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A simulation study of a proposed computer installation

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A SIMULATION STUDY
OF A PROPOSED COMPUTER INSTALLATION

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ABSTRACT

The operation of a data processing center has been studied with the objective of investigating the effect of various facilities, job loads, and operating policies as measured by job turnaround time. The mechanism for study was digital computer simulation.

This thesis purports to review the technology of simulation and the associated computer techniques, defines the problem and the alternatives available, and analyzes the results derived from the experiments.

Conclusions drawn from this study support the current practice of a functioning data processing center.

ACKNOWLEDGEMENT

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I. INTRODUCTION

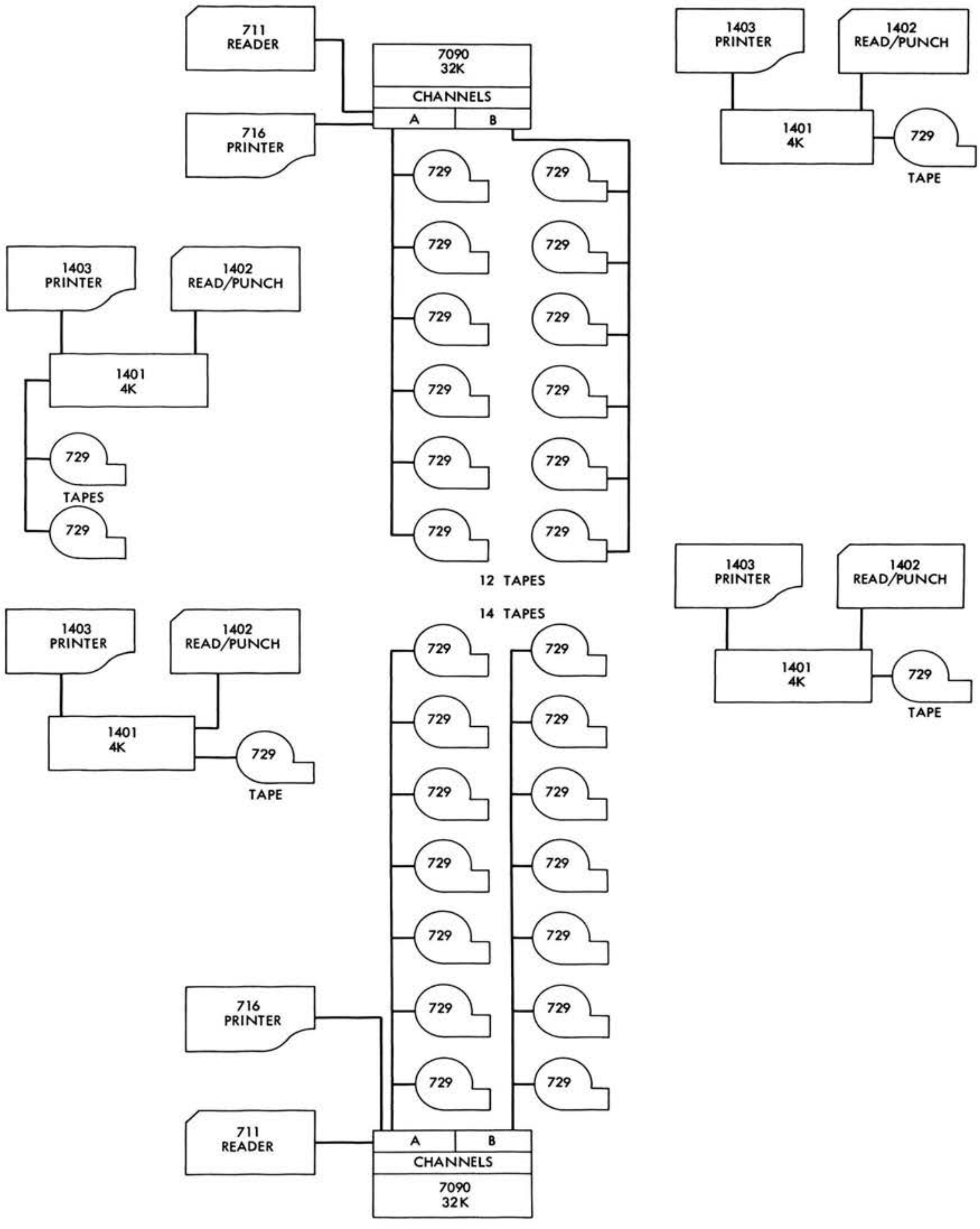
The purpose of this study is to build a computer simulation model of the proposed system and to experiment with the model in order to find an efficient level of operation and also to determine the effects of an increased workload.

The measure of performance is job turnaround time, i.e., the time elapsed between job entry and job departure from the system. The system is considered to be more efficient if "many" jobs have shorter turnaround time at the expense of longer turnaround time for the "few."

Proposed: A computer installation (see Figure 1) consisting of two IBM 7090 computers operating in parallel and four IBM 1401 computers performing the input/output functions. Since all the equipment used in this study was manufactured by International Business Machines Corporation, for brevity, machines will be referred to by number only, e.g., 7090, 1401. The operating policy is first-in-first-out (FIFO). Jobs are aggregated, or "batched," into "monitors" with about ten jobs in each monitor.

Five system configurations are to be scrutinized:

1. The "base case." The results of a simulation of the above system.
2. Policy change I. Jobs are segregated according to their characteristics, e.g., compute time.
3. Increased workload.
4. Additional input/output hardware.
5. Policy change II. Jobs are further segregated by their origins.



SCHEMATIC DIAGRAM OF PROPOSED SYSTEM

Figure 1

Simulation is the technique of abstracting a system by a model, manipulating the model with data inputs while structurally replicating the present system or modifying it, observing system behavior as expressed by changes in variables, and drawing inferences or hypotheses about the system and the effectiveness of alterations thereto. Models can be as concrete or as abstract as the particular situation necessitates. The following are types of models that have been used and are being used successfully.

1. The real system itself can be used as the 'model' to gain knowledge about itself. This procedure is the simplest and most obvious, but is usually impractical. For example, a large scale computer installation would not consider halting all operations in order to experiment with a series of new computers.
2. Physical analogs or scale models are but one step removed from the real world. Scale modeling is often the transition phase between design and construction. Chemical plants are often built to scale and tested before full scale construction is begun. The major disadvantages of scale modeling are: a) the expense involved is second only to full scale production, b) experimentation is limited by the physical structure.
3. Surrogates have been used most notably in the field of medical science. Artificial kidneys, rats, and fruitflys are examples. A surrogate is a model, with no necessary physical resemblance to the object system, selected because it has certain attributes similar to corresponding attributes of the object system.

4. The mathematical approach to modeling is the most abstract. A mathematical model is a complete analytical representation of the object system. While this sounds like an ideal approach, it may be neither practical nor desirable to strive for a complete mathematical representation. Such a thorough mathematical description could easily exceed the capacities of the professional staff and of the computing equipment, or it could require an inordinate amount of time for accomplishment.
5. A computer simulation model is a set of algorithms representing the system activities based on the simulator's concept of what the key elements of the system are, of how they act, and of how they interact.

In general, models lack dynamism. Evaluation of the model parameters at times T_i will yield a time series of parameter values reflecting system status over time $[S(T_1), S(T_2), \ldots, S(T_n)]$. This evaluation procedure over a time series is called dynamic simulation.

In the past, the huge quantity of repetitive computation associated with some simulation problems has ruled these problems infeasible. As the cost and time per computer computation has sharply decreased, the volume of technologically feasible problems has sharply increased. With high-speed computing came the ability to time dimension models.

Simulation models may be stochastic or deterministic. A stochastic model has elements of probability, risk, or uncertainty within it. The system contains probability distributions and random events or choices. A deterministic model represents the system with a definite set of mathematical and/or logical expressions.

The steps taken to simulate a system are straightforward. First, define the object (real world) system and decide which properties are of interest. In particular establish some measure of system performance (effectiveness). Also determine those properties which could conceivably affect the areas of interest. Then specify the inter-relationships between these properties. Next choose a modeling tool and construct a model.

Since this paper deals with computer simulation, the tools of the trade will be programming languages. Several terms that are frequently encountered in connection with computer simulation techniques will now be defined.

Entity - an entity is any type of unit independently identified, e.g. a machine in a machine shop, a job in a computer center.

Attributes - the properties associated with entities which reflect their status at any given point in time.

Activity - the alteration of one or more of the attributes of an entity.

Model - a chosen set of entities, attributes, and activities whose interactions are described by a set of logical inter-relationships which represent the characteristics of an object system.

When such a model has been designed, correspondence between reality and the identified entities and relationships of the model must be established. It is at this point that data pertinent to model variables are assembled and probability distributions, if any, are determined. A random number source is used to produce 'typical' sequences subject to these probability distributions. Once a correspondence is established, the model can be manipulated, e.g., a sensitivity analysis, new system policies. The results of the model manipulation are then related to the measure of effectiveness. Obviously the value of this entire procedure depends upon the interpretation of the results.

Simulation techniques are not always the best techniques available for system study. They often consume excessive amounts of both man and machine time. Extensive data collection is often required. Insufficient transformation from the object system to the model is often a major source of error. The detection and understanding of subtle inter-relationships within the system can be quite difficult.

If used with care and under the proper conditions, the advantageous features of simulation can overshadow these objectionable points. The ability to expand or compress time and to replicate a system in various environments often results in a useful and economical form of experimentation.

Before proceeding, it should be clearly understood that simulation is merely a form of experimentation - not an optimization technique.

II. REVIEW OF THE LITERATURE

Literature concerned with computer simulation is prevalent in programming, operations research, technical, and management oriented magazines. Both general discussions and explicit case studies are available. The following are short synopses of several case studies.

A truck dispatching simulation was developed by N. H. Van Wie [17]. This study deals with the inter-plant transportation of supplies and equipment in a large plant complex. One or more dispatching groups operated within each plant conventionally servicing a job request by sending a truck to the job source, loading materials, and transporting these materials directly to their destination. The purpose of the study was to find alternate servicing procedures which would reduce the customer wait time.

Using wait time as the measure of effectiveness, a model was designed to include not only the conventional (or dispatch) mode of delivery for both priority and non-priority jobs; but also, route servicing procedures. Route services of two types were included: 1) unrestricted, trucks service many stops, and 2) restricted, trucks service a limited number of stops.

A flow-chart, or schematic diagram, representing the object system was developed and this information was converted into FORTRAN IV code.

Actual data was available from which 14 unique probability distribution functions (e.g., job interarrival times, truck breakdowns) and various program parameters (e.g., percent of priority jobs) were derived.

An initial run was made with dispatch service only and the results corresponded with actual experience. Later runs provided for pure route service and mixed route and dispatch service. By mixing service modes, the wait time was reduced from a 78 minute average wait (with pure dispatch) to a 34 minute wait.

When mixed service was introduced in the object system, the observed average wait time was 32 minutes. Furthermore, ten trucks were originally required, but under the new policy only seven trucks were necessary to handle the same work load with the same improved efficiency.

Calhoun and Green [2] studied open hearth furnace repairs. Periodically, open hearth furnace linings must be replaced. The purpose of this study was to schedule maintenance work on furnaces in order to avoid "bunching" of furnaces waiting for repairs, thereby increasing furnace availability. All cost considerations were deleted in the article for the purpose of simplification.

Three factors are cited as criteria for choosing the measure of effectiveness: 1) validity i.e., does it in reality reflect a true measure of effectiveness of operation, 2) sensitivity i.e., is this measurement reasonably stable when subjected to change, 3) understanding i.e., is there a common understanding between research and operating personnel.

Furnace availability was chosen as the measure of effectiveness.

Only two variables were discussed in the paper: 1) furnace life, and 2) furnace rebuild time. Scattergram inspections were sufficient to rule both variables independent. Probability distributions were established and Monte Carlo techniques were applied. A series of five pairs of two-digit random numbers was generated for each furnace. Each pair was used to attain, through the use of the distribution curves, a value for furnace life and a value for rebuild time. These sequences describe an "experience." Large samples of these "experiences" were gathered. The results were verified by comparison with past experience.

Next, the effect of reducing rebuild time by two days was tested by the same procedure. As would be expected, the furnace availability was increased but since, for simplification in the paper, the cost considerations were deleted, the overall effect of the alternate procedure was not revealed. Although the conclusions of this particular experiment are withheld, Monte Carlo techniques are demonstrated as valuable simulation tools.

Philip Morse [12] presented a simulation of demographic dynamics. Every ten years the U.S. Census gives an instantaneous snapshot of the economic status of the nation. The purpose of this study is to forecast economic behavior between census years.

A 'typical' group of 2,000 people was chosen appropriately distributed in age, marital, and economic status to simulate census data for a town. Each person was checked monthly. A Monte Carlo process was used to determine whether he got a raise, whether he married or bought a car, etc. His status change and its effect on others was then taken into account. Some probabilities are known and others are supplied empirically and corrected as new data is supplied.

The problem is quite complex. The coding fills an IBM 704 and the run time is ten hours. The results were considered good enough to more than justify the expensive computer costs involved. The checks with the 1960 census data were "excellent." Further investigations in this area are to be made as a result of this study.

Baker and Dzielinski [1] modeled a simplified job shop and applied simulation techniques to make exploratory tests.

The model was designed to represent a job shop with a small number (9 to 30) of single processing facilities each of which could service one, and only one, job at a time. The expected processing time for each job was known and a random dispersion about the expected time reflects a departure of performance from schedule.

Several very important simplifying assumptions were included to cut testing cost. The model does not specify the number of identical parts that are being manufactured together as one job. It does not consider setup times or transit times as separate variables. It does not allow for common shop practices such as dividing a job into parts. Once the shop size is specified it cannot be altered to account for subcontracting, overtime, etc. The inclusion of these factors would admittedly effect the model's behavior.

