AN ANALYSIS OF LONG DISTANCE TELEPHONE FACILITIES BY SIMULATION

By

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PREFACE

In modern business and industry, the manager of operations is charged with the responsibility of meeting certain objectives within the strict limits of time, cost, and available resources. As he evaluates the demands of the situation and selects the support facilities for his operations, he often faces very complex problems. Many of these problems are not mentioned in the textbooks. They are difficult to define, are not related to any one particular solution technique, and are subject to change from day-to-day. Still, the problems must be solved with sound practical methods.

This thesis is a summary of research done on such a problem. It explains a simulation program analyzing the traffic load on a dispatch center; it allows the operations manager to model his own problem situation, and to select that combination of telephone facilities providing satisfactory service at minimum cost.

The program has been written in the General Purpose Simulation System language for the IBM 360 computer. Accepting a simple description of the actual inbound telephone traffic pattern, it simulates a work-month of telephone operations and computes the cost for service by three separate procedures: ordinary station-to-station long

distance, measured Wide Area Telephone Service, and full-time Wide Area Telephone Service. The occurrence of busy signals is also tabulated to reflect overloading of the lines.

In designing this procedure, I assured first that the analysis was theoretically sound. Then, since it was my opinion that the manager has the right to make his own decision, I made it possible for him to see the results of each type of facility insofar as cost and service are concerned. In addition, the manager can see what changes would take place if additional lines were added or if the nature or frequency of the calls were altered. The objective was to provide managers a means of satisfying questions accurately, quickly, economically, and at no risk to the day-to-day business operation.

This thesis is the culmination of my Ph.D. program, which was begun with the support of a fifteen-month National Science Foundation Faculty Fellowship while on educational leave of absence from the General Motors Corporation. The opportunity to continue the program was provided by Professor Wilson J. Bentley, Head of the School of Industrial Engineering and Management at the Oklahoma State University, in the form of a Graduate Assistantship.

My Committee Chairman, Dr. Hamed K. Eldin, encouraged me continuously and made possible the finding and the formulation of the thesis problem. Dr. Earl J. Ferguson advised

me well on the selection of courses in his role as committee member.

Particularly, I am indebted to Professor Fred M. Black, of the Computer Science Department. His advice and cooperation in the actual GPSS programming saved countless hours of frustration.

Many others have contributed to my successful completion of the program: Miss Velda Davis, whose editing and typing was most professional; Mr. Frank Cochran and my other friends at Bray Lines, Incorporated at Cushing, Oklahoma, for guidelines and data on the thesis problem; Mr. Robert Gumm and the staff of the Oklahoma State Computer Center where efficient and courteous service was always available; all the members of the School of Industrial Engineering and Management who have taught so much by word and by example.

Finally, I must express my sincere gratefulness to my wife, Jo Anne, and my children, Philip, Amy, and Audrey. In addition to their support and their sacrifices, their confidence in my success was truly heartening.

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CHAPTER I

INTRODUCTION

A digital simulation program is herein designed for the analysis of long-distance telephone service inbound to a dispatch center from remote locations across the country. It will assist an organizational systems analyst in accomplishing the following:

(1) calculating the cost of inbound long distance service for any selected number of calls on the basis of full-time WATS (Wide Area Telephone Service), measured WATS or conventional station-to-station long distance day rate procedures for comparative purposes;

(2) showing the effect of regulation of the average time spent per call;

(3) showing the effect of increases in the arrival rate of the calls;

(4) showing the effect of added lines on the total cost and on the frequency of busy signals;

(5) considering the redesign of facilities as changes are made in the cost of specific services (namely, full-time WATS, measured

WATS, and long distance service).

The problem presented itself among many others in the course of the design of a specific management information system. Data essential to the business of a firm was received continuously in a dispatch center. This center was primarily manned with five operators, each assigned to a different area of the country. The attention of the manager was directed to the telephone facilities used by the dispatchers when he received a monthly telephone bill in excess of ten thousand dollars. Realizing that certain levels of activity merit the use of full-time WATS lines and that others deserve measured WATS or simple long distance service, the manager formulated this basic problem: For each of the seven concentric telephone zones surrounding a given geographic point, what is the proper combination of services (full-time WATS, measured WATS, or conventional station-to-station long distance) and guidelines that will result in low cost and reasonable customer satisfaction?

This is not a classic problem in optimization for several reasons:

(1) The interaction of the variables involved is far too complex to allow a single mathematical model or algorithm to represent the situation.

(2) There are difficulties in gathering data that force the use of some theoretical distributions and there are opportunities that easily allow the use of empirical data to represent

the situation at hand.

(3) The ability of the operator to influence the duration of an individual call introduces another option in controlling over-all cost.

(4) Continuous changes in the telephone rates and in the proportion of telephone traffic from each zone tend to limit the useful life of an optimal decision for any single set of circumstances.

The search for previous work on this problem began with the Southewestern Bell Telephone Company. Local district managers and sales personnel were most interested and eager to help, but could provide no reference to substantial research on this specific problem. Rates, costs, and billing procedures were provided with the assurance of continued cooperation.

A review of professional publications revealed a very limited amount of telephone systems analysis on similar problems; therefore, the history of simulation was reviewed beginning with the early works of Conway (1) and Maxwell (2). This led to more extensive study of simulation techniques employing FORTRAN and GPSS (General Purpose Simulation System). Mize and Cox (3), McMillan and Gonzalez (4), Schmidt and Taylor (5) show that the problems can be treated successfully with simulation techniques, especially where the theoretical and empirical distributions must be merged in fairly complicated interaction.

Over the period of one year, the simulation model described in this thesis was assembled with GPSS and was expanded and tested in the course of some sixty runs on the IBM 360.

In general, the user describes the problem situation by specifying the arrival rate of the calls, the mean duration of the calls, and the pattern of the sources of the calls across the country in terms of zone. In addition, the number of lines from each zone can be selected and the caller's delay before replacing an incomplete call is an optional part of the input. A more permanent part of the program, but still classified as input, is a translation of the prevailing costs and rate tables for the services considered. These can be modified to agree with the use of additional lines or changes in service charges.

The simulation handles the problem by generating calls at the predesignated mean interval, programmed as an exponential distribution.

Durations of the calls are also randomly selected from an exponential distribution with the desired mean. After the complete run has simulated this flow of calls along with conflict over the use of available lines resulting in busy signals and replaced calls, the costs of operation in each zone are calculated for each of the three modes of operation, full-time WATS, measured WATS, and common long distance service. There is also a tally of the number of busy signals met in each zone.

The following chapters explain this program in detail. There is justification for the selection of certain theoretical distributions and instructions for the substitution of others. Examples of several runs are provided with explicit notes on each.

CHAPTER II

ANALYSIS OF THE COSTS

Cost Calculation

The Bell Telephone System provides a Wide Area Telephone Service (WATS) for high volume users of long distance lines. In most cases, it is to the advantage of the commercial user to choose full-time WATS lines with a fixed cost or measured WATS lines with a minimum fixed cost and an incremental cost over the common long distance service. To simplify the process of displaying and calculating costs for WATS service, the entire United States has been divided into zones. For each state, there is a set of seven irregular but concentric zones radiating from that state. The bounaries of the zones coincide with state lines and as a result the larger western states form fewer but wider zones than the eastern states. (See Figure 1 for an example of a zone map for Oklahoma.) Once the zones are established for a given base state, rates for full-time WATS and measured WATS service are quoted by zone. Table I shows sample costs for the State of Oklahoma.

To simulate the accumulation of cost, each call is randomly assigned a source zone according to an empirical distribution and a random duration from another distribution.

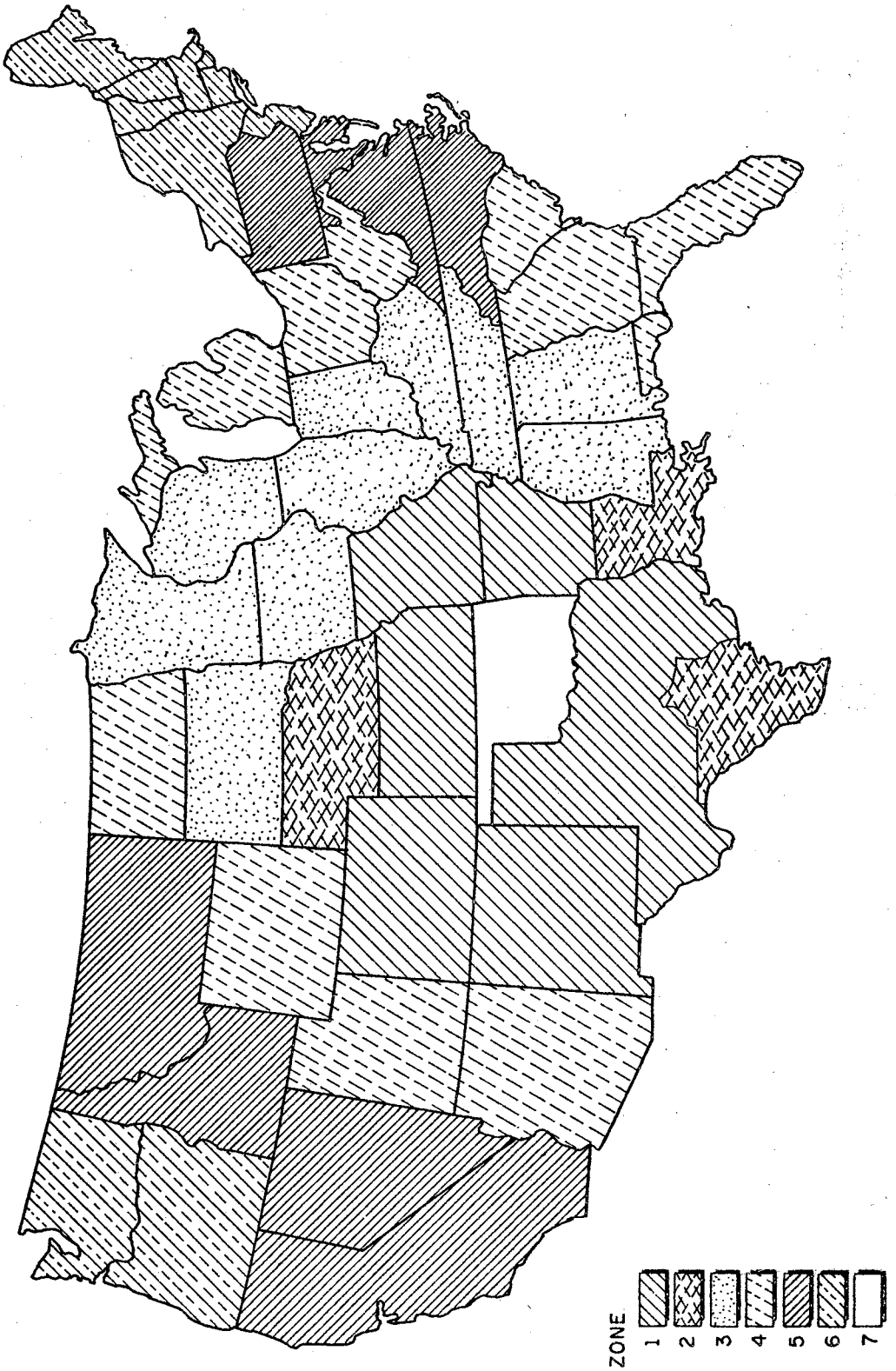

Figure 1. Wide Area Telephone Service to Oklahoma

TABLE I

MONTHLY RATES FOR WIDE AREA TELEPHONE SERVICE

Zone	Full Time	Measured Time	
		First 10 Hours	Each Additional Hour
1	$ 900.00	$ 220.00	$ 16.50
2	1100.00	240.00	18.50
3	1300.00	260.00	20.50
4	1500.00	280.00	22.00
5	1750.00	310.00	23.50
6	1850.00	325.00	24.50
7	545.00	165.00	13.00

A cost table was constructed to hold the equivalent long distance charges for calls to the center of the respective zones. For example, to Oklahoma City, a call from Zone 5 spans an average of 1100 miles. The costs for that distance were drawn from long distance station-to-station day rate tables for call durations of one to fifteen minutes and were loaded as entries one through fifteen on line 5 of the long distance cost table. The zone and duration of a simulated call are used as entering arguments to the cost table and the total cost for the call is extracted. Tables II, III, and IV illustrate these points.

The cost of measured WATS service is based on the total time used regardless of the number of calls made. Therefore, it was necessary to accumulate the time spent on each of the simulated calls until the run was complete and conduct the measured WATS cost procedure for each zone separately. The rate structure specifies a fixed cost for the first ten hours and an additional cost for each hour thereafter. This is best managed in simulation by the use of continuous functions; again, one for each zone with the total usage time expressed as the independent variable. Figure 2 shows these cost functions, merely graphic translations of the costs in Table I under measured WATS.

There is no calculation required for the full-time WATS data. It is initialized and printed out in the proper table to permit easy comparison with the alternate modes of cost calculation.

TABLE II

LONG DISTANCE RATE TABLE – INTERSTATE

INTERSTATE COMPUTED CHARGE TABLE
OPERATOR HANDLED ONLY

NON-COIN (BLACK) **COIN DEPOSITS (RED)** LONG LINES SCHEDULE NO. 1

RULES GOVERNING USE OF X, A & B SECTIONS

1. Amounts shown in Section X should not be added together nor added to amounts in Sections A and B.
2. Amounts in Section A must never be added together nor added to an amount in Section X, but may be added to one or more amounts in Section B.
3. Amounts in Section B are to be used only for addition to an amount in Section A and must never be used alone, nor added to amounts in Section X.

COMPOSITION OF TABLE

RATE STEP CLASS	HOURS DAYS	X	A				
		3	4	5	6	7	Minutes of Conversation
15 S 16 S	5P-8A Mon-Fri	60	75	90	105	120	Computed Toll Charge—Excluding Tax
	All Sat, Sun & H	65	20	35	50	65	Coin Deposit—Including Tax
197-244							Miles

H - Holidays

Holiday Rates apply on:
Christmas, New Years, July 4, Thanksgiving & Labor Day.

RATE STEP CLASS	HOURS DAYS	X		A												B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
2 S (PD)	ALL HOURS	15	20	25	30	35	40	45	50	55	60	65	70	75	80	50	100	150
	ALL DAYS	15	05	15	20	25	30	35	40	45	50	55	60	70	75	55	110	165
1– (COL)	ALL HOURS	30	35	40	45	50	55	60	65	70	75	80	85	90	95	50	100	150
	ALL DAYS	35	05	10	15	20	25	30	35	40	50	55	60	65	70	55	110	165
10 2 P	ALL HOURS	50	55	60	65	70	75	80	85	90	95	100	105	110	115	50	100	150
	ALL DAYS	55	05	10	15	20	30	35	40	45	50	55	60	65	70	55	110	165
3 S (PD)	ALL HOURS	20	25	30	35	40	45	50	55	60	65	70	75	80	85	50	100	150
	ALL DAYS	20	10	15	20	25	30	35	40	45	50	55	65	70	75	55	110	165
11– (COL)	ALL HOURS	30	35	40	45	50	55	60	65	70	75	80	85	90	95	50	100	150
	ALL DAYS	35	05	10	15	20	25	30	35	40	50	55	60	65	70	55	110	165
16 3 P	ALL HOURS	50	55	60	65	70	75	80	85	90	95	100	105	110	115	50	100	150
	ALL DAYS	55	05	10	15	20	30	35	40	45	50	55	60	65	70	55	110	165
4 S (PD)	ALL HOURS	25	30	35	40	45	50	55	60	65	70	75	80	85	90	50	100	150
	ALL DAYS	30	05	10	15	20	25	30	35	40	45	55	60	65	70	55	110	165
17– (COL)	ALL HOURS	30	35	40	45	50	55	60	65	70	75	80	85	90	95	50	100	150
	ALL DAYS	35	05	10	15	20	25	30	35	40	50	55	60	65	70	55	110	165
22 4 P	ALL HOURS	50	55	60	65	70	75	80	85	90	95	100	105	110	115	50	100	150
	ALL DAYS	55	05	10	15	20	30	35	40	45	50	55	60	65	70	55	110	165

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RATE STEP CLASS	HOURS DAYS	X	A													B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
5 S 23–	ALL HOURS	30	40	50	60	70	80	90	100	110	120	130	140	150	160	100	200	300
	ALL DAYS	35	10	20	30	40	55	65	75	85	95	110	120	130	140	110	220	330
30 5 P	ALL HOURS	50	60	70	80	90	100	110	120	130	140	150	160	170	180	100	200	300
	ALL DAYS	55	10	20	35	45	55	65	75	90	100	110	120	130	145	110	220	330
6 S 31–	ALL HOURS	35	45	55	65	75	85	95	105	115	125	135	145	155	165	100	200	300
	ALL DAYS	40	10	20	30	45	55	65	75	85	100	110	120	130	140	110	220	330
40 6 P	ALL HOURS	55	65	75	85	95	105	115	125	135	145	155	165	175	185	100	200	300
	ALL DAYS	60	10	25	35	45	55	65	80	90	100	110	120	135	145	110	220	330
7 S 41–	ALL HOURS	40	50	60	70	80	90	100	110	120	130	140	150	160	170	100	200	300
	ALL DAYS	45	10	20	30	45	55	65	75	85	100	110	120	130	140	110	220	330
55 7 P	ALL HOURS	65	75	85	95	105	115	125	135	145	155	165	175	185	195	100	200	300
	ALL DAYS	70	15	25	35	45	55	70	80	90	100	110	125	135	145	110	220	330
8 S 56–	8A-5P Mon-Fri	45	60	75	90	105	120	135	150	165	180	195	210	225	240	150	300	450
		50	15	35	50	65	80	100	115	130	150	165	180	200	215	165	330	495
	5P-8A Mon-Fri	40	50	60	70	80	90	100	110	120	130	140	150	160	170	100	200	300
	All Sat, Sun & H	45	10	20	30	45	55	65	75	85	100	110	120	130	140	110	220	330
70 8 P	8A-5P Mon-Fri	70	85	100	115	130	145	160	175	190	205	220	235	250	265	150	300	450
		75	20	35	50	70	85	100	120	135	150	165	185	200	215	165	330	495
	5P-8A Mon-Fri	70	80	90	100	110	120	130	140	150	160	170	180	190	200	100	200	300
	All Sat, Sun & H	75	15	25	35	45	55	70	80	90	100	110	125	135	145	110	220	330
9 S 71–	8A-5P Mon-Fri	50	65	80	95	110	125	140	155	170	185	200	215	230	245	150	300	450
		55	15	35	50	65	85	100	115	130	150	165	180	200	215	165	330	495
	5P-8A Mon-Fri	40	50	60	70	80	90	100	110	120	130	140	150	160	170	100	200	300
	All Sat, Sun & H	45	10	20	30	45	55	65	75	85	100	110	120	130	140	110	220	330
85 9 P	8A-5P Mon-Fri	80	95	110	125	140	155	170	185	200	215	230	245	260	275	150	300	450
		90	15	30	50	65	80	95	115	130	145	165	180	195	215	165	330	495
	5P-8A Mon-Fri	80	90	100	110	120	130	140	150	160	170	180	190	200	210	100	200	300
	All Sat, Sun & H	90	10	20	30	40	55	65	75	85	95	110	120	130	140	110	220	330

TABLE II (Continued)

