.9	.123	-.918
3	562	3.93	20.9	79.0	.184	-.853
4	519	3.62	24.5	75.4	.246	-.789
5	567	3.96	28.5	71.4	.308	-.724
6	621	4.34	32.8	67.1	.369	-.660
7	639	4.46	37.3	62.6	.431	-.595
8	559	3.90	41.2	58.7	.492	-.531
9	507	3.54	44.8	55.1	.554	-.466
10	489	3.42	48.2	51.7	.616	-.402
11	461	3.22	51.4	48.5	.677	-.337
12	431	3.01	54.4	45.5	.739	-.273
13	404	2.82	57.3	42.6	.800	-.208
14	388	2.71	60.0	39.9	.862	-.144
15	348	2.43	62.4	37.5	.924	-.079
16	310	2.16	64.6	35.3	.985	-.015
17	275	1.92	66.5	33.4	1.047	.049
18	231	1.61	68.1	31.8	1.108	.113
19	205	1.43	69.5	30.4	1.170	.178
20	182	1.27	70.8	29.1	1.232	.242
21	213	1.48	72.3	27.6	1.293	.307
22	216	1.51	73.8	26.1	1.355	.371
23	154	1.07	74.9	25.0	1.416	.436
24	123	.86	75.8	24.1	1.478	.500
25	123	.86	76.6	23.3	1.540	.565
26	123	.86	77.5	22.4	1.601	.629
27	145	1.01	78.5	21.4	1.663	.694

28	148	1.03	79.5	20.4	1.724	.758
29	129	.90	80.4	19.5	1.786	.823
30	110	.76	81.2	18.7	1.848	.887
31	113	.79	82.0	17.9	1.909	.952
32	114	.79	82.8	17.1	1.971	1.016
33	96	.67	83.5	16.4	2.032	1.081
34	118	.82	84.3	15.6	2.094	1.145
35	117	.81	85.1	14.8	2.156	1.210
36	146	1.02	86.1	13.8	2.217	1.274
37	141	.98	87.1	12.8	2.279	1.339
38	131	.91	88.0	11.9	2.340	1.403
39	104	.72	88.8	11.1	2.402	1.468
40	83	.58	89.3	10.6	2.464	1.532
41	76	.53	89.9	10.0	2.525	1.597
42	80	.55	90.4	9.5	2.587	1.661
43	84	.58	91.0	8.9	2.648	1.726
44	81	.56	91.6	8.3	2.710	1.790
45	83	.58	92.2	7.7	2.772	1.855
46	81	.56	92.7	7.2	2.833	1.919
47	96	.67	93.4	6.5	2.895	1.984
48	95	.66	94.1	5.8	2.956	2.048
49	97	.67	94.7	5.2	3.018	2.113
50	96	.67	95.4	4.5	3.080	2.177
51	79	.55	96.0	3.9	3.141	2.242
52	78	.54	96.5	3.4	3.203	2.306
53	82	.57	97.1	2.8	3.264	2.371
54	72	.50	97.6	2.3	3.326	2.435
55	61	.42	98.0	1.9	3.388	2.500
56	37	.25	98.3	1.6	3.449	2.564
57	32	.22	98.5	1.4	3.511	2.629
58	31	.21	98.7	1.2	3.572	2.693
59	26	.18	98.9	1.0	3.634	2.758
60	31	.21	99.1	.8	3.696	2.822
61	34	.23	99.3	.6	3.757	2.887
62	29	.20	99.6	.3	3.819	2.951
63	27	.18	99.7	.2	3.881	3.016
64	18	.12	99.9	.0	3.942	3.080
65	6	.04	99.9	.0	4.004	3.145
66	2	.01	99.9	.0	4.065	3.209
67	3	.02	99.9	.0	4.127	3.274
68	1	.00	100.0	.0	4.189	3.338

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 11

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
1380	2.734	3.351	3774.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	546	39.56	39.5	60.4	-.000	-.815
2	289	20.94	60.5	39.4	.731	-.219
4	202	14.63	75.1	24.8	1.462	.377
6	123	8.91	84.0	15.9	2.193	.974
8	115	8.33	92.3	7.6	2.925	1.570
10	65	4.71	97.1	2.8	3.656	2.167
12	21	1.52	98.6	1.3	4.387	2.764
14	11	.79	99.4	.5	5.119	3.361
16	5	.36	99.7	.2	5.850	3.957
18	2	.14	99.9	.0	6.581	4.554

20	1	.07	100.0	.0	7.313	5.151

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 12

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
2423	6.114	4.179	14816.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	256	10.56	10.5	89.4	-.000	-1.462
2	279	11.51	22.0	77.9	.327	-.984
4	360	14.85	36.9	63.0	.654	-.505
6	457	18.86	55.7	44.2	.981	-.027
8	430	17.74	73.5	26.4	1.308	.451
10	267	11.01	84.5	15.4	1.635	.929
12	189	7.80	92.3	7.6	1.962	1.408
14	101	4.16	96.5	3.4	2.289	1.886
16	49	2.02	98.5	1.4	2.616	2.365
18	24	.99	99.5	.4	2.943	2.843
20	8	.33	99.8	.1	3.270	3.322
22	2	.08	99.9	.0	3.597	3.800
24	1	.04	100.0	.0	3.924	4.279

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 13

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
3711	7.922	5.757	29400.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	454	12.23	12.2	87.7	-.000	-1.375
2	374	10.07	22.3	77.6	.252	-1.026
4	369	9.94	32.2	67.7	.504	-.681
6	396	10.67	42.9	57.0	.757	-.333
8	458	12.34	55.2	44.7	1.009	.013
10	436	11.74	67.0	32.9	1.262	.360
12	378	10.18	77.2	22.7	1.514	.709
14	339	9.13	86.3	13.6	1.767	1.055
16	249	6.70	93.0	6.9	2.019	1.402
18	151	4.06	97.1	2.8	2.272	1.750
20	55	1.48	98.5	1.4	2.524	2.097
22	17	.45	99.0	.9	2.776	2.444
24	6	.16	99.2	.7	3.029	2.792
26	8	.21	99.4	.5	3.281	3.139
28	7	.18	99.6	.3	3.534	3.487
30	6	.16	99.7	.2	3.786	3.834
32	3	.08	99.8	.1	4.039	4.181
34	5	.13	100.0	.0	4.291	4.529

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 14

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
565	13.980	5.675	7899.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	2	.35	.3	99.6	-.000	-2.463

2	6	1.06	1.4	98.5	.143	-2.110
4	19	3.36	4.7	95.2	.286	-1.758
6	33	5.84	10.6	89.3	.429	-1.406
8	33	5.84	16.4	83.5	.572	-1.053
10	51	9.02	25.4	74.5	.715	-.701
12	93	16.46	41.9	58.0	.858	-.348
14	91	16.10	58.0	41.9	1.001	.003
16	62	10.97	69.0	30.9	1.144	.355
18	40	7.07	76.1	23.8	1.287	.708
20	54	9.55	85.6	14.3	1.430	1.060
22	34	6.01	91.6	8.3	1.573	1.412
24	29	5.13	96.8	3.1	1.716	1.765
26	8	1.41	98.2	1.7	1.859	2.117
28	10	1.76	100.0	.0	2.002	2.470

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 15

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
640	9.001	7.554	5761.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	74	11.56	11.5	88.4	-.000	-1.191
2	59	9.21	20.7	79.2	.222	-.926
4	73	11.40	32.1	67.8	.444	-.662
6	87	13.59	45.7	54.2	.666	-.397
8	83	12.96	58.7	41.2	.888	-.132
10	40	6.25	64.9	35.0	1.110	.132
12	35	5.46	70.4	29.5	1.333	.396
14	41	6.40	76.8	23.1	1.555	.661
16	45	7.03	83.9	16.0	1.777	.926
18	36	5.62	89.5	10.4	1.999	1.191
20	15	2.34	91.8	8.1	2.221	1.455
22	10	1.56	93.4	6.5	2.444	1.720
24	14	2.18	95.6	4.3	2.666	1.985
26	6	.93	96.5	3.4	2.888	2.250
28	4	.62	97.1	2.8	3.110	2.514
30	5	.78	97.9	2.0	3.332	2.779
32	10	1.56	99.5	.4	3.554	3.044
34	3	.46	100.0	.0	3.777	3.308

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 16

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
5579	30.551	15.066	170448.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	72	1.29	1.2	98.7	-.000	-2.027
2	24	.43	1.7	98.2	.065	-1.895
4	58	1.03	2.7	97.2	.130	-1.762
6	92	1.64	4.4	95.5	.196	-1.629
8	79	1.41	5.8	94.1	.261	-1.496
10	137	2.45	8.2	91.7	.327	-1.364
12	176	3.15	11.4	88.5	.392	-1.231
14	209	3.74	15.1	84.8	.458	-1.098
16	243	4.44	19.6	80.3	.523	-.965
18	253	4.53	24.1	75.8	.589	-.833

20	254	4.55	28.7	71.2	.654	-.700
22	366	6.56	35.2	64.7	.720	-.567
24	227	4.06	39.3	60.6	.785	-.434
26	224	4.01	43.3	56.6	.851	-.302
28	272	4.87	48.2	51.7	.916	-.169
30	228	4.08	52.3	47.6	.981	-.036
32	214	3.83	56.1	43.8	1.047	.096
34	206	3.69	59.8	40.1	1.112	.228
36	263	4.71	64.5	35.4	1.178	.361
38	272	4.87	69.4	30.5	1.243	.494
40	187	3.35	72.7	27.2	1.309	.627
42	156	2.79	75.5	24.4	1.374	.759
44	165	2.95	78.5	21.4	1.440	.892
46	164	2.93	81.4	18.5	1.505	1.025
48	191	3.42	84.9	15.0	1.571	1.158
50	193	3.45	88.3	11.6	1.636	1.290
52	157	2.81	91.1	8.8	1.702	1.423
54	154	2.76	93.9	6.0	1.767	1.556
56	98	1.75	95.6	4.3	1.832	1.689
58	63	1.12	96.8	3.1	1.898	1.821
60	57	1.02	97.8	2.1	1.963	1.954
62	63	1.12	98.9	1.0	2.029	2.087
64	45	.80	99.7	.2	2.094	2.220
66	8	.14	99.9	.0	2.160	2.352
68	4	.07	100.0	.0	2.225	2.485

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 18

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
1536	15.319	15.210	23530.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	103	6.70	6.7	93.2	-.000	-1.000
1	63	4.10	10.8	89.1	.065	-.941
2	69	4.49	15.2	84.7	.130	-.875
3	72	4.68	19.9	80.0	.195	-.809
4	64	4.16	24.1	75.8	.261	-.744
5	67	4.36	28.5	71.4	.326	-.678
6	48	3.12	31.6	68.3	.391	-.612
7	66	4.29	35.9	64.0	.456	-.546
8	68	4.42	40.3	59.6	.522	-.481
9	61	3.97	44.3	55.6	.587	-.415
10	72	4.68	49.0	50.9	.652	-.349
11	70	4.55	53.5	46.4	.718	-.283
12	57	3.71	57.2	42.7	.783	-.218
13	53	3.45	60.7	39.2	.848	-.152
14	38	2.47	63.2	36.7	.913	-.086
15	43	2.79	66.0	33.9	.979	-.020
16	34	2.21	68.2	31.7	1.044	.044
17	35	2.27	70.5	29.4	1.109	.110
18	30	1.95	72.4	27.5	1.175	.176
19	30	1.95	74.4	25.5	1.240	.241
20	28	1.82	76.2	23.7	1.305	.307
21	26	1.69	77.9	22.0	1.370	.373
22	16	1.04	78.9	21.0	1.436	.439
23	22	1.43	80.4	19.5	1.501	.504
24	22	1.43	81.8	18.1	1.566	.570
25	10	.65	82.4	17.5	1.631	.636

26	11	.71	83.2	16.7	1.697	.702
27	15	.97	84.1	15.8	1.762	.767
28	9	.58	84.7	15.2	1.827	.833
29	16	1.04	85.8	14.1	1.893	.899
30	12	.78	86.5	13.4	1.958	.965
31	7	.45	87.0	12.9	2.023	1.030
32	3	.19	87.2	12.7	2.088	1.096
33	3	.19	87.4	12.5	2.154	1.162
34	5	.32	87.7	12.2	2.219	1.228
35	9	.58	88.3	11.6	2.284	1.293
36	12	.78	89.1	10.8	2.350	1.359
37	10	.65	89.7	10.2	2.415	1.425
38	3	.19	89.9	10.0	2.480	1.491
39	3	.19	90.1	9.8	2.545	1.556
40	6	.39	90.5	9.4	2.611	1.622
41	7	.45	91.0	8.9	2.676	1.688
42	6	.39	91.4	8.5	2.741	1.754
43	3	.19	91.6	8.3	2.806	1.819
44	14	.91	92.5	7.4	2.872	1.885
45	7	.45	92.9	7.0	2.937	1.951
46	4	.26	93.2	6.7	3.002	2.017
47	9	.58	93.8	6.1	3.068	2.082
48	5	.32	94.1	5.8	3.133	2.149
49	1	.06	94.2	5.7	3.198	2.214
50	3	.19	94.4	5.5	3.263	2.280
51	6	.39	94.7	5.2	3.329	2.345
52	6	.39	95.1	4.8	3.394	2.411
53	3	.19	95.3	4.6	3.459	2.477
54	8	.52	95.8	4.1	3.525	2.542
55	6	.39	96.2	3.7	3.590	2.608
56	9	.58	96.8	3.1	3.655	2.674
57	3	.19	97.0	2.9	3.720	2.740
58	4	.26	97.3	2.6	3.786	2.805
59	5	.32	97.6	2.3	3.851	2.871
60	4	.26	97.9	2.0	3.916	2.937
61	8	.52	98.4	1.5	3.981	3.003
62	4	.26	98.6	1.3	4.047	3.068
63	2	.13	98.8	1.1	4.112	3.134
64	3	.19	99.0	.9	4.177	3.200
65	4	.26	99.2	.7	4.243	3.266
66	0	.00	99.2	.7	4.308	3.331
67	1	.06	99.3	.6	4.373	3.397
68	1	.06	99.4	.5	4.438	3.463
69	1	.06	99.4	.5	4.504	3.529
70	4	.26	99.7	.2	4.569	3.594
71	2	.13	99.8	.1	4.634	3.660
72	1	.06	99.9	.0	4.700	3.726
73	1	.06	100.0	.0	4.765	3.792

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 20

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
1536	4.444	2.144	6826.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-2.072
1	0	.00	.0	100.0	.225	-1.605
2	378	24.60	24.6	75.3	.450	-1.139

3	267	17.38	41.9	58.0	.675	-.573
4	260	16.92	58.9	41.0	.900	-.207
5	162	10.54	69.4	30.5	1.125	.259
6	137	8.91	78.3	21.6	1.350	.725
7	59	3.34	82.2	17.7	1.575	1.191
8	273	17.77	100.0	.0	1.800	1.658

REMAINING FREQUENCIES ARE ALL ZERO

TABLE 25

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
14298	39.724	19.937	567985.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.992
2	12	.08	.0	99.9	.050	-1.892
4	41	.28	.3	99.6	.100	-1.791
6	276	1.93	2.3	97.6	.151	-1.691
8	137	.95	3.2	96.7	.201	-1.591
10	422	2.95	6.2	93.7	.251	-1.490
12	276	1.93	8.1	91.8	.302	-1.390
14	244	1.70	9.8	90.1	.352	-1.290
16	622	4.35	14.1	85.8	.402	-1.189
18	326	2.28	16.4	83.5	.453	-1.089
20	601	4.20	20.6	79.3	.503	-.989
22	370	2.58	23.2	76.7	.553	-.889
24	314	2.19	25.4	74.5	.604	-.788
26	621	4.34	29.8	70.1	.654	-.688
28	329	2.30	32.1	67.8	.704	-.586
30	592	4.14	36.2	63.7	.755	-.487
32	391	2.73	38.9	61.0	.805	-.387
34	306	2.14	41.1	58.8	.855	-.287
36	791	5.53	46.6	53.3	.906	-.186
38	407	2.84	49.5	50.4	.956	-.086
40	650	4.54	54.0	45.9	1.006	.013
42	392	2.74	56.7	43.2	1.057	.114
44	363	2.53	59.3	40.6	1.107	.214
46	794	5.55	64.8	35.1	1.157	.314
48	438	3.06	67.9	32.0	1.208	.415
50	534	3.73	71.6	28.3	1.258	.515
52	395	2.76	74.4	25.5	1.309	.615
54	276	1.93	76.3	23.6	1.359	.715
56	588	4.11	80.4	19.5	1.409	.816
58	352	2.46	82.9	17.0	1.460	.916
60	297	2.07	85.0	14.9	1.510	1.016
62	199	1.39	86.4	13.5	1.560	1.117
64	128	.89	87.3	12.6	1.611	1.217
66	292	2.04	89.3	10.6	1.661	1.317
68	185	1.29	90.6	9.3	1.711	1.418
70	175	1.22	91.8	8.1	1.762	1.518
72	202	1.41	93.2	6.7	1.812	1.618
74	117	.31	94.1	5.8	1.862	1.719
76	219	1.53	95.6	4.3	1.913	1.619
78	156	1.09	96.7	3.2	1.963	1.919
80	94	.65	97.3	2.6	2.013	2.020
82	70	.48	97.8	2.1	2.064	2.120
84	35	.24	98.1	1.8	2.114	2.220
86	79	.55	98.6	1.3	2.164	2.321
88	64	.44	99.1	.8	2.215	2.421