Two measures of performance were evaluated: the average of the jobs' total manufacturing times and the predictability of the jobs' completion times i.e., the ratio of the recorded total manufacturing time to the expected total manufacturing time.

A comparison of two queueing disciplines was made. The results of a simulation run using random choices from existing queues were compared with a run using a first-in-first-out policy, and the first-in-first-out procedure was significantly better. Consequently another policy was imposed: the shortest impending process time. This policy appeared to be the best of the three tested.

Tayyabkhan and Richardson [15] cite another example demonstrating the value of Monte Carlo techniques in simulation. A particular chemical production complex produced a range of intermediate products which are combined in specific proportions and sold as mixtures. Because of a lack of inventory space for finished products, and the peculiar specifications of each order, each order must be prepared immediately before shipment. In order to prepare a mixture, the intermediates are transferred in the proper proportions to the mixing tanks. Assume that the intermediate products are always available, that the preparation of each mix requires one working day, and that each order is a unit mix load. Five mixtures were considered. The problem was to determine the number of mixers required to sustain a satisfactory working level.

Distribution curves for the daily number of orders for each of the five mixtures were established and a 2000-day sample of each curve was taken from which total daily orders were computed. A simulation run was made to determine how many days were completed with no delay using a given number of mixers. A delay was encountered if the number of orders for a particular day plus the number of orders that could not be processed the previous day exceeded the number of mixers in the system. Eight separate runs were made, one for each value of n = 13, 14, ..., 20 where n was the number of mixers available. A satisfactory level of operation was maintained when 15 mixers were available. Ninety-one and four-tenths percent of the days in the sample had no delays while 99.2% of the orders were processed without delay.

Forrester [3] introduced the term industrial dynamics which is the investigation of the information-feedback character of industrial systems and the use of models for the design of improved organizational form and guiding policy. Information-feedback systems are those in which conditions are converted into information which forms the basis for decisions which, in turn, affect the system conditions. Roughly speaking, some of the studies previously mentioned were information-feedback systems since the results of one simulation run suggested new policies which were implemented on subsequent runs.

Forrester is merely emphasizing that the really important points in a system are the decision points and that an intense study of their locations, their information sources, and their influence in the system are of foremost importance. Although his remarks are aimed at industrial systems, they are by no means restricted to those systems. DYNAMO [18] is a simulation language designed specifically for this type of problem.

The range of simulation applications is as wide as the imagination of the user. Simulation techniques have been used in such areas as:

1. The economic simulation of a business concern.

2. The life cycle of a cell.

3. Army-Air Force war games.

As the applicability of computer simulation became increasingly apparent, computer manufacturers and computer services organizations began writing both special and general purpose simulation languages for their own use as well as for their customer's use. Some of the simulation oriented languages available at present are:

1. "General Purpose Systems Simulator" (GPSS) by International Business Machines Corporation
2. "SIMSCRIPT" by Rand Corporation
3. "SIMPAC" by System Development Corporation
4. "Control and Simulation Language" (CSL) by Routledge Company, London
5. "DYNAMO" by Massachusetts Institute of Technology

References [9, 14] provide comprehensive comparisons of these languages and are the basis for the following brief descriptions.

GPSS[1] is an interpretive language written for the IBM 7040-90 series (but since written for other computers). The basic assumption is that a system can be depicted in terms of a specific set of block types i.e., basic algorithms of functions common to simulation. Transactions proceeding from block to block modify the state of the system. Clock updating is accomplished by setting it equal to the starting time of the next most emminent event. As an interpretive language GPSS has good

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[1]Much of this discussion of GPSS will be repeated and expanded in a later chapter.

debugging aids but execution is slow. User alterations or extensions must be programmed in MAP. Large problems cannot be handled and it is difficult to program complex decision rules.

SIMSCRIPT presupposes that the state of a system can be described by its entities (objects of which the system is composed) and their properties. The user specifies the entities, their attributes, and their possible set memberships. He also defines the events which change the system state. The language is FORTRAN-like and the compile phase produces a FORTRAN program which can then be used independent of the SIMSCRIPT system.

SIMPAC creates models from five basic components: activities, transactions, queues, resources, and reference files. Transactions are created by user specified SCAT routines. Activities are user defined SCAT or GTASK macro routines which modify the state of the system. Each activity has an input and an output queue of transactions and is supplied with information through the reference files. Resources are user defined and used by the transactions. The SIMPAC clock is updated by fixed increments of time.

CSL programs are input to an IBM 1401 which produces a FORTRAN deck that can be run on an IBM 7090. CSL describes system activities in terms of operations upon sets. Set membership of an entity is determined by the attributes of that entity and an extensive algebra of ordered sets is provided through which activities alter the system. Timing is controlled by scanning and manipulating "T cells". A T cell is associated with each entity and contains the time at which that entity is next due to change its status.

DYNAMO is directed at studying the stability (over time) of closed loop systems of continuous variables in which the broad characteristics of information-feedback within the system are significant to its dynamic performance. A closed loop system is one in which the successive states of the system are not dependent upon the variables outside of the system. DYNAMO approximates the continuous process by a set of first order difference equations. At each point in time (periodically incremented by a standard DT), a set of equations (not simultaneous) representing the system, are evaluated and the rates of change of the system variables are computed. The values are retained and used in the computation at the next point in time.

The general concensus of a workshop on simulation languages at The University of Pennsylvania in March 1966 was that GPSS was used most often due to its simplicity. But when elaborate output or decision rules are required, or when the problem size exceeds the GPSS limitations, or finally when run time is crucial, SIMSCRIPT was preferred.

III. GENERAL PURPOSE SYSTEMS SIMULATOR

GPSS III is the simulation tool used in this study. GPSS, as a simulation language, belongs to a class of programs known as problem-oriented languages. It is the function of a problem-oriented language to bridge the communication gap between machine and man (in particular, the non-programmer). Simulation languages are designed to permit the user to communicate with the computer in terms familiar to the user.

A simulation language is the result of an attempt to isolate common simulation functions and to define these functions to a computer, thus relieving the modeler of the tedious and expensive task of programming the model in the language of the machine.

A few of these common simulation functions follow:

1. The recurrence of inter-related activities.
2. The tendency to form queues between activities carried out at different times or at different rates.
3. Proper facility requirements and logical conditions must be met before an activity can take place.

The controls to which these functions are sensitive are:

1. Queue discipline: Rules governing the ordering and selection of transaction entities in queues.
2. Resource allocation: Assignment of activities to activity performers.
3. Information routing: Specification of the source of information input to an activity and the destination of output information.

GPSS[1] develops simulation models in terms of block diagrams depicting the physical and logical flow of transactions or information through a system. GPSS uses a very specific set of block types which represent the "common simulation functions" mentioned earlier.

The units of traffic are called transactions which are the only temporary GPSS entities. Transactions are conventionally moved through the model on a first come, first serve basis within one of eight priority levels.

In addition to the two basic entities, blocks and transactions, GPSS has eight other fixed types of entities listed below. Each entity has one or more of the block types associated with it.

Basic Entities

Blocks

Transactions

Equipment Entities

Facilities

Storages

Logic Switches

Statistical Entities

Queues

Distribution Tables

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[1] This description of GPSS is drawn from The Past, Present, and Future of General Simulation Languages, by H. S. Krasnow and R. A. Merikallio. Yorktown Heights, New York: IBM Corporation. It has been revised to include the capabilities of GPSS III.

Reference Entities

Save Values

Computational Entities

Arithmetic Variables

Functions[1]

Of the numerous attributes associated with these entities, there is a subset of attributes, called Standard Numerical Attributes (SNA), whose values can be addressed in a simulation model by name and index number. For example, Q6 references an integer indicating the current number of transactions in Queue 6.

Transactions periodically encounter positive time delays in the system. These transactions are merged into a "future events chain" in ascending order of departure time from their blocks. Most of the remaining transactions are linked in a "current events chain," in which they are ordered, within priority class, by the length of time that they have been delayed.

The over-all GPSS scan at each clock time will continually recycle through the current events chain attempting to move its transactions into some possible next block. When the over-all scan succeeds in moving a transaction into some next block, the scan attempts to keep that transaction moving through as many blocks as possible until generally one of three things occurs:

[1] For a more detailed explanation of entities and their uses see General Purpose System Simulator III User's Manual. White Plains, New York: IBM Technical Publications Department.

1. The transaction encounters a positive time delay in a block, and is merged into the future events chain.
2. The transaction is finally blocked from entering a next block, and remains in the current events chain.
3. The transaction is destroyed in a TERMINATE or ASSEMBLE block.

GPSS concentrates almost exclusively on processing the single transaction which it is currently moving. Other transactions are only indirectly affected.

Eventually the over-all GPSS scan makes a complete pass through the current events chain without being able to move any transaction into some next block. The clock time is then updated to the block departure time of the first transaction in the future events chain. The first transaction and all other transactions with the same block departure time are transferred to the current events chain. Then the entire procedure is repeated.

Run length is governed by specifications in a START control card and may be a function of either simulated clock time or by total count of transactions having traversed the model.

At the end of the run a standard statistical printout occurs. This printout includes the cumulative time integral of the contents of the particular entity (any facility, storage, or queue) and a count of the number of transactions which used or entered the entity. Among the computed statistics are the average and maximum contents; the average time spent by transactions within the entity; and the average utilization of the facility or storage capacity.

Distribution tables can be built at the discretion of the modeler. A table can use any standard system variable as its argument. Table printout includes the mean and standard deviation of tabulated values and also the absolute and relative frequency with which the argument values occur in predefined intervals.

In addition, standard output includes a count of the total number of transactions which have entered each block during the run, and also the current number of transactions in each block at the end of the run.

A uniform zero-one pseudo-random number generator is provided by GPSS and may be called at any time. Random numbers are generally used as arguments for referencing either a function or a known interval with a specified mean and spread.

Several important, and sometimes critical, restrictions are:

1. Very large problems cannot be implemented. GPSS III allows a maximum of 500 blocks and 750 simultaneous transactions.
2. Complicated algebraic decision rules are difficult to express in GPSS.
3. GPSS III is an interpretive language and, as a result, has a slow execution phase.

Generally, if these restrictions can be met, the ease of learning and using GPSS makes it a desirable simulation language.

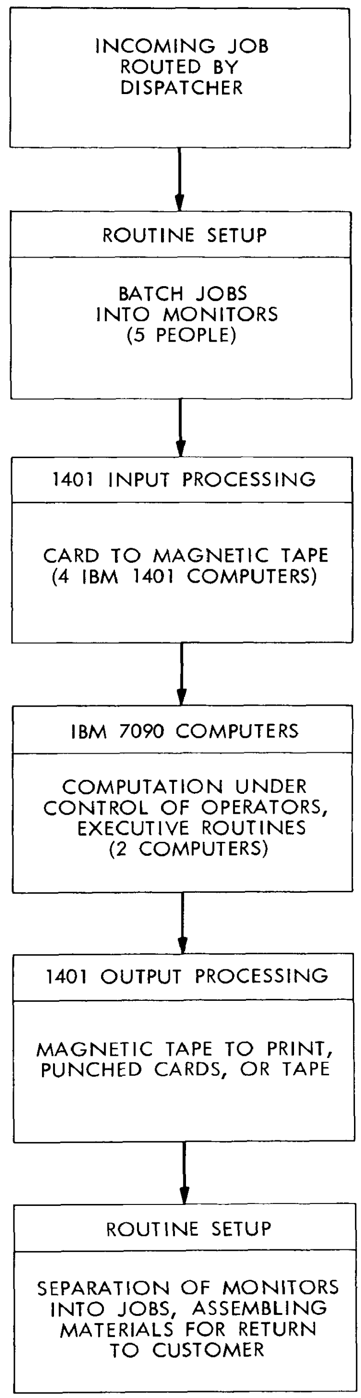
IV. DESIGNING THE MODEL

A job entering the system goes immediately to "Routine Handling" where it will be logged in and batched, with other jobs, into a monitor. Monitors leave Routine Handling and proceed to a 1401 where they are converted from card information to magnetic tape records to be used as input to a 7090. When a 7090 becomes available, its central processing unit reads the input tape, compiles and/or executes the jobs on that tape, and produces output which is again stored on tape. These 7090 output tapes are input to a 1401 which converts the information to either printed output or to punched cards. Finally the input cards and the output media are returned to Routine Handling to be separated into finished jobs, logged out, and returned to the customer.

The system operates 24 hours a day for at least 6 days a week. The model was designed to simulate a 17-shift week and print out information about those jobs left in the system at the end of that time.