RATE STEP CLASS	HOURS DAYS	X	A													B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
10S 86–	8A-5P Mon-Fri	55	70	85	100	115	130	145	160	175	190	205	220	235	250	150	300	450
		60	15	35	50	65	85	100	115	135	150	165	180	200	215	165	330	495
	5P-8A Mon-Fri	40	50	60	70	80	90	100	110	120	130	140	150	160	170	100	200	300
	All Sat, Sun & H	45	10	20	30	45	55	65	75	85	100	110	120	130	140	110	220	330
100 10P	8A-5P Mon-Fri	85	100	115	130	145	160	175	190	205	220	235	250	265	280	150	300	450
		95	15	30	50	65	80	100	115	130	145	165	180	195	215	165	330	495
	5P-8A Mon-Fri	85	95	105	115	125	135	145	155	165	175	185	195	205	215	100	200	300
	All Sat, Sun & H	95	10	20	30	45	55	65	75	85	100	110	120	130	140	110	220	330
11S 101–	8A-5P Mon-Fri	60	75	90	105	120	135	150	165	180	195	210	225	240	255	150	300	450
		65	20	35	50	65	85	100	115	135	150	165	185	200	215	165	330	495
	5P-8A Mon-Fri	45	60	75	90	105	120	135	150	165	180	195	210	225	240	150	300	450
	All Sat, Sun & H	50	15	35	50	65	80	100	115	130	150	165	180	200	215	165	330	495
124 11P	ALL HOURS	95	110	125	140	155	170	185	200	215	230	245	260	275	290	150	300	450
	ALL DAYS	105	15	35	50	65	80	100	115	130	150	165	180	200	215	165	330	495
12S 125–	8A-5P Mon-Fri	65	85	105	125	145	165	185	205	225	245	265	285	305	325	200	400	600
		70	25	45	70	90	110	135	155	180	200	220	245	265	290	220	440	660
	5P-8A Mon-Fri	50	65	80	95	110	125	140	155	170	185	200	215	230	245	150	300	450
	All Sat, Sun & H	55	15	35	50	65	85	100	115	130	150	165	180	200	215	165	330	495
148 12P	8A-5P Mon-Fri	100	120	140	160	180	200	220	240	260	280	300	320	340	360	200	400	600
		110	20	45	65	90	110	130	155	175	200	220	240	265	285	220	440	660
	5P-8A Mon-Fri	100	115	130	145	160	175	190	205	220	235	250	265	280	295	150	300	450
	All Sat, Sun & H	110	15	35	50	65	85	100	115	130	150	165	180	200	215	165	330	495
13 14S 149–	8A-5P Mon-Fri	70	90	110	130	150	170	190	210	230	250	270	290	310	330	200	400	600
		75	25	45	70	90	110	135	155	180	200	220	245	265	290	220	440	660
	5P-8A Mon-Fri	55	70	85	100	115	130	145	160	175	190	205	220	235	250	150	300	450
	All Sat, Sun & H	60	15	35	50	65	85	100	115	135	150	165	180	200	215	165	330	495
196 13 14P	8A-5P Mon-Fri	110	130	150	170	190	210	230	250	270	290	310	330	350	370	200	400	600
		120	25	45	65	90	110	135	155	175	200	220	245	265	285	220	440	660
	5P-8A Mon-Fri	110	125	140	155	170	185	200	215	230	245	260	275	290	305	150	300	450
	All Sat, Sun & H	120	20	35	50	65	85	100	115	135	150	165	185	200	215	165	330	495

FEBRUARY 1, 1970

RATE STEP CLASS	HOURS DAYS	X	A													B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
15 16S 197–	8A-5P Mon-Fri	80	100	120	140	160	180	200	220	240	260	280	300	320	340	200	400	600
		90	20	40	65	85	110	130	150	175	195	220	240	260	285	220	440	660
	5P-8A Mon-Fri	60	75	90	105	120	135	150	165	180	195	210	225	240	255	150	300	450
	All Sat, Sun & H	65	20	35	50	65	85	100	115	135	150	165	185	200	215	165	330	495
244 15 16P	8A-5P Mon-Fri	120	140	160	180	200	220	240	260	280	300	320	340	360	380	200	400	600
		130	25	45	70	90	110	135	155	180	200	220	245	265	290	220	440	660
	5P-8A Mon-Fri	120	135	150	165	180	195	210	225	240	255	270	285	300	315	150	300	450
	All Sat, Sun & H	130	20	35	50	70	85	100	120	135	150	165	185	200	215	165	330	495
17 18S 245–	8A-5P Mon-Fri	90	115	140	165	190	215	240	265	290	315	340	365	390	415	250	500	750
		100	25	55	80	110	135	165	190	220	245	275	300	330	355	275	550	825
	5P-8A Mon-Fri	65	80	95	110	125	140	155	170	185	200	215	230	245	260	150	300	450
	All Sat, Sun & H	70	20	35	50	70	85	100	115	135	150	165	185	200	215	165	330	495
292 17 18P	8A-5P Mon-Fri	135	160	185	210	235	260	285	310	335	360	385	410	435	460	250	500	750
		150	25	55	80	110	135	165	190	220	245	275	300	330	355	275	550	825
	5P-8A Mon-Fri	135	150	165	180	195	210	225	240	255	270	285	300	315	330	150	300	450
	All Sat, Sun & H	150	15	30	50	65	80	100	115	130	145	165	180	195	215	165	330	495
19S 20 293–	8A-5P Mon-Fri	100	125	150	175	200	225	250	275	300	325	350	375	400	425	250	500	750
		110	30	55	85	110	140	165	195	220	250	275	305	330	360	275	550	825
	5P-8A Mon-Fri	70	85	100	115	130	145	160	175	190	205	220	235	250	265	150	300	450
	All Sat, Sun & H	75	20	35	50	70	85	100	120	135	150	165	185	200	215	165	330	495
354 19P 20	8A-5P Mon-Fri	150	175	200	225	250	275	300	325	350	375	400	425	450	475	250	500	750
		165	30	55	85	110	140	165	195	220	250	275	305	330	360	275	550	825
	5P-8A Mon-Fri	150	165	180	195	210	225	240	255	270	285	300	315	330	345	150	300	450
	All Sat, Sun & H	165	15	35	50	65	85	100	115	130	150	165	180	200	215	165	330	495

TABLE II (Continued)

RATE STEP CLASS	HOURS DAYS	X	A													B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
21 S	8A-5P Mon-Fri	110	135	160	185	210	235	260	285	310	335	360	385	410	435	250	500	750
22 S		120	30	55	85	110	140	165	195	220	250	275	305	330	360	275	550	825
355–	5P-8A Mon-Fri	75	95	115	135	155	175	195	215	235	255	275	295	315	335	200	400	600
	All Sat, Sun & H	85	20	40	65	85	110	130	150	175	195	220	240	260	285	220	440	660
430	8A-5P Mon-Fri	165	190	215	240	265	290	315	340	365	390	415	440	465	490	250	500	750
21 P		180	30	55	85	110	140	165	195	220	250	275	305	330	360	275	550	825
22 P	5P-8A Mon-Fri	165	185	205	225	245	265	285	305	325	345	365	385	405	425	200	400	600
	All Sat, Sun & H	180	25	45	70	90	110	135	155	180	200	220	245	265	290	220	440	660
23	8A-5P Mon-Fri	120	150	180	210	240	270	300	330	360	390	420	450	480	510	300	600	900
24 S		130	35	70	100	135	165	200	235	265	300	330	365	400	430	330	660	990
25 S	5P-8A Mon-Fri	75	95	115	135	155	175	195	215	235	255	275	295	315	335	200	400	600
26 431–	All Sat, Sun & H	85	20	40	65	85	110	130	150	175	195	220	240	260	285	220	440	660
675 23	8A-5P Mon-Fri	190	220	250	280	310	340	370	400	430	460	490	520	550	580	300	600	900
24 P		210	30	65	100	130	165	195	230	265	295	330	360	390	430	330	660	990
25 P	5P-8A Mon-Fri	190	210	230	250	270	290	310	330	350	370	390	410	430	450	200	400	600
26	All Sat, Sun & H	210	20	45	65	85	110	130	155	175	195	220	240	265	285	220	440	660
27 S	8A-5P Mon-Fri	130	165	200	235	270	305	340	375	410	445	480	515	550	585	350	700	1050
		145	35	75	115	150	190	230	270	305	345	385	420	460	500	385	770	1155
28 S	5P-8A Mon-Fri	80	100	120	140	160	180	200	220	240	260	280	300	320	340	200	400	600
676–	All Sat, Sun & H	90	20	40	65	85	110	130	150	175	195	220	240	260	285	220	440	660
925	8A-5P Mon-Fri	220	255	290	325	360	395	430	465	500	535	570	605	640	675	350	700	1050
27 P		240	40	80	120	155	195	235	270	310	350	385	425	465	505	385	770	1155
28 P	5P-8A Mon-Fri	220	240	260	280	300	320	340	360	380	400	420	440	460	480	200	400	600
	All Sat, Sun & H	240	25	45	70	90	110	135	155	180	200	220	245	265	290	220	440	660

FEBRUARY 1, 1970

RATE STEP CLASS	HOURS DAYS	X	A													B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
29	8A-5P Mon-Fri	140	175	210	245	280	315	350	385	420	455	490	525	560	595	350	700	1050
30 S		155	40	75	115	155	190	230	270	305	345	385	425	460	500	385	770	1155
31 S	5P-8A Mon-Fri	90	110	130	150	170	190	210	230	250	270	290	310	330	350	200	400	600
926–	All Sat, Sun & H	100	20	45	65	85	110	130	155	175	195	220	240	265	285	220	440	660
1360	8A-5P Mon-Fri	240	275	310	345	380	415	450	485	520	555	590	625	660	695	350	700	1050
29		265	40	75	115	155	190	230	270	305	345	385	425	460	500	385	770	1155
30 P	5P-8A Mon-Fri	240	260	280	300	320	340	360	380	400	420	440	460	480	500	200	400	600
31	All Sat, Sun & H	265	20	45	65	85	110	130	155	175	195	220	240	265	285	220	440	660
32 S	8A-5P Mon-Fri	155	185	235	275	315	355	395	435	475	515	555	595	635	675	400	800	1200
		170	45	90	135	175	220	265	310	355	395	440	485	530	575	440	880	1320
33 S	5P-8A Mon-Fri	100	125	150	175	200	225	250	275	300	325	350	375	400	425	250	500	750
1361–	All Sat, Sun & H	110	30	55	85	110	140	165	195	220	250	275	305	330	360	275	550	825
1910	8A-5P Mon-Fri	285	325	365	405	445	485	525	565	605	645	685	725	765	805	400	800	1200
32 P		315	45	85	130	175	220	265	305	350	395	440	485	525	570	440	880	1320
33 P	5P-8A Mon-Fri	285	310	335	360	385	410	435	460	485	510	535	560	585	610	250	500	750
	All Sat, Sun & H	315	25	55	80	110	135	165	190	220	245	275	300	330	355	275	550	825
34 S	8A-5P Mon-Fri	170	215	260	305	350	395	440	485	530	575	620	665	710	755	450	900	1350
		185	50	100	150	200	250	300	350	400	450	495	545	595	645	495	990	1485
35 S	5P-8A Mon-Fri	110	135	160	185	210	235	260	285	310	335	360	385	410	435	250	500	750
1911–	All Sat, Sun & H	120	30	55	85	110	140	165	195	220	250	275	305	330	360	275	550	825
3000	8A-5P Mon-Fri	330	375	420	465	510	555	600	645	690	735	780	825	870	915	450	900	1350
34 P		365	50	95	145	195	245	295	345	395	445	495	545	590	640	495	990	1485
35 P	5P-8A Mon-Fri	330	355	380	405	430	455	480	505	530	555	580	605	630	655	250	500	750
	All Sat, Sun & H	365	25	55	80	110	135	165	190	220	245	275	300	330	355	275	550	825

TABLE II

LONG DISTANCE RATE TABLE – INTRASTATE

OKLAHOMA INTRASTATE COMPUTED CHARGE TABLE

NON-COIN (BLACK) **COIN DEPOSITS (RED)**

RULES GOVERNING USE OF X, A & B SECTIONS

1. Amounts shown in Section X should not be added together nor added to amounts in Sections A & B.
2. Amounts in Section A must never be added together nor added to an amount in Section X, but may be added to one or more amounts in Section B.
3. Amounts in Section B are to be used only for addition to an amount in Section A and must never be used alone, nor added to amounts in Section X.

RATE STEP CLASS	HOURS DAYS	X			A											B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
AS (PD)	ALL HOURS	10	13	16	19	22	25	28	31	34	37	40	43	46	49	30	60	90
	ALL DAYS	10	05	05	10	10	20	25	25	30	35	35	40	40	45			
1– (COL)	ALL HOURS	25	28	31	34	37	40	43	46	49	52	55	58	61	64	30	60	90
	ALL DAYS	30	05	05	10	15	15	20	20	25	30	30	35	35	40			
8 AP	ALL HOURS	30	40	50	60	63	66	69	72	75	78	81	84	87	90	30	60	90
	ALL DAYS	35	10	20	30	35	35	40	45	45	55	60	60	65	65			
BS (PD)	ALL HOURS	15	20	25	30	35	40	45	50	55	60	65	70	75	80	50	100	150
	ALL DAYS	15	05	15	20	25	30	35	40	45	50	55	60	65	75			
9– (COL)	ALL HOURS	30	35	40	45	50	55	60	65	70	75	80	85	90	95	50	100	150
	ALL DAYS	35	05	10	15	20	25	30	35	40	45	55	60	65	70			
12 BP	ALL HOURS	35	47	59	71	76	81	86	91	96	101	106	111	116	121	50	100	150
	ALL DAYS	40	15	25	35	50	55	60	65	70	75	80	85	90	95			
CS (PD)	ALL HOURS	20	27	34	41	48	55	62	69	76	83	90	97	104	111	70	140	210
	ALL DAYS	20	15	20	25	35	40	50	55	70	75	80	90	95	105			
13– (COL)	ALL HOURS	30	37	44	51	58	65	72	79	86	93	100	107	114	121	70	140	210
	ALL DAYS	35	10	15	20	30	35	45	55	65	70	75	85	90	100			
17 CP	ALL HOURS	40	53	66	79	86	93	100	107	114	121	128	135	142	149	70	140	210
	ALL DAYS	45	15	25	45	55	60	65	75	80	90	100	110	115	120			
DS (PD)	ALL HOURS	25	33	41	49	57	65	73	81	89	97	105	113	121	129	80	160	240
	ALL DAYS	30	10	15	25	35	40	50	65	70	80	85	95	105	115			
18– (COL)	ALL HOURS	30	38	46	54	62	70	78	86	94	102	110	118	126	134	80	160	240
	ALL DAYS	35	10	15	25	35	40	55	65	70	80	85	95	110	115			
22 DP	ALL HOURS	45	60	75	90	98	106	114	122	130	138	146	154	162	170	80	160	240
	ALL DAYS	50	15	30	50	60	70	75	85	100	105	115	120	130	140			

(ISSUED 8-1-69) APRIL 1, 1966

RATE STEP CLASS	HOURS DAYS	X			A											B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
ES 23–	ALL HOURS	30	40	50	60	70	80	90	100	110	120	130	140	150	160	100	200	300
	ALL DAYS	35	10	20	30	40	55	65	75	85	95	115	125	135	145			
27 EP	ALL HOURS	50	67	84	101	111	121	131	141	151	161	171	181	191	201	100	200	300
	ALL DAYS	55	20	40	60	70	80	95	105	115	125	135	150	160	170			
FS 28–	ALL HOURS	35	47	59	71	83	95	107	119	131	143	155	167	179	191	120	240	360
	ALL DAYS	40	15	25	35	55	65	80	90	110	120	135	145	165	175			
32 FP	ALL HOURS	60	80	100	120	132	144	156	168	180	192	204	216	228	240	120	240	360
	ALL DAYS	65	25	45	65	85	95	110	120	140	150	165	175	195	205			
GS 33–	ALL HOURS	40	53	66	79	92	105	118	131	144	157	170	183	196	209	130	260	390
	ALL DAYS	45	15	25	45	60	70	85	105	115	130	145	160	175	190			
38 GP	ALL HOURS	70	93	116	139	152	165	178	191	204	217	230	243	256	269	130	260	390
	ALL DAYS	75	30	55	80	95	110	125	140	155	165	185	200	210	225			
HS 39–	ALL HOURS	45	60	75	90	105	120	135	150	165	180	195	210	225	240	150	300	450
	ALL DAYS	50	15	30	50	65	80	105	120	135	155	170	185	205	220			
46 HP	ALL HOURS	75	100	125	150	165	180	195	210	225	240	255	270	285	300	150	300	450
	ALL DAYS	85	25	60	85	100	120	135	150	170	185	200	215	235	250			
IS 47–	ALL HOURS	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
	ALL DAYS	55	20	40	60	75	100	115	130	155	170	190	210	230	245			
54 IP	ALL HOURS	85	113	141	169	186	203	220	237	254	271	288	305	322	339	170	340	510
	ALL DAYS	85	30	65	90	115	130	150	170	190	205	230	245	265	285			
JS 55–	4:30A-6P Mon-Fri	55	73	91	109	127	145	163	181	199	217	235	253	271	289	180	360	540
		60	20	45	60	85	105	120	145	165	180	205	225	240	265			
	6P-4:30A Mon-Fri All Sat & Sun	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
		55	20	40	60	75	100	115	130	155	170	190	210	230	245			
66 JP	4:30A-6P Mon-Sat	95	127	159	191	209	227	245	263	281	299	317	335	353	371	180	360	540
		105	40	70	110	130	150	170	190	210	230	250	270	290	310			
	6P-4:30A Mon-Sat All Sun	90	120	150	180	197	214	231	248	265	282	299	316	333	350	170	340	510
		100	30	70	105	120	140	160	180	195	220	235	250	275	290			

TABLE II (Continued)

RATE STEP CLASS	HOURS DAYS	X			A											B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
KS	4:30A-6P Mon-Fri	60	80	100	120	140	160	180	200	220	240	260	280	300	320	200	400	600
		65	25	45	65	95	115	140	160	180	205	225	250	270	290			
	6P-4:30A Mon-Fri	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
67–	All Sat & Sun	55	20	40	60	75	100	115	130	155	170	190	210	230	245			
82	4:30A-6P Mon-Sat	100	133	166	199	219	239	259	279	299	319	339	359	379	399	200	400	600
KP		110	40	75	115	135	160	180	205	225	245	270	290	315	335			
	6P-4:30A Mon-Sat	90	120	150	180	197	214	231	248	265	282	299	316	333	350	170	340	510
	All Sun	100	30	70	105	120	140	160	180	195	220	235	250	275	290			
	4:30A-6P Mon-Fri	65	87	109	131	153	175	197	219	241	263	285	307	329	351	220	440	660
		70	30	50	80	100	130	150	175	200	225	250	275	300	325			
LS	6P-8P Mon-Fri	55	73	91	109	127	145	163	181	198	217	235	253	271	289	180	360	540
	4:30A-8P Sat	60	20	45	60	85	105	120	145	165	180	205	225	240	265			
	8P-4:30A Mon-Sat	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
83–	All Sun	55	20	40	60	75	100	115	130	155	170	190	210	230	245			
100	4:30A-6P Mon-Sat	110	147	184	221	243	265	287	309	331	353	375	397	419	441	220	440	660
LP		120	45	80	125	155	175	205	225	255	275	305	325	345	375			
	6P-4:30A Mon-Sat	100	133	166	199	217	235	253	271	289	307	325	343	361	379	180	360	540
	All Sun	110	40	75	115	130	155	175	190	215	235	250	275	295	315			
	4:30A-6P Mon-Fri	70	93	116	139	162	185	208	231	254	277	300	323	346	369	230	460	690
		75	30	55	80	105	135	155	185	210	240	260	285	315	335			
MS	6P-8P Mon-Fri	60	80	100	120	140	160	180	200	220	240	260	280	300	320	200	400	600
	4:30A-8P Sat	65	25	45	65	95	115	140	160	180	205	225	250	270	290			
	8P-4:30A Mon-Sat	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
101–	All Sun	55	20	40	60	75	100	115	130	155	170	190	210	230	245			
122	4:30A-6P Mon-Sat	120	160	200	240	263	286	309	332	355	378	401	424	447	470	230	460	690
MP		130	50	85	140	165	190	215	245	265	295	320	340	370	395			
	6P-4:30A Mon-Sat	110	147	184	221	241	261	281	301	321	341	361	381	401	421	200	400	600
	All Sun	120	45	80	125	150	170	195	215	235	265	285	310	330	350			