90	47	.32	99.4	.5	2.265	2.521
92	24	.16	99.6	.3	2.315	2.621
94	4	.02	99.6	.3	2.366	2.722
96	18	.12	99.7	.2	2.416	2.822
98	0	.00	99.7	.2	2.466	2.922
100	11	.07	99.8	.1	2.517	3.023
102	0	.00	99.8	.1	2.567	3.123
104	0	.00	99.8	.1	2.618	3.223
106	7	.04	99.9	.0	2.668	3.324
108	0	.00	99.9	.0	2.718	3.424
110	6	.04	99.9	.0	2.769	3.524
112	0	.00	99.9	.0	2.819	3.625
114	0	.00	99.9	.0	2.869	3.725
116	4	.02	99.9	.0	2.920	3.825
118	0	.00	99.9	.0	2.970	3.926
120	4	.02	100.0	.0	3.020	4.026

REMAINING FREQUENCIES ARE ALL ZERO

STATISTICS OF INTEREST

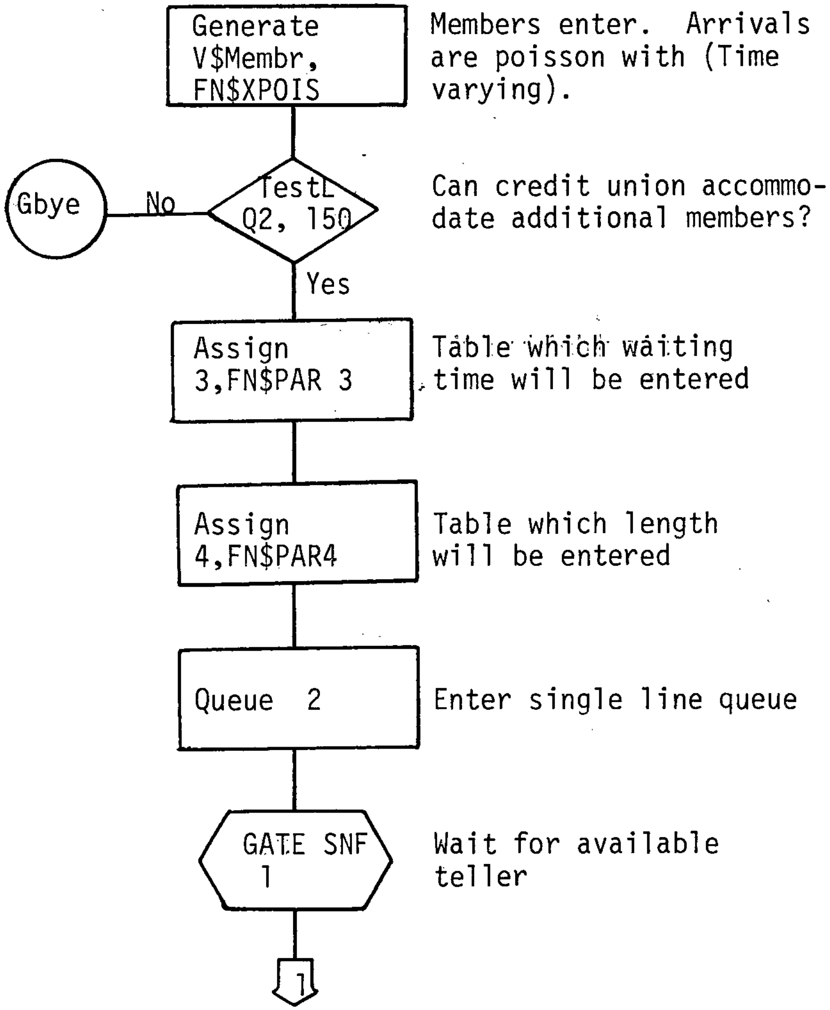
Table 2	Frequency distribution of the member waiting time. The interval length for each class is 0.5 minutes. For example, the following output shows that for the 14298 members which were serviced a total of 832 waited between 6.5 and 7.0 minutes before receiving service.
Table 10	Frequency distribution of the number of members waiting in the system. For example, 62.4% of the time there were at most 15 members waiting for service.
Table 20	Frequency distribution of the number of wickets utilized. For example, 60% of the time there were at least 4 tellers available for service.
Table 25	Frequency distribution of the queue length per available wicket. The interval length for each class is 0.2 members. For example the following output shows that 91.8% of the time, the average queue length was at most 7.

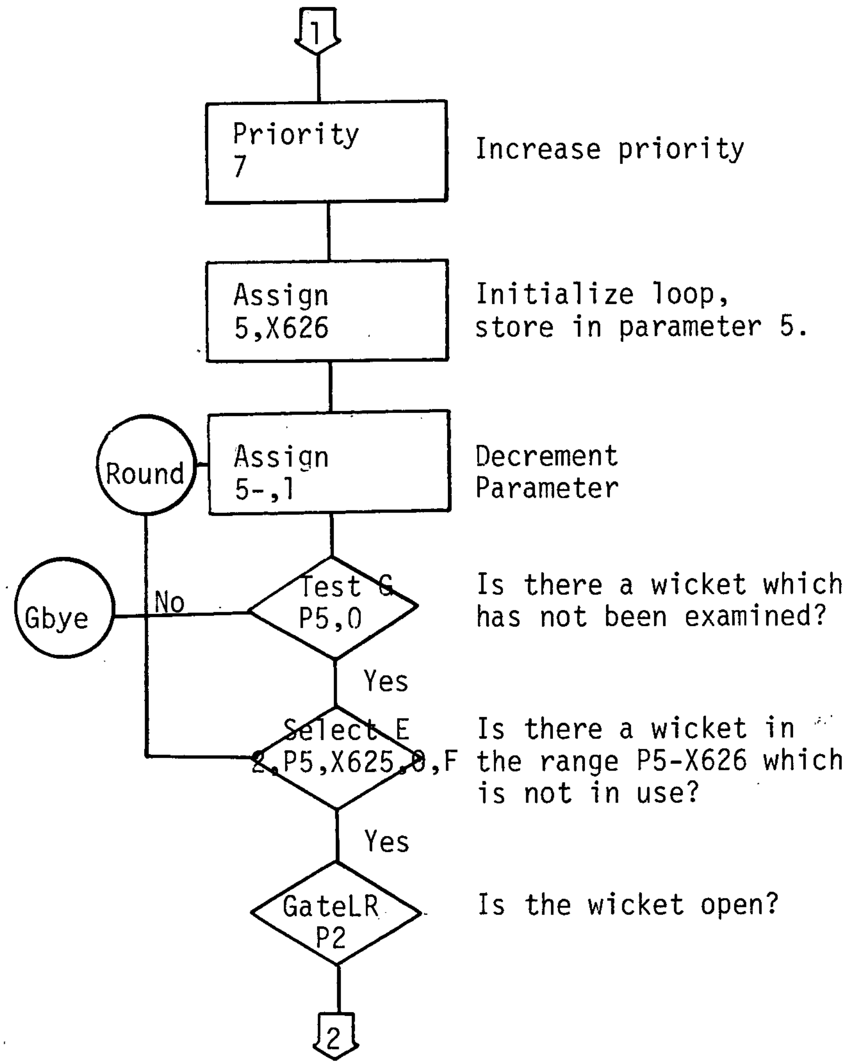
APPENDIX 2

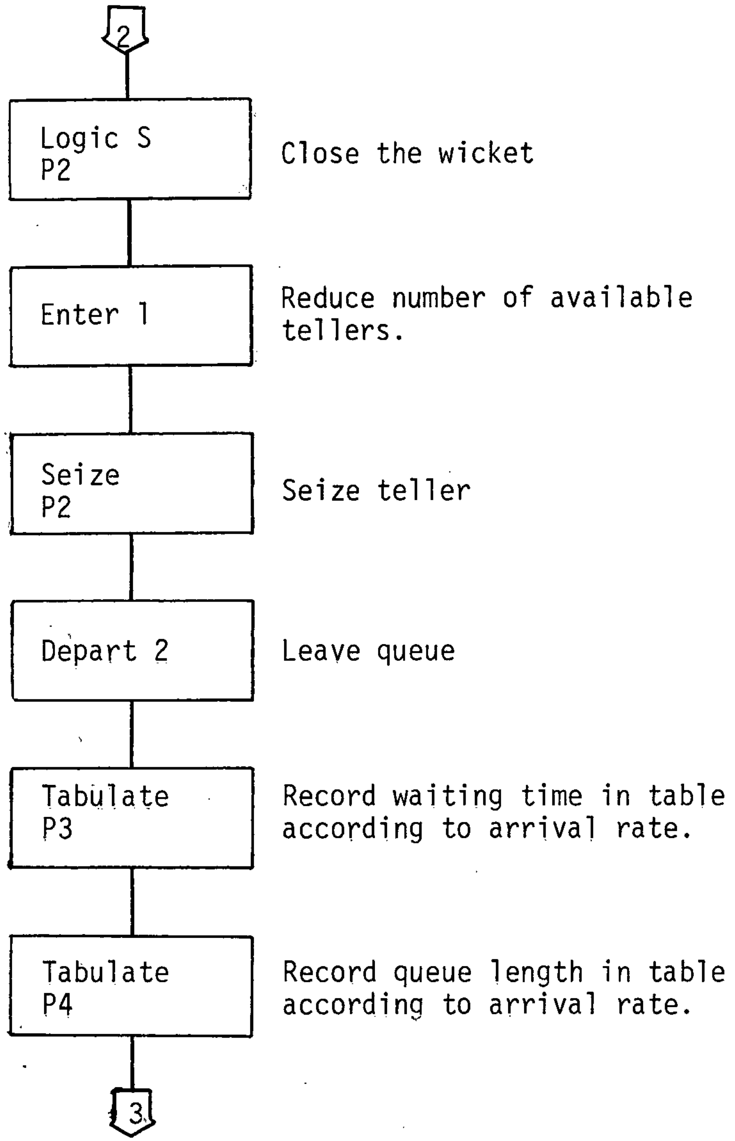
MODEL DOCUMENTATION

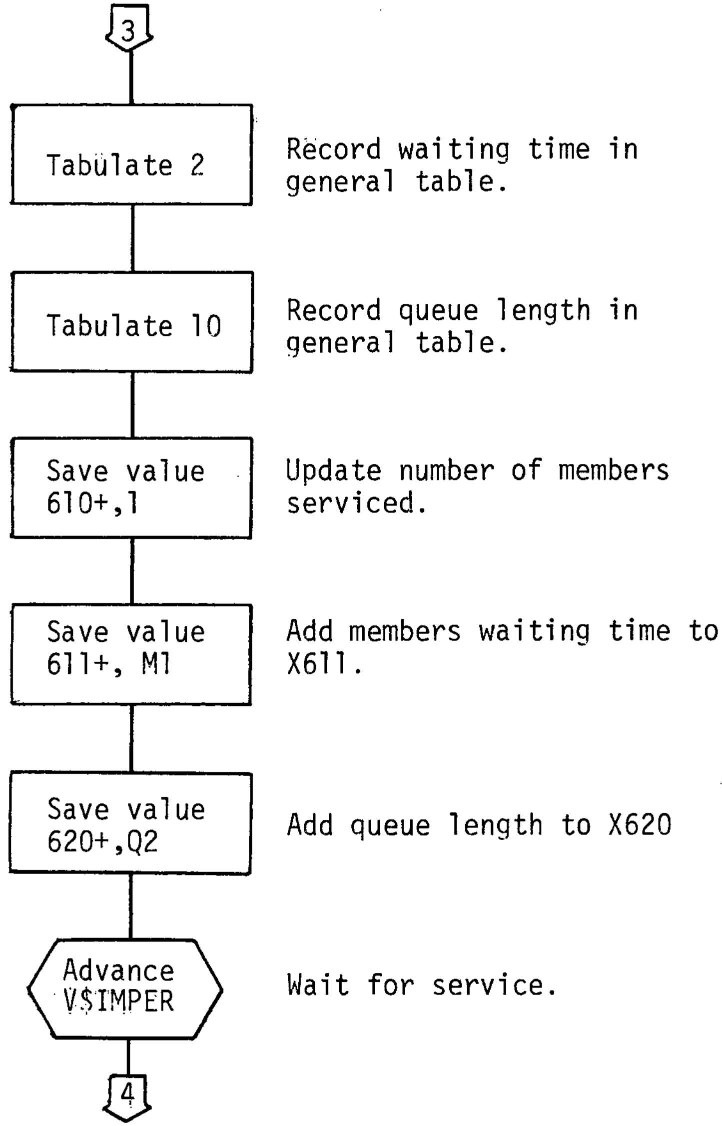
Segment 1

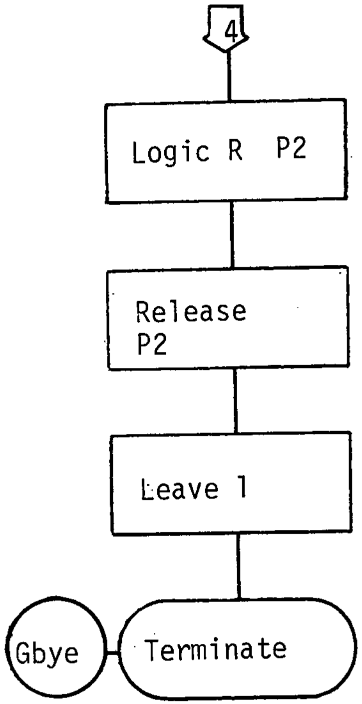
This segment simulates the arrival, queuing, and service to members.






2
Logic S
P2
Close the wicket
Enter 1
Reduce number of available tellers.
Seize
P2
Seize teller
Depart 2
Leave queue
Tabulate
P3
Record waiting time in table according to arrival rate.
Tabulate
P4
Record queue length in table according to arrival rate.
3


3
Tabulate 2
Record waiting time in general table.
Tabulate 10
Record queue length in general table.
Save value
610+,1
Update number of members serviced.
Save value
611+, M1
Add members waiting time to X611.
Save value
620+,Q2
Add queue length to X620
Advance
V$IMPER
Wait for service.
4