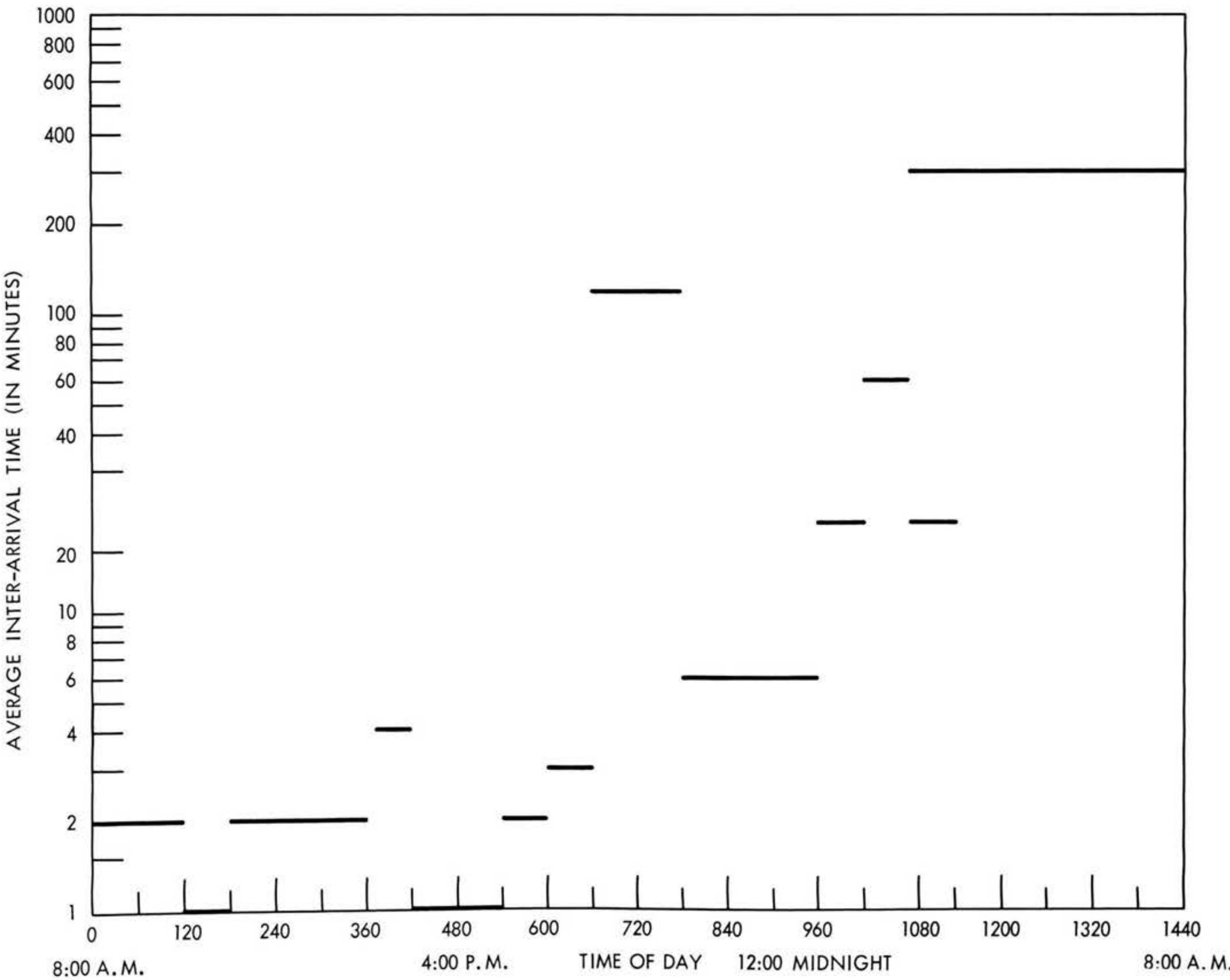
A system flow diagram (see Appendix) was constructed to reflect the inter-relationships of the elements and policies of the system described above. The only people represented by the model are those in Routine Handling: five people for day shift, (8:00 - 4:00), three for evening shift, (4:00 - 12:00), and one for night shift (12:00 - 8:00). Elsewhere, the assumption is that if a machine is available, a machine operator will also be available.

Potential queue locations are at: Routine Handling, the 1401's, and the 7090's. Separate queues are provided at Routine Handling for jobs to be set up and for monitors to be separated. Similarly, separate queues are kept for card-to-tape and for tape-to-print operations.



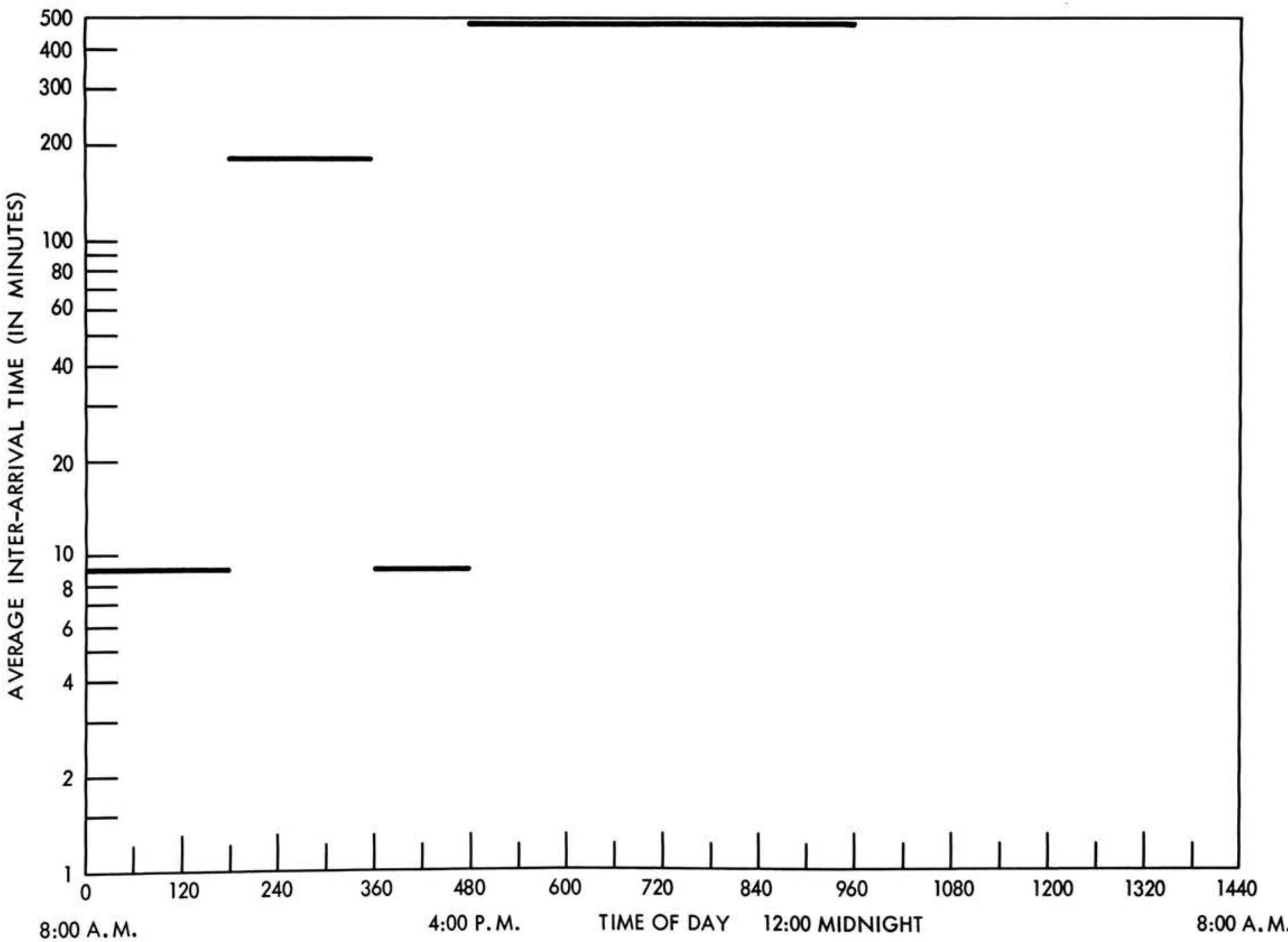
SIMPLIFIED FLOW OF A TYPICAL JOB

Figure 2



JOB INTER-ARRIVAL TIME
MONDAY THROUGH FRIDAY

Figure 3

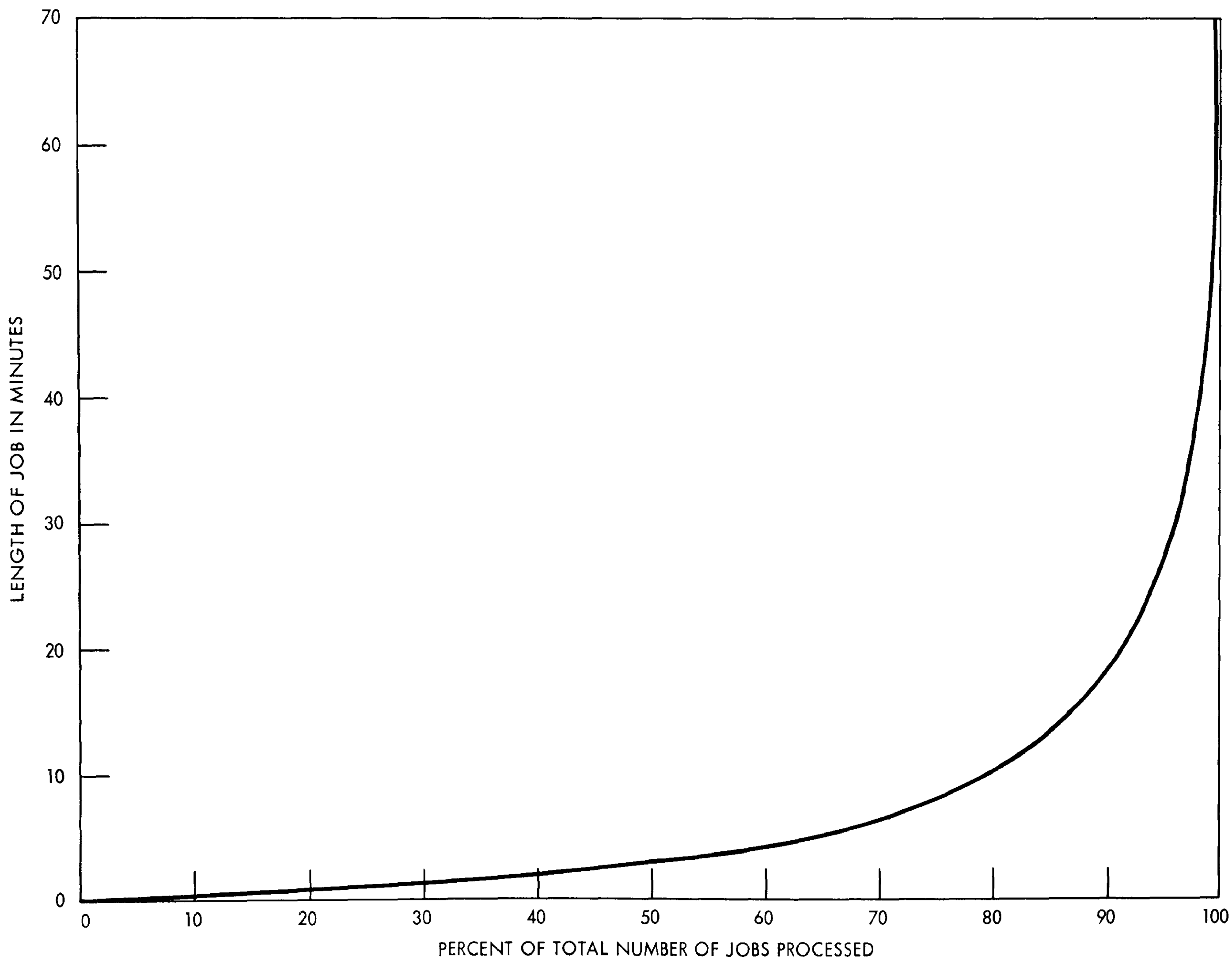


JOB INTER-ARRIVAL TIME
SATURDAY
Figure 4

Model parameters were provided for as follows:

1. Job interarrival time (i.e., the time elapsed between the arrival of any two consecutive jobs) is generally a function of the time of day. Figures 3-4 are graphs of the functions initially used by the model. Figure 3 is repeated Monday through Friday and Figure 4 represents Saturday.
2. Routine Handling times are given as three minutes for each job set up and two minutes for each job separated.
3. The times required for 1401 functions are supplied randomly within predetermined intervals.
4. A probability distribution is sampled in order to generate the 7090 compile and compute times. Figure 5 is a graph of the cumulative distribution which is referenced in the model. A random number between zero and one is generated as the argument from which a compute time is found.
5. Probability distributions representing machine failure frequencies and durations are referenced in a similar manner.

Statistical output is printed immediately before and after the day shift. This output includes: equipment utilization, queue statistics, total and current number of jobs at any point in the system, queue tables indicating absolute and relative frequencies of queue delays falling into predetermined time intervals, and tables indicating the frequency distribution of job turnaround times in given intervals. At the end of 17 shifts, the current and future events chains are printed.



7090 CUMULATIVE JOB FREQUENCY AS A FUNCTION OF JOB LENGTH

Figure 5

Jobs requiring 1401 time but no 7090 time are also represented in the model since these jobs compete with 7090 jobs for 1401 time. However no tables are included with which to collect statistics concerning these jobs.

The model uses 339 blocks and simulates 17 shifts in about 12 minutes on a 7090. The basic unit of time is one minute.

V. EXPERIMENTS AND RESULTS

First-in-first-out (FIFO) is probably the simplest and the most obvious scheduling policy. Therefore, it was selected as the policy with which to establish a base case. This base case contains all of the features as presented in the previous section. The interarrival rate used as input is shown in Figure 3.

Tables I-IV indicate the week's cumulative results as of Friday at 4:00 p.m. The results of all subsequent runs will likewise be cumulative through Friday at 4:00 p.m. Seventeen hundred and eighty-two jobs were batched with about ten jobs per monitor and these jobs had an average turnaround time of 569 minutes (9-1/2 hours). Of this turnaround time, an average wait time in the queue at the 7090's was 372 minutes. Since the 1401 queues had very small wait times, apparently the input/output hardware is sufficient to handle this job load. Machine utilization figures are biased in that machine downtime is included as utilization. Also, the compile and compute times include the time required for tape hanging. However, all subsequent runs will also be biased in the same way so that relative results should be valid. At the end of the seventeenth shift, all work for the week had been processed.

In addition to being the most obvious policy, FIFO is also the least likely policy for a real-world system of this magnitude. Almost invariably priority levels are established. In some installations the bulk of the work has special priority. A real-time problem is an extreme example. More commonly, production jobs, such as payroll, have associated priorities.