APRIL 1, 1966

RATE STEP CLASS	HOURS DAYS	X			A											B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
NS	4:30A-6P Mon-Fri	75	100	125	150	175	200	225	250	275	300	325	350	375	400	250	500	750
		85	25	60	85	115	140	170	195	225	250	275	305	340	365			
	6P-8P Mon-Fri	65	87	109	131	153	175	197	219	241	263	285	307	329	351	220	440	660
	4:30A-8P Sat	70	30	50	80	100	130	150	175	200	225	250	275	300	325			
	8P-4:30A Mon-Sat	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
123–	All Sun	55	20	40	60	75	100	115	130	155	170	190	210	230	245			
144	4:30A-6P Mon-Sat	130	173	216	259	284	309	334	359	384	409	434	459	484	509	250	500	750
NP		145	45	95	145	175	200	230	255	285	310	345	370	400	425			
	6P-4:30A Mon-Sat	120	160	200	240	262	284	306	328	350	372	394	416	438	460	220	440	660
	All Sun	130	50	95	140	160	190	210	240	260	285	310	335	360	385			
	4:30A-6P Mon-Fri	80	107	134	161	188	215	242	269	296	323	350	377	404	431	270	540	810
		90	30	60	90	120	150	180	210	240	270	300	335	360	395			
OS	6P-8P Mon-Fri	70	93	116	139	162	185	208	231	254	277	300	323	346	369	230	460	690
	4:30A-8P Sat	75	30	55	80	105	135	155	185	210	240	260	285	315	335			
	8P-4:30A Mon-Sat	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
145–	All Sun	55	20	40	60	75	100	115	130	155	170	190	210	230	245			
168	4:30A-6P Mon-Sat	135	180	225	270	297	324	351	378	405	432	459	486	513	540	270	540	810
OP		150	55	105	150	185	210	245	275	305	335	365	395	425	455			
	6P-4:30A Mon-Sat	125	167	209	251	274	297	320	343	366	389	412	435	458	481	230	460	690
	All Sun	140	45	95	140	170	195	215	245	270	295	320	350	370	400			
	4:30A-6P Mon-Fri	85	113	141	169	197	225	253	281	309	337	365	393	421	449	280	560	840
		95	30	65	90	125	160	190	220	250	285	310	345	375	410			
PS	6P-8P Mon-Fri	70	93	116	139	162	185	208	231	254	277	300	323	346	369	230	460	690
	4:30A-8P Sat	75	30	55	80	105	135	155	185	210	240	260	285	315	335			
	8P-4:30A Mon-Sat	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
169–	All Sun	55	20	40	60	75	100	115	130	155	170	190	210	230	245			
194	4:30A-6P Mon-Sat	145	193	241	289	317	345	373	401	429	457	485	513	541	569	280	560	840
PP		160	55	110	165	195	225	255	290	325	350	385	415	445	475			
	6P-4:30A Mon-Sat	130	173	216	259	282	305	328	351	374	397	420	443	466	489	230	460	690
	All Sun	145	45	95	145	175	195	225	250	270	300	325	350	375	405			

TABLE II (Continued)

RATE STEP CLASS	HOURS DAYS	X			A											B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
QS 195–	4:30A-6PMon-Fri	90	120	150	180	210	240	270	300	330	360	390	420	450	480	300	600	900
		100	30	70	105	135	170	200	235	270	300	340	370	405	440			
	6P-8PMon-Fri 4:30A-8P Sat	75	100	125	150	175	200	225	250	275	300	325	350	375	400	250	500	750
		85	25	60	85	115	140	170	195	225	250	275	305	340	365			
	8P-4:30AMon-Sat All Sun	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
		55	20	40	60	75	100	115	130	155	170	190	210	230	245			
222 QP	4:30A-6PMon-Sat	155	207	259	311	341	371	401	431	461	491	521	551	581	611	300	600	900
		170	60	120	175	215	245	280	315	345	380	410	445	485	515			
	6P-4:30AMon-Sat All Sun	140	187	234	281	306	331	356	381	406	431	456	481	506	531	250	500	750
		155	55	110	160	185	220	245	275	300	330	355	385	410	440			
RS 223–	4:30A-6PMon-Fri	95	127	159	191	223	255	287	319	351	383	415	447	479	511	320	640	960
		105	40	70	110	140	180	220	250	290	325	360	395	435	465			
	6P-8PMon-Fri 4:30A-8P Sat	80	107	134	161	188	215	242	269	296	323	350	377	404	431	270	540	810
		90	30	60	90	120	150	180	210	240	270	300	335	360	395			
	8P-4:30AMon-Sat All Sun	50	67	84	101	118	135	152	169	186	203	220	237	254	271	170	340	510
		55	20	40	60	75	100	115	130	155	170	190	210	230	245			
252 RP	4:30A-6PMon-Sat	160	213	266	319	351	383	415	447	479	511	543	575	607	639	320	640	960
		176	60	120	180	220	255	290	325	365	395	435	465	505	540			
	6P-4:30AMon-Sat All Sun	145	193	241	289	316	343	370	397	424	451	478	505	532	559	270	540	810
		160	55	110	165	190	225	250	285	310	345	380	405	440	465			
SS 253–	4:30A-6PMon-Fri	100	133	166	199	232	265	298	331	364	397	430	463	496	529	330	660	990
		110	40	75	115	150	185	225	265	295	335	375	405	445	485			
	6P-8PMon-Fri 4:30A-8P Sat	85	113	141	169	197	225	253	281	309	337	365	393	421	449	280	560	840
		95	30	65	90	125	160	190	220	250	285	310	345	375	410			
	8P-4:30AMon-Sat All Sun	60	80	100	120	140	160	180	200	220	240	260	280	300	320	200	400	600
		65	25	45	65	95	115	140	160	180	205	225	250	270	290			
286 SP	4:30A-6PMon-Sat	170	227	284	341	374	407	440	473	506	539	572	605	638	671	330	660	990
		185	70	135	200	230	270	310	340	380	420	455	490	530	565			
	6P-4:30AMon-Sat All Sun	155	207	259	311	339	367	395	423	451	478	507	535	563	591	280	560	840
		170	60	120	175	210	240	275	300	335	370	395	430	460	495			

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RATE STEP CLASS	HOURS DAYS	X			A											B		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	10	20	30
TS 287	4:30A-6PMon-Fri	105	140	175	210	245	280	315	350	385	420	455	490	525	560	350	700	1050
		115	45	85	120	160	200	235	275	320	355	395	435	470	510			
	6P-8PMon-Fri 4:30A-8P Sat	90	120	150	180	210	240	270	300	330	360	390	420	450	480	300	600	900
		100	30	70	105	135	170	200	235	270	300	340	370	405	440			
	8P-4:30AMon-Sat All Sun	60	80	100	120	140	160	180	200	220	240	260	280	300	320	200	400	600
		65	25	45	65	95	115	140	160	180	205	225	250	270	290			
322 TP	4:30A-6PMon-Sat	180	240	300	360	395	430	465	500	535	570	605	640	675	710	350	700	1050
		200	70	135	200	245	285	320	360	400	435	475	520	560	595			
	6P-4:30AMon-Sat All Sun	165	220	275	330	360	390	420	450	480	510	540	570	600	630	300	600	900
		180	65	125	190	220	260	290	325	360	390	425	455	490	530			
US 323–	4:30A-6PMon-Fri	110	147	184	221	258	295	332	369	406	443	480	517	554	591	370	740	1110
		120	45	90	125	170	210	255	290	335	375	420	455	500	545			
	6P-8PMon-Fri 4:30A-8P Sat	95	127	159	191	223	255	287	319	351	383	415	447	479	511	320	640	960
		105	40	70	110	140	180	220	250	290	325	360	395	435	465			
	8P-4:30AMon-Sat All Sun	60	80	100	120	140	160	180	200	220	240	260	280	300	320	200	400	600
		65	25	45	65	95	115	140	160	180	205	225	250	270	290			
360 UP	4:30A-6PMon-Sat	185	247	309	371	408	445	482	519	556	593	630	667	704	741	370	740	1110
		205	70	140	210	250	295	335	375	415	460	505	540	585	625			
	6P-4:30AMon-Sat All Sun	170	227	284	341	373	405	437	469	501	533	565	597	629	661	320	640	960
		185	70	135	200	230	270	305	340	375	415	445	485	520	555			
VS 361–	4:30A-6PMon-Fri	115	153	191	229	267	305	343	381	419	457	495	533	571	609	380	760	1140
		125	45	90	135	170	215	260	305	340	385	430	475	510	555			
	6P-8PMon-Fri 4:30A-8P Sat	100	133	166	199	232	265	298	331	364	397	430	463	496	529	330	660	990
		110	40	75	115	150	185	225	265	295	335	375	405	445	485			
	8P-4:30AMon-Sat All Sun	60	80	100	120	140	160	180	200	220	240	260	280	300	320	200	400	600
		65	25	45	65	95	115	140	160	180	205	225	250	270	290			
400 VP	4:30A-6PMon-Sat	195	260	325	390	428	466	504	542	580	618	656	694	732	770	380	760	1140
		215	75	145	225	265	305	350	395	435	475	520	565	605	645			
	6P-4:30AMon-Sat All Sun	180	240	300	360	393	426	459	492	525	558	591	624	657	690	330	660	990
		200	70	135	200	240	280	315	350	385	425	465	495	535	575			

TABLE IV

LONG DISTANCE COST BY ZONE AND TIME

LONG DISTANCE COSTS BY ZONE AND BY MINUTES

MATRIX FULLWORD SAVEVALUE 1

	COLUMN	1	2	3	4	5	6	7	8	9
ROW	1	55	55	55	70	85	100	115	130	145
	2	110	110	110	135	160	185	210	235	260
	3	120	120	120	150	180	210	240	270	300
	4	130	130	130	165	200	235	270	305	340
	5	140	140	140	175	210	245	280	315	350
	6	155	155	155	195	235	275	315	355	395
	7	65	65	65	87	109	131	153	175	197

	COLUMN	10	11	12	13	14	15
ROW	1	160	175	190	205	220	235
	2	285	310	335	360	385	410
	3	330	360	390	420	450	480
	4	375	410	445	480	515	550
	5	385	420	455	490	525	560
	6	435	475	515	555	595	635
	7	219	241	263	285	307	329

GPSS Program Language

The long distance cost tables are loaded by means of INITIAL cards (cards 27-145).

```
INITIAL   MX 1(1,1),55
```

reads load matrix save value 1 with the value 55 (cents) in the position corresponding to row (zone) 1 and column (minutes) 1.

```
INITIAL   MX 1(4,15),550
```

would store the cost of $5.50 in the proper position for a 15 minute call from Zone 4.

Full-time WATS costs are loaded in the same manner, but in matrix 2(cards 148-155)

```
INITIAL   MX 2(6,2)185000
```

reads "load matrix save value 2 with the value of 185000 ($1850) in the position corresponding to row (zone) 6 and column 2.

Measured WATS rates are loaded as continuous functions in sets of three cards for each zone (cards 180-201).

```
11 FVARIABLE   (MX2(1,1)/60 + 99/100)
```

converts the total time used in Zone 1 from seconds to minutes.

```
11 FUNCTION    V11,C2
600,22000/6600,170500
```

describes the continuous cost function for Zone 1 by two points as in Figure 2 and names the entering argument to be V11, the equivalent usage in minutes.

Functions 11-17 account for all seven zones and permit

the calculation of the cost of measured WATS operation by zone. Table V shows the complete listing of the basic simulation program.

The Activity Record - Time, Cost, and Busy Signals

The most important output of the program is presented in Table VI. The five columns indicate respectively:

(1) the total time (in seconds) used in the zone,

(2) the cost of service to the zone of equipped with the specified number of full-time WATS lines,

(3) the cost of service to the zone if equipped with the specified number of measured WATS lines,

(4) the cost of service to the zone if equipped with the specified number of common telephone lines billed on a station-to-station day rate basis,

(5) the total number of calls cycled because an open line was not available.

Line 8 provides total time and cost figures for the first four columns.

This table will allow the user to scan each zone for the least cost mode of operation. Consideration of the number of busy signals in relation to the total number of calls

TABLE V

LISTING OF THE BASIC PROGRAM

```
BLOCK                                                                                    CARD
NUMBER  *LOC   OPERATION  A,B,C,D,E,F,G            COMMENTS                              NUMBER
        SIMULATE                                                                           1
*                                                                                          2
        RMULT     37,31                          IMPROVE RN GENERATORS                   3
*INPUT- MEAN OF EXPONENTIAL DISTRIBUTION OF CALL INTERARRIVAL TIMES                       4
        INITIAL   X1,90                          MEAN TIME - 90 SEC.                     5
*INPUT- MEAN OF EXPONENTIAL DISTRIBUTION OF CALL DURATIONS                               6
        INITIAL   X2,180                         MEAN CALL DUR.  180 SEC.                7
*INPUT- CUMULATIVE DISTRIBUTION OF CALLS FROM EACH ZONE                                  8
     2 FUNCTION   RN2,D7                         DIST. OF CALLS BY ZONE                  9
.17   7     .59   1     .64   2     .75   3     .86   4     .95   5                      10
1.0   6                                                                                  11
*                                                                                         12
*INPUT- MEAN OF NORMAL DISTRIBUTION OF WAITING TIMES BEFORE RECALLING                     13
        INITIAL   X3,900                         MEAN OF NORMAL DIST. 900 SEC            14
*INPUT- STD. DEV. OF NORMAL DISTRIBUTION OF SAME WAITING TIMES                           15
        INITIAL   X4,60                          STD. DEV. 60 SEC.                       16
*                                                                                         17
* INPUT- THE NUMBER OF LINES FROM EACH ZONE                                              18
     1 STORAGE    2                              ZONE 1 LINES - 2                        19
     2 STORAGE    1                              ZONE 2 LINES - 1                        20
     3 STORAGE    1                              ZONE 3 LINES - 1                        21
     4 STORAGE    1                              ZONE 4 LINES - 1                        22
     5 STORAGE    1                              ZONE 5 LINES - 1                        23
     6 STORAGE    1                              ZONE 6 LINES - 1                        24
     7 STORAGE    1                              ZONE 7 LINES - 1                        25
*                                                                                         26
*INPUT- COST OF LD CALLS FROM ZONE 1 BY DURATION IN MINUTES                              27
     1 MATRIX     X,7,15                         LD COST BY ZONE                         28
       INITIAL    MX1(1,1),55                                                            29
       INITIAL    MX1(1,2),55                                                            30
       INITIAL    MX1(1,3),55                                                            31
       INITIAL    MX1(1,4),70                                                            32
       INITIAL    MX1(1,5),85                                                            33
       INITIAL    MX1(1,6),100                                                           34
       INITIAL    MX1(1,7),115                                                           35
       INITIAL    MX1(1,8),130                                                           36
       INITIAL    MX1(1,9),145                                                           37
       INITIAL    MX1(1,10),160                                                          38
       INITIAL    MX1(1,11),175                                                          39
       INITIAL    MX1(1,12),190                                                          40
       INITIAL    MX1(1,13),205                                                          41
       INITIAL    MX1(1,14),220                                                          42
       INITIAL    MX1(1,15),235                                                          43
*                                                                                         44
*INPUT- COST OF LD CALLS FROM ZONE 2 BY DURATION IN MINUTES                              45
       INITIAL    MX1(2,1),110                                                           46
       INITIAL    MX1(2,2),110                                                           47
       INITIAL    MX1(2,3),110                                                           48
       INITIAL    MX1(2,4),135                                                           49
       INITIAL    MX1(2,5),160                                                           50
       INITIAL    MX1(2,6),185                                                           51
       INITIAL    MX1(2,7),210                                                           52
       INITIAL    MX1(2,8),235                                                           53
       INITIAL    MX1(2,9),260                                                           54
       INITIAL    MX1(2,10),285                                                          55
```

TABLE V (Continued)

```
        INITIAL    MX1(2,11),310                                          56
        INITIAL    MX1(2,12),335                                          57
        INITIAL    MX1(2,13),360                                          58
        INITIAL    MX1(2,14),385                                          59
        INITIAL    MX1(2,15),410                                          60
*                                                                         61
*INPUT- COST OF LD CALLS FROM ZONE 3 BY DURATION IN MINUTES                62
        INITIAL    MX1(3,1),120                                           63
        INITIAL    MX1(3,2),120                                           64
        INITIAL    MX1(3,3),120                                           65
        INITIAL    MX1(3,4),150                                           66
        INITIAL    MX1(3,5),180                                           67
        INITIAL    MX1(3,6),210                                           68
        INITIAL    MX1(3,7),240                                           69
        INITIAL    MX1(3,8),270                                           70
        INITIAL    MX1(3,9),300                                           71
        INITIAL    MX1(3,10),330                                          72
        INITIAL    MX1(3,11),360                                          73
        INITIAL    MX1(3,12),390                                          74
        INITIAL    MX1(3,13),420                                          75
        INITIAL    MX1(3,14),450                                          76
        INITIAL    MX1(3,15),480                                          77
*                                                                         78
*INPUT- COST OF LD CALLS FROM ZONE 4 BY DURATION IN MINUTES               79
        INITIAL    MX1(4,1),130                                           80
        INITIAL    MX1(4,2),130                                           81
        INITIAL    MX1(4,3),130                                           82
        INITIAL    MX1(4,4),165                                           83
        INITIAL    MX1(4,5),200                                           84
        INITIAL    MX1(4,6),235                                           85
        INITIAL    MX1(4,7),270                                           86
        INITIAL    MX1(4,8),305                                           87
        INITIAL    MX1(4,9),340                                           88
        INITIAL    MX1(4,10),375                                          89
        INITIAL    MX1(4,11),410                                          90
        INITIAL    MX1(4,12),445                                          91
        INITIAL    MX1(4,13),480                                          92
        INITIAL    MX1(4,14),515                                          93
        INITIAL    MX1(4,15),550                                          94
*                                                                         95
*INPUT- COST OF LD CALLS FROM ZONE 5 BY DURATION IN MINUTES               96
        INITIAL    MX1(5,1),140                                           97
        INITIAL    MX1(5,2),140                                           98
        INITIAL    MX1(5,3),140                                           99
        INITIAL    MX1(5,4),175                                          100
        INITIAL    MX1(5,5),210                                          101
        INITIAL    MX1(5,6),245                                          102
        INITIAL    MX1(5,7),280                                          103
        INITIAL    MX1(5,8),315                                          104
        INITIAL    MX1(5,9),350                                          105
        INITIAL    MX1(5,10),385                                         106
        INITIAL    MX1(5,11),420                                         107
        INITIAL    MX1(5,12),455                                         108
        INITIAL    MX1(5,13),490                                         109
        INITIAL    MX1(5,14),525                                         110
        INITIAL    MX1(5,15),560                                         111
                                                                         112
```