Reopen Wicket

Release teller

Increase number of available tellers

Leave Credit Union

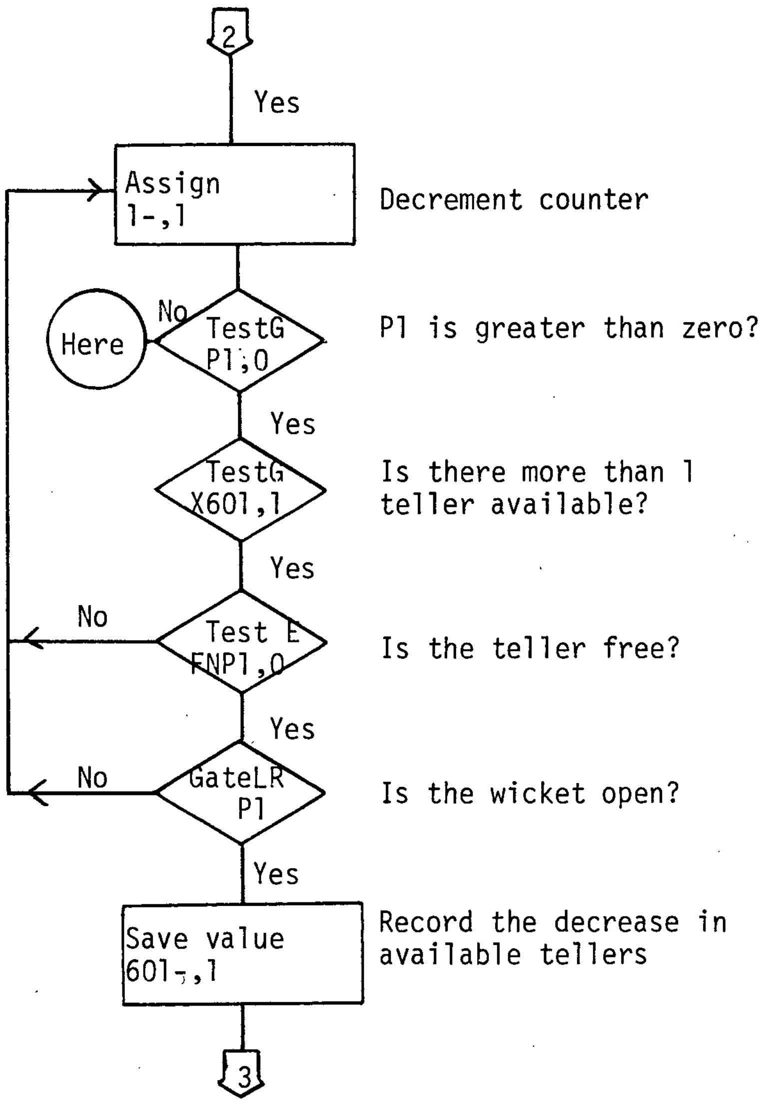
Segment 2

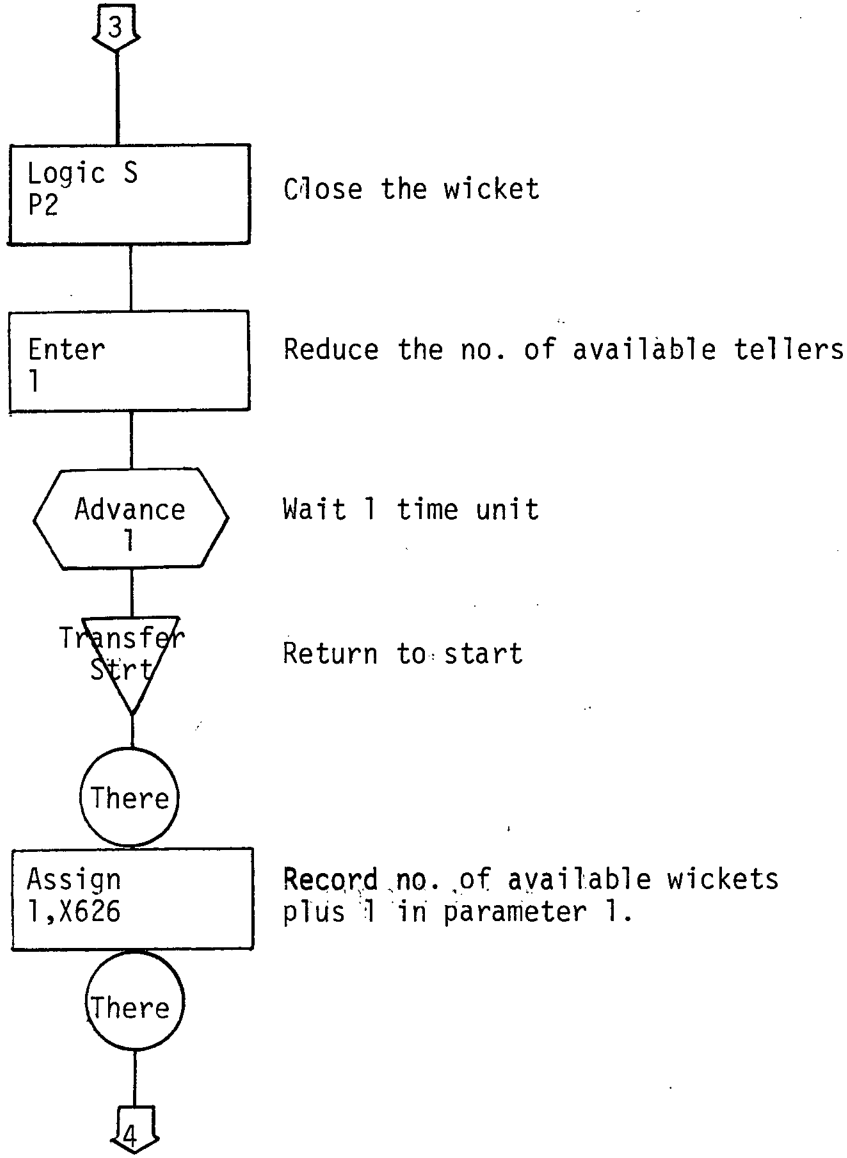
This segment calculates and records average queue length, average waiting time, member arrival rate, and no. of tellers available during the period. It also determines whether tellers are overstaffed or under staffed and takes the appropriate action.

Generate 3000,,,,2	Timer set for every 5 minutes.
Savevalue V$Tellrt,X601	Record no. of tellers available during period.
Savevalue V$Time, V$RATE	Record arrival rate during period.
Savevalue V$Waitit,V$wait	Record waiting time during period
Savevalue V$Lngth,V$Line	Record Queue length during period.
1	

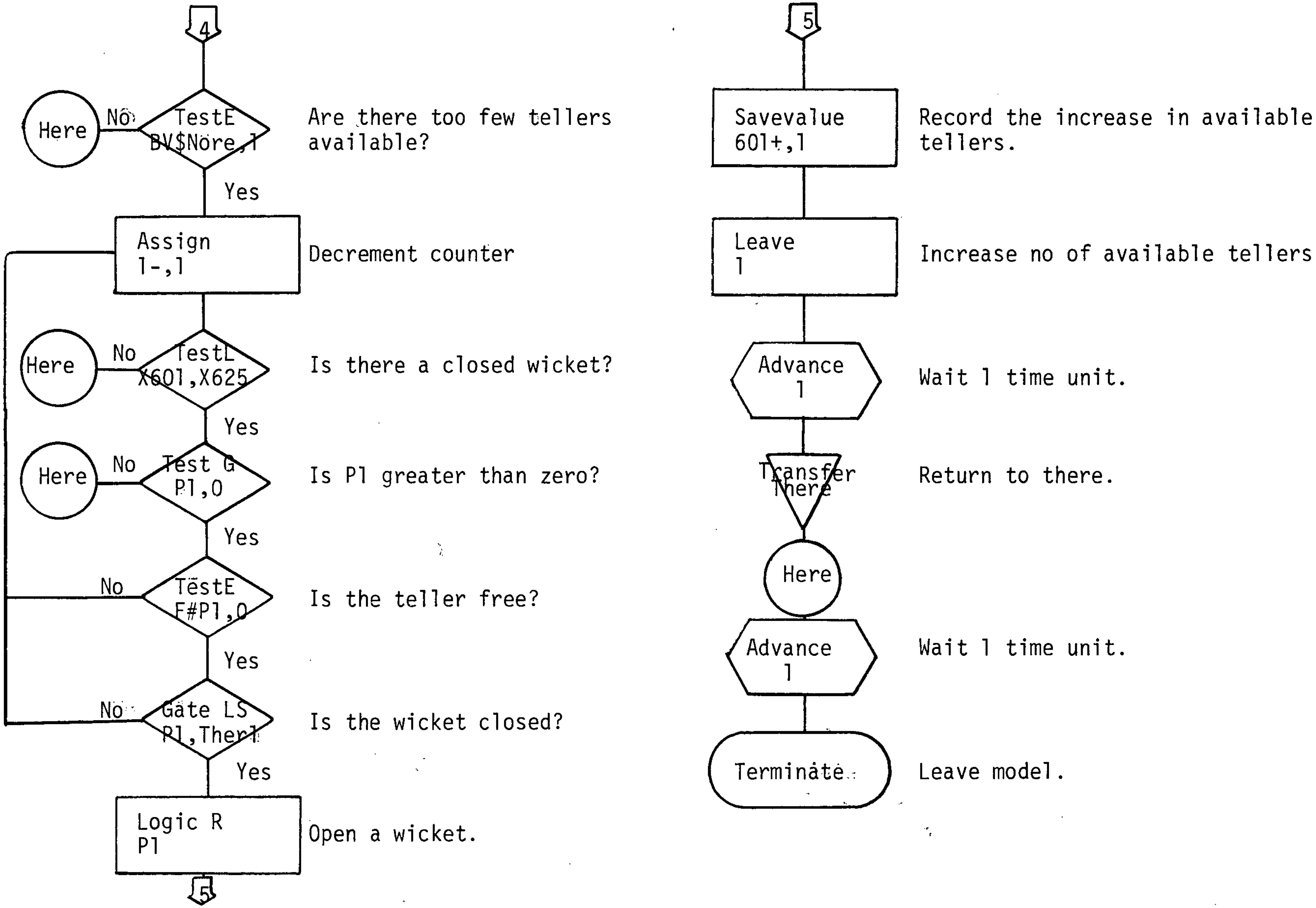
1	
Savevalue 619,1	Increment counter for registering save values.
Savevalue 610,1	Initialize accumulated member statistics.
Savevalue 611,1	Initialize accumulated waiting time statistics.
Savevalue 620,0	Initialize accumulated queue statistics.
Assign 1,X626	Record no. of available wickets, plus 1 in parameter 1.
Strt	
TestE By$Less,1 (No → There)	Are there too many tellers available?
2	

Segment 2 (Continued)





Segment 2 (Continued)



Segment 3

This segment changes the mean arrival rate.

Generate 9000	Timer set to 15 minute intervals
Save value 603+,1	Record arrival rate during interval
Savevalue 604,NXI(X602,X603)	Change the arrival rate
Terminate	Leave model.

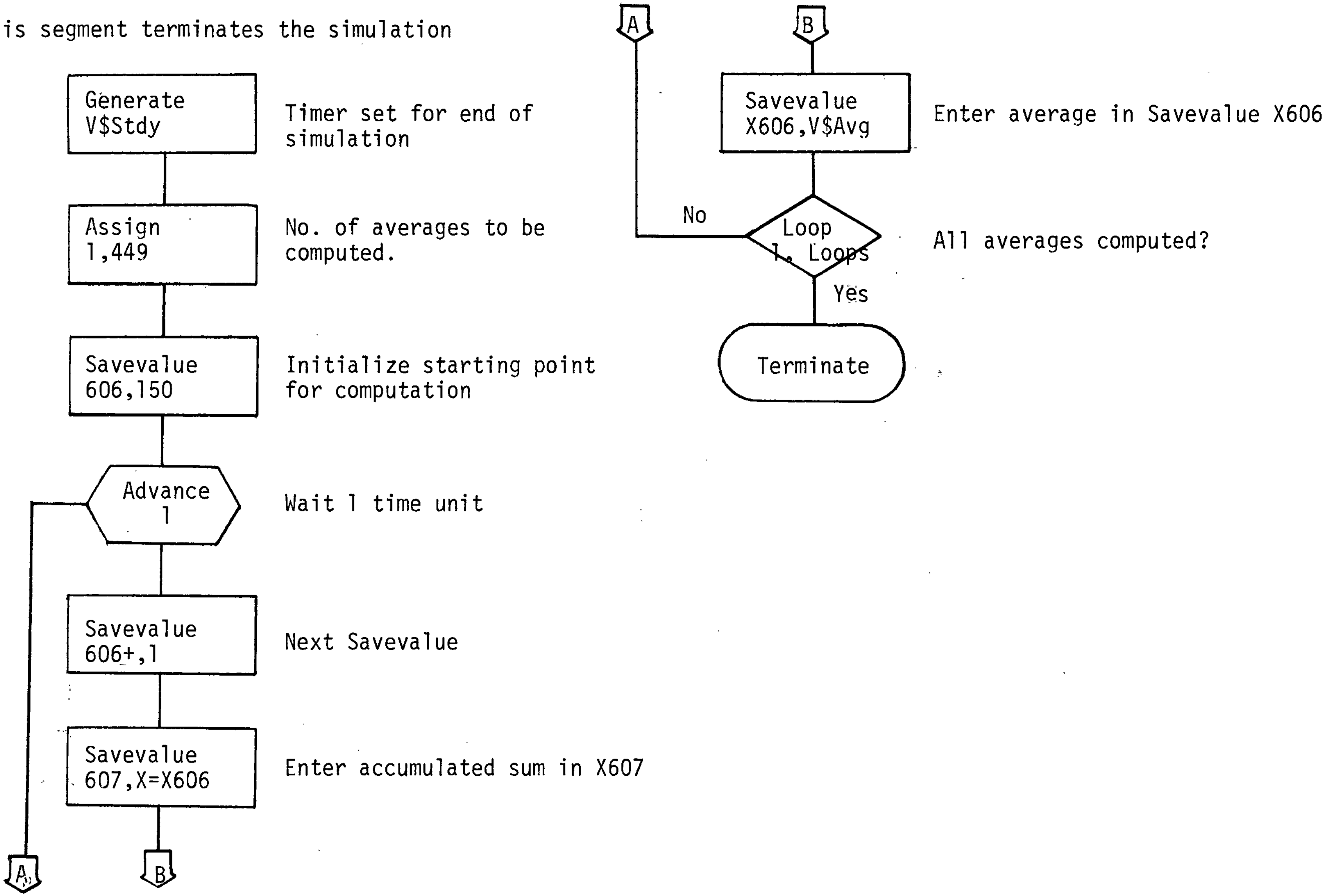
Segment 4

This segment ends business for the day.

Generate V$Day,,,,5	Timer set to length of day
Savevalue 603,1	Initialize index of materix for next day
Savevalue 604,MXI(1,1)	Initialize arrival rate for next day.
Savevalue 609+,V$Day	Increase total time to date
Savevalue 619,1	Initialize savevalue index
Terminate	

Segment 5

This segment terminates the simulation



APPENDIX 3

OTHER FACILITY PLANNING MODELS

OTHER MODELS

1. COMPANY: First National Bank, Statistics and Standards Section.

   PURPOSE: To determine teller requirements for branch offices.

   MODEL DESCRIPTION: Analytic model based on teller activity and the corresponding work standards as defined from Methods-Time-Measurement (MTM) studies.

   CURRENT STATUS: Never been used, project cancelled.

2. COMPANY: Aer Lingus, Irish International Airline, Dublin Airport, Ireland.

   PURPOSE: To determine manpower requirements for the airline booking offices.

   MODEL DESCRIPTION: (i) Analytical model

   (ii) Assumptions

   - exponential service times
   - poisson arrival rate (mean arrival rate is fixed for 1 hour intervals).

OTHER MODELS (Continued)

2. COMMENTS: The model does not answer enough of the questions credit union managers wish to know about their facility requirements.

3. COMPANY: Woods, Gordon & Co., Management Consultants, Toronto, Canada

PURPOSE: To determine the number of tellers and wickets required in bank branches.

MODEL DESCRIPTION:
(i) Analytical model
(ii) Requirements are determined by controlling the average waiting time in the queue.
(iii) Assumptions
- exponential service times
- poisson arrival rates

COMMENTS: The model does not answer enough of the questions credit union managers wish to know about their facility requirements.

APPENDIX 4

A CASE STUDY

A DETERMINATION OF THE REQUIRED TELLER FACILITY FOR CAMPBELL RIVER DISTRICT CREDIT UNION

Table of Contents

1. SCOPE

Determine for Campbell River District Credit Union their facility requirement in order to provide adequate member service for present credit union size and for a 50% and 100% growth in membership.

2. OBJECTIVES

For Campbell River District Credit Union, determine (at present credit union size and for a 50% and 100% growth):

2.1 The required number of wickets

2.2 The required number of tellers

2.3 Teller schedule

2.4 Member service level in terms of waiting time and queue length

2.5 The required member service area

2.6 The required member waiting area

3. METHOD

Simulation Model

In order to achieve the objectives, the member service process (length of time before service and the number of waiting for service) was evaluated by a simulation model. A computer program was developed which simulates the teller services to members.

The simulation was used for four main purposes:

- to evaluate the present level of member service at Campbell River District Credit Union.

- to evaluate the effect on member service on increasing/decreasing the number of tellers at present and with a 50% and 100% growth.

- to provide basic information required to determine the teller schedule.

- to provide basic information required to determine the required member waiting area and teller service area at present and with a 50% and 100% growth.

4. DATA COLLECTION

In order to evaluate the queuing behavior and determine the level of member service, the following information was required:

4.1 Present Teller Time Schedule

The present teller schedule according to the existing policy is described in Table 1.

Table 1

Teller Schedule

Day of the Week	Office Hours	1st Shift	No. of Staff	2nd Shift	No. of Staff	Total No.
Monday	9:00 - 1:00	8:30 - 1:30	3	-	-	3
Tuesday	10:00 - 5:30	9:00 - 5:30	7	-	-	7
Wednesday	10:00 - 5:30	9:00 - 5:30	7	-	-	7
Thursday	10:00 - 5:30	9:00 - 5:30	7	-	-	7
Friday	10:00 - 6:00	9:00 - 6:00	3	9:00 - 5:30	3	6
Saturday	9:00 -12:30	8:30 - 1:30	3	-	-	3
				Total No. of Man days 33		

NOTE: 1 part-time teller also available on Friday between 9:00 - 2:00.

4.2 Member Service Time

The average member service time is 2.1 minutes/member.

4.3 Teller activities requires other than serving members

A major part of each tellers work day is used for various other activities than member service, as described in Table 2, following.

Table 2

TELLER ACTIVITIES OTHER THAN MEMBER SERVICE DURING OFFICE HOURS

Activities	Constraint	Frequency	Required Time per Activity	Total Time Per Teller Per Activity
Tallying sums	At reasonable intervals	3	10 min.	30 min.
Balancing	Before 3:00 p.m.	1	20 min.	20 min.
Coffee Break	At reasonable time	1	15 min.	15 min.
Lunch Break	At reasonable time	1	60 min.	60 min.
			Total Teller Time:	125 min. per teller

Note: 125 minutes or 28% of most teller work days are not available for member service during regular office hours.

4.4 The maximum number of available wickets at Campbell River District Credit Union = 6.

4.5 Member arrivals at teller wicket during July 20 - August 4, 1973

The number of members entering Campbell River District Credit Union to use the teller facility was measured for each 15 minute period during the day. Summary see Table 3, following.

Table 3

MEMBER ARRIVAL SUMMARY

Day of the Week	Total Member Arrival per Day	Member Arrival Rates		
		Average Member Arrival Per Hour	Minimum Arrivals Per Hour	Maximum Arrivals Per Hour
Fri., July 20	527	66	50	91
Sat., July 21	224	64	33	87
Tues., July 24	376	50	42	72
Fri., July 27	434	54	33	84
Sat., July 28	247	70	44	103
Mon., July 30	131	33	19	40
Tues., July 31	435	58	45	72
Wed., Aug. 1	339	45	28	57
Thurs., Aug. 2	515	69	30	115
Fri., Aug. 3	591	74	58	90
Sat., Aug. 4	226	65	38	87
For sample:	4045	59	19	115

4.6 General Assumptions

- The length of time required by a teller to service members is not dependent on the hour of the day.

- The waiting area required for a member = wickets length x 2 feet.

5. EVALUATIONS

The evaluations illustrate how the situation at Campbell River District Credit Union is best described within the model, specifically:

5.1 Teller and wicket requirements (within and between days).

5.2 Level of service to members.

5.3 Effect of growth on wicket and teller requirements.

5.4 Teller schedule.

5.5 Area requirements for wickets and members waiting for service.

5.1 Teller and wicket requirements

5.1.1 Present wicket requirements

The maximum number of wickets which are required to provide satisfactory member service varies between days. See Table 4.