TABLE I

TIME SPENT IN CARD-TO-TAPE QUEUE
RUN I (FIFO)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
207	5.923	8.210

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	96	46.38	46.4
0- 5	33	15.94	62.3
5- 10	26	12.56	74.9
10- 15	24	11.59	86.5
15- 20	13	6.28	92.8
20- 25	8	3.86	96.6
25- 30	4	1.93	98.6
30- 35	1	.48	99.0
35- 40	2	.97	100.0

TABLE II

TIME SPENT IN 7090 QUEUE
RUN I (FIFO)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
182	372.385	198.463

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	9	4.95	4.9
0- 30	2	1.10	6.0
30- 60	5	2.75	8.8
60- 90	2	1.10	9.9
90- 120	5	2.75	12.6
120- 150	6	3.30	15.9
150- 180	14	7.69	23.6
180- 210	1	.55	24.2
210- 240	2	1.10	25.3
240- 270	9	4.95	30.2
270- 300	8	4.40	34.6
300- 330	8	4.40	39.0
330- 360	14	7.69	46.7
360- 390	9	4.95	51.6
390- 420	7	3.85	55.5
420- 450	10	5.49	61.0
450- 480	11	6.04	67.0
480- 510	10	5.49	72.5
510- 540	8	4.40	76.9
540- 570	7	3.85	80.8
570- 600	7	3.85	84.6
600- 630	11	6.04	90.7
630- 660	4	2.20	92.9
660- 690	7	3.85	96.7
690- 720	4	2.20	98.9
720- 750	2	1.10	100.0

TABLE III

TIME SPENT IN TAPE-TO-PRINT QUEUE
RUN I (FIFO)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
178	4.225	7.090

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	101	56.74	56.7
0- 5	27	15.17	71.9
5- 10	21	11.80	83.7
10- 15	17	9.55	93.3
15- 20	5	2.81	96.1
20- 25	3	1.69	97.8
25- 30	1	.56	98.3
30- 35	3	1.69	100.0

TABLE IV

OVERALL JOB TURNAROUND
RUN I (FIFO)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
1782	569.264	229.443

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	0	.00	.0
60- 120	31	1.74	1.7
120- 180	30	1.68	3.4
180- 240	90	5.05	8.5
240- 300	88	4.94	13.4
300- 360	93	5.22	18.6
360- 420	160	8.98	27.6
420- 480	134	7.52	35.1
480- 540	199	11.17	46.3
540- 600	211	11.84	58.1
600- 660	122	6.85	65.0
660- 720	145	8.14	73.1
720- 780	151	8.47	81.6
780- 840	109	6.12	87.7
840- 900	100	5.61	93.3
900- 960	70	3.93	97.3
960-1020	26	1.46	98.7
1020-1080	0	.00	98.7
1080-1140	0	.00	98.7
1140-1200	0	.00	98.7
1200-1260	0	.00	98.7
1260-1320	8	.45	99.2
1320-1380	15	.84	100.0

Another consideration for the design of system policy is the problem of debugging programs. It is extremely desirable to have rapid turnaround for this phase of programming. Usually however, programmers work day shift only; therefore, if a debug job cannot be returned during the current day shift, it need not be returned until the beginning of the following day shift. So the time of day may be a priority factor.

It is clear that if someone gains by a priority system, someone else is suffering a loss. The extent of this loss must also weigh heavily on policy decisions.

The first experiment replaced the FIFO policy with a more complex set of job categorization rules. Jobs were segregated by their characteristics.

The first monitor type was designed primarily to aid debugging. This type was called "Express." The requirements for express monitors were: 1) 7090 time no greater than seven minutes, 2) no more than two non-system tapes, and 3) no more than 2000 lines of output. Express jobs were batched so that $\sum_{i=1}^{n} T_i \leq 60$ minutes, where T_i was the 7090 time required for job i, and $7 \leq n \leq 12$.

The second type of monitor was called "Special." There were three criteria for specials and if a job met any one of these criteria, it was eligible for special consideration. First, some production type jobs run on a regular schedule (e.g., weekly, monthly, etc.) were guaranteed 24-hour service. Most of these were deferred to the evening shift. Second, certain jobs were time scheduled. The model had four such runs daily: one at 1:00 a.m., one at 8:00 a.m., one at 11:00 a.m., and one at 4:00 p.m. The third criterion represented the discretion of a manager. Those jobs considered important enough and that could not otherwise meet express requirements were given special service. This third type of special was run as soon as possible, often batched with a time scheduled run. In the model, about 20% of the jobs (selected randomly) were specials.

A third monitor type was known as "Local." Local jobs were those jobs which failed to qualify as either express or special and which had a 7090 time of less than 30 minutes. These jobs were batched into monitors with a total compute time of about one hour.

Finally, jobs requiring 30 minutes or more of 7090 time and not considered as specials were run as single job monitors. These are referred to simply as "Long" jobs.

The same job profile was input to this first experimental run as was input to the base case.

Tables V-XII are results of this run. Table XXXIX compares these results with the base case results. Note that about the same number of jobs were processed with a shorter average turnaround. But the backlog at the end of the week indicates that the sequencing had been changed i.e., longer jobs are being delayed until the week-end.

Of the total 1783 jobs processed, 1044 were express jobs whose average turnaround was 321 minutes - an average reduction of four hours.[1]

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[1]In general the average values will be discussed herein, but a better picture of the system can be obtained by a more careful inspection of the tables provided by each run.

TABLE V

TIME SPENT IN CARD-TO-TAPE QUEUE
RUN II (MONITOR TYPES)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
318	144.393	263.551

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	25	7.86	7.9
0- 5	41	12.89	20.8
5- 10	36	11.32	32.1
10- 15	28	8.81	40.9
15- 20	25	7.86	48.7
20- 25	13	4.09	52.8
25- 30	18	5.66	58.5
30- 35	12	3.77	62.3
35- 40	17	5.35	67.6
40- 45	5	1.57	69.2
45- 50	1	.31	69.5
50- 55	5	1.57	71.1
55- 60	5	1.57	72.6
60- 65	3	.94	73.6
65- 70	3	.94	74.5
70- 75	1	.31	74.8
75- 80	5	1.57	76.4
80- 85	0	.00	76.4
85- 90	1	.31	76.7
OVERFLOW	74	23.27	100.0

AVERAGE VALUE OF OVERFLOW 555.74

TABLE VI

TIME SPENT IN 7090 QUEUE
RUN II (MONITOR TYPES)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
306	299.098	412.642

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	21	6.86	6.9
0- 30	87	28.43	35.3
30- 60	29	9.48	44.8
60- 90	11	3.59	48.4
90- 120	7	2.29	50.7
120- 150	12	3.92	54.6
150- 180	5	1.63	56.2
180- 210	10	3.27	59.5
210- 240	2	.65	60.1
240- 270	11	3.59	63.7
270- 300	10	3.27	67.0
300- 330	6	1.96	69.0
330- 360	5	1.63	70.6
360- 390	1	.33	70.9
390- 420	10	3.27	74.2
420- 450	11	3.59	77.8
450- 480	5	1.63	79.4
480- 510	6	1.96	81.4
510- 540	5	1.63	83.0
540- 570	3	.98	84.0
570- 600	2	.65	84.6
600- 630	3	.98	85.6
630- 660	3	.98	86.6
660- 690	3	.98	87.6
690- 720	1	.33	87.9
720- 750	2	.65	88.6
750- 780	1	.33	88.9
780- 810	2	.65	89.5
810- 840	1	.33	89.9
840- 870	0	.00	89.9
870- 900	1	.33	90.2
900- 930	2	.65	90.8
930- 960	0	.00	90.8
960- 990	0	.00	90.8
990-1020	0	.00	90.8
1020-1050	0	.00	90.8
1050-1080	0	.00	90.8
1080-1110	0	.00	90.8
1110-1140	0	.00	90.8
1140-1170	0	.00	90.8
1170-1200	2	.65	91.5
1200-1230	2	.65	92.2
1230-1260	2	.65	92.8
1260-1290	2	.65	93.5
1290-1320	4	1.31	94.8
1320-1350	1	.33	95.1
1350-1380	2	.65	95.8
1380-1410	0	.00	95.8
1410-1440	0	.00	95.8
OVERFLOW	13	4.25	100.0

AVERAGE VALUE OF OVERFLOW 1551.62

TABLE VII

TIME SPENT IN TAPE-TO-PRINT QUEUE
RUN II (MONITOR TYPES)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
291	60.065	173.824

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	34	11.68	11.7
0- 5	88	30.24	41.9
5- 10	43	14.78	56.7
10- 15	27	9.28	66.0
15- 20	17	5.84	71.8
20- 25	10	3.44	75.3
25- 30	8	2.75	78.0
30- 35	10	3.44	81.4
35- 40	3	1.03	82.5
40- 45	5	1.72	84.2
45- 50	4	1.37	85.6
OVERFLOW	42	14.43	100.0

AVERAGE VALUE OF OVERFLOW 356.12

TABLE VIII

OVERALL JOB TURNAROUND
RUN II (MONITOR TYPES)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
1444	591.620	677.114

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	15	1.04	1.0
60- 120	132	9.14	10.2
120- 180	413	28.60	38.8
180- 240	187	12.95	51.7
240- 300	67	4.64	56.4
300- 360	9	.62	57.0
360- 420	21	1.45	58.4
420- 480	28	1.94	60.4
480- 540	29	2.01	62.4
540- 600	47	3.25	65.7
600- 660	73	5.06	70.7
660- 720	49	3.39	74.1
720- 780	56	3.88	78.0
780- 840	7	.48	78.5
840- 900	15	1.04	79.5
900- 960	46	3.19	82.7
960-1020	5	.35	83.0
1020-1080	12	.83	83.9
1080-1140	30	2.08	85.9
1140-1200	7	.48	86.4
1200-1260	1	.07	86.5
1260-1320	0	.00	86.5
1320-1380	0	.00	86.5
1380-1440	2	.14	86.6
1440-1500	5	.35	87.0
1500-1560	16	1.11	88.1
1560-1620	8	.55	88.6
1620-1680	15	1.04	89.7
1680-1740	2	.14	89.8
1740-1800	0	.00	89.8
1800-1860	9	.62	90.4
1860-1920	12	.83	91.3
1920-1980	1	.07	91.3
1980-2040	5	.35	91.7
2040-2100	3	.21	91.9
2100-2160	4	.28	92.2
OVERFLOW	113	7.83	100.0

AVERAGE VALUE OF OVERFLOW 2413.26

Note: Special monitors enter this table as single jobs. The numbers cited in context were derived by merging specials as jobs - not as monitors.

TABLE IX

EXPRESS JOB TURNAROUND
RUN II (MONITOR TYPES)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
1044	321.810	255.668

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	0	.00	.0
60- 120	92	8.81	8.8
120- 180	403	38.60	47.4
180- 240	177	16.95	64.4
240- 300	65	6.23	70.6
300- 360	8	.77	71.4
360- 420	4	.38	71.7
420- 480	14	1.34	73.1
480- 540	14	1.34	74.4
540- 600	38	3.64	78.1
600- 660	57	5.46	83.5
660- 720	45	4.31	87.8
720- 780	56	5.36	93.2
780- 840	6	.57	93.8
840- 900	14	1.34	95.1
900- 960	46	4.41	99.5
960-1020	5	.48	100.0

TABLE X

SPECIAL MONITOR TURNAROUND
RUN II (MONITOR TYPES)

MONITORS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
108	426.907	204.077

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	0	.00	.0
60- 120	8	7.41	7.4
120- 180	10	9.26	16.7
180- 240	10	9.26	25.9
240- 300	2	1.85	27.8
300- 360	1	.93	28.7
360- 420	17	15.74	44.4
420- 480	14	12.96	57.4
480- 540	15	13.89	71.3
540- 600	9	8.33	79.6
600- 660	16	14.81	94.4
660- 720	4	3.70	98.1
720- 780	0	.00	98.1
780- 840	0	.00	98.1
840- 900	0	.00	98.1
900- 960	0	.00	98.1
OVERFLOW	2	1.85	100.0

AVERAGE VALUE OF OVERFLOW 1155.00

TABLE XI

LOCAL JOB TURNAROUND
RUN II (MONITOR TYPES)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
289	1607.799	834.121

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 120	47	16.26	16.3
120- 180	0	.00	16.3
180- 240	0	.00	16.3
240- 300	0	.00	16.3
300- 360	0	.00	16.3
360- 420	0	.00	16.3
420- 480	0	.00	16.3
480- 540	0	.00	16.3
540- 600	0	.00	16.3
600- 660	0	.00	16.3
660- 720	0	.00	16.3
720- 780	0	.00	16.3
780- 840	1	.35	16.6
840- 900	1	.35	17.0
900- 960	0	.00	17.0
960-1020	0	.00	17.0
1020-1080	12	4.15	21.1
1080-1140	29	10.03	31.1
1140-1200	7	2.42	33.6
1200-1260	0	.00	33.6
1260-1320	0	.00	33.6
1320-1380	0	.00	33.6
1380-1440	2	.69	34.3
1440-1500	5	1.73	36.0
1500-1560	16	5.54	41.5
1560-1620	8	2.77	44.3
1620-1680	15	5.19	49.5
1680-1740	2	.69	50.2
1740-1800	0	.00	50.2
1800-1860	9	3.11	53.3
1860-1920	12	4.15	57.4
1920-1980	1	.35	57.8
1980-2040	5	1.73	59.5
2040-2100	3	1.04	60.6
2100-2160	4	1.38	61.9
2160-2220	9	3.11	65.1
OVERFLOW	101	34.95	100.0

AVERAGE VALUE OF OVERFLOW 2429.26

TABLE XII

EXPRESS JOB TURNAROUND--DAY SHIFT ONLY
RUN II (MONITOR TYPES)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
584	232.289	210.145

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	0	.00	.0
60- 120	54	9.25	9.2
120- 180	331	56.68	65.9
180- 240	113	19.35	85.3
240- 300	20	3.42	88.7
300- 360	0	.00	88.7
360- 420	0	.00	88.7
420- 480	2	.34	89.0
480- 540	5	.86	89.9
540- 600	2	.34	90.2
600- 660	9	1.54	91.8
660- 720	9	1.54	93.3
720- 780	0	.00	93.3
780- 840	0	.00	93.3
840- 900	11	1.88	95.2
900- 960	23	3.94	99.1
960-1020	5	.86	100.0

Of these express jobs 584 were returned during the day shift and their average turnaround was 232 minutes. Eighty-nine percent of these jobs were submitted and returned during the day shift. To pay for these improvements, only 292 local and long jobs were processed during the week - 495 were generated. And of those locals processed, only 34% were returned within 24 hours. But the stiffest penalty was the backlog of one shift of work observed at the end of the week.