TABLE V (Continued)

```
*INPUT- COST OF LD CALLS FROM ZONE 6 BY DURATION IN MINUTES                    113
       INITIAL    MX1(6,1),155                                                114
       INITIAL    MX1(6,2),155                                                115
       INITIAL    MX1(6,3),155                                                116
       INITIAL    MX1(6,4),195                                                117
       INITIAL    MX1(6,5),235                                                118
       INITIAL    MX1(6,6),275                                                119
       INITIAL    MX1(6,7),315                                                120
       INITIAL    MX1(6,8),355                                                121
       INITIAL    MX1(6,9),395                                                122
       INITIAL    MX1(6,10),435                                               123
       INITIAL    MX1(6,11),475                                               124
       INITIAL    MX1(6,12),515                                               125
       INITIAL    MX1(6,13),555                                               126
       INITIAL    MX1(6,14),595                                               127
       INITIAL    MX1(6,15),635                                               128
*                                                                              129
*INPUT- COST OF LD CALLS FROM ZONE 7 BY DURATION IN MINUTES                    130
       INITIAL    MX1(7,1),65                                                 131
       INITIAL    MX1(7,2),65                                                 132
       INITIAL    MX1(7,3),65                                                 133
       INITIAL    MX1(7,4),87                                                 134
       INITIAL    MX1(7,5),109                                                135
       INITIAL    MX1(7,6),131                                                136
       INITIAL    MX1(7,7),153                                                137
       INITIAL    MX1(7,8),175                                                138
       INITIAL    MX1(7,9),197                                                139
       INITIAL    MX1(7,10),219                                               140
       INITIAL    MX1(7,11),241                                               141
       INITIAL    MX1(7,12),263                                               142
       INITIAL    MX1(7,13),285                                               143
       INITIAL    MX1(7,14),307                                               144
       INITIAL    MX1(7,15),329                                               145
*                                                                              146
*INPUT- COST OF FULL-TIME WATS SERVICE BY ZONE                                 147
     2 MATRIX     X,8,5                    OUTPUT MATRIX OF COSTS             148
       INITIAL    MX2(1,2),180000        2 FULLTIME WATS LINES ZONE 1         149
       INITIAL    MX2(2,2),110000         1 FULLTIME WATS LINE ZONE 2         150
       INITIAL    MX2(3,2),130000         1 FULLTIME WATS LINE ZONE 3         151
       INITIAL    MX2(4,2),150000         1 FULLTIME WATS LINE ZONE 4         152
       INITIAL    MX2(5,2),175000         1 FULLTIME WATS LINE ZONE 5         153
       INITIAL    MX2(6,2),185000         1 FULLTIME WATS LINE ZONE 6         154
       INITIAL    MX2(7,2),54500          1 FULLTIME WATS LINE ZONE 7         155
*                                                                              156
     3 MATRIX     X,10,5                   PARAMETER PRINTOUT                 157
     1 FVARIABLE  (IP2/60)+99/100)         CONV. SEC. TO MIN.                 158
*                                                                              159
*DESCRIBE THE STANDARDIZED NEGATIVE EXPONENTIAL DISTRIBUTION                   160
     1 FUNCTION   RN1,C20                  STAND. NEG. EXPON. FUN.            161
0     0     .1    .104  .2    .222  .3    .355  .4    .509  .5    .69        162
.6    .915  .7    1.2   .75   1.38  .8    1.6   .84   1.83  .88   2.12       163
.9    2.3   .92   2.52  .94   2.81  .95   2.99  .96   3.2   .97   3.5        164
.98   3.9   1.0   5                                                          165
*                                                                              166
*DESCRIBE THE STANDARDIZED NORMAL DISTRIBUTION                                 167
     5 FUNCTION   RN2,C39                  STAND. NORMAL DIST.                168
0     -6.   .00023-3.5  .00034-3.4  .00069-3.2  .00135-3.0  .0026 -2.8       169
```

TABLE V (Continued)

```
          .0047 -2.6   .0082 -2.4   .0139 -2.2   .0228 -2.0   .0359 -1.8   .0548 -1.6                    170
          .0808 -1.4   .1151 -1.2   .1587 -1.0   .2119 -0.8   .2743 -0.6   .3446 -0.4                    171
          .4207 -0.2   .5000 0.0    .5793 0.2    .6554 0.4    .7257 0.6    .7881 0.8                     172
          .8413 1.0    .8849 1.2    .9192 1.4    .9452 1.6    .9641 1.8    .9773 2.0                     173
          .9861 2.2    .9918 2.4    .9953 2.6    .9974 2.8    .998653.0    .999313.2                     174
          .999663.4    .999773.5    1.0    6.0                                                           175
               5 VARIABLE    FN5*X4/10000+X3                                                             176
               3 FUNCTION    V5,C2                    REF. FUN. FOR NORMAL DIST.                         177
          0,0/99999,99999                                                                                178
          *                                                                                              179
          *INPUT- MEASURED WATS RATES IN FUN.11-17, CONV. SEC. TO MIN., RND. UP                           180
              11 FVARIABLE  (MX2(1,1)/60+99/100)                                                         181
              11 FUNCTION   V11,C2                                                                       182
          1200,44000/6600,192500                    2 MEASURED WATS LINES - ZONE 1                       183
              12 FVARIABLE  (MX2(2,1)/60+99/100)                                                         184
              12 FUNCTION   V12,C2                                                                       185
          600,24000/6600,209000                     1 MEASURED WATS LINE - ZONE 2                        186
              13 FVARIABLE  (MX2(3,1)/60+99/100)                                                         187
              13 FUNCTION   V13,C2                                                                       188
          600,26000/6600,231000                     1 MEASURED WATS LINE - ZONE 3                        189
              14 FVARIABLE  (MX2(4,1)/60+99/100)                                                         190
              14 FUNCTION   V14,C2                                                                       191
          600,28000/6600,248000                     1 MEASURED WATS LINE - ZONE 4                        192
              15 FVARIABLE  (MX2(5,1)/60+99/100)                                                         193
              15 FUNCTION   V15,C2                                                                       194
          600,31000/6600,266000                     1 MEASURED WATS LINE - ZONE 5                        195
              16 FVARIABLE  (MX2(6,1)/60+99/100)                                                         196
              16 FUNCTION   V16,C2                                                                       197
          600,32500/6600,277500                     1 MEASURED WATS LINE - ZONE 6                        198
              17 FVARIABLE  (MX2(7,1)/60+99/100)                                                         199
              17 FUNCTION   V17,C2                                                                       200
          600,16500/6600,146500                     1 MEASURED WATS LINE - ZONE 7                        201
          *                                                                                              202
          *BEGIN THE ACTUAL SIMULATION OF CALLS COMING IN                                                 203
1             GENERATE   X1,FN1                     GENERATE CALLS AT INT. X1                            204
          *                                                                                              205
          *COUNT AND RECORD THE INCOMING CALLS                                                           206
2             SAVEVALUE  10+,K1                     RECORD NO. OF THE CALL                               207
3             ASSIGN     1,X10                      NO. OF CALL IN P1                                    208
          *                                                                                              209
          *ASSIGN TO THE CALL A RANDOM DURATION FROM FUNCTION 1                                          210
4             ASSIGN     2,X2,1                     CALL DUR. SEC. IN P2                                 211
          *                                                                                              212
          *CHECK TO ASSURE A MINIMUM DURATION OF 10 SECONDS TO THE CALL                                  213
5             TEST L     P2,K10,MAX                 MIN. CALL DUR.-10 SEC.                               214
6             ASSIGN     2,K10                                                                           215
7             TRANSFER   ,MIN                                                                            216
          *                                                                                              217
          *CHECK TO ASSURE A MAXIMUM DURATION OF 15 MINUTES TO THE CALL                                  218
8          MAX TEST G    P2,K900,MIN                MAX. CALL DUR.-15 MIN.                               219
9             ASSIGN     2,K900                                                                          220
          *                                                                                              221
          *RECALCULATE DURATION OF THE CALL IN MINUTES FOR LD BILLING                                    222
10         MIN ASSIGN    3,V1                       DURATION OF CALL IN P3 MIN.                          223
          *                                                                                              224
          *ASSIGN TO THE CALL A ZONE FROM FUNCTION 2                                                     225
11            ASSIGN     4,FN2                      ZONE OF CALL IN P4                                   226
```

TABLE V (Continued)

```
                *                                                                    227
                *COMPUTE THE LD COST OF THE CALL FROM COST TABLE 1                    228
12              ASSIGN      5,MX1(P4,P3)            COST OF LD CALL IN P5            229
                *                                                                    230
                *ALLOW 10 CALLS TO BE PRINTED OUT TO CHECK THE PARAMETERS            231
13              TEST LE     P1,K10,CALL             PRINT PARA. FOR  10 CALLS        232
14              MSAVEVALUE  3,P1,1,P1                                                233
15              MSAVEVALUE  3,P1,2,P2                                                234
16              MSAVEVALUE  3,P1,3,P3                                                235
17              MSAVEVALUE  3,P1,4,P4                                                236
18              MSAVEVALUE  3,P1,5,P5                                                237
                *                                                                    238
                *ATTEMPT TO USE A PARTICULAR ZONE LINE                               239
19              CALL GATE SNF   P4,BUSY             TRY TO USE LINE                  240
                *                                                                    241
                *USE THE AVAILABLE LINE                                              242
20              ENTER       P4                      USE LINE FOR ZONE IN P4          243
                *                                                                    244
                *       SIMULATE THE DURATION OF THE CALL                            245
21              ADVANCE     P2                      DUR. OF CALL                     246
                *                                                                    247
                *TERMINATE THE CALL                                                  248
22              LEAVE       P4                      HANG UP                          249
23              TRANSFER    ,BILL                   TERMINATE CALL                   250
                *                                                                    251
                *RECORD THE FACT THAT A PARTICULAR ZONE LINE WAS BUSY WHEN NEEDED     252
24              BUSY MSAVEVALUE 2+,P4,5,K1          RECORD A BUSY LINE               253
                *                                                                    254
                *       SIMULATE WAITING WITH A TIME FROM FUNCTION 3                 255
25              ADVANCE     1,FN3                   WAIT BEFORE CALLING AGAIN        256
                *                                                                    257
                *TRY TO PLACE THE CALL AGAIN                                         258
26              TRANSFER    ,CALL                   CALL AGAIN                       259
                *                                                                    260
                *ACCUMULATE CALL DURATIONS BY ZONE FOR MEASURED WATS BILLING         261
27              BILL MSAVEVALUE 2+,P4,1,P2          ACCUM TIME IN MX2 BY ZONE AND    262
                *                                                                    263
                *ACCUMULATE LONG DISTANCE COSTS BY ZONE                              264
28              MSAVEVALUE  2+,P4,4,P5              ACCUM LD COST IN MX2 BY ZONE     265
                *                                                                    266
                *DESTROY THE TRANSACTION SIMULATING A CALL                           267
29              TERMINATE   1                                                        268
                *                                                                    269
                *ALLOW A CERTAIN NUMBER OF CALLS TO BE SIMULATED COMPLETELY          270
                START       8000                    SIMULATE 8000 CALLS              271
                *                                                                    272
                *BEGIN A SUMMARY PHASE OF THE SIMULATION                             273
30              GENERATE    ,,,1                                                     274
                *                                                                    275
                *SUMMARIZE THE DURATIONS OF THE CALLS IN SECONDS                     276
31              MSAVEVALUE  2+,8,1,MX2(1,1)         SUM CALL DURATIONS               277
32              MSAVEVALUE  2+,8,1,MX2(2,1)                                          278
33              MSAVEVALUE  2+,8,1,MX2(3,1)                                          279
34              MSAVEVALUE  2+,8,1,MX2(4,1)                                          280
35              MSAVEVALUE  2+,8,1,MX2(5,1)                                          281
36              MSAVEVALUE  2+,8,1,MX2(6,1)                                          282
37              MSAVEVALUE  2+,8,1,MX2(7,1)                                          283
```

TABLE V (Continued)

```
                *                                                                    284
                *SUMMARIZE THE FULL-TIME WATS COSTS FOR ALL ZONES                     285
38              MSAVEVALUE 2+,8,2,MX2(1,2)          SUM F T WATS COSTS               286
39              MSAVEVALUE 2+,8,2,MX2(2,2)                                           287
40              MSAVEVALUE 2+,8,2,MX2(3,2)                                           288
41              MSAVEVALUE 2+,8,2,MX2(4,2)                                           289
42              MSAVEVALUE 2+,8,2,MX2(5,2)                                           290
43              MSAVEVALUE 2+,8,2,MX2(6,2)                                           291
44              MSAVEVALUE 2+,8,2,MX2(7,2)                                           292
                *                                                                    293
                *COMPUTE AND SUMMARIZE THE MEASURED WATS COSTS BY ZONE                294
45              MSAVEVALUE 2,1,3,FN11               COMPUTE MEASURED WATS COST       295
46              MSAVEVALUE 2+,8,3,MX2(1,3)                                           296
47              MSAVEVALUE 2,2,3,FN12                                                297
48              MSAVEVALUE 2+,8,3,MX2(2,3)                                           298
49              MSAVEVALUE 2,3,3,FN13                                                299
50              MSAVEVALUE 2+,8,3,MX2(3,3)                                           300
51              MSAVEVALUE 2,4,3,FN14                                                301
52              MSAVEVALUE 2+,8,3,MX2(4,3)                                           302
53              MSAVEVALUE 2,5,3,FN15                                                303
54              MSAVEVALUE 2+,8,3,MX2(5,3)                                           304
55              MSAVEVALUE 2,6,3,FN16                                                305
56              MSAVEVALUE 2+,8,3,MX2(6,3)                                           306
57              MSAVEVALUE 2,7,3,FN17                                                307
58              MSAVEVALUE 2+,8,3,MX2(7,3)                                           308
                *                                                                    309
                *SUMMARIZE THE LONG DISTANCE COSTS FOR ALL ZONES                      310
59              MSAVEVALUE 2+,8,4,MX2(1,4)          SUM LD CALL COSTS                311
60              MSAVEVALUE 2+,8,4,MX2(2,4)                                           312
61              MSAVEVALUE 2+,8,4,MX2(3,4)                                           313
62              MSAVEVALUE 2+,8,4,MX2(4,4)                                           314
63              MSAVEVALUE 2+,8,4,MX2(5,4)                                           315
64              MSAVEVALUE 2+,8,4,MX2(6,4)                                           316
65              MSAVEVALUE 2+,8,4,MX2(7,4)                                           317
66              TERMINATE  1                                                         318
                START      1.                                                        319
                *                                                                    320
                REPORT                                                               321
                EJECT      START A NEW PAGE                                          322
 MSAV           TITLE      1,LONG DISTANCE COSTS BY ZONE AND BY MINUTES              323
                EJECT      START A NEW PAGE                                          324
 MSAV           TITLE      2,ZONE, TOTAL SECONDS, FULLTIME WATS COST, MEASURED WA    325
ATS COST, LONG DISTANCE COST AND NUMBER OF TIMES BUSY                                326
                EJECT      START A NEW PAGE                                          327
 MSAV           TITLE      3,CALL NUMBER, SECONDS, MINUTES, ZONE AND LONG DISTANC    328
CE COST FOR EACH OF THE FIRST TEN CALLS                                              329
                END                                                                  330
```

TABLE VI

ACTIVITY RECORD (TIME, COST, AND BUSY SIGNALS)

ZONE, TOTAL SECONDS, FULLTIME WATS COST, MEASURED WATS COST, LONG DISTANCE COST AND NUMBER OF TIMES BUSY

MATRIX FULLWORD SAVEVALUE 2

	COLUMN 1	2	3	4	5
ROW 1	588656	90000	17500	245825	32451
2	55714	110000	34144	47610	25
3	170626	130000	102670	148320	330
4	153782	150000	100013	150920	280
5	127367	175000	90650	131495	144
6	74277	185000	58551	87075	68
7	245465	54500	92160	128096	865
8	1415887	894500	495688	939341	0

simulated will result in a measure of customer (caller) satisfaction and need for additional lines to any particular zone.

CHAPTER III

MECHANICS OF THE SIMULATION

General Procedure

The General Purpose Simulation System allows each call to be represented by a single transaction. Since the exponential distribution is commonly used to represent the interval between random events ordered in time, both the interarrival times and call durations are generated from exponential distribution with mean values specified by the analyst (3). A serial number, the duration, and a source zone drawn from a known empirical distribution uniquely identify each call. This set of parameters travels with the transaction through the system. It serves as the basis for calculating costs and simulating facility usage.

As a call arrives, it attempts to use one of the available lines corresponding to its zone assignment. If the line is open it becomes engaged for the duration of the call. If no line is available, a busy signal is recorded, the transaction goes into a delay status for a random normal duration before returning to the flow of calls vying for the connections. Once a call has completed the route through the system, it is destroyed leaving only a note of its duration, cost, and conflict with other simulated calls (Appendix B).

Generation of Calls

Several attempts were made to record the frequency and pattern of incoming traffic at a large dispatching center. So frequently was the existing system saturated that the actual number of calls attempting to enter during peak periods was never known. The congestion was further complicated by the dispatchers putting calls on HOLD status, thereby accumulating service cost and at the same time blocking an otherwise open line.

Assuming that the calls are placed independently of one another and are not under the influence of the dispatch center before initiating the call, the pattern of incoming traffic is recognized as Poisson as is the practice in many queuing studies (4). Under this assumption, the durations between call arrivals are exponentially distributed (5). The GPSS language allows this to be effected most easily by means of the standardized exponential distribution wherein the user need only to specify the mean of the distribution of interarrival times in conjunction with the generation procedure, referring to the standardized exponential function for the proper spread of sampled values (6). Random selections from this continuous function are used as multipliers of the mean (ranging from 0 to 5 in this application). Table V, Cards 160-165, illustrate these entries in the program.

The mean of the interarrival times is to be entered as input data. It is stored in a SAVEVALUE for repeated

reference by the use of an INITIAL card:

INITIAL X1,90

designates the interval to be 90 seconds in mean value (Table V, Card 5).

Duration of Calls

Accurate measurement of the duration of actual conversations met with biased results. Because the dispatchers felt that the recording of this data was an attempt to rate their performance, the calls were apparently abbreviated while under observation.

The HOLDING of calls introduced unnecessary costs and utilization not considered in this study. For these reasons, the literature was again searched for precedent in the treatment of service times. Bellman (7), Saaty (8), and the corps of queueing theorists use the negative exponential assumption for service times independent of system pressures and order of arrival; therefore, this distribution was called upon for the simulation of call durations.

The mean of the duration of calls is specified by the user in a SAVEVALUE (X2) in the following manner:

INITIAL X2,180

This example fixes the mean at 180 seconds.

ASSIGN 2,X2,1

The ASSIGN instruction draws a random value from this function and fixes the duration to the transaction as PARAMETER 2. Theoretically, this value can range from 0 to 5

times the mean. Because any realistic call would last at least ten seconds, this minimum has been established by this sequence of instructions:

```
TEST  L    P2,K10,MIN
ASSIGN     2,K10
```

This reads "test to determine if parameter 2 (duration) is less than 10 (seconds); if so, reassign 10 (seconds) to that parameter; if not, branch to statement MIN".

In a similar manner, the duration of the call was limited to 15 minutes.

Dimensions of the Time Base

The GPSS language moves through simulated time by a variable time step procedure (3). It is also limited to the use of integer values of the selected time unit. This simulation is programmed to use the second as the primary time unit. Interarrival times, call durations, and delay data are expressed in seconds initially with the necessary conversions to minutes carried out for billing purposes only.

The more stable input table of long distance station-to-station charges (Table IV) uses the unit of <u>minutes</u> because the normal practice is to round up the individual call durations prior to computing cost. Measured WATS service charges (Figure 2) are also based upon total time in minutes, but with the rounding taking place only after the total usage in the simulation run has been summed for the respective zone.