Table 4

THE MAXIMUM NUMBER OF REQUIRED WICKETS

Day of the week	Maximum number of wickets required
Thursday	5
Friday	4
Saturday	4

At present, 6 wickets are available, whereas, only 5 wickets are required to provide adequate member service.

5.1.2 Present teller requirements

The maximum number of tellers required for serving members in each hour of the day of the week varies. See Table 5.

Table 5

TELLER REQUIREMENTS

Day of the week	Hour of the Day 9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6
Thursday	-	3	3	3	2	2	3	5	5
Friday	-	3	3	3	2	3	3	4	4
Saturday	3	4	4	4	-	-	-	-	-

During the hour of 4:00 - 5:30, on Thursday, 5 tellers are required to provide adequate member service. On all other days, the maximum is 4 or less.

5.2 Level of service to members during the week

Assuming that layout changes suggested for the existing facility will be implemented, there will be no significant changes in member service level during the week.

The member service level will be as described in Table 6.

Table 6

MEMBER SERVICE LEVEL

Day	Number of Members waiting/available teller		Member waiting time in minutes	
	Average	Maximum	Average	Maximum
Thursday	3	7	3	9
Friday	2	6	4	9
Saturday	3	7	4	9

Member service does not differ significantly during the busy days of the week.

NOTE: Maximum implies that 99% of all values are equal to or less than the indicated value.

5.3 Effect of growth on wicket and teller requirements

For a 50% and 100% increase in the demand made on the teller facility, and assuming that members receive the same level of service, the following evaluations were made:

5.3.1 Wickets required to meek peak periods

- present membership
- 50% increase in membership

5. EVALUATIONS (Continued)

- 100% increase in membership

Increasing the number of wickets and changing the teller schedule so that the required number of tellers are available will significantly improve the level of service to members. The following analysis gives a broad conceptual approach to the problem of determining the required number of wickets and member service.

Level of service for present membership

In this section, as in previous sections, the level of service is determined by the member waiting time and the number of members waiting for service.

By increasing the number of wickets from 4 to 5 the waiting time during the peak day is significantly decreased as shown in Figure 1. The maximum waiting time is decreased form 19 minutes to 11 minutes while the average waiting time is decreased from 7 minutes to 4 minutes. It should be noted that any additional wickets would not significantly decrease the waiting time.

5. EVALUATIONS (Continued)

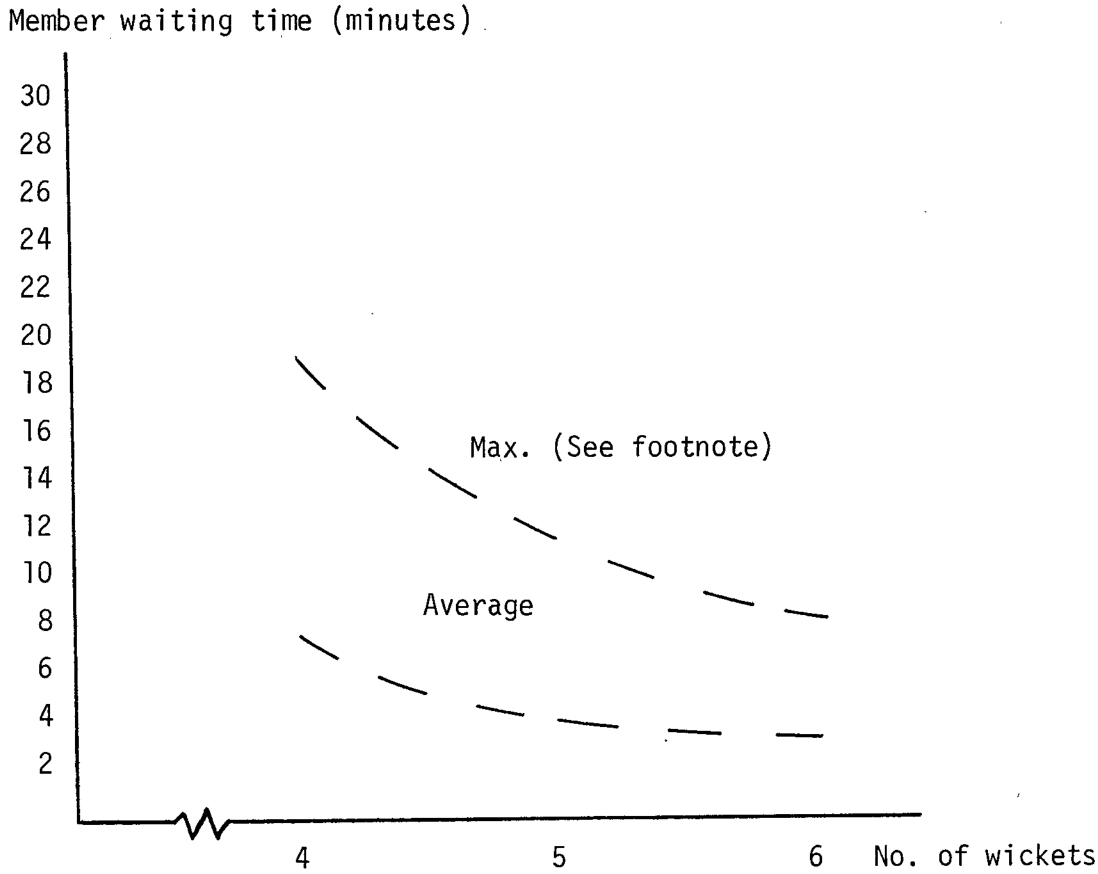


Figure 1 - Relationship between member waiting time during the peak day and maximum available wickets.

Note: Maximum implies that 99% of all values are equal to or less than the plotted value for the corresponding number of wickets.

With an increase in the number of wickets from 4 to 5, the number of members waiting at each wicket during the peak day is significantly decreased. Figure 2 shows that the maximum number waiting at each wicket is decreased from 9 to 7, while the average number waiting at each wicket is decreased from 4 to 3.

5. EVALUATIONS (Continued)

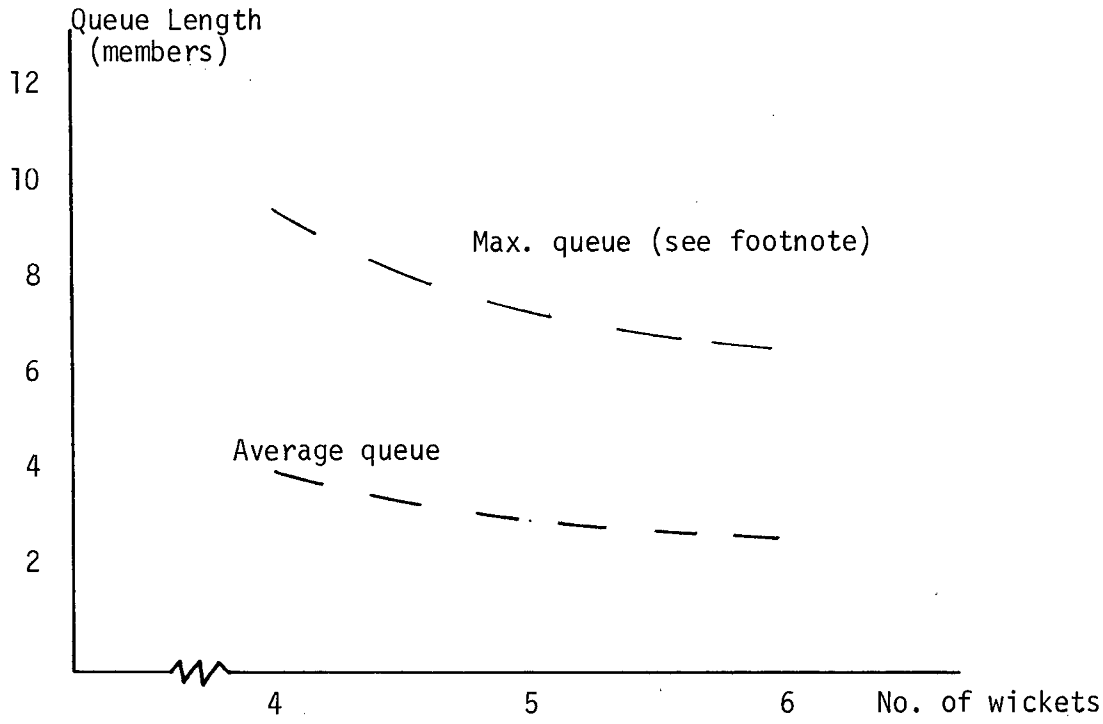


Figure 2 - Relationship between members waiting during the peak day at each wicket and maximum available wickets.

Note: Maximum implies that 99% of all values are equal to or less than the plotted value for the corresponding number of wickets.

Level of service for 50% growth in membership

By increasing the number of wickets form 5 to 7, the waiting time during the peak day decreases significantly, as shown in Figure 3. The maximum waiting time is decreased from 25 minutes to 11 minutes while the average waiting time is decreased from 9 to 5 minutes.

5. EVALUATIONS (Continued)

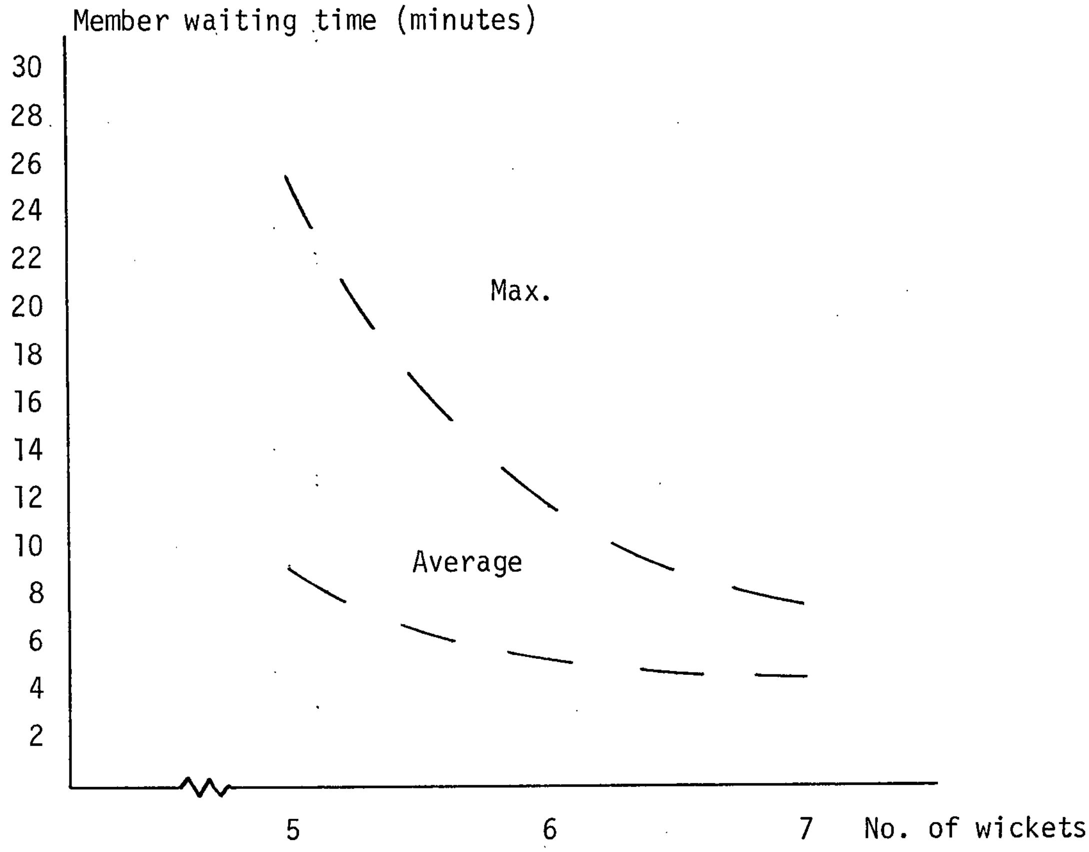


Figure 3 - Relationship between member waiting time during the peak day and available wickets for a 50% increase in membership.

Level of service for 50% growth in membership

By increasing the number of wickets from 5 to 7, the number of members waiting during the peak day at each wicket is significantly decreased. Figure 4 shows that the maximum number of waiting at each wicket is decreased from 12 to 7, while the average number waiting at each wicket is decreased from 5 to 3.

5. EVALUATIONS (Continued)

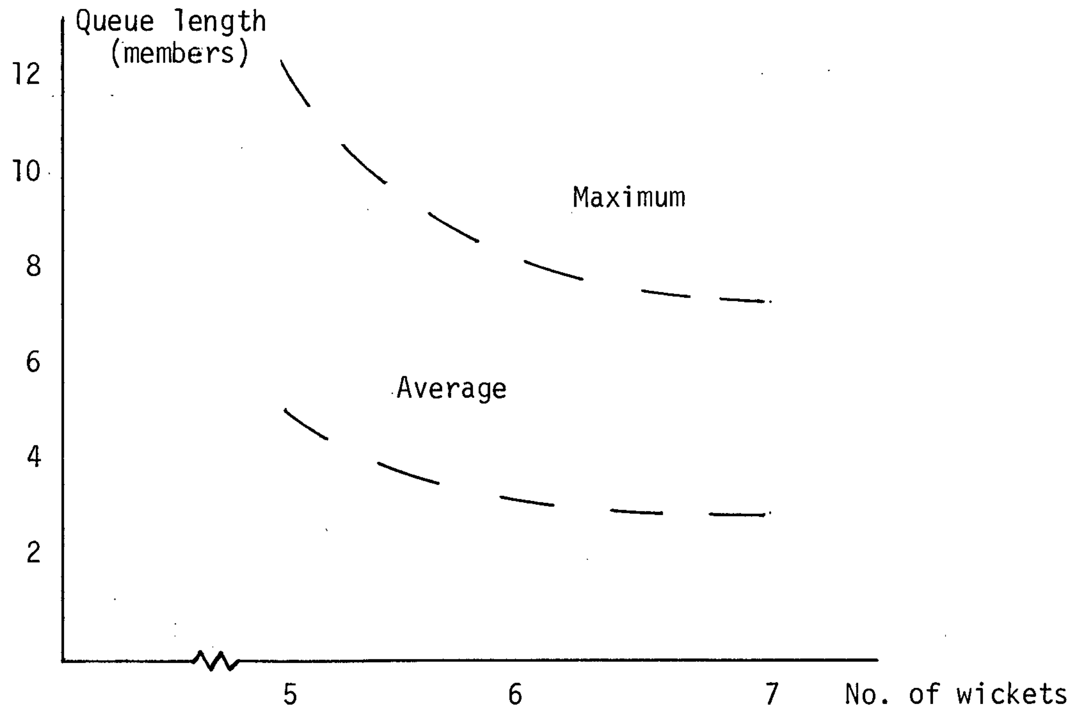


Figure 4 - Relationship between members waiting at each wicket during the peak day and maximum available wickets for a 50% increase in membership.

Level of service for 100% growth in membership

By increasing the number of wickets from 8 to 9, the waiting time decreases significantly, as shown in Figure 5. The maximum waiting time is decreased from 17 minutes to 13 minutes while the average waiting time is decreased from 6 minutes to 5 minutes.

5. EVALUATION (Continued)

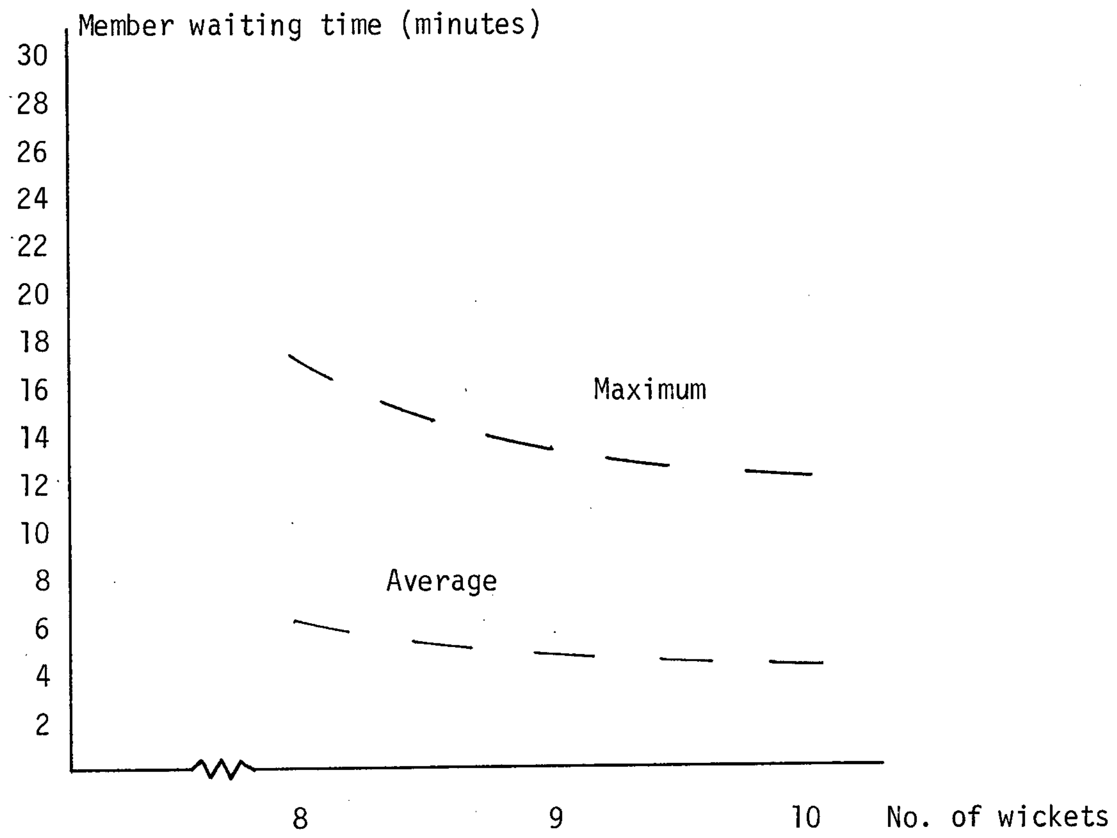


Figure 5 - Relationship between waiting time during the day and available wickets for 100% increase in membership.