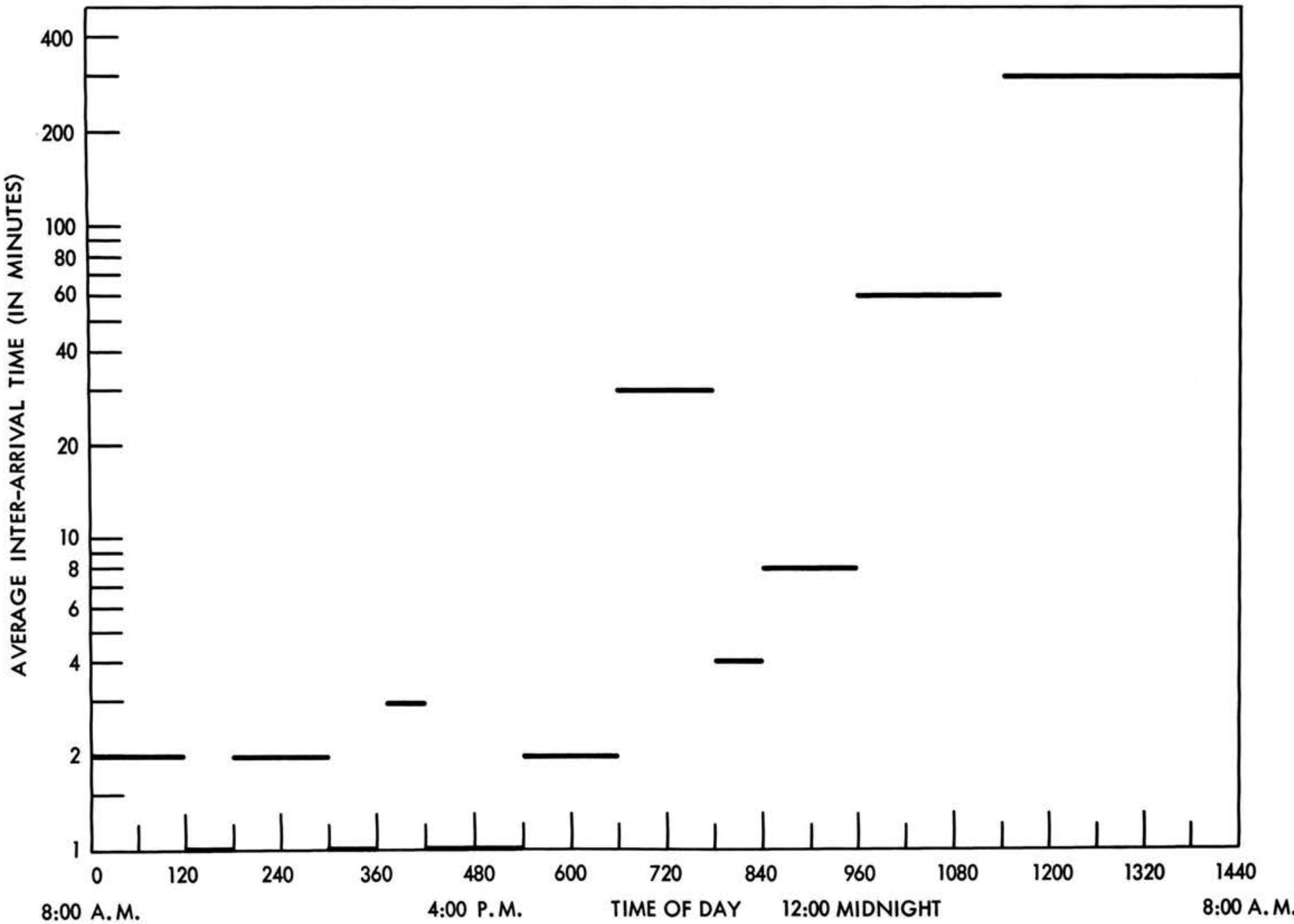
Another interesting point is the effect of increasing the number of monitors produced. The 1401 utilizations jumped 16% and the queues behind the 1401's lengthened sharply. However, the time spent in the 1401 queue is still small relative to the time spent in the 7090 queue indicating that the bottleneck is still at the 7090's.

Using turnaround time as the measure of effectiveness, this run must be considered quite successful. But the next question was: How would this new system procedure react to an increased load?

The only difference between the second and third runs was that a new interarrival curve (see Figure 6) was input for Monday through Friday. This new curve represents about a 10% increase of work entering the system.

The results of the third run are in Tables XIII-XX, and these results are compared with those from the second run in Table XXXIX.

A total of 1821 jobs were returned in an average time of 577 minutes. About 55% were processed in four hours or less. The small increase of jobs completed and the statistics on jobs by monitor type indicate that the system cannot completely handle this workload.



JOB INTER-ARRIVAL TIME
MONDAY THROUGH FRIDAY
Figure 6

TABLE XIII

TIME SPENT IN CARD-TO-TAPE QUEUE
RUN III (INCREASED LOAD)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
330	276.3C6	584.823

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	22	6.67	6.7
0- 5	53	16.06	22.7
5- 10	26	7.88	30.6
10- 15	25	7.58	38.2
15- 20	19	5.76	43.9
20- 25	11	3.33	47.3
25- 30	17	5.15	52.4
30- 35	19	5.76	58.2
35- 40	17	5.15	63.3
40- 45	9	2.73	66.1
45- 50	5	1.52	67.6
50- 55	2	.61	68.2
55- 60	1	.30	68.5
60- 65	3	.91	69.4
65- 70	1	.30	69.7
70- 75	6	1.82	71.5
75- 80	1	.30	71.8
80- 85	4	1.21	73.0
85- 90	3	.91	73.9
OVERFLOW	86	26.06	100.0

AVERAGE VALUE OF OVERFLOW 999.73

TABLE XIV

TIME SPENT IN 7090 QUEUE
RUN III (INCREASED LOAD)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
324	186.250	241.708

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	37	11.42	11.4
0- 30	83	25.62	37.0
30- 60	38	11.73	48.8
60- 90	10	3.09	51.9
90- 120	13	4.01	55.9
120- 150	10	3.09	59.0
150- 180	7	2.16	61.1
180- 210	9	2.78	63.9
210- 240	11	3.40	67.3
240- 270	6	1.85	69.1
270- 300	14	4.32	73.5
300- 330	15	4.63	78.1
330- 360	14	4.32	82.4
360- 390	6	1.85	84.3
390- 420	8	2.47	86.7
420- 450	11	3.40	90.1
450- 480	2	.62	90.7
480- 510	7	2.16	92.9
510- 540	3	.93	93.8
540- 570	5	1.54	95.4
570- 600	2	.62	96.0
600- 630	0	.00	96.0
630- 660	1	.31	96.3
660- 690	0	.00	96.3
690- 720	0	.00	96.3
720- 750	0	.00	96.3
750- 780	0	.00	96.3
780- 810	2	.62	96.9
810- 840	1	.31	97.2
840- 870	0	.00	97.2
870- 900	0	.00	97.2
900- 930	0	.00	97.2
930- 960	0	.00	97.2
960- 990	0	.00	97.2
990-1020	0	.00	97.2
1020-1050	1	.31	97.5
1050-1080	0	.00	97.5
1080-1110	2	.62	98.1
1110-1140	2	.62	98.8
1140-1170	0	.00	98.8
1170-1200	1	.31	99.1
1200-1230	1	.31	99.4
1230-1260	1	.31	99.7
1260-1290	1	.31	100.0

TABLE XV

TIME SPENT IN TAPE-TO-PRINT QUEUE
RUN III (INCREASED LOAD)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
299	165.355	456.484

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	24	8.03	8.0
0- 5	90	30.10	38.1
5- 10	35	11.71	49.8
10- 15	16	5.35	55.2
15- 20	16	5.35	60.5
20- 25	15	5.02	65.6
25- 30	9	3.01	68.6
30- 35	10	3.34	71.9
35- 40	7	2.34	74.2
40- 45	10	3.34	77.6
45- 50	4	1.34	78.9
OVERFLOW	63	21.07	100.0

AVERAGE VALUE OF OVERFLOW 740.14

TABLE XVI

OVERALL JOB TURNAROUND
RUN III (INCREASED LOAD)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
1459	613.231	888.886

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	19	1.30	1.3
60- 120	197	13.50	14.8
120- 180	350	23.99	38.8
180- 240	222	15.22	54.0
240- 300	39	2.67	56.7
300- 360	39	2.67	59.4
360- 420	26	1.78	61.1
420- 480	26	1.78	62.9
480- 540	46	3.15	66.1
540- 600	30	2.06	68.1
600- 660	69	4.73	72.9
660- 720	106	7.27	80.1
720- 780	40	2.74	82.9
780- 840	96	6.58	89.4
840- 900	1	.07	89.5
900- 960	0	.00	89.5
960-1020	0	.00	89.5
1020-1080	0	.00	89.5
1080-1140	0	.00	89.5
1140-1200	0	.00	89.5
1200-1260	0	.00	89.5
1260-1320	1	.07	89.6
1320-1380	3	.21	89.8
1380-1440	0	.00	89.8
1440-1500	0	.00	89.8
1500-1560	1	.07	89.9
1560-1620	1	.07	89.9
1620-1680	0	.00	89.9
1680-1740	0	.00	89.9
1740-1800	0	.00	89.9
1800-1860	0	.00	89.9
1860-1920	0	.00	89.9
1920-1980	0	.00	89.9
1980-2040	0	.00	89.9
2040-2100	0	.00	89.9
2100-2160	0	.00	89.9
OVERFLOW	147	10.08	100.0

AVERAGE VALUE OF OVERFLOW 3113.98

Note: Special monitors enter this table as single jobs. The numbers cited in context were derived by merging specials as jobs - not as monitors.

TABLE XVII

EXPRESS JOB TURNAROUND
RUN III (INCREASED LOAD)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
1127	330.342	248.421

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	0	.00	.0
60- 120	141	12.51	12.5
120- 180	340	30.17	42.7
180- 240	221	19.61	62.3
240- 300	37	3.28	65.6
300- 360	35	3.11	68.7
360- 420	20	1.77	70.5
420- 480	9	.80	71.3
480- 540	17	1.51	72.8
540- 600	15	1.33	74.1
600- 660	59	5.24	79.3
660- 720	97	8.61	87.9
720- 780	40	3.55	91.5
780- 840	96	8.52	100.0

TABLE XVIII

SPECIAL MONITOR TURNAROUND
RUN III (INCREASED LOAD)

MONITORS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
118	433.551	190.175

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	0	.00	.0
60- 120	15	12.71	12.7
120- 180	10	8.47	21.2
180- 240	1	.85	22.0
240- 300	2	1.69	23.7
300- 360	4	3.39	27.1
360- 420	6	5.08	32.2
420- 480	17	14.41	46.6
480- 540	28	23.73	70.3
540- 600	15	12.71	83.1
600- 660	10	8.47	91.5
660- 720	9	7.63	99.2
720- 780	0	.00	99.2
780- 840	0	.00	99.2
840- 900	1	.85	100.0

TABLE XIX

LOCAL JOB TURNAROUND
RUN III (INCREASED LOAD)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
214	2202.103	1443.826

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 120	60	28.04	28.0
120- 180	0	.00	28.0
180- 240	0	.00	28.0
240- 300	0	.00	28.0
300- 360	0	.00	28.0
360- 420	0	.00	28.0
420- 480	0	.00	28.0
480- 540	1	.47	28.5
540- 600	0	.00	28.5
600- 660	0	.00	28.5
660- 720	0	.00	28.5
720- 780	0	.00	28.5
780- 840	0	.00	28.5
840- 900	0	.00	28.5
900- 960	0	.00	28.5
960-1020	0	.00	28.5
1020-1080	0	.00	28.5
1080-1140	0	.00	28.5
1140-1200	0	.00	28.5
1200-1260	0	.00	28.5
1260-1320	1	.47	29.0
1320-1380	3	1.40	30.4
1380-1440	0	.00	30.4
1440-1500	0	.00	30.4
1500-1560	1	.47	30.8
1560-1620	1	.47	31.3
1620-1680	0	.00	31.3
1680-1740	0	.00	31.3
1740-1800	C	.00	31.3
1800-1860	0	.00	31.3
1860-1920	0	.00	31.3
1920-1980	0	.00	31.3
1980-2040	0	.00	31.3
2040-2100	0	.00	31.3
2100-2160	0	.00	31.3
2160-2220	0	.00	31.3
OVERFLOW	147	68.69	100.0

AVERAGE VALUE OF OVERFLOW 3113.98

TABLE XX

EXPRESS JOB TURNAROUND--DAY SHIFT ONLY
RUN III (INCREASED LOAD)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
552	172.357	111.092

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	0	.00	.0
60- 120	126	22.83	22.8
120- 180	286	51.81	74.6
180- 240	117	21.20	95.8
240- 300	0	.00	95.8
300- 360	0	.00	95.8
360- 420	2	.36	96.2
420- 480	0	.00	96.2
480- 540	1	.18	96.4
540- 600	2	.36	96.7
600- 660	6	1.09	97.8
660- 720	5	.91	98.7
720- 780	1	.18	98.9
780- 840	6	1.09	100.0

The reaction, as would be expected, was to process as much priority work (specials and express) as possible and to push more and more non-priority work to the week-end.