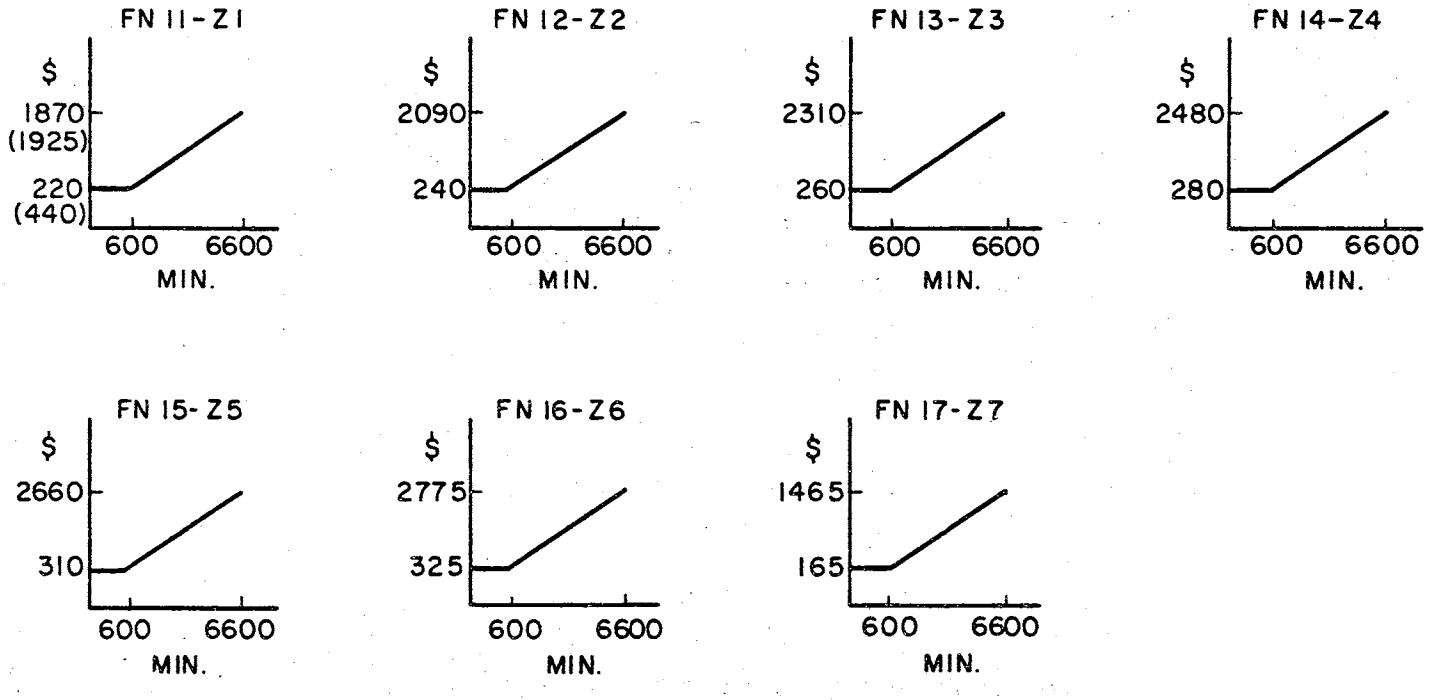


Figure 2. Measured WATS Cost Functions

Review of the Parameters

It has been mentioned several times that each transaction simulating a call has a number of parameters or labels to which one can attach certain characteristics of the call. Statements 208, 211, 218, 221, and 224 assign the following values to the parameters of each transaction:

Parameter	Assignment
1	Serial number of the call
2	Duration of the call in seconds
3	Duration of the call in minutes
4	Zone of origin of the call
5	Long distance station-to-station charge for the call

As a check on the functioning of the program, the user is provided a review of the parameters on the first 10 calls as a normal part of the output (Table VII). An extended review can be accomplished by the changing of the value K10 to a larger value (Table V, Card 227)

```
TEST  L    P1,K10,CALL
```

The main program is outlined in the form of a flow chart (Appendix B).

TABLE VII

REVIEW OF PARAMETERS FOR TEN CALLS

CALL NUMBER, SECONDS, MINUTES, ZONE AND LONG DISTANCE COST FOR EACH OF THE FIRST TEN CALLS

```
MATRIX FULLWORD SAVEVALUE    3
```

	COLUMN	1	2	3	4	5
ROW	1	1	160	3	7	65
	2	2	38	1	4	130
	3	3	96	2	7	65
	4	4	404	7	7	153
	5	5	59	1	1	55
	6	6	153	3	3	120
	7	7	209	4	1	70
	8	8	158	3	7	65
	9	9	245	5	3	180
	10	10	26	1	3	120

```
*
      END
```

CHAPTER IV

A SAMPLE PROBLEM

To describe the simulation program further, a sample problem is presented in this chapter. Input to the program will be explained and output will be interpreted as it pertains to the improvement of the situation.

The Problem Statement

A dispatch center located in Oklahoma City receives long distance telephone reports of operations from various locations across the United States. The calls are similar in nature and duration. The proportion of calls to the center from the various WATS zones designated for the State of Oklahoma are as shown in Table VIII.

It is estimated that these calls (Table VIII) are placed at the rate of 45 calls per hour and that the distribution of interarrival times is negative exponential. Durations of the calls have been measured to average three minutes, also distributed exponentially by assumption. Persons placing the calls have been instructed to replace their calls in fifteen minutes if a busy signal is encountered.

TABLE VIII

DISTRIBUTION OF CALLS IN THE SAMPLE PROBLEM

Zone	Percentage
7 (Okla.)	16%
1	43%
2	5%
3	11%
4	11%
5	9%
6	5%

The system presently uses seven full-time inbound WATS lines to cover all the zones and operates on a 22-workday month. The objectives of the solution by simulation are to:

(1) determine the proper combination of full-time WATS lines, measured WATS lines, and long distance connections allowing no more than fifteen per cent of the calls in any one zone to find a busy signal, and still minimizing cost;

(2) compare the cost of operation (under the selected arrangement) varying the average call duration from two to four minutes;

(3) calculate the costs for an increase in traffic density to 60 calls per hour.

Input to the Program

Traffic density must be converted to average interarrival time of calls in seconds. In this case, a rate of 45 calls per hour equals an interarrival time of 90 seconds. This figure is entered in Table V, Card 5, as:

```
INITIAL    X1,90
```

The average call duration of three minutes is read in as 180 seconds on Card 7 (Table V):

```
INITIAL    X2,180
```

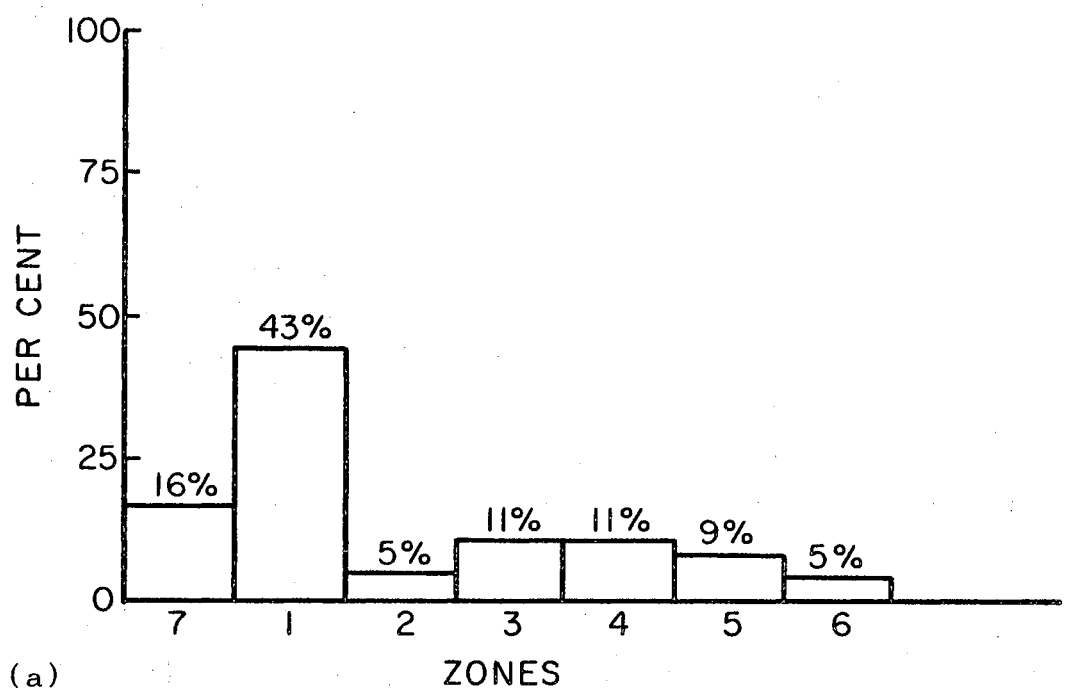
Figure 3(a) shows a histogram of the origins of calls by zone; 3(b) shows the corresponding cumulative function which is to be entered into the simulation program. In terms of the GPSS format, this is cut on Cards 9-11 (Table V):

```
2  FUNCTION  RN2,D7
.17  7    .59  1    .64  2    .75  3    .86  4    .95  5
1.0  6
```

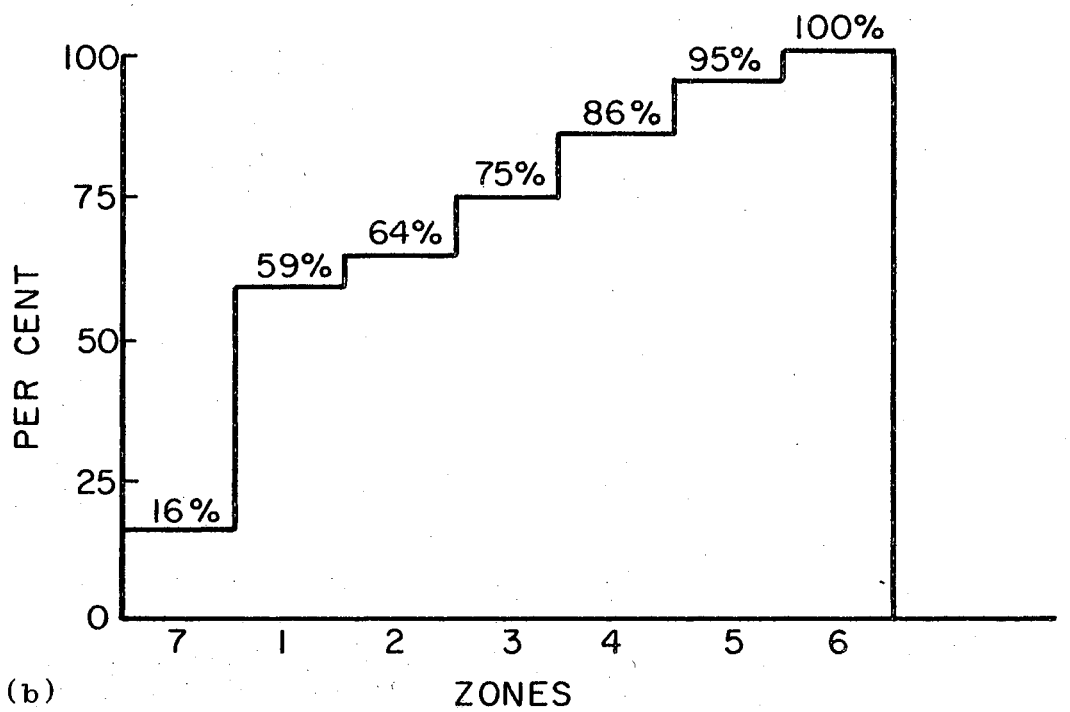
Waiting times before recalling are assumed to be normally distributed. The mean of 15 minutes is converted to 900 seconds for Card 14 (Table V) and a standard deviation of 60 seconds is added by means of Card 16 (Table V):

```
INITIAL    X3,900
INITIAL    X4,60
```

The number of lines per zone is specified by designating storage capacities on Table V, Cards 19-25, such as:



(a)



(b)

Figure 3. Source of Calls by Zone (Sample Problem)

```
1    STORAGE     1
2    STORAGE     1
      .
      .
      .
7    STORAGE     1
```

Since the basic program is designed for the use of one line per zone, no other data is required for the proper cost calculation. However, if a second or third line is added to any zone, not only must the storage capacity be increased, the full-time WATS service charge must be doubled or tripled accordingly and the measured WATS rate in functions 11-17 must be adjusted (see Appendix A).

Output From the Program

The two major tables of interest to the systems analyst are Table VII, the review of the parameters and Table VI, an activity record of performance and cost. For the simulation of one 8000 call month of telephone service, the following report was generated (Table IX).

The first factor to be considered is utilization. This is reflected in the number of busy signals occurring in each zone. In the example under discussion, it is obvious that a saturated condition exists in Zone 1 when there were 32,451 busy signals met by the 8000 calls; that is, each call had to be placed five times, meeting four busy signals before one successful connection. In a real situation, customers would have given up calling long before this. Therefore,

another simulation run is necessary to test the system with two lines to Zone 1.

TABLE IX

ACTIVITY RECORD (REJECTED)

Zone	Total Time in Seconds	Full-Time WATS Cost	Measured WATS Cost	Long Distance Cost	Busy Signals
1	588,656	$ 900.00	$ 1750.00	$ 2458.25	32,451
2	55,714	1100.00	341.44	476.10	25
3	170,626	1300.00	1026.70	1483.20	330
4	153,782	1500.00	1000.13	1509.20	280
5	127,367	1750.00	906.50	1314.95	144
6	74,277	1850.00	585.51	870.75	68
7	245,465	545.00	921.60	1280.96	865
	1,415,887	$ 8945.00	$ 6531.88	$ 9393.41	

The activity record for the second run with an additional line to Zone 1 reads as shown in Table X.

Utilization has definitely improved. Only 14% of the calls made in Zone 1 were recycled because of a busy signal. This meets part of the first requirement of the problem.

Scanning each zone permits the minimum cost combination of lines to be determined. The result is noted on the report of Table X and recapped in Table XI.

TABLE X

ACTIVITY RECORD FOR PART ONE OF THE SAMPLE PROBLEM

Zone	Total Time in Seconds	Full-Time WATS Cost	Measured WATS Cost	Long Distance Cost	Busy Signals
1	580,638	$ 1800.00*	$ 1925.00	$ 2436.40	1120**
2	62,021	1100.00	373.81*	514.50	25
3	163,715	1300.00	987.40*	1437.90	281
4	161,543	1500.00	1047.43*	1543.80	270
5	131,334	1750.00	932.35*	1364.65	187
6	72,703	1850.00	574.90*	842.30	52
7	245,333	545.00*	920.95	1281.53	929
	1,417,287	$ 9845.00	$ 6761.84	$ 9421.08	

*Selected in scanning.

**Used for measuring utilization.

TABLE XI

MINIMUM COST COMBINATION FOR THE SAMPLE PROBLEM

Zone	Service	Cost
1	Full-time WATS	$ 1800.00
2	Measured WATS	373.81
3	Measured WATS	987.40
4	Measured WATS	1047.43
5	Measured WATS	932.35
6	Measured WATS	574.90
7	Full-time WATS	545.00
	Minimum Total Cost	$ 6260.89

The second part of the problem asked for a comparison of cost as the average call duration varied from two to four minutes. The three activity records have been extracted from the output of the respective simulations and are summarized in Table XII. Selection of the minimum cost combination reveals a common pattern, full-time WATS facilities in the two nearest zones and measured WATS facilities in the balance. The utilization measured by the number of busy signals indicates that Zone 1 is again saturated and needs a third line when the average call duration rises to four minutes.

Part three of the sample problem asked for a performance and cost record for a simulation of 60 calls per hour. Ten thousand calls were generated with results as given in Table XIII.

Again, it is evident that Zone 1 would be overburdened with more than one-half of the calls having to call again. In Zone 7, one-quarter of the calls met busy signals. Regardless of the service combinations selected, this level of traffic density requires at least two additional lines and further analysis.

TABLE XII

ACTIVITY RECORD FOR PART TWO OF THE SAMPLE PROBLEM

Zone	Full-Time WATS Cost	Measured WATS Cost	Long Distance Cost	Busy Signals
1	$ 1800.00*	$ 1912.90	$ 2098.80	375
2	1100.00	280.39*	464.65	26
3	1300.00	645.74*	1201.50	161
4	1500.00	696.53*	1315.70	147
5	1750.00	660.54*	1194.20	122
6	1850.00	387.06*	680.05	32
7	545.00*	634.73	1069.96	491
Average call duration = 2 min.; minimum cost = $5015.26				
1	$ 1800.00*	$ 1925.00	$ 2436.00	1120
2	1100.00	373.81*	514.50	25
3	1300.00	987.40*	1437.90	281
4	1500.00	1047.43*	1543.80	270
5	1750.00	932.35*	1364.65	187
6	1850.00	574.90*	842.30	52
7	545.00*	920.95	1281.53	929
Average call duration = 3 min.; minimum cost = $6260.89				
1	$ 1800.00*	$ 1925.00	$ 2827.30	2250**
2	1100.00	511.64*	611.15	51
3	1300.00	1252.88*	1624.20	477
4	1500.00	1238.46*	1663.10	374
5	1750.00	1172.84*	1535.45	249
6	1850.00	738.23*	971.50	71
7	545.00*	1239.23	1556.21	1678
Average call duration = 4 min.; minimum cost = $7259.05				

*Selected in scanning.

**Measuring utilization.

TABLE XIII

ACTIVITY RECORD FOR PART THREE OF THE SAMPLE PROBLEM

Zone	Full-Time WATS Cost	Measured WATS Cost	Long Distance Cost	Busy Signals
1	$ 1800.00	$ 1925.00	$ 3107.95	5643*
2	1100.00	464.15	660.35	78
3	1300.00	1208.80	1752.90	742
4	1500.00	1239.20	1885.00	616
5	1750.00	1066.30	1598.45	311
6	1850.00	676.57	1007.55	107
7	545.00	1175.31	1638.48	2616*

*Used for measuring utilization.

This sample problem has exercised only a few of the options in the program. The analyst could also study the effect of shifts in traffic from one zone to another. Repeated simulation runs with varied parameters controlling the time delay before recall may show that immediate recall is a poor procedure when compared to waiting for a specific extended period. The delay, of course, depends upon the values of the other parameters representing interarrivals, durations, etc.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER INVESTIGATION

General Conclusions About Simulation

There are two major conclusions drawn as a result of this research. The first is addressed to the manager or user with a problem in systems operation.

Simulation can be used to analyze situations whose complex structure and dynamic nature defy the most capable mathematician. The modern computers and simulation languages allow the man actually responsible for the solution to describe the problem as he sees it, to define the measures of performance, and to specify the form of the output. With these guidelines and with sufficient time, an industrial engineer specializing in simulation techniques can test any number of plans for the solution of the problem. The highest level of theoretical sophistication can be invoked where it is necessary, yet the outcome can be interpreted easily and explained to the decision-maker with the original problem. His personal evaluation would then determine whether a satisfactory answer has been found or whether additional work is necessary to support the decision making process.

This research has demonstrated that such a realistic problem situation can be modeled accurately and analyzed thoroughly by means of simulation. The process of analysis escalates from a level of practical understanding to higher levels of sophisticated mathematics for computational purposes. Then the reverse process provides a variety of feasible solutions for the responsible decision-maker. All of this can be done without disturbing the normal flow of business in the actual problem area.

The second conclusion is directed to the systems analyst who is presumably a qualified industrial engineer.

Experience on this investigation has confirmed the author's observations of several years of simulation work. The process is one requiring industry, patience, and understanding of the humans involved with the system under analysis. The program described herein required some sixty separate computer runs several months of observation to determine what the operations manager needed. As the original model unfolded and grew, fresh ideas and new difficulties came up, each one extending the program. Simulations using the present program to study an 8000-call work-month under the ideal combinations of telephone facilities use four to five minutes of IBM 360 Model 50 time. The systems analyst must be aware, therefore, that the results of the study must justify the expenditure of large amounts of time and money and should make this known before the analysis is begun.