Level of service for 100% growth in membership

By increasing the number of wickets from 7 to 9, the number of members waiting during the peak day at each wicket is significantly decreased. Figure 6 shows that the maximum number waiting at each wicket is decreased from 12 to 7, while the average number waiting is decreased from 5 to 3.

5. EVALUATIONS (Continued)

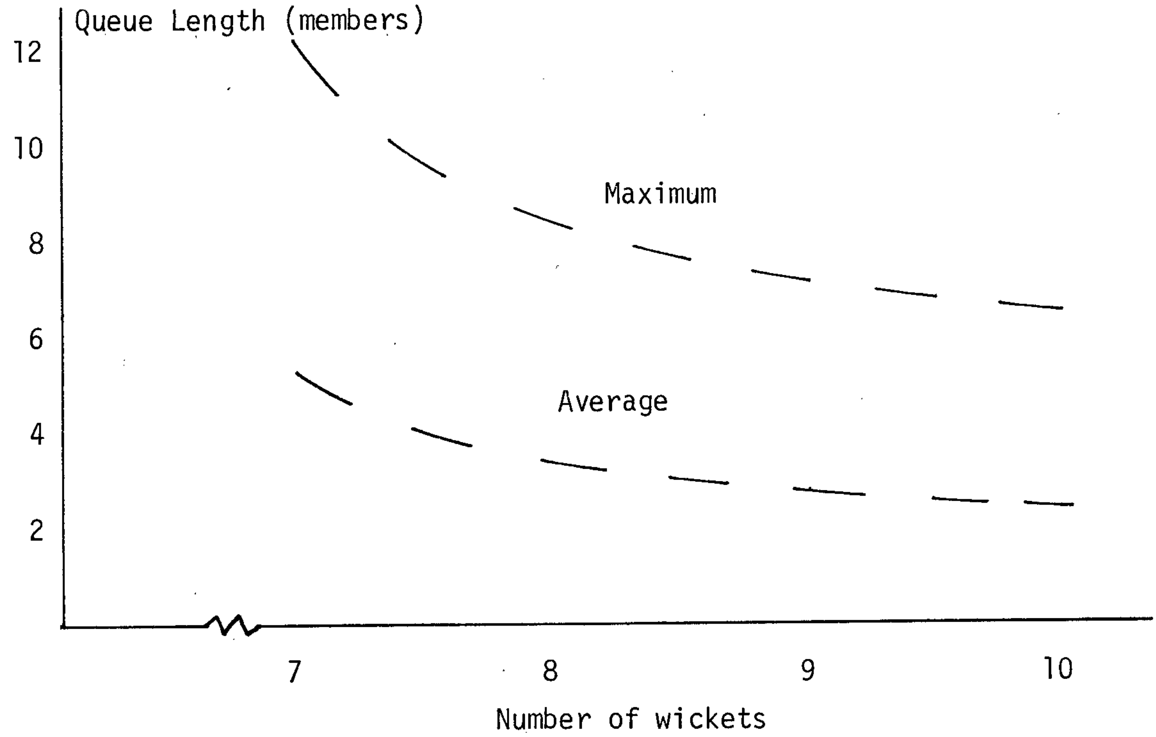


Figure 6 - Relationship between members waiting at each wicket during the peak day and the maximum available wickets for a 100% growth in membership.

5.4 Teller schedule for busy day (Thursday, Friday, Saturday). See Appendix C.

5.5 <u>Area requirements for wickets and members waiting for service</u>

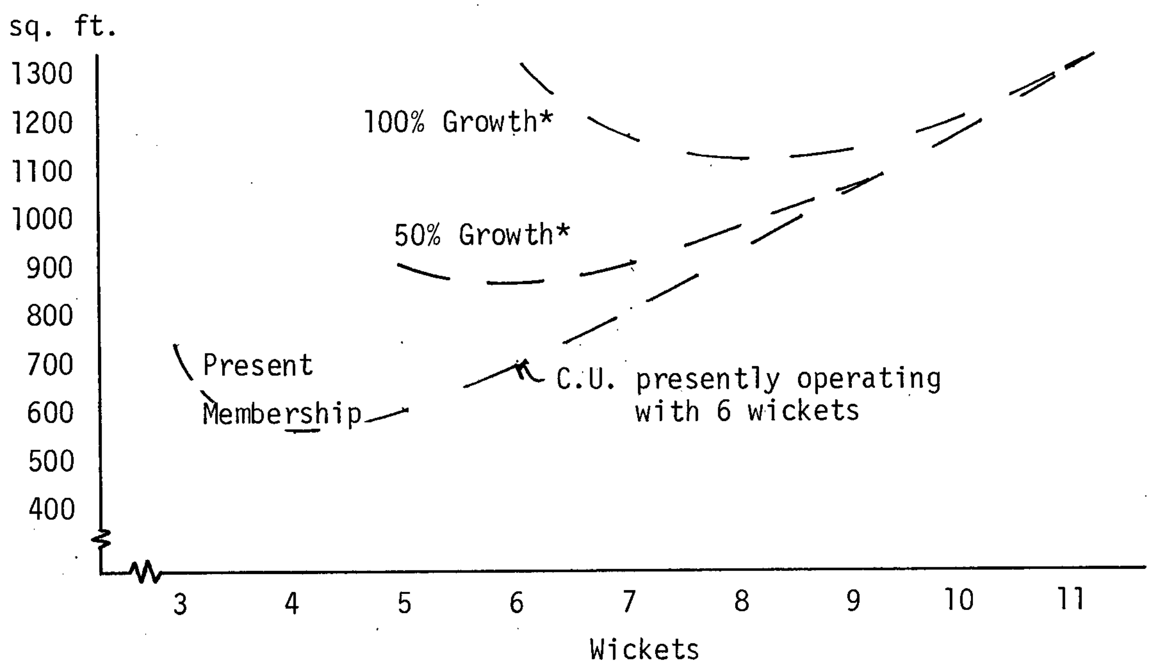
The amount of space required to accommodate members waiting is dependent on the number of members waiting for service at any given time.

5. EVALUATIONS (Continued)

If too few wickets are provided so that the Credit Union cannot meet the demand during peak periods, then large queues will develop and the waiting time will be very large.

If too many wickets are provided so that the Credit Union never uses all wickets even during peak periods, then again space is poorly utilized.

The following (see Figure 7) shows the space required to accommodate wickets and members for a given number of wickets. As seen below, the minimum space required to accommodate wickets and members is 550 sq ft., at present, and 840 sq. ft. when the membership has increased by 50%.



* Growth = membership

5. EVALUATIONS (Continued)

Figure 7 - Relationship between space required for the teller facility. (i.e. Wickets and member waiting area and number of wickets)

The existing facility with 6 wickets and member waiting area is sufficient for a growth of 30%.

6. CONCLUSIONS

6.1 The present facility with 6 wickets and member waiting area is sufficient for a 30% growth in membership.

6.2 In order to provide adequate member service, the Campbell River District Credit Union will require the following number of wickets as the membership increases:

Membership	Wickets Required
Present - 8200	5
8300 - 10000	6
10100 - 12000	7
12100 - 13900	8
14000 - 15900	9

6. CONCLUSIONS (Contined)

Note: If the Manager feels that 9 wickets in one branch is too many then he should consider a branch office.

6.3 The following teller schedule would benefit the Credit Union by increasing teller utilization and reduce member waiting time significantly.

6.3.1 Teller schedule for Thursday

NUMBER OF TELLERS PER SHIFT

Schedule	Shift 1 9:00-5:30	Shift 2 1:30-5:30
Present	5	
50% growth in members	7	
100% growth in members	6	4

6.3.2 Teller schedule for Friday

NUMBER OF TELLERS PER SHIFT

Schedule	Shift 1 9:00-6:00
Present	6

6. CONCLUSIONS (Continued)

6.3.3 Teller schedule for Saturday

NUMBER OF TELLERS PER SHIFT

Schedule	Shift 1 8:30-12:30
Present	4
100% growth	9

7. RECOMMENDATIONS

7.1 It is not necessary to expand the present teller facility (wickets and waiting area) until a 30% growth in membership is realized.

7.2 Increase the number of presently available tellers on Saturday to 4.

7.3 Decrease the number of presently available tellers on Thursday to 5.

7.4 Decrease the number of presently available tellers on Friday to 5.

7.5 Re-evaluate the number of tellers required on Monday, Tuesday,

7. RECOMMENDATIONS (Continued)

and Wednesday, since the demand made on the teller facility during these days is less than the demand made on any of the above days.

SUB-APPENDICES TO APPENDIX 4

Appendix 4.A Space required to accommodate members and wickets

Figure 1 - Space requirements for present membership, 50% growth and 100% growth.

Appendix 4.B Level of service for peak day of the week

Relationship between maximum available wickets and member waiting time.

Figure 2 - Present membership
Figure 3 - 50% increase in membership
Figure 4 - 100% increase in membership

Relationship between maximum available wickets and the number of members waiting at each available wicket.

Figure 5 - Present membership
Figure 6 - 50% increase in membership
Figure 7 - 100% increase in membership

SUB-APPENDICES TO APPENDIX 4 (Continued)

Relationship between maximum available wickets and the number of members waiting.

Figure 8 - Present membership

Figure 9 - 50% increase in membership

Figure 10 - 100% increase in membership

Appendix 4.C <u>Teller Schedule</u>

Teller schedule for Thursday

Figure 11 - Present membership

Figure 12 - 50% growth in membership

Figure 13 - 100% growth in membership

Teller schedule for Friday

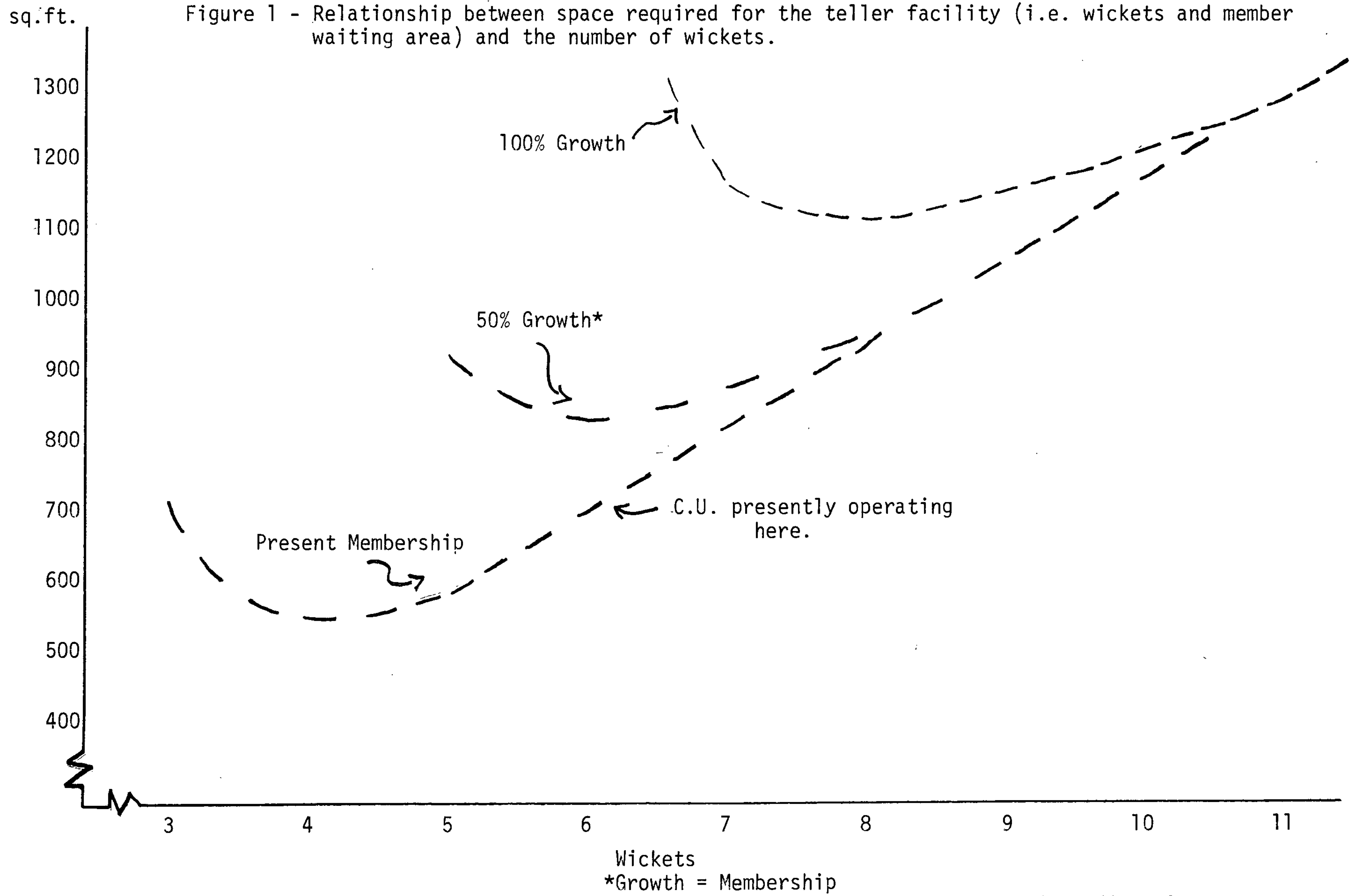
Figure 14 - Present Membership

Teller schedule for Saturday

Figure 15 - Present Membership

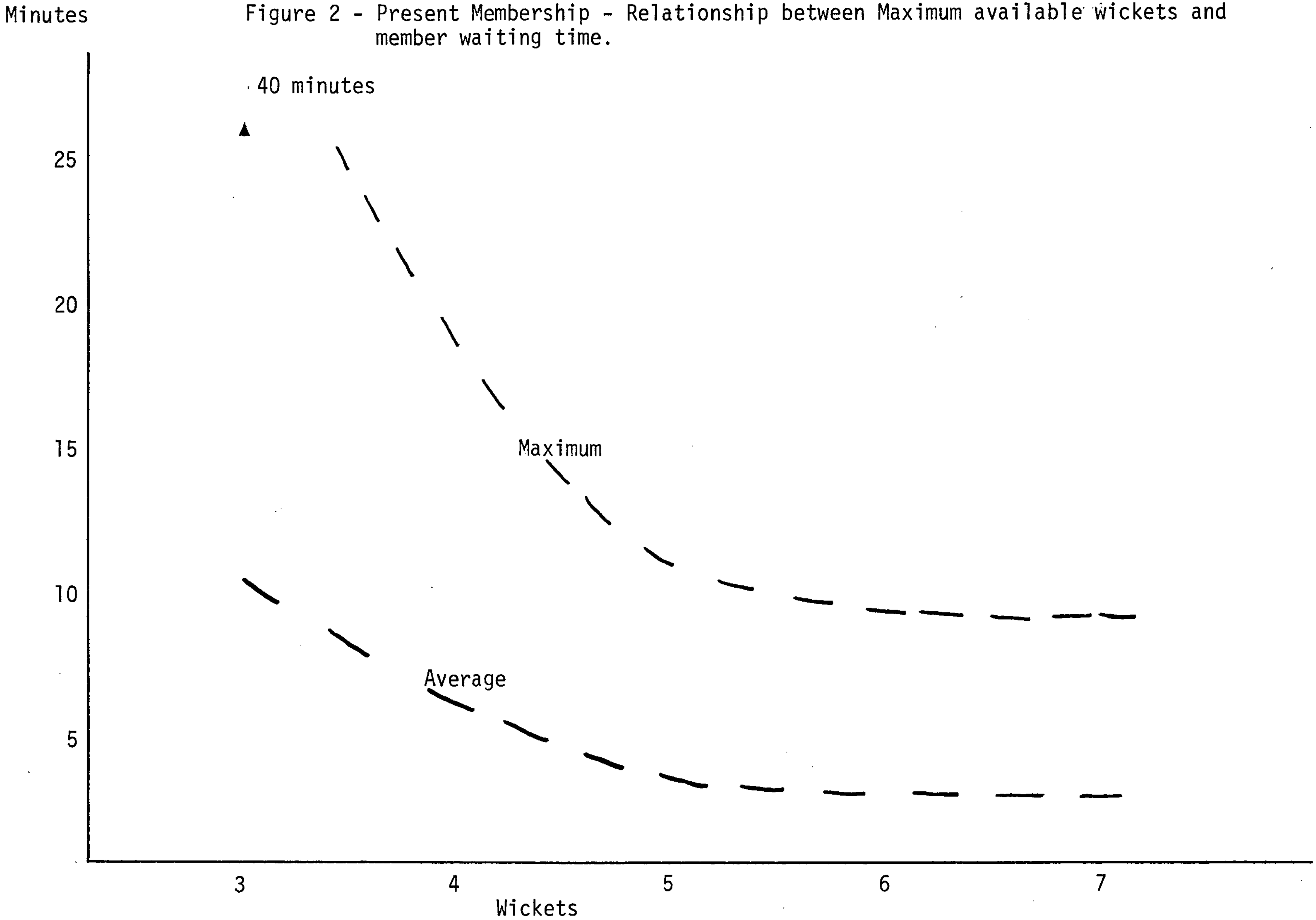
Figure 16 - 100% increase in membership

Figure 1 - Relationship between space required for the teller facility (i.e. wickets and member waiting area) and the number of wickets.