Another major point of interest was the shifting of the queues. The increase in the ratio of 1401 wait time to 7090 wait time together with the increased 7090 utilization revealed a new system bottleneck at the 1401's.

In order to alleviate this problem an IBM System/360 Model 40 replaced one 1401. The /360 had 25% faster card-to-tape capabilities and 83% faster tape-to-print operation, and further, input and output functions could be accomplished simultaneously. The fourth run was the same as the third except for the substitution of the /360 for a 1401 (see Tables XXI-XXVIII).

More than 200 additional jobs were processed at an overall average turnaround of 485 minutes. Fifty-one percent of the jobs were returned in four hours or less. Seventy percent of the express jobs were completed within four hours. Six hundred and seventy-four express jobs were completely processed during the day shift. The input/output queues dropped sharply and the growth of the queue at the 7090's reflected the continuing overloaded state of the system. At Saturday midnight, almost twenty-four 7090-hours of work remained in the system.

Many installations the size of the one represented herein process jobs submitted by off-site programmers. This may be due to subcontracting computer time or to multi-plant servicing by a centralized computer center.

TABLE XXI

TIME SPENT IN CARD-TO-TAPE QUEUE
RUN IV (ADDITION OF/360)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
385	8.569	17.338

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	177	45.97	46.0
0- 5	88	22.86	68.8
5- 10	24	6.23	75.1
10- 15	21	5.45	80.5
15- 20	13	3.38	83.9
20- 25	17	4.42	88.3
25- 30	18	4.68	93.0
30- 35	8	2.08	95.1
35- 40	7	1.82	96.9
40- 45	2	.52	97.4
45- 50	0	.00	97.4
50- 55	1	.26	97.7
55- 60	2	.52	98.2
60- 65	3	.78	99.0
65- 70	0	.00	99.0
70- 75	0	.00	99.0
75- 80	0	.00	99.0
80- 85	0	.00	99.0
85- 90	1	.26	99.2
OVERFLOW	3	.78	100.0

AVERAGE VALUE OF OVERFLOW 139.67

TABLE XXII

TIME SPENT IN 7090 QUEUE
RUN IV (ADDITION OF/360)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
330	350.621	451.144

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	9	2.73	2.7
0- 30	93	28.18	30.9
30- 60	36	10.91	41.8
60- 90	8	2.42	44.2
90- 120	7	2.12	46.4
120- 150	6	1.82	48.2
150- 180	10	3.03	51.2
180- 210	10	3.03	54.2
210- 240	7	2.12	56.4
240- 270	9	2.73	59.1
270- 300	8	2.42	61.5
300- 330	10	3.03	64.5
330- 360	3	.91	65.5
360- 390	10	3.03	68.5
390- 420	4	1.21	69.7
420- 450	6	1.82	71.5
450- 480	10	3.03	74.5
480- 510	3	.91	75.5
510- 540	4	1.21	76.7
540- 570	5	1.52	78.2
570- 600	2	.61	78.8
600- 630	7	2.12	80.9
630- 660	5	1.52	82.4
660- 690	2	.61	83.0
690- 720	0	.00	83.0
720- 750	0	.00	83.0
750- 780	4	1.21	84.2
780- 810	1	.30	84.5
810- 840	1	.30	84.8
840- 870	1	.30	85.2
870- 900	1	.30	85.5
900- 930	2	.61	86.1
930- 960	5	1.52	87.6
960- 990	2	.61	88.2
990-1020	4	1.21	89.4
1020-1050	0	.00	89.4
1050-1080	2	.61	90.0
1080-1110	0	.00	90.0
1110-1140	1	.30	90.3
1140-1170	3	.91	91.2
1170-1200	8	2.42	93.6
1200-1230	0	.00	93.6
1230-1260	3	.91	94.5
1260-1290	0	.00	94.5
1290-1320	2	.61	95.2
1320-1350	3	.91	96.1
1350-1380	0	.00	96.1
1380-1410	0	.00	96.1
1410-1440	0	.00	96.1
OVERFLOW	13	3.94	100.0

AVERAGE VALUE OF OVERFLOW 1715.85

TABLE XXIII

TIME SPENT IN TAPE-TO-PRINT QUEUE
RUN IV (ADDITION OF/360)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
328	1.274	3.001

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	252	76.83	76.8
0- 5	45	13.72	90.5
5- 10	25	7.62	98.2
10- 15	5	1.52	99.7
15- 20	0	.00	99.7
20- 25	1	.30	100.0

TABLE XXIV

OVERALL JOB TURNAROUND
RUN IV (ADDITION OF/360)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
1672	490.009	508.781

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	12	.72	.7
60- 120	573	34.27	35.0
120- 180	276	16.51	51.5
180- 240	33	1.97	53.5
240- 300	14	.84	54.3
300- 360	18	1.08	55.4
360- 420	29	1.73	57.1
420- 480	29	1.73	58.9
480- 540	38	2.27	61.1
540- 600	38	2.27	63.4
600- 660	67	4.01	67.4
660- 720	67	4.01	71.4
720- 780	69	4.13	75.5
780- 840	66	3.95	79.5
840- 900	48	2.87	82.4
900- 960	10	.60	83.0
960-1020	23	1.38	84.3
1020-1080	31	1.85	86.2
1080-1140	38	2.27	88.5
1140-1200	10	.60	89.1
1200-1260	17	1.02	90.1
1260-1320	43	2.57	92.6
1320-1380	27	1.61	94.3
1380-1440	7	.42	94.7
1440-1500	10	.60	95.3
1500-1560	6	.36	95.6
1560-1620	21	1.26	96.9
1620-1680	6	.36	97.2
1680-1740	11	.66	97.9
1740-1800	0	.00	97.9
1800-1860	0	.00	97.9
1860-1920	0	.00	97.9
1920-1980	4	.24	98.1
1980-2040	2	.12	98.3
2040-2100	0	.00	98.3
2100-2160	3	.18	98.4
OVERFLOW	26	1.56	100.0

AVERAGE VALUE OF OVERFLOW 2390.15

Note: Special monitors enter this table as single jobs. The numbers cited in context were derived by merging specials as jobs - not as monitors.

TABLE XXV

EXPRESS JOB TURNAROUND
RUN IV (ADDITION OF/360)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
1193	289.137	278.776

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	4	.34	.3
60- 120	538	45.10	45.4
120- 180	265	22.21	67.6
180- 240	31	2.60	70.2
240- 300	0	.00	70.2
300- 360	2	.17	70.4
360- 420	12	1.01	71.4
420- 480	14	1.17	72.6
480- 540	22	1.84	74.4
540- 600	14	1.17	75.6
600- 660	48	4.02	79.6
660- 720	62	5.20	84.8
720- 780	67	5.62	90.4
780- 840	65	5.45	95.9
840- 900	47	3.94	99.8
900- 960	2	.17	100.0

TABLE XXVI

SPECIAL MONITOR TURNAROUND
RUN IV (ADDITION OF/360)

MONITORS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
113	463.336	203.717

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	2	1.77	1.8
60- 120	12	10.62	12.4
120- 180	6	5.31	17.7
180- 240	1	.88	18.6
240- 300	4	3.54	22.1
300- 360	4	3.54	25.7
360- 420	5	4.42	30.1
420- 480	11	9.73	39.8
480- 540	16	14.16	54.0
540- 600	24	21.24	75.2
600- 660	19	16.81	92.0
660- 720	5	4.42	96.5
720- 780	1	.88	97.3
780- 840	1	.88	98.2
840- 900	1	.88	99.1
900- 960	0	.00	99.1
OVERFLOW	1	.88	100.0

AVERAGE VALUE OF OVERFLOW 1069.00

TABLE XXVII

LOCAL JOB TURNAROUND
RUN IV (ADDITION OF/360)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
366	1153.000	587.940

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 120	29	7.92	7.9
120- 180	5	1.37	9.3
180- 240	1	.27	9.6
240- 300	10	2.73	12.3
300- 360	12	3.28	15.6
360- 420	12	3.28	18.9
420- 480	4	1.09	19.9
480- 540	0	.00	19.9
540- 600	0	.00	19.9
600- 660	0	.00	19.9
660- 720	0	.00	19.9
720- 780	1	.27	20.2
780- 840	0	.00	20.2
840- 900	0	.00	20.2
900- 960	8	2.19	22.4
960-1020	23	6.28	28.7
1020-1080	30	8.20	36.9
1080-1140	38	10.38	47.3
1140-1200	10	2.73	50.0
1200-1260	17	4.64	54.6
1260-1320	43	11.75	66.4
1320-1380	27	7.38	73.8
1380-1440	7	1.91	75.7
1440-1500	10	2.73	78.4
1500-1560	6	1.64	80.1
1560-1620	21	5.74	85.8
1620-1680	6	1.64	87.4
1680-1740	11	3.01	90.4
1740-1800	0	.00	90.4
1800-1860	0	.00	90.4
1860-1920	0	.00	90.4
1920-1980	4	1.09	91.5
1980-2040	2	.55	92.1
2040-2100	0	.00	92.1
2100-2160	3	.82	92.9
2160-2220	2	.55	93.4
OVERFLOW	24	6.56	100.0

AVERAGE VALUE OF OVERFLOW 2407.33

TABLE XXVIII

EXPRESS JOB TURNAROUND--DAY SHIFT ONLY
RUN IV (ADDITION OF/360)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
727	158.249	170.718

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	4	.55	.6
60- 120	466	64.10	64.6
120- 180	182	25.03	89.7
180- 240	17	2.34	92.0
240- 300	0	.00	92.0
300- 360	0	.00	92.0
360- 420	4	.55	92.6
420- 480	1	.14	92.7
480- 540	3	.41	93.1
540- 600	3	.41	93.5
600- 660	13	1.79	95.3
660- 720	3	.41	95.7
720- 780	1	.14	95.9
780- 840	21	2.89	98.8
840- 900	7	.96	99.7
900- 960	2	.28	100.0

The fifth and final run was made assuming that 25% of the work entering the system was submitted by 'outside' programmers. Since these programmers are not on location, day shift turnaround is probably of little or no more value than 24-hour service because of delivery times. Therefore, those jobs entering the system that were eligible for express service were segregated by their origins so that express monitors for 'inside' programmers had priority over express monitors for 'outside' programmers. This new procedure was inserted into the system represented by the previous run.

The results (Tables XXIX-XXXVIII) of this run were surprising. Not only did 'inside' programmer turnaround fail to improve, but it increased. This was attributed to two facts, one a property of the system and the other due to the model. First, the addition of a new monitor type apparently interrupted the steady flow of express monitors. The slight drop in total jobs processed (2028 in run four to 1997 in this run) can be accounted for with the drop in express jobs completed (1193 to 1178). Upon inspection of the distribution tables for locals (XXVII and XXXVIII) it was observed that local monitors were more thoroughly interspersed with express in the latter run. Only 20% (73 jobs) of the locals in run four were completed in less than 15 hours, but in the latter run 60% (195 jobs) were turned around in the same time.

The second point was more basic to simulation, or more generally, to experimentation. While experimentally testing two alternatives, it is extremely important to reproduce the same environment for each test. Care was taken to input the same number of jobs with the same compile and compute times and the same interarrival rates.

TABLE XXIX

TIME SPENT IN CARD-TO-TAPE QUEUE
RUN V (INSIDE-OUTSIDE)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
381	8.869	17.490

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	177	46.46	46.5
0- 5	79	20.73	67.2
5- 10	32	8.40	75.6
10- 15	13	3.41	79.0
15- 20	19	4.99	84.0
20- 25	19	4.99	89.0
25- 30	11	2.89	91.9
30- 35	10	2.62	94.5
35- 40	7	1.84	96.3
40- 45	4	1.05	97.4
45- 50	1	.26	97.6
50- 55	0	.00	97.6
55- 60	0	.00	97.6
60- 65	2	.52	98.2
65- 70	1	.26	98.4
70- 75	1	.26	98.7
75- 80	0	.00	98.7
80- 85	0	.00	98.7
85- 90	0	.00	98.7
OVERFLOW	5	1.31	100.0

AVERAGE VALUE OF OVERFLOW 115.00

TABLE XXX

TIME SPENT IN 7090 QUEUE
RUN V (INSIDE-OUTSIDE)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
325	399.843	649.117

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	10	3.08	3.1
0- 30	90	27.69	30.8
30- 60	33	10.15	40.9
60- 90	15	4.62	45.5
90- 120	9	2.77	48.3
120- 150	9	2.77	51.1
150- 180	8	2.46	53.5
180- 210	9	2.77	56.3
210- 240	13	4.00	60.3
240- 270	5	1.54	61.8
270- 300	9	2.77	64.6
300- 330	10	3.08	67.7
330- 360	6	1.85	69.5
360- 390	8	2.46	72.0
390- 420	4	1.23	73.2
420- 450	7	2.15	75.4
450- 480	5	1.54	76.9
480- 510	5	1.54	78.5
510- 540	5	1.54	80.0
540- 570	5	1.54	81.5
570- 600	2	.62	82.2
600- 630	3	.92	83.1
630- 660	1	.31	83.4
660- 690	2	.62	84.0
690- 720	1	.31	84.3
720- 750	8	2.46	86.8
750- 780	2	.62	87.4
780- 810	0	.00	87.4
810- 840	3	.92	88.3
840- 870	2	.62	88.9
870- 900	3	.92	89.8
900- 930	1	.31	90.2
930- 960	0	.00	90.2
960- 990	0	.00	90.2
990-1020	0	.00	90.2
1020-1050	0	.00	90.2
1050-1080	0	.00	90.2
1080-1110	0	.00	90.2
1110-1140	0	.00	90.2
1140-1170	0	.00	90.2
1170-1200	1	.31	90.5
1200-1230	0	.00	90.5
1230-1260	1	.31	90.8
1260-1290	0	.00	90.8
1290-1320	0	.00	90.8
1320-1350	2	.62	91.4
1350-1380	1	.31	91.7
1380-1410	0	.00	91.7
1410-1440	0	.00	91.7
OVERFLOW	27	8.31	100.0