It is also true that once the model has been constructed and tested it will serve for a long period of time as a tool for monitoring operations. As changes in the flow of traffic inevitably occur, their effects can be forecast. Proposed raises in costs can also be evaluated easily. Thus, the relatively heavy cost of building the simulation model can be defrayed by later benefits as with any other capital expenditure.

Specific Conclusions and Recommendations on This Program

This program has been tested extensively. It meets all of the claims made in the Introduction. Its present form limits the durations of the calls to a range of ten seconds to fifteen minutes and to a maximum of 110 hours of use in each zone. Instructions for extending these limits and for making simple changes such as the substitution of other forms of statistical or empirical distributions are provided in Appendix I.

In summary, the simulation program will allow the decision-maker, with the assistance of a systems analyst, to model an existing telephone traffic flow situation. Once the model has been initialized a normal work-month can be simulated closely with service charges calculated for each of three optional procedures. The decision-maker can also alter the number of telephone lines simulated, the frequency and duration of calls, the pattern of call sources,

the response to busy signals and the individual rates to extend the application of the procedure. This program can be adapted for use with any central dispatching operation in the continental United States.

Extensions to this program would include:

(1) provision for varying the levels of telephone traffic throughout the workday to describe a particular application more precisely with modification to exercise the simulation on a timed-run basis,

(2) inclusion of night-rates for long-distance billing analysis,

(3) combination of the storage specification (number of lines per zone) with the corresponding rate table to simplify the testing of added lines.

It is also recommended that these extensions be carried out by rewriting the program in that version of the General Purpose Simulation System which permits the use of the FORTRAN language in subroutines designed by the user.

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APPENDIX A

MODIFICATIONS TO THE PRESENT PROGRAM

Other Statistical and Empirical Distributions

The exponential distribution has been used for both interarrival times and for call durations by using samplings from a continuous function of this form to spread values around certain mean values.

```
GENERATE    X1,FN1      and
ASSIGN      1,X2,1
```

refer to Function 1. If the normal distribution is more appropriate for either of these purposes, it is necessary to make the following changes to these statements:

```
GENERATE    X1,FN2      and
ASSIGN      2,X2,2
```

as the normal distribution is also loaded into the program as Function 2.

Assuming that some other form of distribution must be used, it should be written as a continuous cumulative function and called upon, not as a modifier, but for the actual value to be used. For example,

```
        20    FUNCTION    RN3,C2
0,10/5000,900
              GENERATE    FN20        or
              ASSIGN      2,FN20
```

Additional Lines to a Zone

Each zone has 1 line in the basic program. This is stated in 3 places in the listing for 3 different reasons. The addition of one or more lines to a zone requires that

changes be made in each of the 3 places.

For example, Card 19 (Table V) reads:

1 STORAGE 1 ZONE 1 LINES - 1

To account for a second line, this should read:

1 STORAGE 2 ZONE 1 LINES - 2

Secondly, Card 149 (Table V) reads:

INITIAL MX2(1,2)90000 1 FULLTIME WATS LINE ZONE 1

or "the cost of a single line in Zone 1 on a full-time WATS rate is $900." A second full-time WATS line would double that cost:

INITIAL MX2(1,2)180000 2 FULLTIME WATS LINES ZONE 1

Lastly, Card 183 (Table V) reads:

600,22000/6600,175000 1 MEASURED WATS LINE - ZONE 1

saying: "the rate is a continuous function beginning at $220 for the first 660 seconds and climbing (at the rate of $16.50/hour) to a cost of $1750.00 for 6600 seconds or 110 hours. The inclusion of a second line changes this to:

1200,44000/6600,192500 2 MEASURED WATS LINES - ZONE 1

Consideration of Figure 2 will verify the values.

Extension of Run Length

Card 271 (Table V) controls the number of calls to be simulated completely:

START 8000 SIMULATE 8000 CALLS

This value can be enlarged or reduced by simply altering the constant. Caution must be taken, however, to assure that extremely long runs do not cause overflow in the cost tables

or exceed the present limits on the measured WATS cost functions.

Revision of Rate Tables and Functions

The rate tables for long distance service, the rate functions for measured WATS service and the monthly cost of full-time WATS service are not current. Sample values have been used for demonstration purposes only.

The long distance rates are stored in MATRIX 1 with 1 row for each zone and 15 columns for 15 one-minute increments. Thus, a charge of $.55 for a three-minute call from Zone 1 is read into the program as:

```
INITIAL   MX1(1,3),55
```

These rates have been drawn from interstate and intrastate charge tables provided by Southwestern Bell Telephone Company. In order to relate the long distance charges to a call described by duration and zone of origin, an approximation has been made by measuring the average distance from the point of operations to the geographic center of each zone. This measurement resulted in the figures shown in Table XIV.

It would be necessary to correct this data for the application of the program to another point of operation by consulting the proper WATS area map.

Information needed for the revision of the measured WATS service and full-time WATS service may be secured from the telephone sales representative.

TABLE XIV

DISTANCE APPROXIMATION FOR ZONES

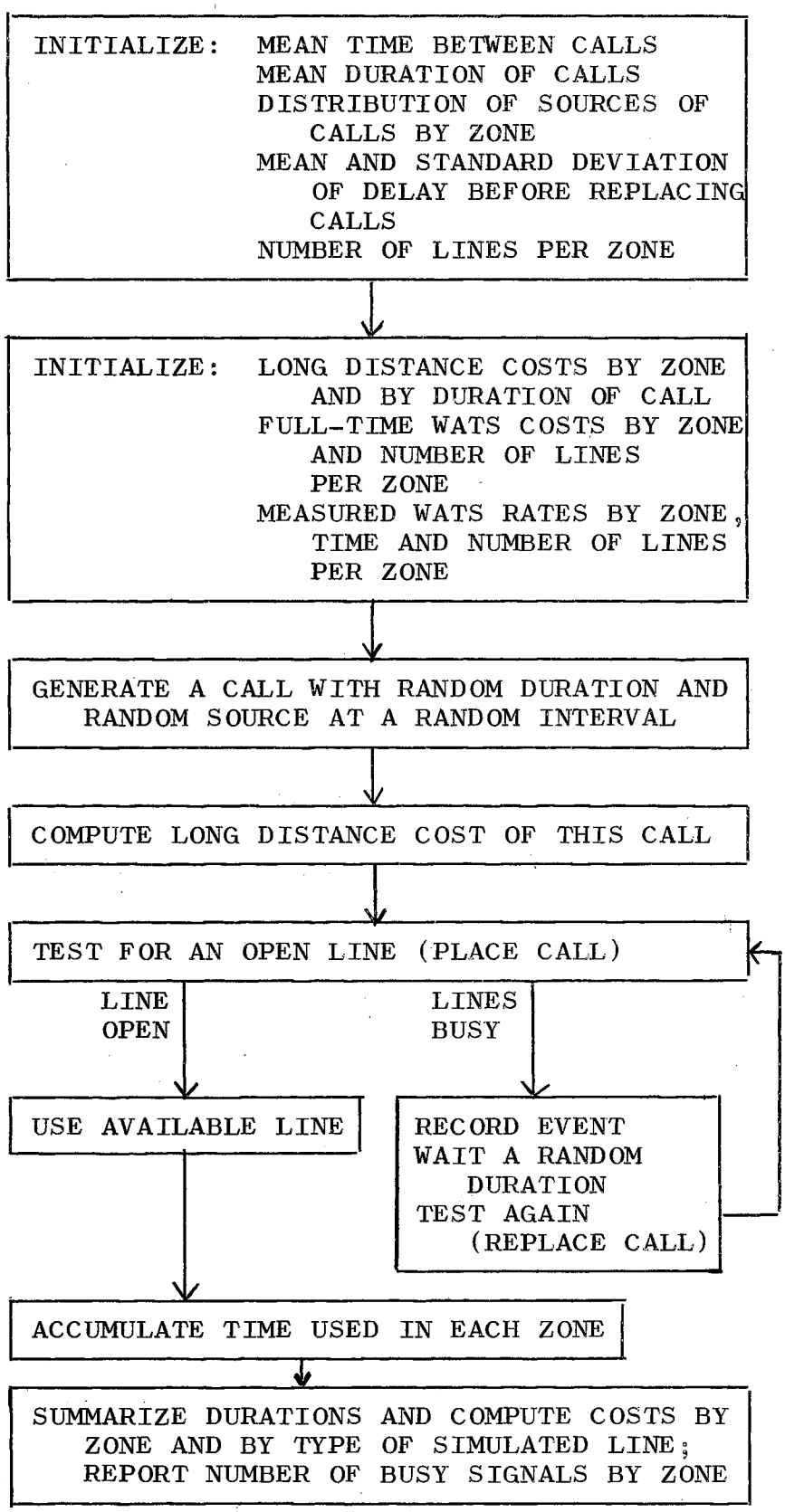
Zone	Distance from Oklahoma City
1	100 miles
2	400 "
3	550 "
4	850 "
5	1100 "
6	1200 "
7	1440 "

The proper program changes would be made to both the measured WATS cost functions and full-time WATS table (Matrix 2) as indicated under the heading titled Additional Lines to a Zone (in this section).