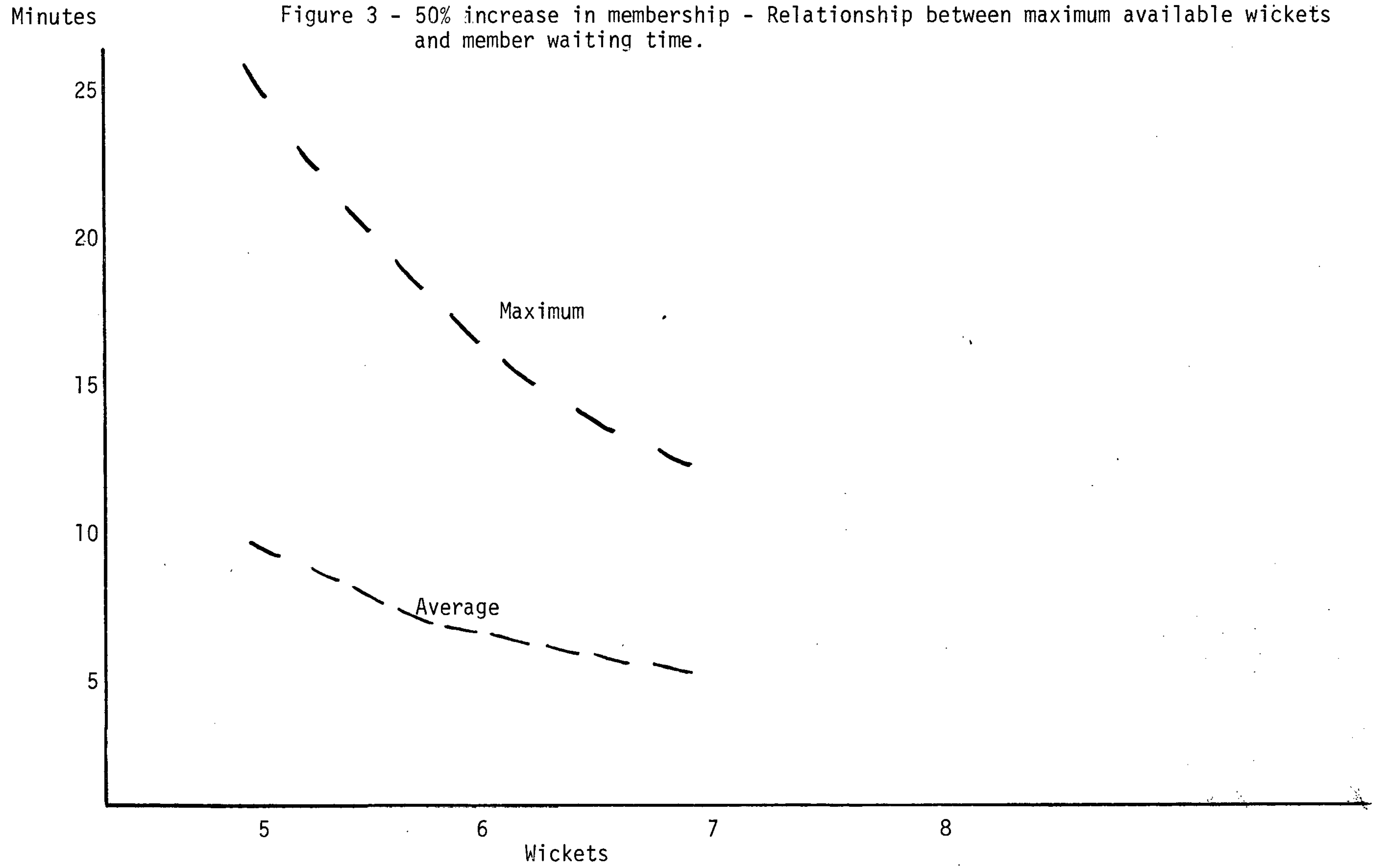
Appendix 4.A

Figure 2 - Present Membership - Relationship between Maximum available wickets and member waiting time.



Appendix 4.B

Figure 3 - 50% increase in membership - Relationship between maximum available wickets and member waiting time.



Appendix 4.B

Figure 4 - 100% increase in membership - Relationship between maximum available wickets and member waiting time.

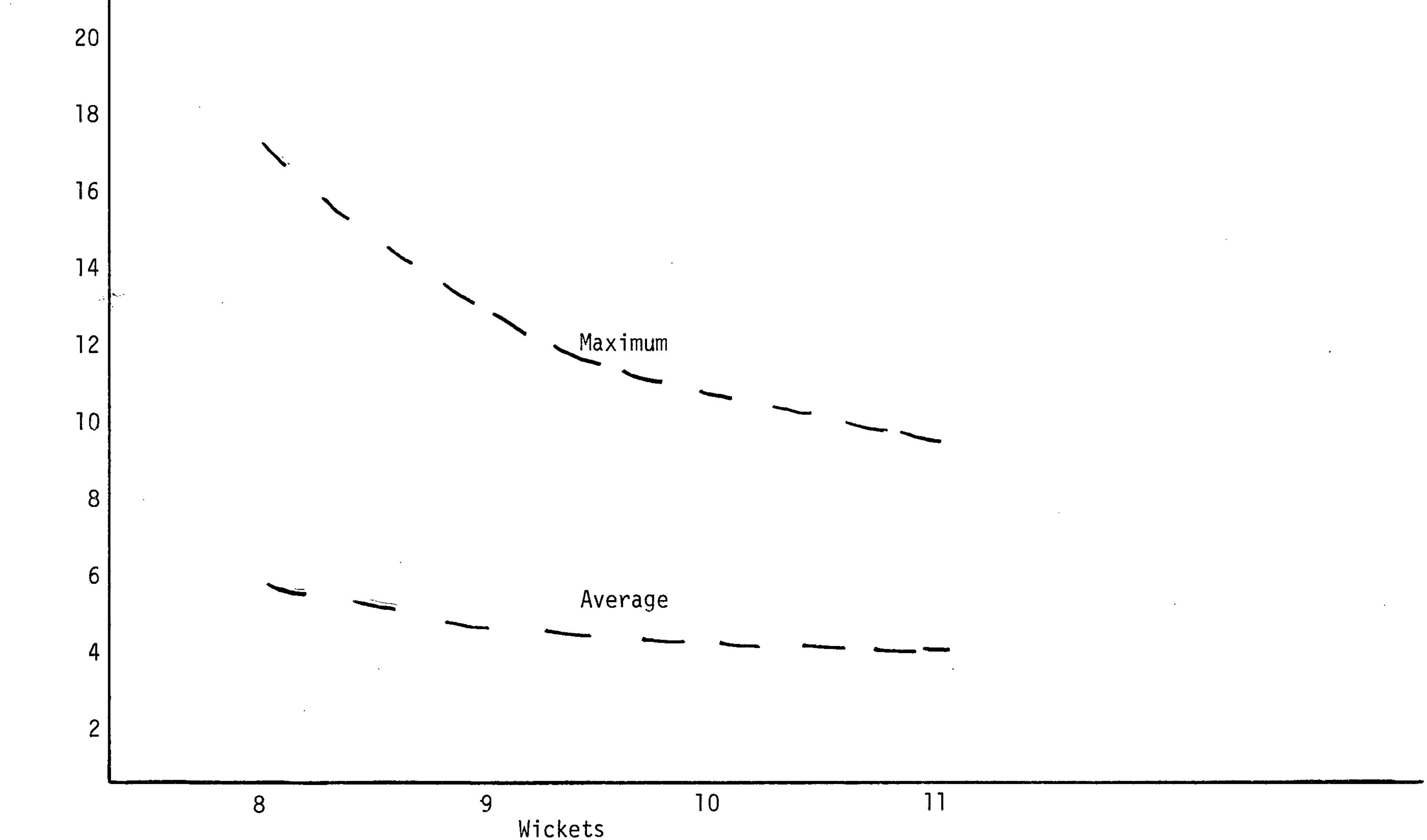
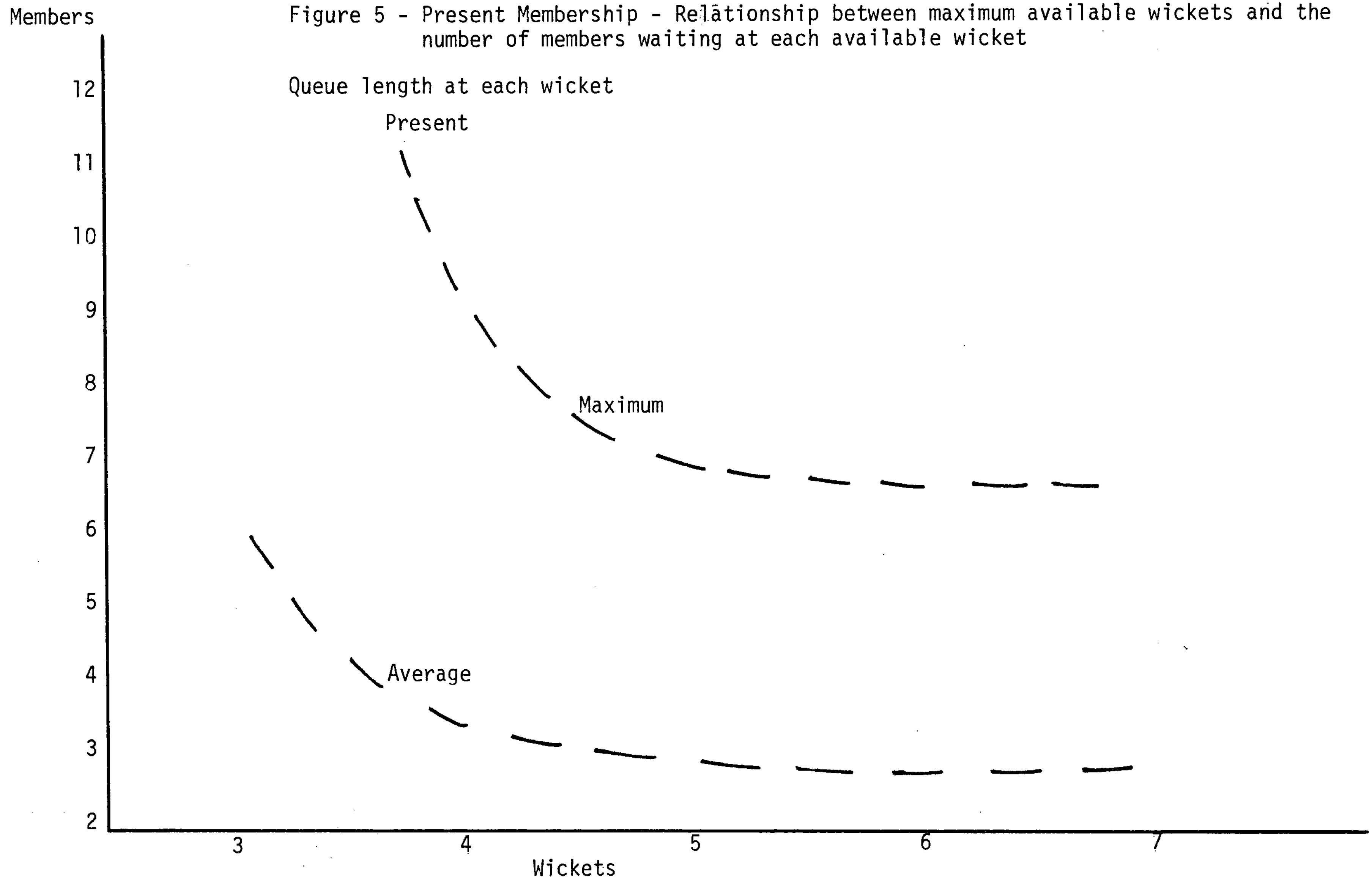
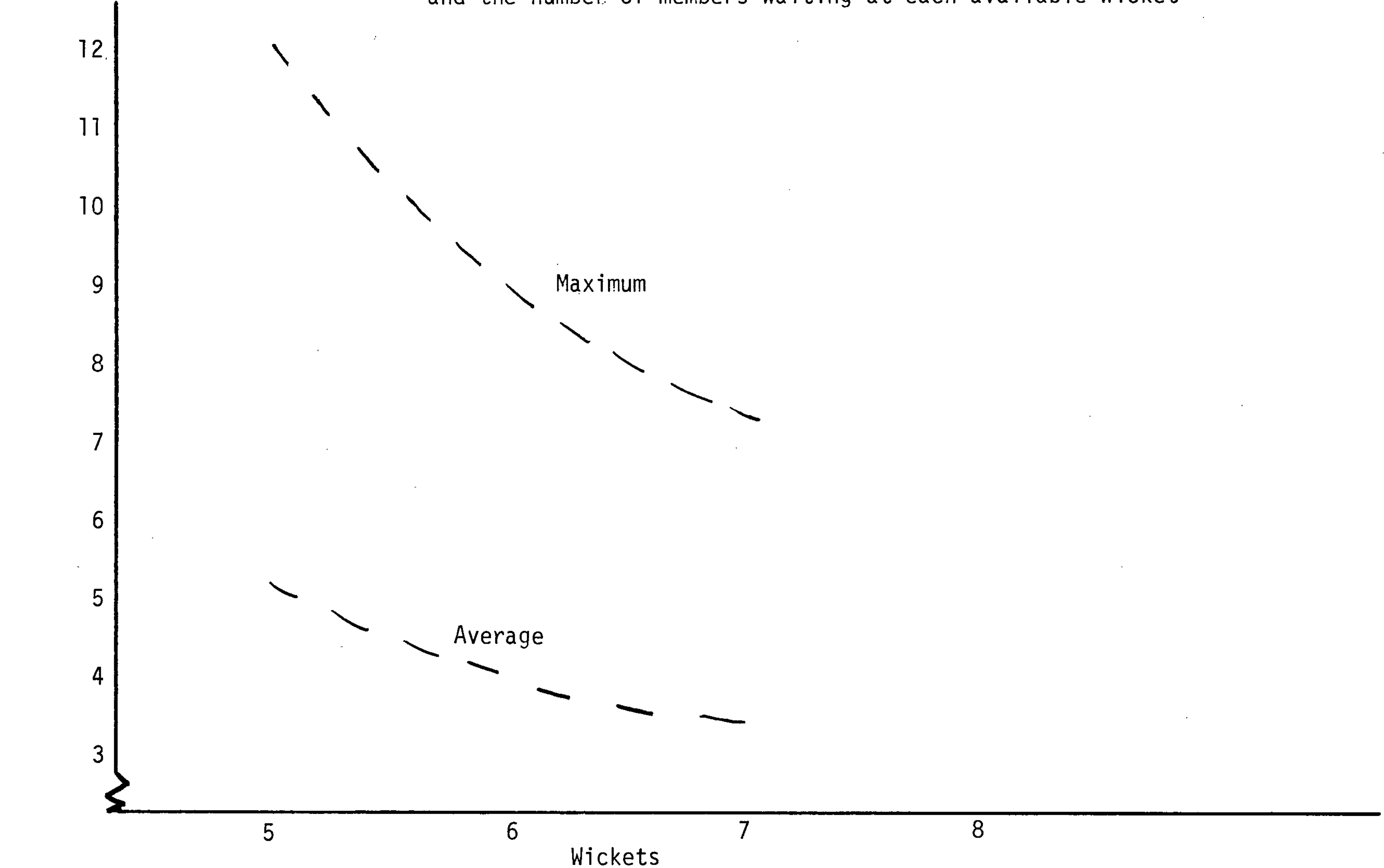


Figure 5 - Present Membership - Relationship between maximum available wickets and the number of members waiting at each available wicket



Appendix 4.B

Figure 6 - 50% increase in membership - Relationship between maximum available wickets and the number of members waiting at each available wicket



Appendix 4.B

Figure 7 - 100% increase in membership - Relationship between maximum available wickets and number of members waiting at each available wicket.