AVERAGE VALUE OF OVERFLOW 2359.74

TABLE XXXI

TIME SPENT IN TAPE-TO-PRINT QUEUE
RUN V (INSIDE-OUTSIDE)

MONITORS PROCESSED	AVERAGE DELAY	STANDARD DEVIATION
318	1.019	3.426

TIME IN QUEUE (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
- 0	250	78.62	78.6
0- 5	48	15.09	93.7
5- 10	13	4.09	97.8
10- 15	5	1.57	99.4
15- 20	0	.00	99.4
20- 25	0	.00	99.4
25- 30	1	.31	99.7
30- 35	0	.00	99.7
35- 40	0	.00	99.7
40- 45	1	.31	100.0

TABLE XXXII

OVERALL JOB TURNAROUND
RUN V (INSIDE-OUTSIDE)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
1621	496.300	585.497

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	23	1.42	1.4
60- 120	449	27.70	29.1
120- 180	292	18.01	47.1
180- 240	96	5.92	53.1
240- 300	18	1.11	54.2
300- 360	21	1.30	55.5
360- 420	24	1.48	56.9
420- 480	24	1.48	58.4
480- 540	47	2.90	61.3
540- 600	60	3.70	65.0
600- 660	108	6.66	71.7
660- 720	103	6.35	78.0
720- 780	69	4.26	82.3
780- 840	29	1.79	84.1
840- 900	39	2.41	86.5
900- 960	66	4.07	90.6
960-1020	22	1.36	91.9
1020-1080	17	1.05	93.0
1080-1140	0	.00	93.0
1140-1200	0	.00	93.0
1200-1260	0	.00	93.0
1260-1320	0	.00	93.0
1320-1380	9	.56	93.5
1380-1440	1	.06	93.6
1440-1500	15	.93	94.5
1500-1560	0	.00	94.5
1560-1620	0	.00	94.5
1620-1680	0	.00	94.5
1680-1740	0	.00	94.5
1740-1800	0	.00	94.5
1800-1860	0	.00	94.5
1860-1920	0	.00	94.5
1920-1980	6	.37	94.9
1980-2040	0	.00	94.9
2040-2100	0	.00	94.9
2100-2160	0	.00	94.9
OVERFLOW	83	5.12	100.0

AVERAGE VALUE OF OVERFLOW 2566.18

Note: Special monitors enter this table as single jobs. The numbers cited in context were derived by merging specials as jobs - not as monitors.

TABLE XXXIII

EXPRESS JOB TURNAROUND--INSIDE PROGRAMMERS
RUN V (INSIDE-OUTSIDE)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
858	309.240	278.916

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	3	.35	.3
60- 120	340	39.63	40.0
120- 180	191	22.26	62.2
180- 240	32	3.73	66.0
240- 300	0	.00	66.0
300- 360	1	.12	66.1
360- 420	9	1.05	67.1
420- 480	8	.93	68.1
480- 540	15	1.75	69.8
540- 600	30	3.50	73.3
600- 660	68	7.93	81.2
660- 720	69	8.04	89.3
720- 780	41	4.78	94.1
780- 840	4	.47	94.5
840- 900	6	.70	95.2
900- 960	41	4.78	100.0

TABLE XXXIV

EXPRESS JOB TURNAROUND--OUTSIDE PROGRAMMERS
RUN V (INSIDE-OUTSIDE)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
320	458.447	342.349

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	4	1.25	1.2
60- 120	32	10.00	11.2
120- 180	67	20.94	32.2
180- 240	50	15.63	47.8
240- 300	13	4.06	51.9
300- 360	13	4.06	55.9
360- 420	6	1.87	57.8
420- 480	1	.31	58.1
480- 540	3	.94	59.1
540- 600	4	1.25	60.3
600- 660	8	2.50	62.8
660- 720	6	1.87	64.7
720- 780	27	8.44	73.1
780- 840	18	5.62	78.7
840- 900	20	6.25	85.0
900- 960	23	7.19	92.2
960-1020	8	2.50	94.7
1020-1080	17	5.31	100.0

TABLE XXXV

EXPRESS JOB TURNAROUND--INSIDE PROGRAMMERS--DAY SHIFT ONLY
RUN V (INSIDE-OUTSIDE)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
540	181.450	207.535

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	3	.56	.6
60- 120	304	56.30	56.9
120- 180	160	29.63	86.5
180- 240	20	3.70	90.2
240- 300	0	.00	90.2
300- 360	0	.00	90.2
360- 420	0	.00	90.2
420- 480	1	.19	90.4
480- 540	1	.19	90.6
540- 600	5	.93	91.5
600- 660	4	.74	92.2
660- 720	10	1.85	94.1
720- 780	1	.19	94.3
780- 840	4	.74	95.0
840- 900	5	.93	95.9
900- 960	22	4.07	100.0

TABLE XXXVI

EXPRESS JOB TURNAROUND--OUTSIDE PROGRAMMERS--DAY SHIFT ONLY
RUN V (INSIDE-OUTSIDE)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
180	351.183	331.392

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	4	2.22	2.2
60- 120	30	16.67	18.9
120- 180	52	28.89	47.8
180- 240	31	17.22	65.0
240- 300	9	5.00	70.0
300- 360	3	1.67	71.7
360- 420	6	3.33	75.0
420- 480	1	.56	75.6
480- 540	0	.00	75.6
540- 600	2	1.11	76.7
600- 660	0	.00	76.7
660- 720	1	.56	77.2
720- 780	4	2.22	79.4
780- 840	4	2.22	81.7
840- 900	4	2.22	83.9
900- 960	14	7.78	91.7
960-1020	5	2.78	94.4
1020-1080	10	5.56	100.0

TABLE XXXVII

SPECIAL MONITOR TURNAROUND
RUN V (INSIDE-OUTSIDE)

MONITORS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
118	445.771	192.809

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 60	0	.00	.0
60- 120	14	11.86	11.9
120- 180	7	5.93	17.8
180- 240	3	2.54	20.3
240- 300	3	2.54	22.9
300- 360	4	3.39	26.3
360- 420	6	5.08	31.4
420- 480	11	9.32	40.7
480- 540	28	23.73	64.4
540- 600	24	20.34	84.7
600- 660	10	8.47	93.2
660- 720	5	4.24	97.5
720- 780	0	.00	97.5
780- 840	1	.85	98.3
840- 900	1	.85	99.2
900- 960	0	.00	99.2
OVERFLOW	1	.85	100.0

AVERAGE VALUE OF OVERFLOW 979.00

TABLE XXXVIII

LOCAL JOB TURNAROUND
RUN V (INSIDE-OUTSIDE)

JOBS PROCESSED	AVERAGE TURNAROUND	STANDARD DEVIATION
325	1045.754	990.761

TURNAROUND (IN MINUTES)	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE
0- 120	79	24.31	24.3
120- 180	27	8.31	32.6
180- 240	11	3.38	36.0
240- 300	2	.62	36.6
300- 360	3	.92	37.5
360- 420	3	.92	38.5
420- 480	4	1.23	39.7
480- 540	1	.31	40.0
540- 600	2	.62	40.6
600- 660	22	6.77	47.4
660- 720	23	7.08	54.5
720- 780	1	.31	54.8
780- 840	6	1.85	56.6
840- 900	12	3.69	60.3
900- 960	2	.62	60.9
960-1020	13	4.00	64.9
1020-1080	0	.00	64.9
1080-1140	0	.00	64.9
1140-1200	0	.00	64.9
1200-1260	0	.00	64.9
1260-1320	0	.00	64.9
1320-1380	9	2.77	67.7
1380-1440	1	.31	68.0
1440-1500	15	4.62	72.6
1500-1560	0	.00	72.6
1560-1620	0	.00	72.6
1620-1680	0	.00	72.6
1680-1740	0	.00	72.6
1740-1800	0	.00	72.6
1800-1860	0	.00	72.6
1860-1920	0	.00	72.6
1920-1980	6	1.85	74.5
1980-2040	0	.00	74.5
2040-2100	0	.00	74.5
2100-2160	0	.00	74.5
2160-2220	1	.31	74.8
OVERFLOW	82	25.23	100.0

AVERAGE VALUE OF OVERFLOW 2570.98

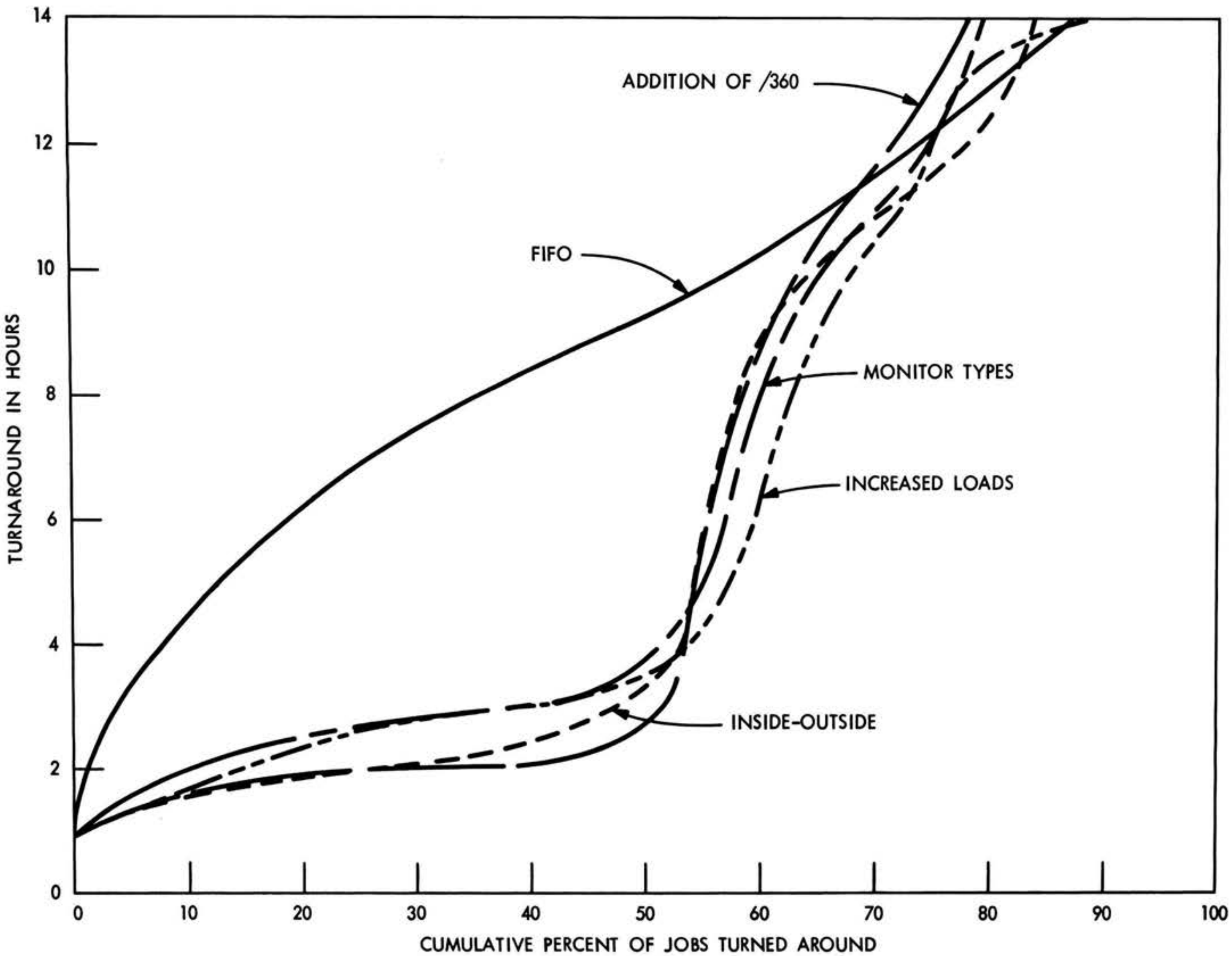
The model was allowed to categorize the jobs and construct the monitors by given sets of rules and a random number generator which will, of course, produce the same sequence of pseudo-random numbers from one initial run to the next. The exact duplication of random number sequences is very desirable since it is a valuable aid to reproducing exactly the same environment from one run to the next, thus sharpening the contrast between alternatives. Although the same sequence was produced between run four and run five, it was used dissimilarly because in run five the model sampled the sequence to determine whether jobs were submitted from 'inside' or 'outside' programmers. This interrupted the sequence as it was used in run four. The selection of special jobs also used the model random number generator; consequently, the jobs selected as specials in run five were not the same as those selected in run four. Note that although the same percentage of jobs were requested in the two runs, 25 more jobs (five monitors) were specials in the latter run and as it happened all were run during the day shift. Therefore, express turnaround could have been adversely affected. However if these specials had been the major influence on express turnaround, a queue of express jobs would have formed behind these specials. Apparently this did not occur since the low priority locals were allowed to move more freely through the system, indicating the absence of express monitors awaiting service. Therefore the <u>a priori</u> conclusion was that further separation of express work was detrimental to system flowthrough and the run was not repeated.