APPENDIX B

BLOCK DIAGRAM FOR THE PROGRAM

BLOCK DIAGRAM FOR THE PROGRAM



APPENDIX C

EXAMPLE OF A COMPLETE PROGRAM PRINTOUT

```
//TBA1@3 JOB (10435,215-30-7307,008,,,,2),'TOM AUER',CLASS=A,MSGLEVEL=1
// EXEC GPSS,TIME.GPSS=8
XXGPSS   EXEC  PGM=DAG01,PARM=8                                    GPSS 00000010
XXSTEPLIB DD DSN=SYS1.GPSS,DISP=SHR                                     00000020
XXDOUTPUT  DD  SYSOUT=A                                            GPSS 00000030
XXDINTERO  DD  UNIT=SYSDA,SPACE=(TRK,(10,10))                      GPSS 00000040
XXDSYMTAB  DD  UNIT=SYSDA,SPACE=(TRK,(10,10))                      GPSS 00000050
XXDREPTGEN DD  UNIT=SYSDA,SPACE=(TRK,(10,10))                      GPSS 00000060
XXDINTWORK DD  UNIT=(SYSDA,SEP=(DINTERO)),SPACE=(TRK,(10,10))      GPSS 00000070
XXDINPUT1  DD  DDNAME=SYSIN                                        GPSS 00000080
//GPSS.SYSIN DD *,DCB=BLKSIZE=80
//
```

```
**************************************************
*            OKLAHOMA STATE UNIVERSITY           *
*          UNIVERSITY COMPUTER CENTER            *
*        MFT-II RELEASE 17 WITH HASP-II          *
**************************************************
*JOB NAMED.............................'TBA1@3  '*
*LOG ON AT.............................. 7:27 AM*
*DATE.........................THURSDAY, JUNE 4, 1970*
*PARTITION IDENTIFICATION.....................'A'*
*PARTITION SIZE.....................168K BYTES*
**************************************************
```

```
IEF236I ALLOC. FOR TBA1@3   GPSS
IEF237I STEPLIB  ON 130
IEF237I DOUTPUT  ON 06E
IEF237I DINTERO  ON 134
IEF237I DSYMTAB  ON 136
IEF237I DREPTGEN ON 134
IEF237I DINTWORK ON 136
IEF237I DINPUT1  ON 040
IEF285I   SYS1.GPSS                                    KEPT
IEF285I   VOL SER NOS= DISK00.
IEF285I   SYS70155.T072651.RF000.TBA1@3.R0000001       DELETED
IEF285I   VOL SER NOS=       .
IEF285I   SYS70155.T072651.RF000.TBA1@3.R0000002       DELETED
IEF285I   VOL SER NOS= DISK04.
IEF285I   SYS70155.T072651.RF000.TBA1@3.R0000003       DELETED
IEF285I   VOL SER NOS= DISK06.
IEF285I   SYS70155.T072651.RF000.TBA1@3.R0000004       DELETED
IEF285I   VOL SER NOS= DISK04.
IEF285I   SYS70155.T072651.RF000.TBA1@3.R0000005       DELETED
IEF285I   VOL SER NOS= DISK06.
IEF285I   SYS70155.T072651.RF000.TBA1@3.R0000006       DELETED
IEF285I   VOL SER NOS=       .
```

```
**************************************************
*STEP NAMED.............................'GPSS    '*
*ENDED AT.............................. 7:37 AM*
*COMPLETION CODE.....................................96*
*PROCESSOR TIME USED.....................00.07.52*
*SELF IMPOSED WAIT TIME..................00.00.53*
*MAXIMUM CORE USED BY THIS STEP.........90K BYTES*
**************************************************
**************************************************
*JOB NAMED.............................'TBA1@3  '*
*LOG OFF AT............................. 7:37 AM*
*TOTAL PROCESSOR TIME USED...............00.07.52*
*TOTAL SELF IMPOSED WAIT TIME............00.01.08*
*TOTAL ENVIRONMENTAL WAIT TIME...........00.00.41*
*MAXIMUM CORE USED BY ANY 'GO' STEP.....0K BYTES*
*PROGRAM RAN IN MAIN STORAGE                     *
**************************************************
```

```
*** TOTAL COST:  $27.14 ***

 HASP-II JOB STATISTICS --     334 CARDS READ --       845 LINES PRINTED --       0 CARDS PUNCHED
```

```
BLOCK
NUMBER  #LOC    OPERATION   A,B,C,D,E,F,G              COMMENTS                                        CARD NUMBER
        SIMULATE                                                                                        1
*                                                                                                       2
        RMULT       37,31                           IMPROVE RN GENERATORS                               3
*INPUT- MEAN OF EXPONENTIAL DISTRIBUTION OF CALL INTERARRIVAL TIMES                                      4
        INITIAL     X1,90                           MEAN TIME - 90 SEC.                                 5
*INPUT- MEAN OF EXPONENTIAL DISTRIBUTION OF CALL DURATIONS                                              6
        INITIAL     X2,180                          MEAN CALL DUR  180 SEC.                             7
*INPUT- CUMULATIVE DISTRIBUTION OF CALLS FROM EACH ZONE                                                 8
     2  FUNCTION    RN2,D7                          DIST. OF CALLS BY ZONE                              9
.17   7      .59   1      .64   2      .75   3      .86   4      .95   5                                 10
1.0   6                                                                                                 11
*                                                                                                       12
*INPUT- MEAN OF NORMAL DISTRIBUTION OF WAITING TIMES BEFORE RECALLING                                    13
        INITIAL     X3,900                          MEAN OF NORMAL DIST. 900 SEC                        14
*INPUT- STD. DEV. OF NORMAL DISTRIBUTION OF SAME WAITING TIMES                                          15
        INITIAL     X4,60                           STD. DEV. 60 SEC.                                   16
*                                                                                                       17
* INPUT- THE NUMBER OF LINES FROM EACH ZONE                                                             18
     1  STORAGE     1                               ZONE 1 LINES - 1                                    19
     2  STORAGE     1                               ZONE 2 LINES - 1                                    20
     3  STORAGE     1                               ZONE 3 LINES - 1                                    21
     4  STORAGE     1                               ZONE 4 LINES - 1                                    22
     5  STORAGE     1                               ZONE 5 LINES - 1                                    23
     6  STORAGE     1                               ZONE 6 LINES - 1                                    24
     7  STORAGE     1                               ZONE 7 LINES - 1                                    25
*                                                                                                       26
*INPUT- COST OF LD CALLS FROM ZONE 1 BY DURATION IN MINUTES                                             27
     1  MATRIX      X,7,15                          LD COST BY ZONE                                     28
        INITIAL     MX1(1,1),55                                                                         29
        INITIAL     MX1(1,2),55                                                                         30
        INITIAL     MX1(1,3),55                                                                         31
        INITIAL     MX1(1,4),70                                                                         32
        INITIAL     MX1(1,5),85                                                                         33
        INITIAL     MX1(1,6),100                                                                        34
        INITIAL     MX1(1,7),115                                                                        35
        INITIAL     MX1(1,8),130                                                                        36
        INITIAL     MX1(1,9),145                                                                        37
        INITIAL     MX1(1,10),160                                                                       38
        INITIAL     MX1(1,11),175                                                                       39
        INITIAL     MX1(1,12),190                                                                       40
        INITIAL     MX1(1,13),205                                                                       41
        INITIAL     MX1(1,14),220                                                                       42
        INITIAL     MX1(1,15),235                                                                       43
*                                                                                                       44
*INPUT- COST OF LD CALLS FROM ZONE 2 BY DURATION IN MINUTES                                             45
        INITIAL     MX1(2,1),110                                                                        46
        INITIAL     MX1(2,2),110                                                                        47
        INITIAL     MX1(2,3),110                                                                        48
        INITIAL     MX1(2,4),135                                                                        49
        INITIAL     MX1(2,5),160                                                                        50
        INITIAL     MX1(2,6),185                                                                        51
        INITIAL     MX1(2,7),210                                                                        52
        INITIAL     MX1(2,8),235                                                                        53
        INITIAL     MX1(2,9),260                                                                        54
        INITIAL     MX1(2,10),285                                                                       55
```

```
      INITIAL    MX1(2,11),310                                          56
      INITIAL    MX1(2,12),335                                          57
      INITIAL    MX1(2,13),360                                          58
      INITIAL    MX1(2,14),385                                          59
      INITIAL    MX1(2,15),410                                          60
*                                                                       61
*INPUT- COST OF LD CALLS FROM ZONE 3 BY DURATION IN MINUTES             62
      INITIAL    MX1(3,1),120                                           63
      INITIAL    MX1(3,2),120                                           64
      INITIAL    MX1(3,3),120                                           65
      INITIAL    MX1(3,4),150                                           66
      INITIAL    MX1(3,5),180                                           67
      INITIAL    MX1(3,6),210                                           68
      INITIAL    MX1(3,7),240                                           69
      INITIAL    MX1(3,8),270                                           70
      INITIAL    MX1(3,9),300                                           71
      INITIAL    MX1(3,10),330                                          72
      INITIAL    MX1(3,11),360                                          73
      INITIAL    MX1(3,12),390                                          74
      INITIAL    MX1(3,13),420                                          75
      INITIAL    MX1(3,14),450                                          76
      INITIAL    MX1(3,15),480                                          77
*                                                                       78
*INPUT- COST OF LD CALLS FROM ZONE 4 BY DURATION IN MINUTES             79
      INITIAL    MX1(4,1),130                                           80
      INITIAL    MX1(4,2),130                                           81
      INITIAL    MX1(4,3),130                                           82
      INITIAL    MX1(4,4),165                                           83
      INITIAL    MX1(4,5),200                                           84
      INITIAL    MX1(4,6),235                                           85
      INITIAL    MX1(4,7),270                                           86
      INITIAL    MX1(4,8),305                                           87
      INITIAL    MX1(4,9),340                                           88
      INITIAL    MX1(4,10),375                                          89
      INITIAL    MX1(4,11),410                                          90
      INITIAL    MX1(4,12),445                                          91
      INITIAL    MX1(4,13),480                                          92
      INITIAL    MX1(4,14),515                                          93
      INITIAL    MX1(4,15),550                                          94
*                                                                       95
*INPUT- COST OF LD CALLS FROM ZONE 5 BY DURATION IN MINUTES             96
      INITIAL    MX1(5,1),140                                           97
      INITIAL    MX1(5,2),140                                           98
      INITIAL    MX1(5,3),140                                           99
      INITIAL    MX1(5,4),175                                          100
      INITIAL    MX1(5,5),210                                          101
      INITIAL    MX1(5,6),245                                          102
      INITIAL    MX1(5,7),280                                          103
      INITIAL    MX1(5,8),315                                          104
      INITIAL    MX1(5,9),350                                          105
      INITIAL    MX1(5,10),385                                         106
      INITIAL    MX1(5,11),420                                         107
      INITIAL    MX1(5,12),455                                         108
      INITIAL    MX1(5,13),490                                         109
      INITIAL    MX1(5,14),525                                         110
      INITIAL    MX1(5,15),560                                         111
                                                                       112
```

```
*INPUT- COST OF LD CALLS FROM ZONE 6 BY DURATION IN MINUTES
       INITIAL    MX1(6,1),155
       INITIAL    MX1(6,2),155
       INITIAL    MX1(6,3),155
       INITIAL    MX1(6,4),195
       INITIAL    MX1(6,5),235
       INITIAL    MX1(6,6),275
       INITIAL    MX1(6,7),315
       INITIAL    MX1(6,8),355
       INITIAL    MX1(6,9),395
       INITIAL    MX1(6,10),435
       INITIAL    MX1(6,11),475
       INITIAL    MX1(6,12),515
       INITIAL    MX1(6,13),555
       INITIAL    MX1(6,14),595
       INITIAL    MX1(6,15),635
*
*INPUT- COST OF LD CALLS FROM ZONE 7 BY DURATION IN MINUTES
       INITIAL    MX1(7,1),65
       INITIAL    MX1(7,2),65
       INITIAL    MX1(7,3),65
       INITIAL    MX1(7,4),87
       INITIAL    MX1(7,5),109
       INITIAL    MX1(7,6),131
       INITIAL    MX1(7,7),153
       INITIAL    MX1(7,8),175
       INITIAL    MX1(7,9),197
       INITIAL    MX1(7,10),219
       INITIAL    MX1(7,11),241
       INITIAL    MX1(7,12),263
       INITIAL    MX1(7,13),285
       INITIAL    MX1(7,14),307
       INITIAL    MX1(7,15),329
*
*INPUT- COST OF FULL-TIME WATS SERVICE BY ZONE
     2 MATRIX     X,8,5                  OUTPUT MATRIX OF COSTS
       INITIAL    MX2(1,2),90000         1 FULLTIME WATS LINE ZONE 1
       INITIAL    MX2(2,2),110000        1 FULLTIME WATS LINE ZONE 2
       INITIAL    MX2(3,2),130000        1 FULLTIME WATS LINE ZONE 3
       INITIAL    MX2(4,2),150000        1 FULLTIME WATS LINE ZONE 4
       INITIAL    MX2(5,2),175000        1 FULLTIME WATS LINE ZONE 5
       INITIAL    MX2(6,2),185000        1 FULLTIME WATS LINE ZONE 6
       INITIAL    MX2(7,2),54500         1 FULLTIME WATS LINE ZONE 7
*
     3 MATRIX     X,10,5                 PARAMETER PRINTOUT
     1 FVARIABLE  ((P2/60)+99/100)       CONV. SEC. TO MIN.
*
*DESCRIBE THE STANDARDIZED NEGATIVE EXPONENTIAL DISTRIBUTION
     1 FUNCTION   RN1,C20                STAND. NEG. EXPON. FUN.
0     0      .1    .104  .2    .222  .3    .355  .4    .509  .5    .69
.6    .915   .7    1.2   .75   1.38  .8    1.6   .84   1.83  .88   2.12
.9    2.3    .92   2.52  .94   2.81  .95   2.99  .96   3.2   .97   3.5
.98   3.9    1.0   5
*
*DESCRIBE THE STANDARDIZED NORMAL DISTRIBUTION
     5 FUNCTION   RN2,C39                STAND. NORMAL DIST.
0     -6.   .00023-3.5  .00034-3.4  .00069-3.2  .00135-3.0  .0026 -2.8
```

```
                .0047 -2.6   .0082 -2.4   .0139 -2.2   .0228 -2.0   .0359 -1.8   .0548 -1.6                    170
                .0808 -1.4   .1151 -1.2   .1587 -1.0   .2119 -0.8   .2743 -0.6   .3446 -0.4                    171
                .4207 -0.2   .5000 0.0    .5793 0.2    .6554 0.4    .7257 0.6    .7881 0.8                     172
                .8413 1.0    .8849 1.2    .9192 1.4    .9452 1.6    .9641 1.8    .9773 2.0                     173
                .9861 2.2    .9918 2.4    .9953 2.6    .9974 2.8    .998653.0    .999313.2                     174
                .999663.4    .999773.5    1.0    6.0                                                          175
                     5 VARIABLE   FN5*X4/10000+X3                                                             176
                     3 FUNCTION   V5,C2                    REF. FUN. FOR NORMAL DIST.                         177
                0,0/99999,99999                                                                               178
                *                                                                                             179
                *INPUT- MEASURED WATS RATES IN FUN.11-17, CONV. SEC. TO MIN., RND. UP                          180
                    11 FVARIABLE  (MX2(1,1)/60+99/100)                                                        181
                    11 FUNCTION   V11,C2                                                                      182
                600,22000/6600,175000                     1 MEASURED WATS LINE - ZONE 1                       183
                    12 FVARIABLE  (MX2(2,1)/60+99/100)                                                        184
                    12 FUNCTION   V12,C2                                                                      185
                600,24000/6600,209000                     1 MEASURED WATS LINE - ZONE 2                       186
                    13 FVARIABLE  (MX2(3,1)/60+99/100)                                                        187
                    13 FUNCTION   V13,C2                                                                      188
                600,26000/6600,231000                     1 MEASURED WATS LINE - ZONE 3                       189
                    14 FVARIABLE  (MX2(4,1)/60+99/100)                                                        190
                    14 FUNCTION   V14,C2                                                                      191
                600,28000/6600,248000                     1 MEASURED WATS LINE - ZONE 4                       192
                    15 FVARIABLE  (MX2(5,1)/60+99/100)                                                        193
                    15 FUNCTION   V15,C2                                                                      194
                600,31000/6600,266000                     1 MEASURED WATS LINE - ZONE 5                       195
                    16 FVARIABLE  (MX2(6,1)/60+99/100)                                                        196
                    16 FUNCTION   V16,C2                                                                      197
                600,32500/6600,277500                     1 MEASURED WATS LINE - ZONE 6                       198
                    17 FVARIABLE  (MX2(7,1)/60+99/100)                                                        199
                    17 FUNCTION   V17,C2                                                                      200
                600,16500/6600,146500                     1 MEASURED WATS LINE - ZONE 7                       201
                *                                                                                             202
                *BEGIN THE ACTUAL SIMULATION OF CALLS COMING IN                                                203
1                      GENERATE   X1,FN1                  GENERATE CALLS AT INT. X1                           204
                *                                                                                             205
                *COUNT AND RECORD THE INCOMING CALLS                                                          206
2                      SAVEVALUE  10+,K1                  RECORD NO. OF THE CALL                              207
3                      ASSIGN     1,X10                   NO. OF CALL IN P1                                   208
                *                                                                                             209
                *ASSIGN TO THE CALL A RANDOM DURATION FROM FUNCTION 1                                          210
4                      ASSIGN     2,X2,1                  CALL DUR. SEC. IN P2                                211
                *                                                                                             212
                *CHECK TO ASSURE A MINIMUM DURATION OF 10 SECONDS TO THE CALL                                  213
5                      TEST L     P2,K10,MAX              MIN. CALL DUR.-10 SEC.                              214
6                      ASSIGN     2,K10                                                                       215
7                      TRANSFER   ,MIN                                                                        216
                *                                                                                             217
                *CHECK TO ASSURE A MAXIMUM DURATION OF 15 MINUTES TO THE CALL                                  218
8                  MAX TEST G     P2,K900,MIN             MAX. CALL DUR.-15 MIN.                              219
9                      ASSIGN     2,K900                                                                      220
                *                                                                                             221
                *RECALCULATE DURATION OF THE CALL IN MINUTES FOR LD BILLING                                    222
10                 MIN ASSIGN     3,V1                    DURATION OF CALL IN P3 MIN.                         223
                *                                                                                             224
                *ASSIGN TO THE CALL A ZONE FROM FUNCTION 2                                                     225
11                     ASSIGN     4,FN2                   ZONE OF CALL IN P4                                  226
```

```
                *                                                                                    227
                *COMPUTE THE LD COST OF THE CALL FROM COST TABLE 1                                   228
12              ASSIGN      5,MX1(P4,P3)            COST OF LD CALL IN P5                       229
                *                                                                                    230
                *ALLOW 10 CALLS TO BE PRINTED OUT TO CHECK THE PARAMETERS                            231
13              TEST LE     P1,K10,CALL             PRINT PARA. FOR  10 CALLS                   232
14              MSAVEVALUE 3,P1,1,P1                                                                233
15              MSAVEVALUE 3,P1,2,P2                                                                234
16              MSAVEVALUE 3,P1,3,P3                                                                235
17              MSAVEVALUE 3,P1,4,P4                                                                236
18              MSAVEVALUE 3,P1,5,P5                                                                237
                *                                                                                    238
                *ATTEMPT TO USE A PARTICULAR ZONE LINE                                               239
19            CALL GATE SNF   P4,BUSY                 TRY TO USE LINE                             240
                *                                                                                    241
                *USE THE AVAILABLE LINE                                                              242
20              ENTER       P4                      USE LINE FOR ZONE IN P4                     243
                *                                                                                    244
                *       SIMULATE THE DURATION OF THE CALL                                            245
21              ADVANCE     P2                      DUR. OF CALL                                    246
                *                                                                                    247
                *TERMINATE THE CALL                                                                  248
22              LEAVE       P4                      HANG UP                                         249
23              TRANSFER    ,BILL                   TERMINATE CALL                                  250
                *                                                                                    251
                *RECORD THE FACT THAT A PARTICULAR ZONE LINE WAS BUSY WHEN NEEDED                     252
24            BUSY MSAVEVALUE 2+,P4,5,K1            RECORD A BUSY LINE                          253
                *                                                                                    254
                *       SIMULATE WAITING WITH A TIME FROM FUNCTION 3                                 255
25              ADVANCE     1,FN3                   WAIT BEFORE CALLING AGAIN                       256
                *                                                                                    257
                *TRY TO PLACE THE CALL AGAIN                                                         258
26              TRANSFER    ,CALL                   CALL AGAIN                                      259
                *                                                                                    260
                *ACCUMULATE CALL DURATIONS BY ZONE FOR MEASURED WATS BILLING                         261
27            BILL MSAVEVALUE 2+,P4,1,P2            ACCUM TIME IN MX2 BY ZONE AND               262
                *                                                                                    263
                *ACCUMULATE LONG DISTANCE COSTS BY ZONE                                              264
28              MSAVEVALUE 2+,P4,4,P5               ACCUM LD COST IN MX2 BY ZONE                265
                *                                                                                    266
                *DESTROY THE TRANSACTION SIMULATING A CALL                                           267
29              TERMINATE   1                                                                       268
                *                                                                                    269
                *ALLOW A CERTAIN NUMBER OF CALLS TO BE SIMULATED COMPLETELY                          270
                START       8000                    SIMULATE 8000 CALLS                             271
                *                                                                                    272
                *BEGIN A SUMMARY PHASE OF THE SIMULATION                                             273
30              GENERATE    ,,,1                                                                    274
                *                                                                                    275
                *SUMMARIZE THE DURATIONS OF THE CALLS IN SECONDS                                     276
31              MSAVEVALUE 2+,8,1,MX2(1,1)          SUM CALL DURATIONS                          277
32              MSAVEVALUE 2+,8,1,MX2(2,1)                                                          278
33              MSAVEVALUE 2+,8,1,MX2(3,1)                                                          279
34              MSAVEVALUE 2+,8,1,MX2(4,1)                                                          280
35              MSAVEVALUE 2+,8,1,MX2(5,1)                                                          281
36              MSAVEVALUE 2+,8,1,MX2(6,1)                                                          282
37              MSAVEVALUE 2+,8,1,MX2(7,1)                                                          283
```

```
                *                                                                284
                *SUMMARIZE THE FULL-TIME WATS COSTS FOR ALL ZONES                 285
38              MSAVEVALUE 2+,8,2,MX2(1,2)          SUM F T WATS COSTS           286
39              MSAVEVALUE 2+,8,2,MX2(2,2)                                       287
40              MSAVEVALUE 2+,8,2,MX2(3,2)                                       288
41              MSAVEVALUE 2+,8,2,MX2(4,2)                                       289
42              MSAVEVALUE 2+,8,2,MX2(5,2)                                       290
43              MSAVEVALUE 2+,8,2,MX2(6,2)                                       291
44              MSAVEVALUE 2+,8,2,MX2(7,2)                                       292
                *                                                                293
                *COMPUTE AND SUMMARIZE THE MEASURED WATS COSTS BY ZONE            294
45              MSAVEVALUE 2,1,3,FN11               COMPUTE MEASURED WATS COST   295
46              MSAVEVALUE 2+,8,3,MX2(1,3)                                       296
47              MSAVEVALUE 2,2,3,FN12                                            297
48              MSAVEVALUE 2+,8,3,MX2(2,3)                                       298
49              MSAVEVALUE 2,3,3,FN13                                            299
50              MSAVEVALUE 2+,8,3,MX2(3,3)                                       300
51              MSAVEVALUE 2,4,3,FN14                                            301
52              MSAVEVALUE 2+,8,3,MX2(4,3)                                       302
53              MSAVEVALUE 2,5,3,FN15                                            303
54              MSAVEVALUE 2+,8,3,MX2(5,3)                                       304
55              MSAVEVALUE 2,6,3,FN16                                            305
56              MSAVEVALUE 2+,8,3,MX2(6,3)                                       306
57              MSAVEVALUE 2,7,3,FN17                                            307
58              MSAVEVALUE 2+,8,3,MX2(7,3)                                       308
                *                                                                309
                *SUMMARIZE THE LONG DISTANCE COSTS FOR ALL ZONES                  310
59              MSAVEVALUE 2+,8,4,MX2(1,4)          SUM LD CALL COSTS            311
60              MSAVEVALUE 2+,8,4,MX2(2,4)                                       312
61              MSAVEVALUE 2+,8,4,MX2(3,4)                                       313
62              MSAVEVALUE 2+,8,4,MX2(4,4)                                       314
63              MSAVEVALUE 2+,8,4,MX2(5,4)                                       315
64              MSAVEVALUE 2+,8,4,MX2(6,4)                                       316
65              MSAVEVALUE 2+,8,4,MX2(7,4)                                       317
66              TERMINATE  1                                                     318
                START      1                                                     319
                *                                                                320
                REPORT                                                           321
                EJECT      START A NEW PAGE                                      322
 MSAV           TITLE      1,LONG DISTANCE COSTS BY ZONE AND BY MINUTES          323
                EJECT      START A NEW PAGE                                      324
 MSAV           TITLE      2,ZONE, TOTAL SECONDS, FULLTIME WATS COST, MEASURED WA
ATS COST, LONG DISTANCE COST AND NUMBER OF TIMES BUSY                            326
                EJECT      START A NEW PAGE                                      327
 MSAV           TITLE      3,CALL NUMBER, SECONDS, MINUTES, ZONE AND LONG DISTANC
CE COST FOR EACH OF THE FIRST TEN CALLS                                          329
                END                                                              330
```