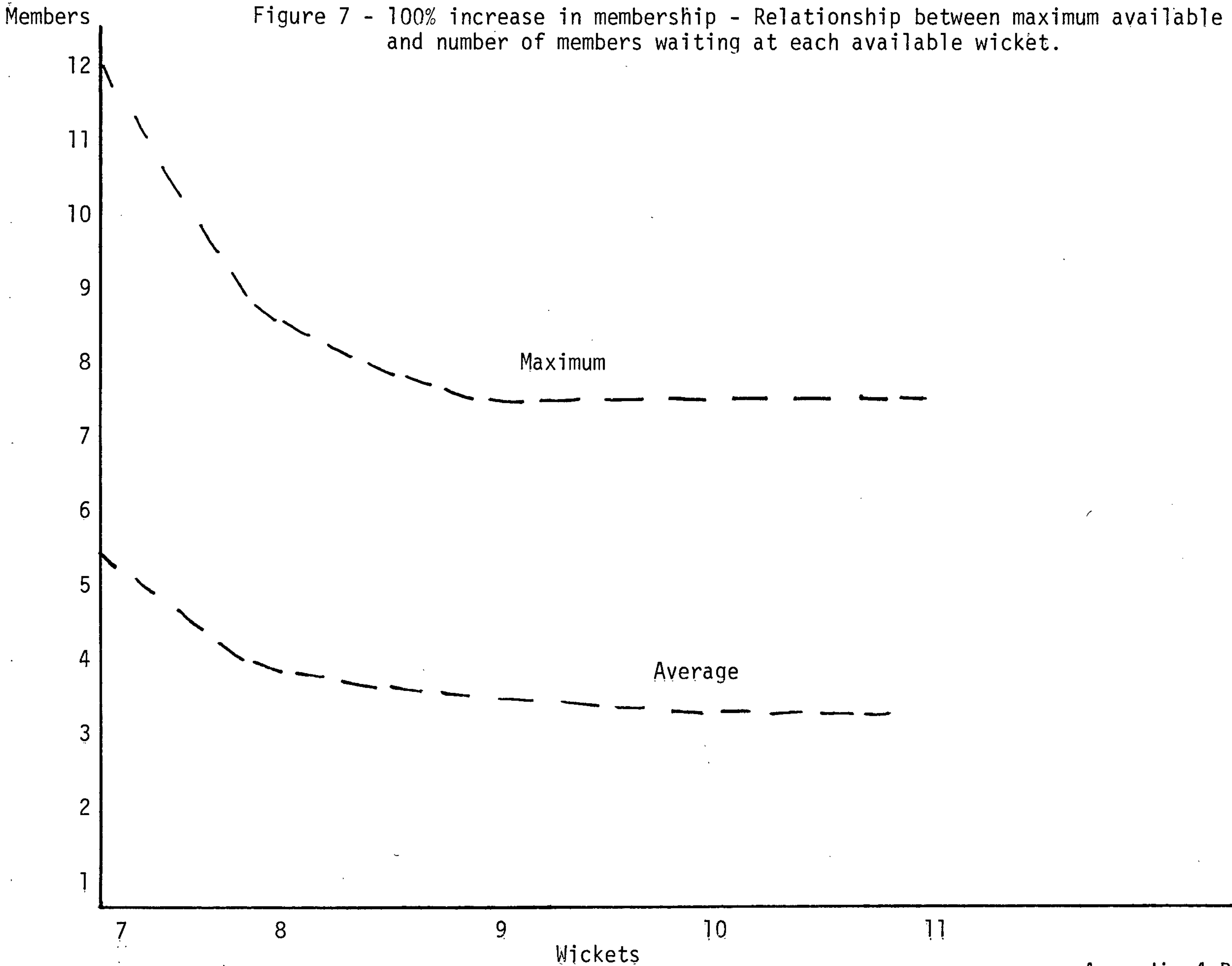
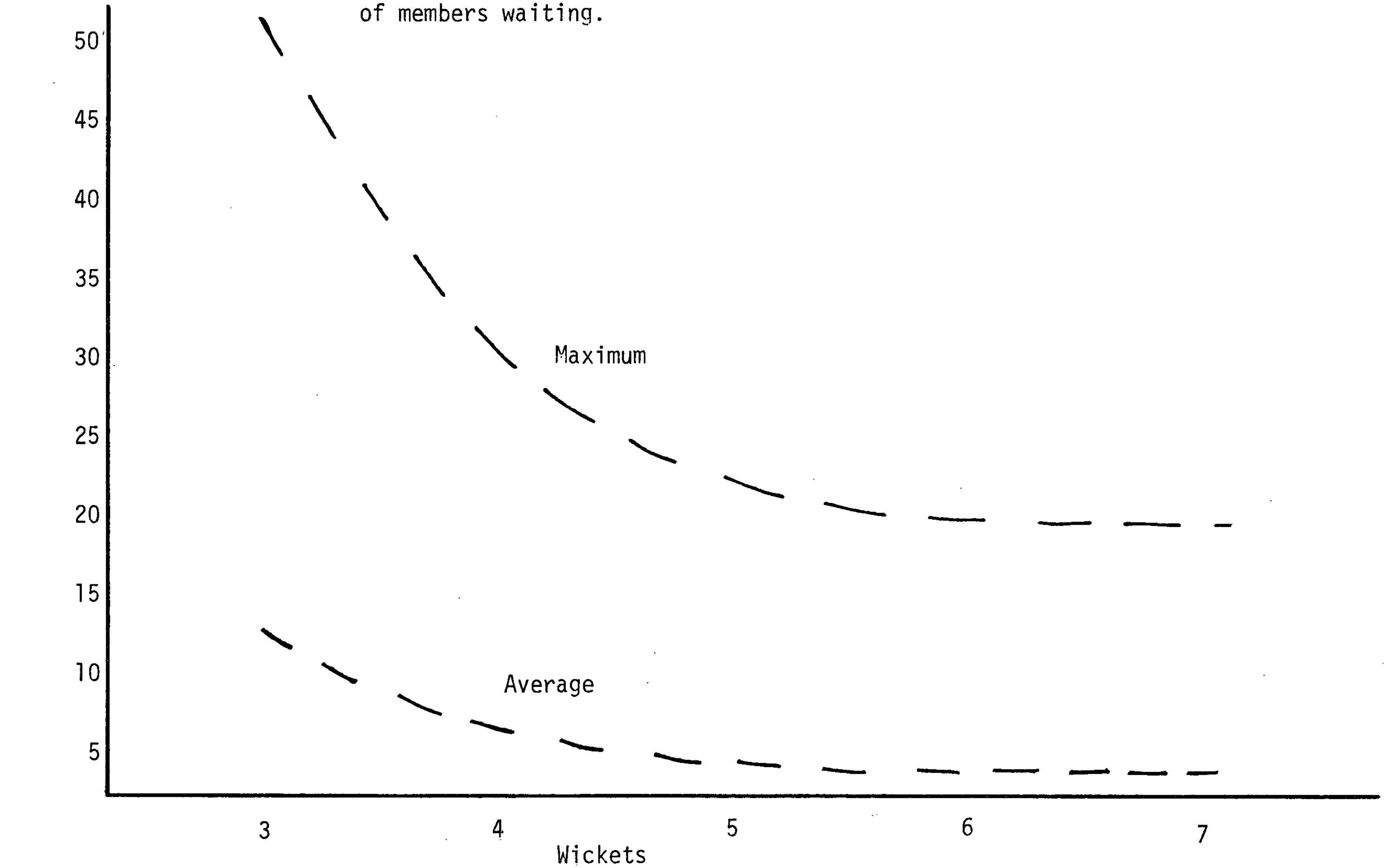
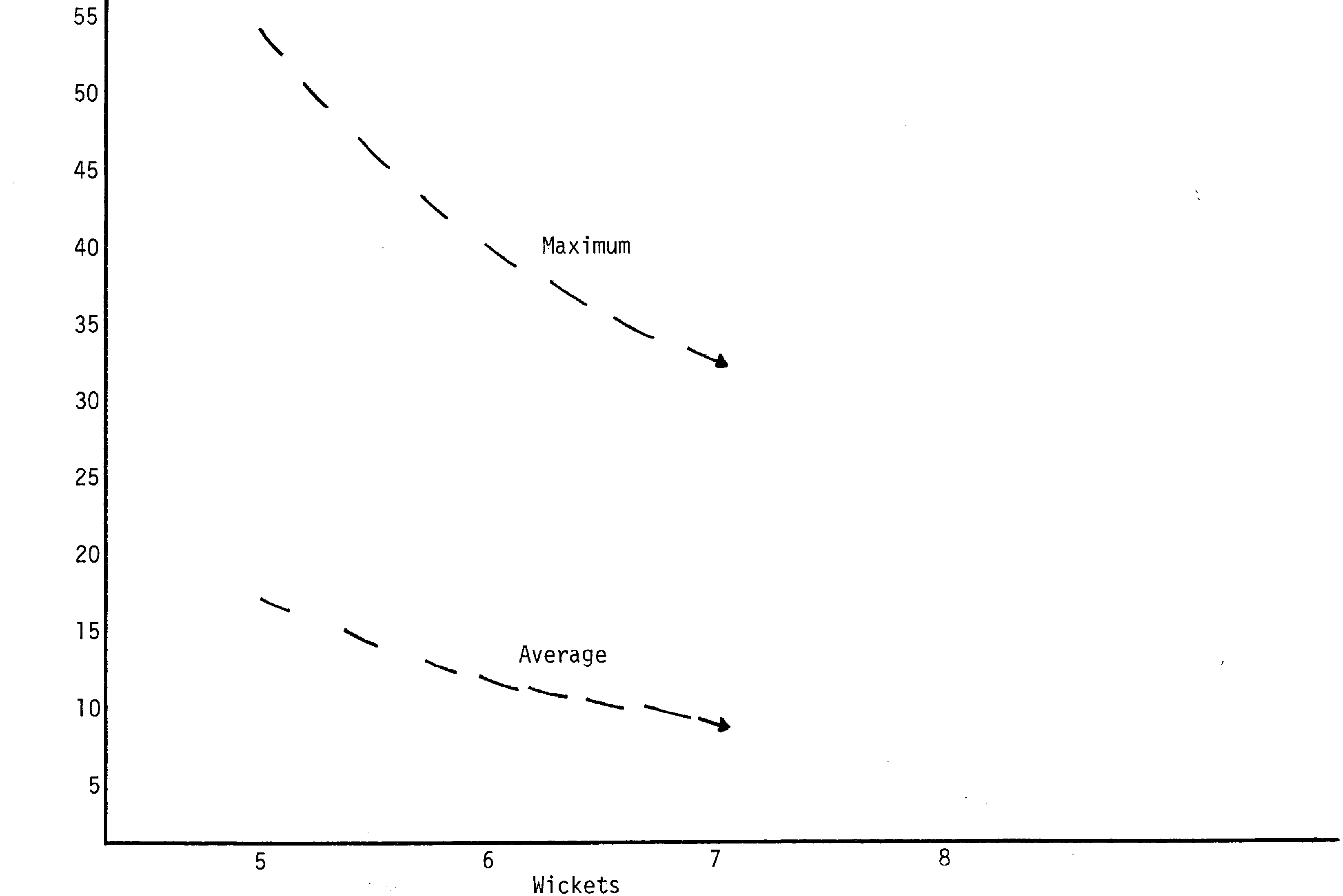


Figure 8 - Present Membership - Relationship between maximum available wickets and the number of members waiting.



Appendix 4.B

Figure 9 - 50% increase in membership - Relationship between maximum available wickets and the number of members waiting



Appendix 4.B

Figure 10 - 100% increase in membership - Relationship between maximum available wickets and the number of members waiting

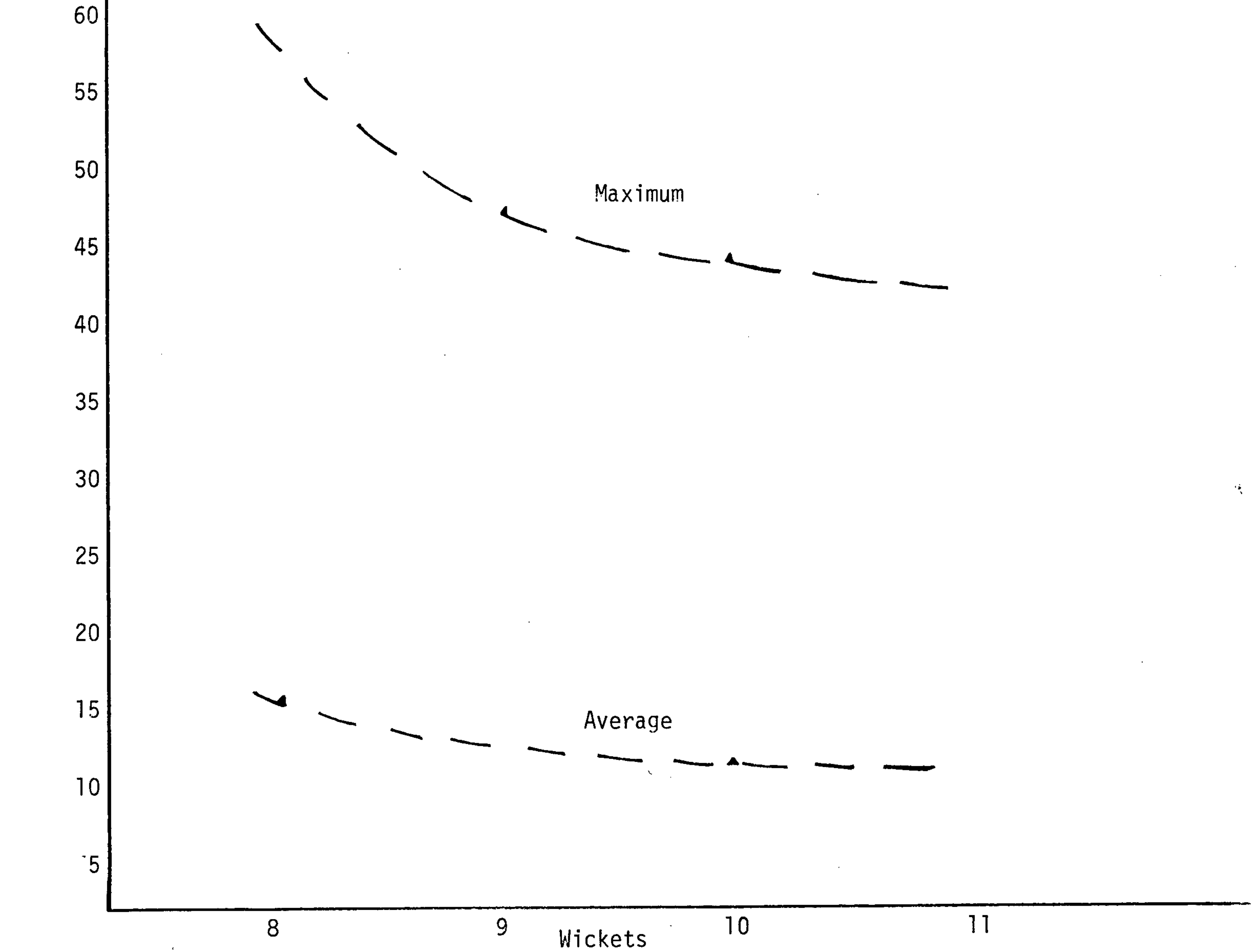
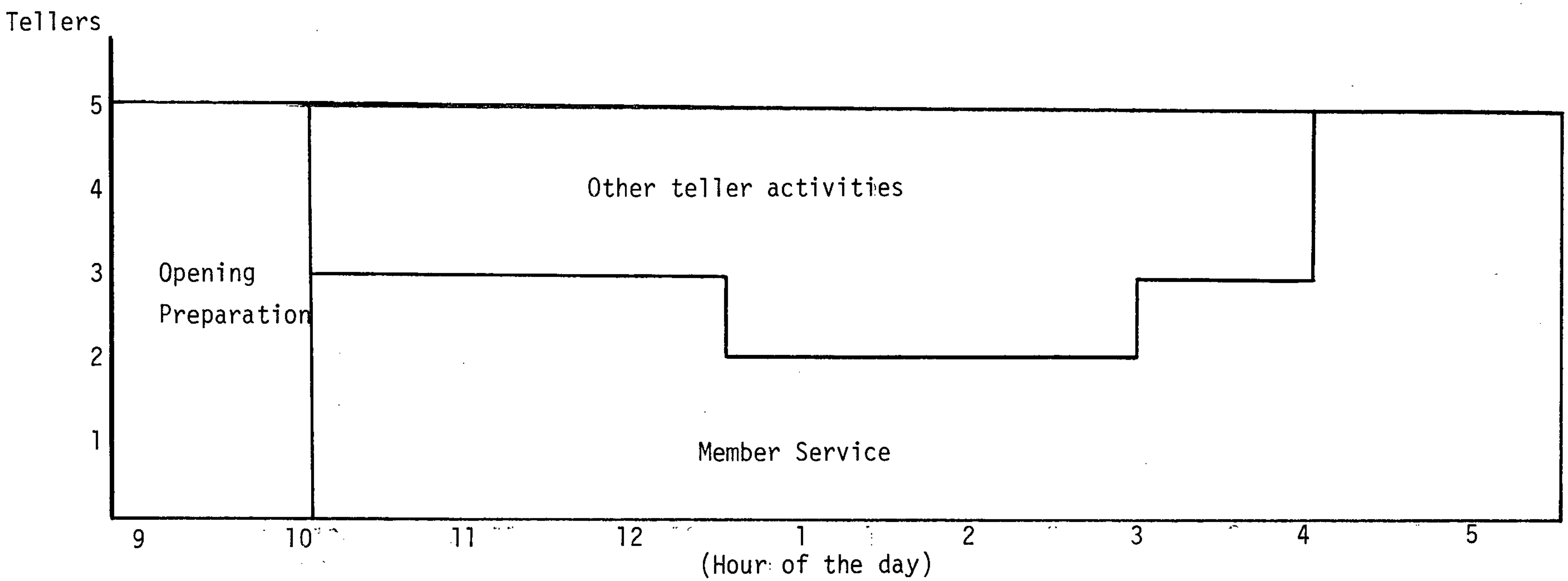
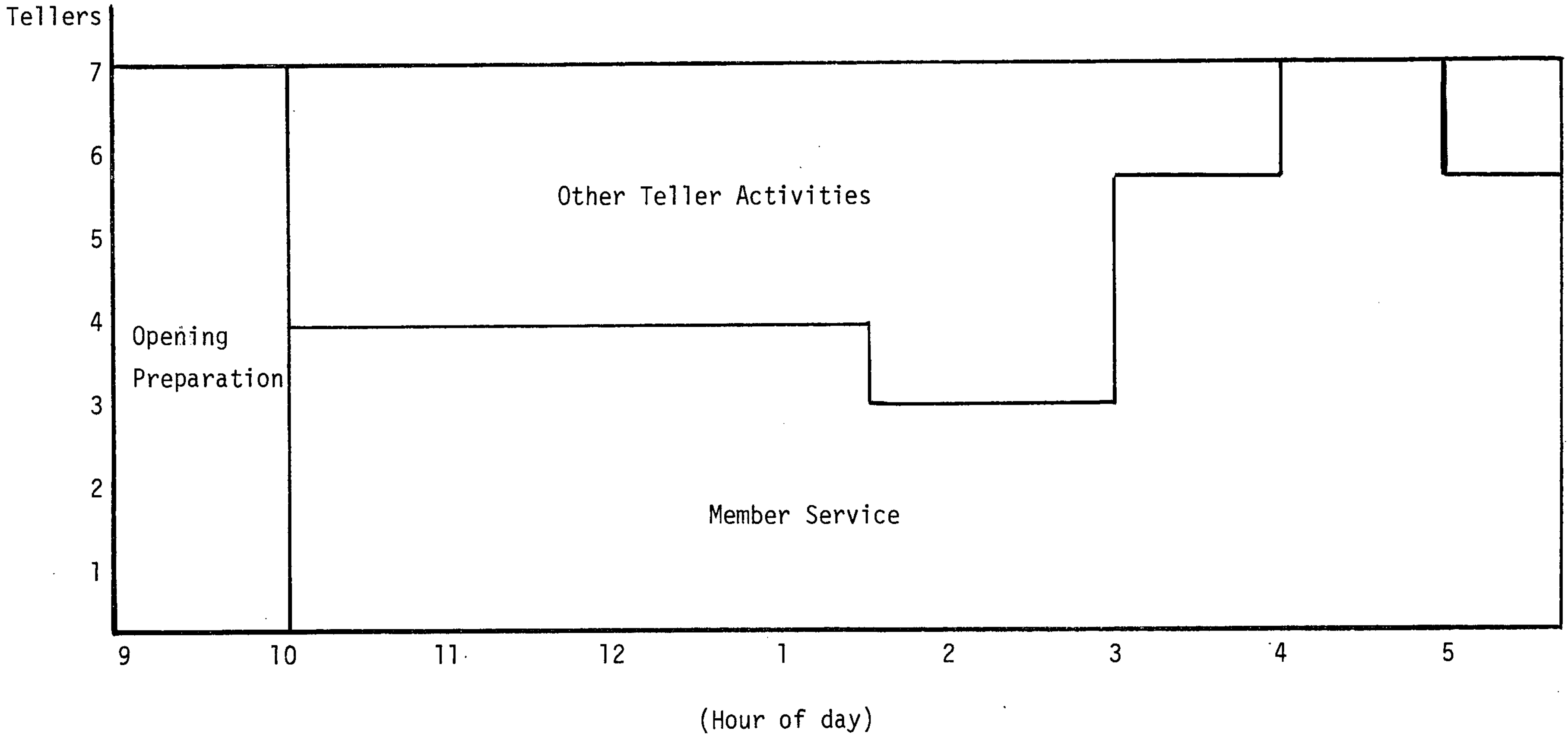