BLOCK NUMBER	SYMBOL	REFERENCES BY CARD NUMBER	
27	BILL	250	
24	BUSY	240	
19	CALL	232	259
8	MAX	214	
10	MIN	216	219

```
*
      RMULT     37,31
*INPUT- MEAN OF EXPONENTIAL DISTRIBUTION OF CALL INTERARRIVAL TIMES
      INITIAL   X1,90
*INPUT- MEAN OF EXPONENTIAL DISTRIBUTION OF CALL DURATIONS
      INITIAL   X2,180
*INPUT- CUMULATIVE DISTRIBUTION OF CALLS FROM EACH ZONE
 2    FUNCTION  RN2   D7
.17   7     .59   1     .64   2     .75   3     .86   4     .95   5
1.0   6
*
*INPUT- MEAN OF NORMAL DISTRIBUTION OF WAITING TIMES BEFORE RECALLING
      INITIAL   X3,900
*INPUT- STD. DEV. OF NORMAL DISTRIBUTION OF SAME WAITING TIMES
      INITIAL   X4,60
*
* INPUT- THE NUMBER OF LINES FROM EACH ZONE
 1    STORAGE   1
 2    STORAGE   1
 3    STORAGE   1
 4    STORAGE   1
 5    STORAGE   1
 6    STORAGE   1
 7    STORAGE   1
*
*INPUT- COST OF LD CALLS FROM ZONE 1 BY DURATION IN MINUTES
 1    MATRIX    X     7     15
      INITIAL   MX1(1,1),55
      INITIAL   MX1(1,2),55
      INITIAL   MX1(1,3),55
      INITIAL   MX1(1,4),70
      INITIAL   MX1(1,5),85
      INITIAL   MX1(1,6),100
      INITIAL   MX1(1,7),115
      INITIAL   MX1(1,8),130
      INITIAL   MX1(1,9),145
      INITIAL   MX1(1,10),160
      INITIAL   MX1(1,11),175
      INITIAL   MX1(1,12),190
      INITIAL   MX1(1,13),205
      INITIAL   MX1(1,14),220
      INITIAL   MX1(1,15),235
*
*INPUT- COST OF LD CALLS FROM ZONE 2 BY DURATION IN MINUTES
      INITIAL   MX1(2,1),110
      INITIAL   MX1(2,2),110
      INITIAL   MX1(2,3),110
      INITIAL   MX1(2,4),135
      INITIAL   MX1(2,5),160
      INITIAL   MX1(2,6),185
      INITIAL   MX1(2,7),210
      INITIAL   MX1(2,8),235
      INITIAL   MX1(2,9),260
      INITIAL   MX1(2,10),285
      INITIAL   MX1(2,11),310
      INITIAL   MX1(2,12),335
      INITIAL   MX1(2,13),360
      INITIAL   MX1(2,14),385
      INITIAL   MX1(2,15),410
*
*INPUT- COST OF LD CALLS FROM ZONE 3 BY DURATION IN MINUTES
      INITIAL   MX1(3,1),120
      INITIAL   MX1(3,2),120
```

```
       INITIAL     MX1(3,3),120
       INITIAL     MX1(3,4),150
       INITIAL     MX1(3,5),180
       INITIAL     MX1(3,6),210
       INITIAL     MX1(3,7),240
       INITIAL     MX1(3,8),270
       INITIAL     MX1(3,9),300
       INITIAL     MX1(3,10),330
       INITIAL     MX1(3,11),360
       INITIAL     MX1(3,12),390
       INITIAL     MX1(3,13),420
       INITIAL     MX1(3,14),450
       INITIAL     MX1(3,15),480
*
*INPUT- COST OF LD CALLS FROM ZONE 4 BY DURATION IN MINUTES
       INITIAL     MX1(4,1),130
       INITIAL     MX1(4,2),130
       INITIAL     MX1(4,3),130
       INITIAL     MX1(4,4),165
       INITIAL     MX1(4,5),200
       INITIAL     MX1(4,6),235
       INITIAL     MX1(4,7),270
       INITIAL     MX1(4,8),305
       INITIAL     MX1(4,9),340
       INITIAL     MX1(4,10),375
       INITIAL     MX1(4,11),410
       INITIAL     MX1(4,12),445
       INITIAL     MX1(4,13),480
       INITIAL     MX1(4,14),515
       INITIAL     MX1(4,15),550
*
*INPUT- COST OF LD CALLS FROM ZONE 5 BY DURATION IN MINUTES
       INITIAL     MX1(5,1),140
       INITIAL     MX1(5,2),140
       INITIAL     MX1(5,3),140
       INITIAL     MX1(5,4),175
       INITIAL     MX1(5,5),210
       INITIAL     MX1(5,6),245
       INITIAL     MX1(5,7),280
       INITIAL     MX1(5,8),315
       INITIAL     MX1(5,9),350
       INITIAL     MX1(5,10),385
       INITIAL     MX1(5,11),420
       INITIAL     MX1(5,12),455
       INITIAL     MX1(5,13),490
       INITIAL     MX1(5,14),525
       INITIAL     MX1(5,15),560
*
*INPUT- COST OF LD CALLS FROM ZONE 6 BY DURATION IN MINUTES
       INITIAL     MX1(6,1),155
       INITIAL     MX1(6,2),155
       INITIAL     MX1(6,3),155
       INITIAL     MX1(6,4),195
       INITIAL     MX1(6,5),235
       INITIAL     MX1(6,6),275
       INITIAL     MX1(6,7),315
       INITIAL     MX1(6,8),355
       INITIAL     MX1(6,9),395
       INITIAL     MX1(6,10),435
       INITIAL     MX1(6,11),475
       INITIAL     MX1(6,12),515
       INITIAL     MX1(6,13),555
       INITIAL     MX1(6,14),595
       INITIAL     MX1(6,15),635
*
*INPUT- COST OF LD CALLS FROM ZONE 7 BY DURATION IN MINUTES
```

```
        INITIAL     MX1(7,1),65
        INITIAL     MX1(7,2),65
        INITIAL     MX1(7,3),65
        INITIAL     MX1(7,4),87
        INITIAL     MX1(7,5),109
        INITIAL     MX1(7,6),131
        INITIAL     MX1(7,7),153
        INITIAL     MX1(7,8),175
        INITIAL     MX1(7,9),197
        INITIAL     MX1(7,10),219
        INITIAL     MX1(7,11),241
        INITIAL     MX1(7,12),263
        INITIAL     MX1(7,13),285
        INITIAL     MX1(7,14),307
        INITIAL     MX1(7,15),329
*
*INPUT- COST OF FULL-TIME WATS SERVICE BY ZONE
 2      MATRIX      X     8     5
        INITIAL     MX2(1,2),90000
        INITIAL     MX2(2,2),110000
        INITIAL     MX2(3,2),130000
        INITIAL     MX2(4,2),150000
        INITIAL     MX2(5,2),175000
        INITIAL     MX2(6,2),185000
        INITIAL     MX2(7,2),54500
*
 3      MATRIX      X     10    5
 1      FVARIABLE   ((P2/60)+99/100)
*
*DESCRIBE THE STANDARDIZED NEGATIVE EXPONENTIAL DISTRIBUTION
 1      FUNCTION    RN1   C20
0     0      .1     .104  .2    .222  .3    .355  .4    .509  .5    .69
.6    .915   .7     1.2   .75   1.38  .8    1.6   .84   1.83  .88   2.12
.9    2.3    .92    2.52  .94   2.81  .95   2.99  .96   3.2   .97   3.5
.98   3.9    1.0    5
*
*DESCRIBE THE STANDARDIZED NORMAL DISTRIBUTION
 5      FUNCTION    RN2   C39
0     -6.    .00023-3.5  .00034-3.4  .00069-3.2  .00135-3.0  .0026 -2.8
.0047 -2.6   .0082 -2.4  .0139 -2.2  .0228 -2.0  .0359 -1.8  .0548 -1.6
.0808 -1.4   .1151 -1.2  .1587 -1.0  .2119 -0.8  .2743 -0.6  .3446 -0.4
.4207 -0.2   .5000 0.0   .5793 0.2   .6554 0.4   .7257 0.6   .7881 0.8
.8413 1.0    .8849 1.2   .9192 1.4   .9452 1.6   .9641 1.8   .9773 2.0
.9861 2.2    .9918 2.4   .9953 2.6   .9974 2.8   .998653.0   .999313.2
.999663.4    .999773.5   1.0   6.0
 5      VARIABLE    FN5*X4/10000+X3
 3      FUNCTION    V5    C2
0         0          99999      99999
*
*INPUT- MEASURED WATS RATES IN FUN.11-17, CONV. SEC. TO MIN., RND. UP
 11     FVARIABLE   (MX2(1,1)/60+99/100)
 11     FUNCTION    V11   C2
600       22000       6600       175000
 12     FVARIABLE   (MX2(2,1)/60+99/100)
 12     FUNCTION    V12   C2
600       24000       6600       209000
 13     FVARIABLE   (MX2(3,1)/60+99/100)
 13     FUNCTION    V13   C2
600       26000       6600       231000
 14     FVARIABLE   (MX2(4,1)/60+99/100)
 14     FUNCTION    V14   C2
600       28000       6600       248000
 15     FVARIABLE   (MX2(5,1)/60+99/100)
 15     FUNCTION    V15   C2
600       31000       6600       266000
 16     FVARIABLE   (MX2(6,1)/60+99/100)
```

```
 16     FUNCTION   V16   C2
600        32500      6600       277500
 17     FVARIABLE  (MX2(7,1)/60+99/100)
 17     FUNCTION   V17   C2
600        16500      6600       146500
*
*BEGIN THE ACTUAL SIMULATION OF CALLS COMING IN
 1      GENERATE   X1      FN1
*
*COUNT AND RECORD THE INCOMING CALLS
 2      SAVEVALUE  10+     K1
 3      ASSIGN     1       X10
*
*ASSIGN TO THE CALL A RANDOM DURATION FROM FUNCTION 1
 4      ASSIGN     2       X2      1
*
*CHECK TO ASSURE A MINIMUM DURATION OF 10 SECONDS TO THE CALL
 5      TEST L     P2      K10     8
 6      ASSIGN     2       K10
 7      TRANSFER           10
*
*CHECK TO ASSURE A MAXIMUM DURATION OF 15 MINUTES TO THE CALL
 8      TEST G     P2      K900    10
 9      ASSIGN     2       K900
*
*RECALCULATE DURATION OF THE CALL IN MINUTES FOR LD BILLING
 10     ASSIGN     3       V1
*
*ASSIGN TO THE CALL A ZONE FROM FUNCTION 2
 11     ASSIGN     4       FN2
*
*COMPUTE THE LD COST OF THE CALL FROM COST TABLE 1
 12     ASSIGN     5,MX1(P4,P3)
*
*ALLOW 10 CALLS TO BE PRINTED OUT TO CHECK THE PARAMETERS
 13     TEST LE    P1      K10     19
 14     MSAVEVALUE 3       P1      1       P1
 15     MSAVEVALUE 3       P1      2       P2
 16     MSAVEVALUE 3       P1      3       P3
 17     MSAVEVALUE 3       P1      4       P4
 18     MSAVEVALUE 3       P1      5       P5
*
*ATTEMPT TO USE A PARTICULAR ZONE LINE
 19     GATE SNF   P4      24
*
*USE THE AVAILABLE LINE
 20     ENTER      P4
*
*       SIMULATE THE DURATION OF THE CALL
 21     ADVANCE    P2
*
*TERMINATE THE CALL
 22     LEAVE      P4
 23     TRANSFER           27
*
*RECORD THE FACT THAT A PARTICULAR ZONE LINE WAS BUSY WHEN NEEDED
 24     MSAVEVALUE 2+      P4      5       K1
*
*       SIMULATE WAITING WITH A TIME FROM FUNCTION 3
 25     ADVANCE    1       FN3
*
*TRY TO PLACE THE CALL AGAIN
 26     TRANSFER           19
*
*ACCUMULATE CALL DURATIONS BY ZONE FOR MEASURED WATS BILLING
 27     MSAVEVALUE 2+      P4      1       P2
```

LONG DISTANCE COSTS BY ZONE AND BY MINUTES

MATRIX FULLWORD SAVEVALUE 1

	COLUMN	1	2	3	4	5	6	7	8	9
ROW	1	55	55	55	70	85	100	115	130	145
	2	110	110	110	135	160	185	210	235	260
	3	120	120	120	150	180	210	240	270	300
	4	130	130	130	165	200	235	270	305	340
	5	140	140	140	175	210	245	280	315	350
	6	155	155	155	195	235	275	315	355	395
	7	65	65	65	87	109	131	153	175	197

	COLUMN	10	11	12	13	14	15
ROW	1	160	175	190	205	220	235
	2	285	310	335	360	385	410
	3	330	360	390	420	450	480
	4	375	410	445	480	515	550
	5	385	420	455	490	525	560
	6	435	475	515	555	595	635
	7	219	241	263	285	307	329

ZONE, TOTAL SECONDS, FULLTIME WATS COST, MEASURED WATS COST, LONG DISTANCE COST AND NUMBER OF TIMES BUSY

MATRIX FULLWORD SAVEVALUE 2

	COLUMN 1	2	3	4	5
ROW. 1	588656	90000	0	245825	32451
2	55714	110000	0	47610	25
3	170626	130000	0	148320	330
4	153782	150000	0	150920	280
5	127367	175000	0	131495	144
6	74277	185000	0	87075	68
7	245465	54500	0	128096	865
8	0	0	0	0	0

CALL NUMBER, SECONDS, MINUTES, ZONE AND LONG DISTANCE COST FOR EACH OF THE FIRST TEN CALLS

MATRIX FULLWORD SAVEVALUE 3

	COLUMN	1	2	3	4	5
ROW	1	1	160	3	7	65
	2	2	38	1	4	130
	3	3	96	2	7	65
	4	4	404	7	7	153
	5	5	59	1	1	55
	6	6	153	3	3	120
	7	7	209	4	1	70
	8	8	158	3	7	65
	9	9	245	5	3	180
	10	10	26	1	3	120

```
*
*BEGIN A SUMMARY PHASE OF THE SIMULATION
 30     GENERATE                    1
*
*SUMMARIZE THE DURATIONS OF THE CALLS IN SECONDS
 31     MSAVEVALUE 2+,8,1,MX2(1,1)
 32     MSAVEVALUE 2+,8,1,MX2(2,1)
 33     MSAVEVALUE 2+,8,1,MX2(3,1)
 34     MSAVEVALUE 2+,8,1,MX2(4,1)
 35     MSAVEVALUE 2+,8,1,MX2(5,1)
 36     MSAVEVALUE 2+,8,1,MX2(6,1)
 37     MSAVEVALUE 2+,8,1,MX2(7,1)
*
*SUMMARIZE THE FULL-TIME WATS COSTS FOR ALL ZONES
 38     MSAVEVALUE 2+,8,2,MX2(1,2)
 39     MSAVEVALUE 2+,8,2,MX2(2,2)
 40     MSAVEVALUE 2+,8,2,MX2(3,2)
 41     MSAVEVALUE 2+,8,2,MX2(4,2)
 42     MSAVEVALUE 2+,8,2,MX2(5,2)
 43     MSAVEVALUE 2+,8,2,MX2(6,2)
 44     MSAVEVALUE 2+,8,2,MX2(7,2)
*
*COMPUTE AND SUMMARIZE THE MEASURED WATS COSTS BY ZONE
 45     MSAVEVALUE 2     1     3     FN11
 46     MSAVEVALUE 2+,8,3,MX2(1,3)
 47     MSAVEVALUE 2     2     3     FN12
 48     MSAVEVALUE 2+,8,3,MX2(2,3)
 49     MSAVEVALUE 2     3     3     FN13
 50     MSAVEVALUE 2+,8,3,MX2(3,3)
 51     MSAVEVALUE 2     4     3     FN14
 52     MSAVEVALUE 2+,8,3,MX2(4,3)
 53     MSAVEVALUE 2     5     3     FN15
 54     MSAVEVALUE 2+,8,3,MX2(5,3)
 55     MSAVEVALUE 2     6     3     FN16
 56     MSAVEVALUE 2+,8,3,MX2(6,3)
 57     MSAVEVALUE 2     7     3     FN17
 58     MSAVEVALUE 2+,8,3,MX2(7,3)
*
*SUMMARIZE THE LONG DISTANCE COSTS FOR ALL ZONES
 59     MSAVEVALUE 2+,8,4,MX2(1,4)
 60     MSAVEVALUE 2+,8,4,MX2(2,4)
 61     MSAVEVALUE 2+,8,4,MX2(3,4)
 62     MSAVEVALUE 2+,8,4,MX2(4,4)
 63     MSAVEVALUE 2+,8,4,MX2(5,4)
 64     MSAVEVALUE 2+,8,4,MX2(6,4)
 65     MSAVEVALUE 2+,8,4,MX2(7,4)
```

```
66    TERMINATE  1
      START      1
```

LONG DISTANCE COSTS BY ZONE AND BY MINUTES

MATRIX FULLWORD SAVEVALUE I

	COLUMN	1	2	3	4	5	6	7	8	9
ROW	1	55	55	55	70	85	100	115	130	145
	2	110	110	110	135	160	185	210	235	260
	3	120	120	120	150	180	210	240	270	300
	4	130	130	130	165	200	235	270	305	340
	5	140	140	140	175	210	245	280	315	350
	6	155	155	155	195	235	275	315	355	395
	7	65	65	65	87	109	131	153	175	197

	COLUMN	10	11	12	13	14	15
ROW	1	160	175	190	205	220	235
	2	285	310	335	360	385	410
	3	330	360	390	420	450	480
	4	375	410	445	480	515	550
	5	385	420	455	490	525	560
	6	435	475	515	555	595	635
	7	219	241	263	285	307	329

ZONE, TOTAL SECONDS, FULLTIME WATS COST, MEASURED WATS COST, LONG DISTANCE COST AND NUMBER OF TIMES BUSY

MATRIX FULLWORD SAVEVALUE 2

	COLUMN 1	2	3	4	5
ROW 1	588656	90000	175000	245825	32451
2	55714	110000	34144	47610	25
3	170626	130000	102670	148320	330
4	153782	150000	100013	150920	280
5	127367	175000	90650	131495	144
6	74277	185000	58551	87075	68
7	245465	54500	92160	128096	865
8	1415887	894500	653188	939341	0

CALL NUMBER, SECONDS, MINUTES, ZONE AND LONG DISTANCE COST FOR EACH OF THE FIRST TEN CALLS

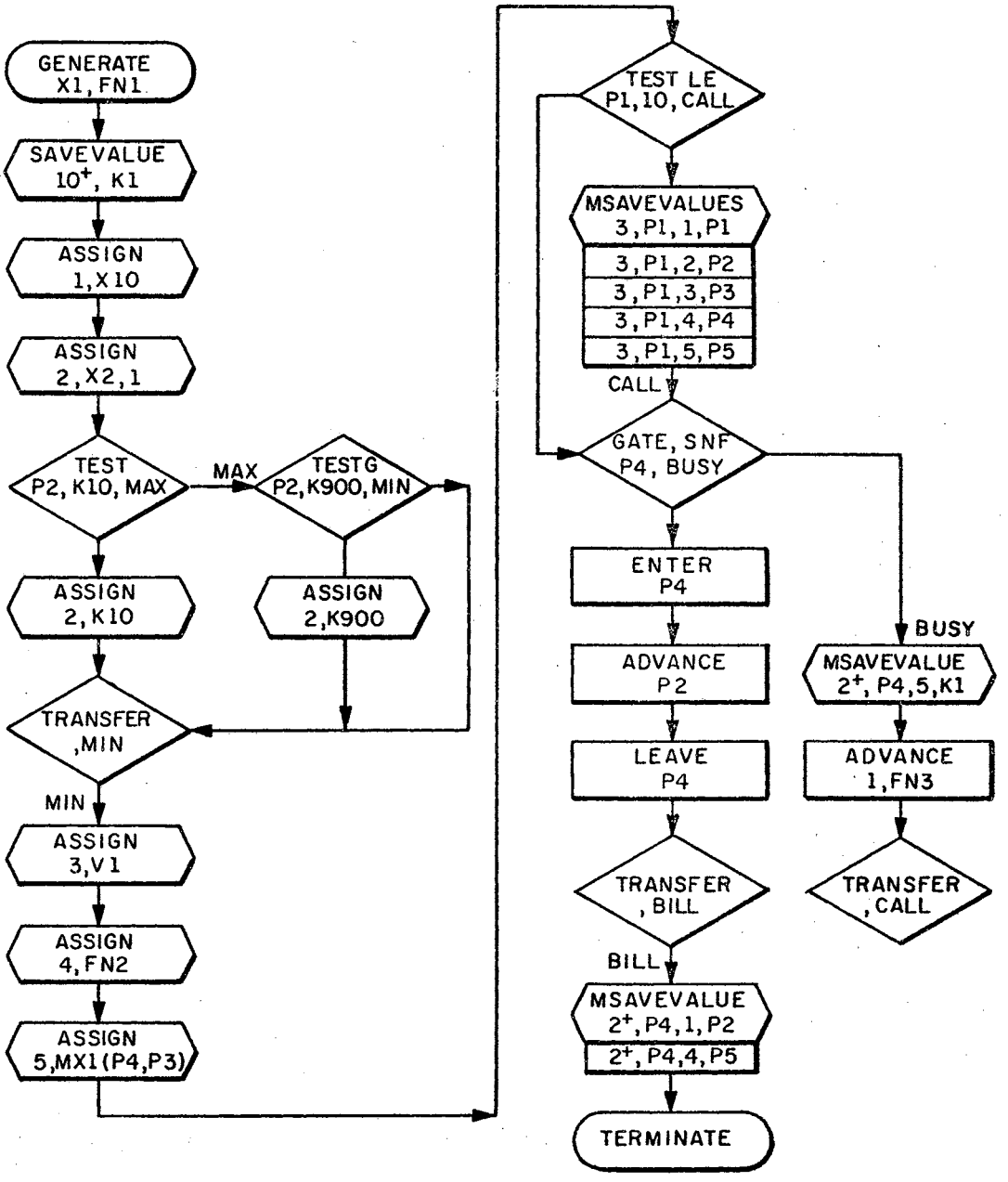
MATRIX FULLWORD SAVEVALUE 3

	COLUMN	1	2	3	4	5
ROW	1	1	160	3	7	65
	2	2	38	1	4	130
	3	3	96	2	7	65
	4	4	404	7	7	153
	5	5	59	1	1	55
	6	6	153	3	3	120
	7	7	209	4	1	70
	8	8	158	3	7	65
	9	9	245	5	3	180
	10	10	26	1	3	120

END

APPENDIX D

FLOW CHART OF THE MAIN PROGRAM


GENERATE
X1, FN1
SAVEVALUE
10+, K1
ASSIGN
1,X10
ASSIGN
2,X2,1
TEST
P2, K10, MAX
MAX
TESTG
P2,K900,MIN
ASSIGN
2,K10
ASSIGN
2,K900
TRANSFER
,MIN
MIN
ASSIGN
3,V1
ASSIGN
4,FN2
ASSIGN
5,MX1(P4,P3)
TEST LE
P1,10,CALL
MSAVEVALUES
3,P1,1,P1
3,P1,2,P2
3,P1,3,P3
3,P1,4,P4
3,P1,5,P5
CALL
GATE, SNF
P4, BUSY
BUSY
ENTER
P4
ADVANCE
P2
LEAVE
P4
TRANSFER
,BILL
BILL
MSAVEVALUE
2+,P4,1,P2
2+,P4,4,P5
TERMINATE
MSAVEVALUE
2+,P4,5,K1
ADVANCE
1,FN3
TRANSFER
,CALL

VITA

2

Thomas Bruce Auer

Candidate for the Degree of

Doctor of Philosophy

Thesis: AN ANALYSIS OF LONG DISTANCE TELEPHONE FACILITIES BY SIMULATION

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Professional Experience: Entered the United States Air Force in 1953 as an Aviation Cadet; served nine years as a navigator and staff officer until requesting a release from active duty in 1962 with the permanent rank of Captain; joined the faculty of the General Motors Institute of Flint, Michigan in 1962 and taught as an Assistant and Associate Professor of Industrial Engineering until returning to full-time graduate school in 1968. Registered Professional Engineer in Oklahoma since 1964.

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