Figure 11 - Teller Schedule for Thursday - Schedule - 5 tellers 9:00 - 5:30



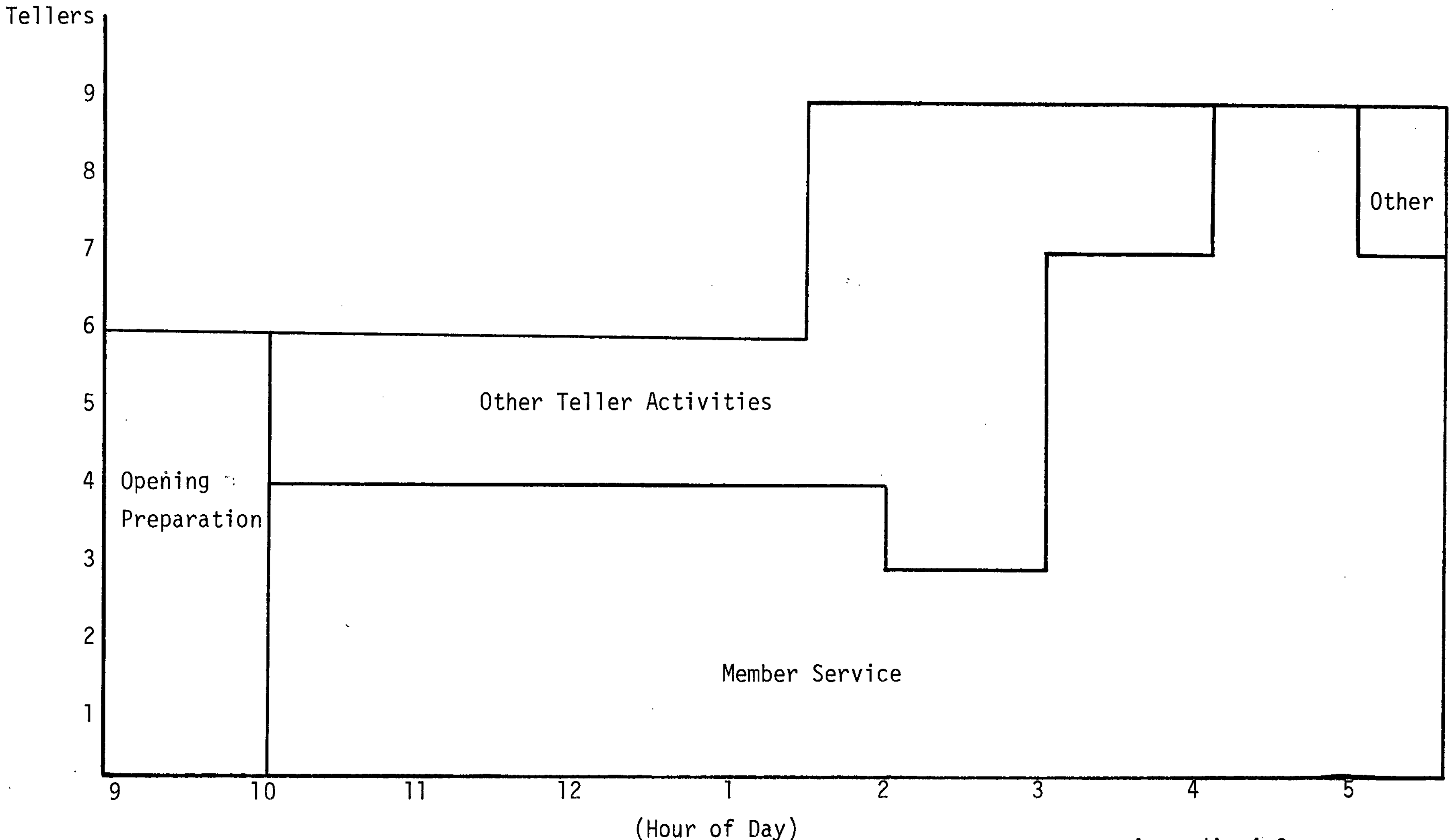
Appendix 4.C

Figure 12 - 50% growth in membership - Teller schedule for Friday
Schedule 7 tellers 9:00 - 5:30



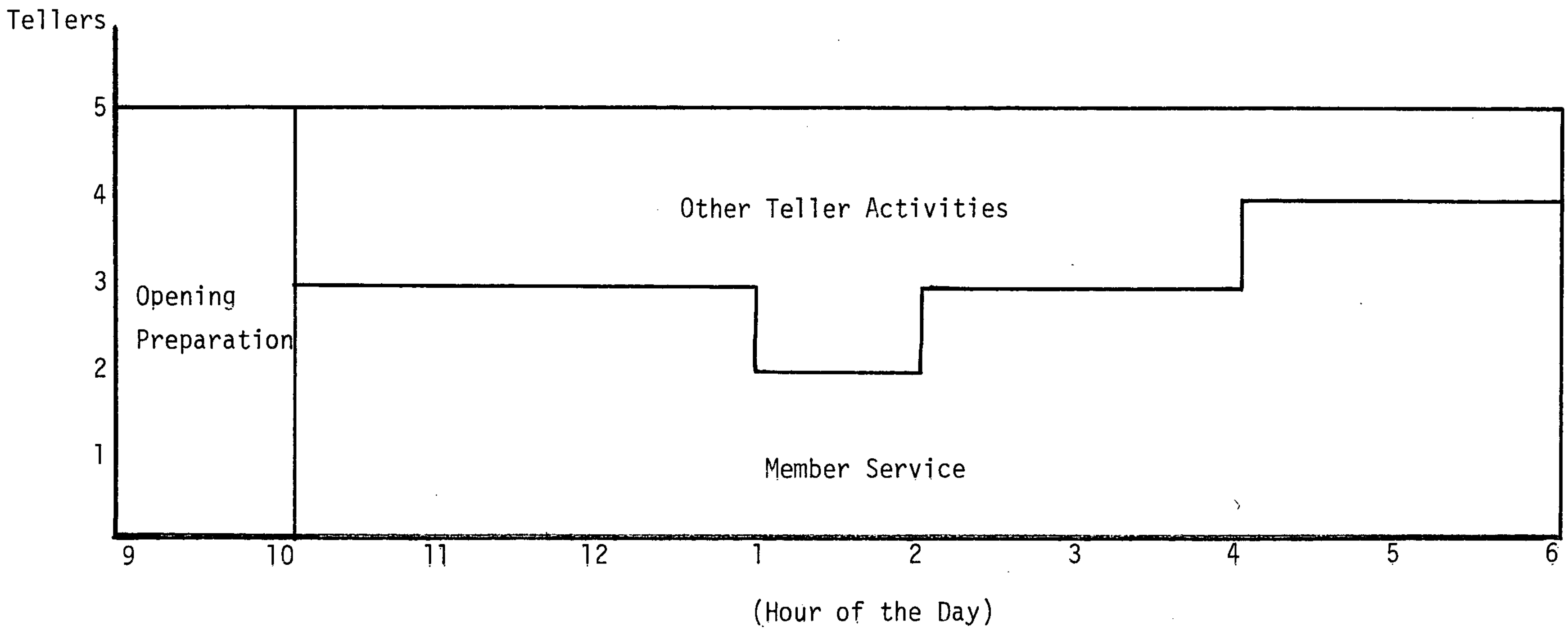
Appendix 4.C

Figure 13 - 100% growth in membership - Teller Schedule for Thursday
Schedule - 6 tellers 9:00 - 5:30, 3 tellers 1:30 - 5:30



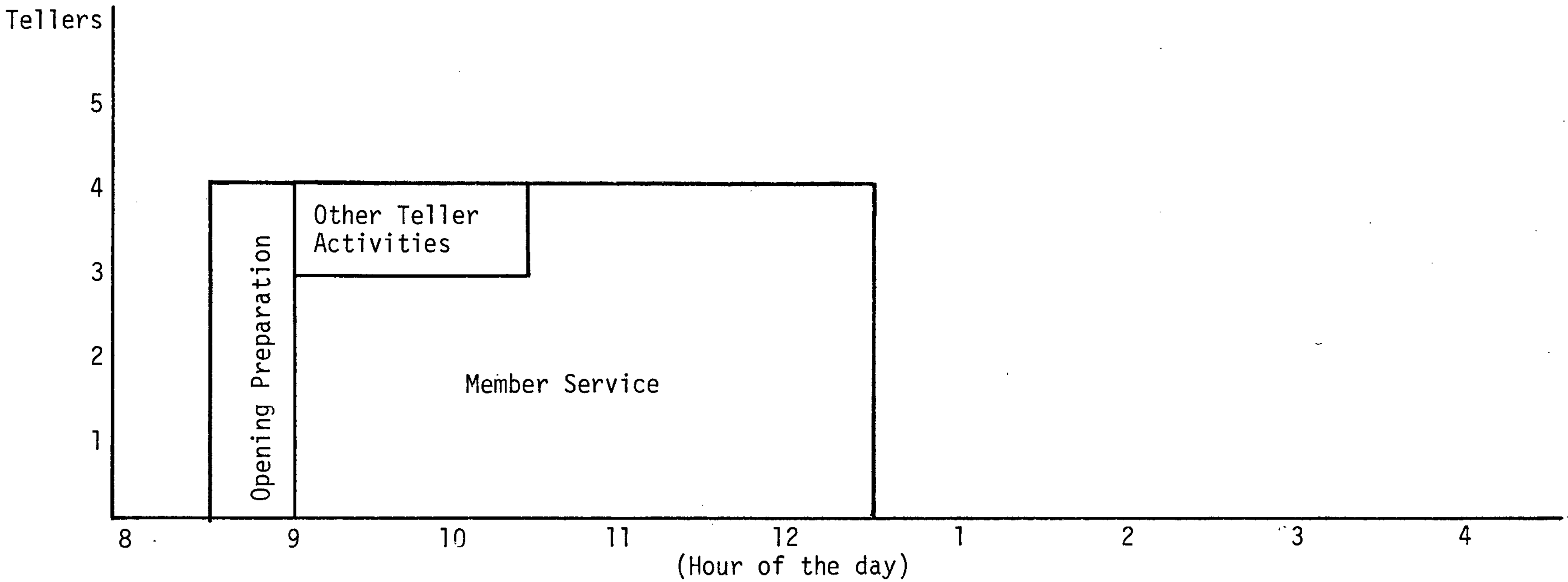
Appendix 4.C

Figure 14 - Present Membership - Teller Schedule for Friday
Schedule - 5 tellers 9:00 - 6:00



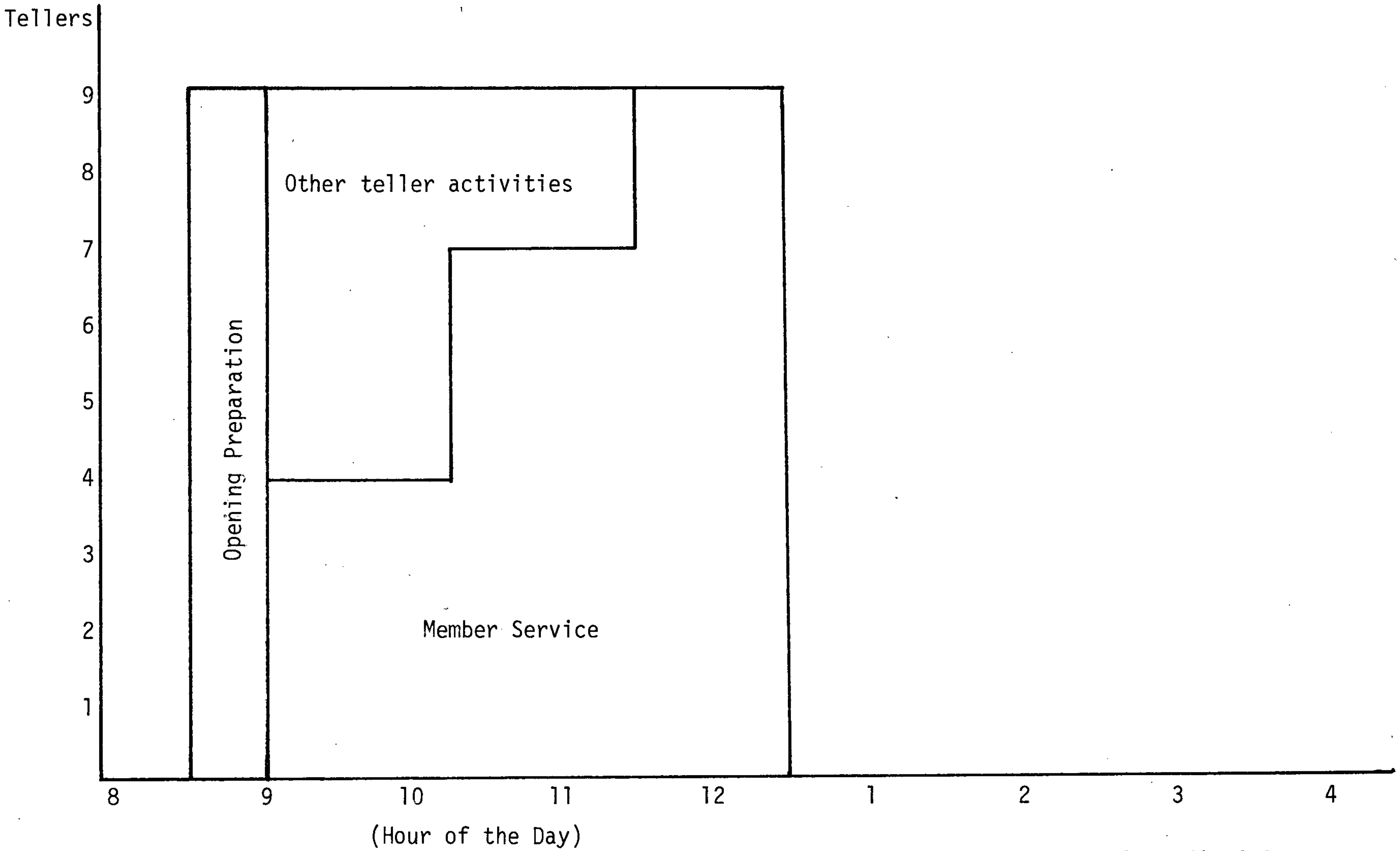
Appendix 4.C

Figure 15 - Present Membership - Teller Schedule for Saturday
Schedule - 4 tellers 8:00 - 12:30



Appendix 4.C

Figure 16 - 100% increase in membership - Teller Schedule for Saturday
Schedule - 9 tellers 8:30 - 12:30



Appendix 4.C