TABLE XXXIX

SUMMARY OF RESULTS AT FRIDAY 4:00 P.M. AND BACKLOG AT SATURDAY MIDNIGHT

		QUEUES			AVERAGE UTILIZATION		WORK COMPLETED								BACKLOG AT SATURDAY MIDNIGHT
								INSIDE					OUTSIDE		
		CARD-TAPE	7090	TAPE-PRINT	1401'S	7090'S	OVERALL	EXPRESS (ALL)	EXPRESS (DAY)	SPECIAL	LOCAL	LONG	EXPRESS (ALL)	EXPRESS (DAY)	
Run I (FIFO) 2066 Jobs Generated	Number of Monitors Completed	207	182	178	293*	187									None
	Number of Jobs Completed						1782	1782	661						
	Mean Time Required (Min.)	5.9	372	4.2			569	569	540						
	Utilization of Resources				.8197	.9899									
Run II (Introduction of Monitor Types) 2066 Jobs Generated	Number of Monitors Completed	318	306	291	344*	311									9 Jobs Requiring 765 7090-Minutes
	Number of Jobs Completed						1783	1044	584	447	289	3			
	Mean Time Required (Min.)	144	299	60			559	321	232	426	1607	2523			
	Utilization of Resources				.9818	.9719									
Run III (Increased Load) 2276 Jobs Generated	Number of Monitors Completed	330	324	299	352*	326									28 Jobs Requiring 2280 7090-Minutes
	Number of Jobs Completed						1821	1127	552	480	214	0			
	Mean Time Required (Min.)	276	186	165			577	330	172	433	2202	0			
	Utilization of Resources				.9961	.9263									
Run IV (Run III Substituting 360 for 1401) 2276 Jobs Generated	Number of Monitors Completed	385	330	328	298*	332									16 Jobs Requiring 1417 7090-Minutes
	Number of Jobs Completed						2028	1193	727	469	366	0			
	Mean Time Required (Min.)	8	350	1			485	289	158	463	1153	0			
	Utilization of Resources				.7171	.9933									
Run V (Run IV with Inside-Outside) 2276 Jobs Generated	Number of Monitors Completed	381	325	318	294*	327									24 Jobs Requiring 1789 7090-Minutes
	Number of Jobs Completed						1997	858	540	494	325	0	320	180	
	Mean Time Required (Min.)	8	399	1			459	309	181	445	1045	0	458	351	
	Utilization of Resources				.7110	.9965									

* This 1401 average includes non-monitor (1401 only) jobs.



OVERALL TURNAROUND TIME DISTRIBUTION CURVES

Figure 7

VI CONCLUSIONS AND RESULTS

It has been shown that the construction of priority monitors for preferred jobs appreciatively reduces turnaround time for those jobs. This effect is illustrated in Figure 7.

The first experiment indicated that more than 50% of the jobs completed were returned in less than four hours as opposed to nine hours (at the 50% level) using the FIFO policy. The range of turnaround time, however, was widened by more than 24 hours. Furthermore, another shift would have been required to "clean up" the backlog of work after 17 shifts. In addition, the increased number of monitors (caused by the monitor run time reductions) created a noticeable growth of the input/output queues.

Increasing the workload demonstrated the stability of the model, i.e., a substantial load change did not cause unreasonable fluctuations of the system variables. It did, however, exhibit the inadequacy of the input/output devices in such an environment.

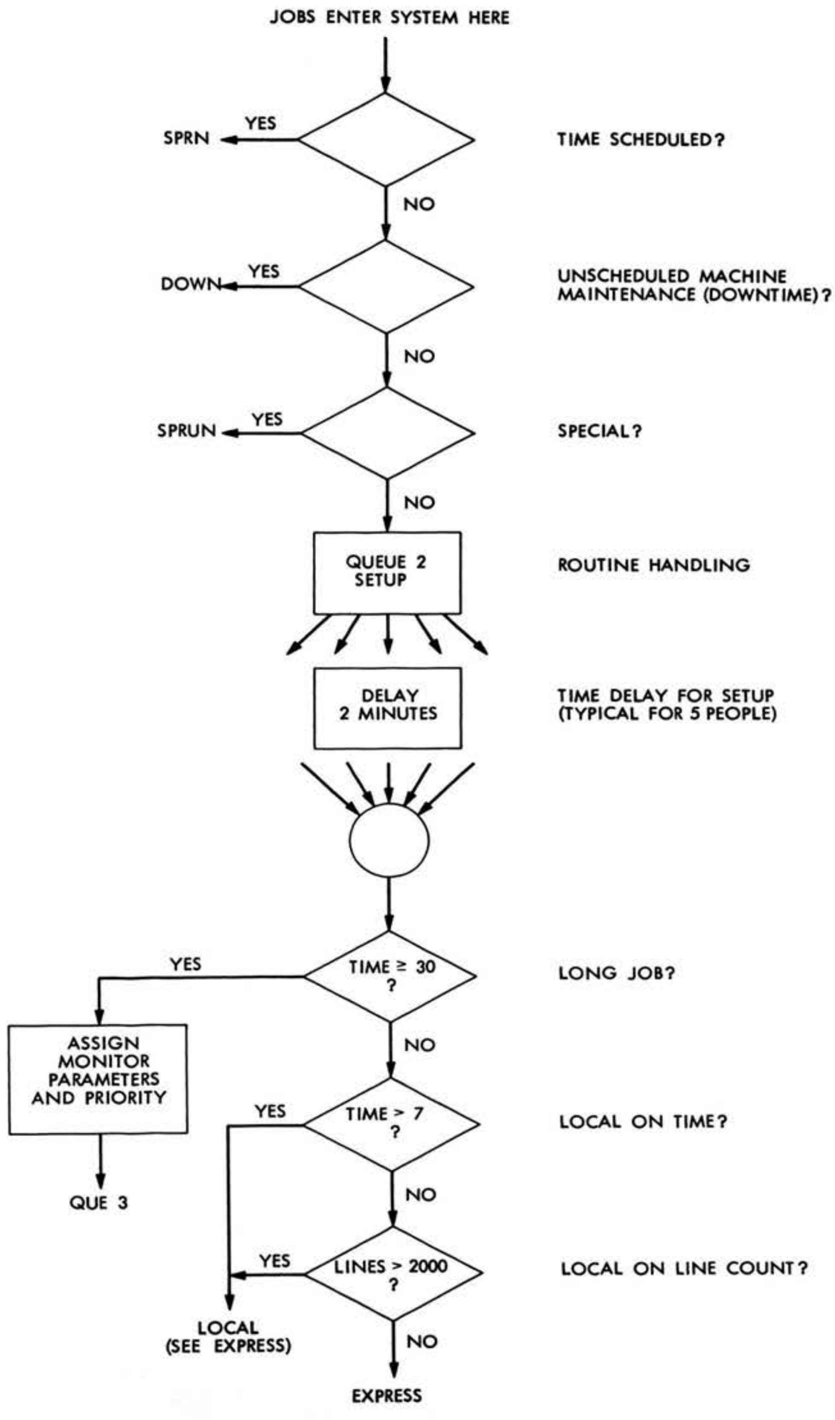
The addition of more input/output capabilities facilitated the completion of 207 jobs in the first 13 shifts and nearly cut the week-end backlog in half. The input/output utilization of only.7171 indicates that perhaps still another 1401 could be released. This possibility was not tested, but further tests of this nature could easily be implemented.

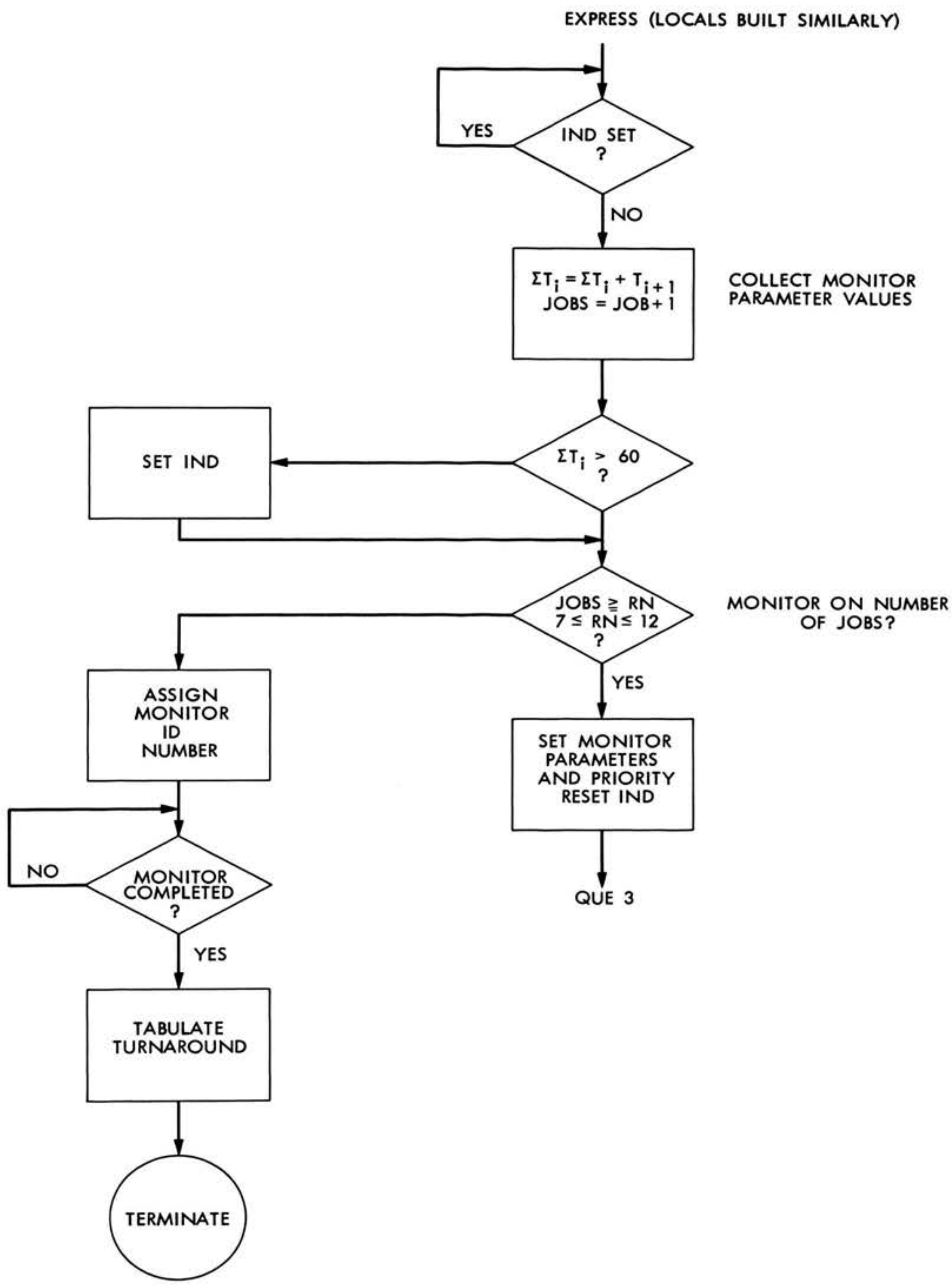
Finally, it has been shown that too many job priority classifications can interrupt a smooth flow of work which can cause poor service for priority groups.

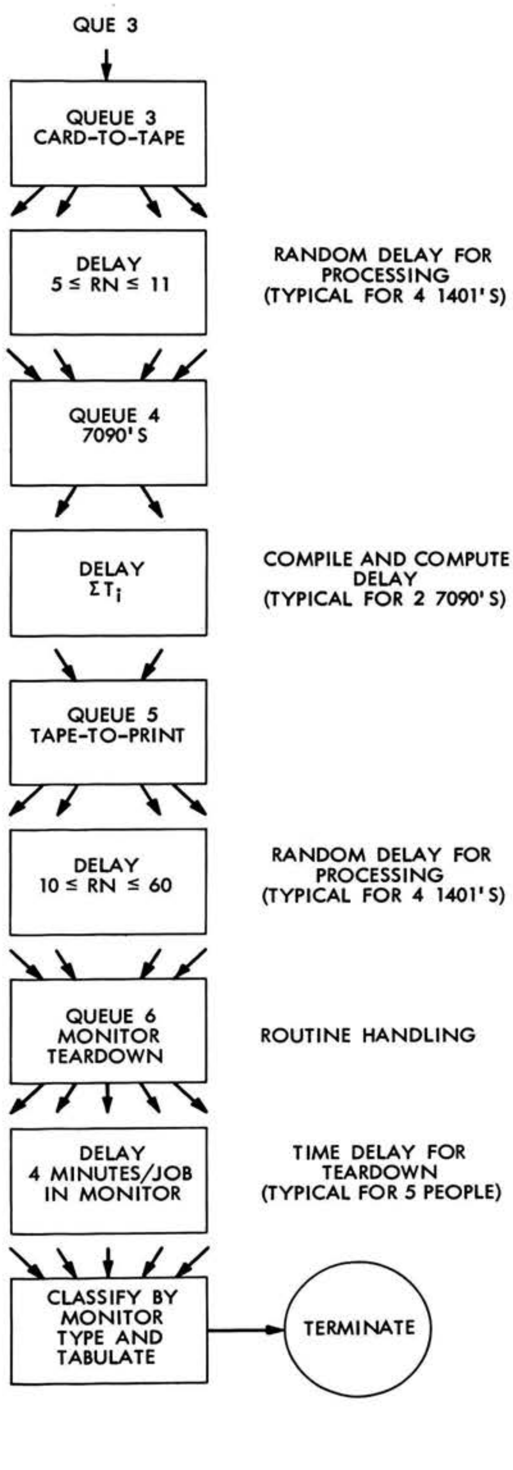
The purpose of this type of study is to provide information for the decision maker. Certainly additional criteria must be weighed with these results. Some computer center managers would argue that equipment utilization, for example, should be the measure of performance. An effective combination of several criteria is the best measure.

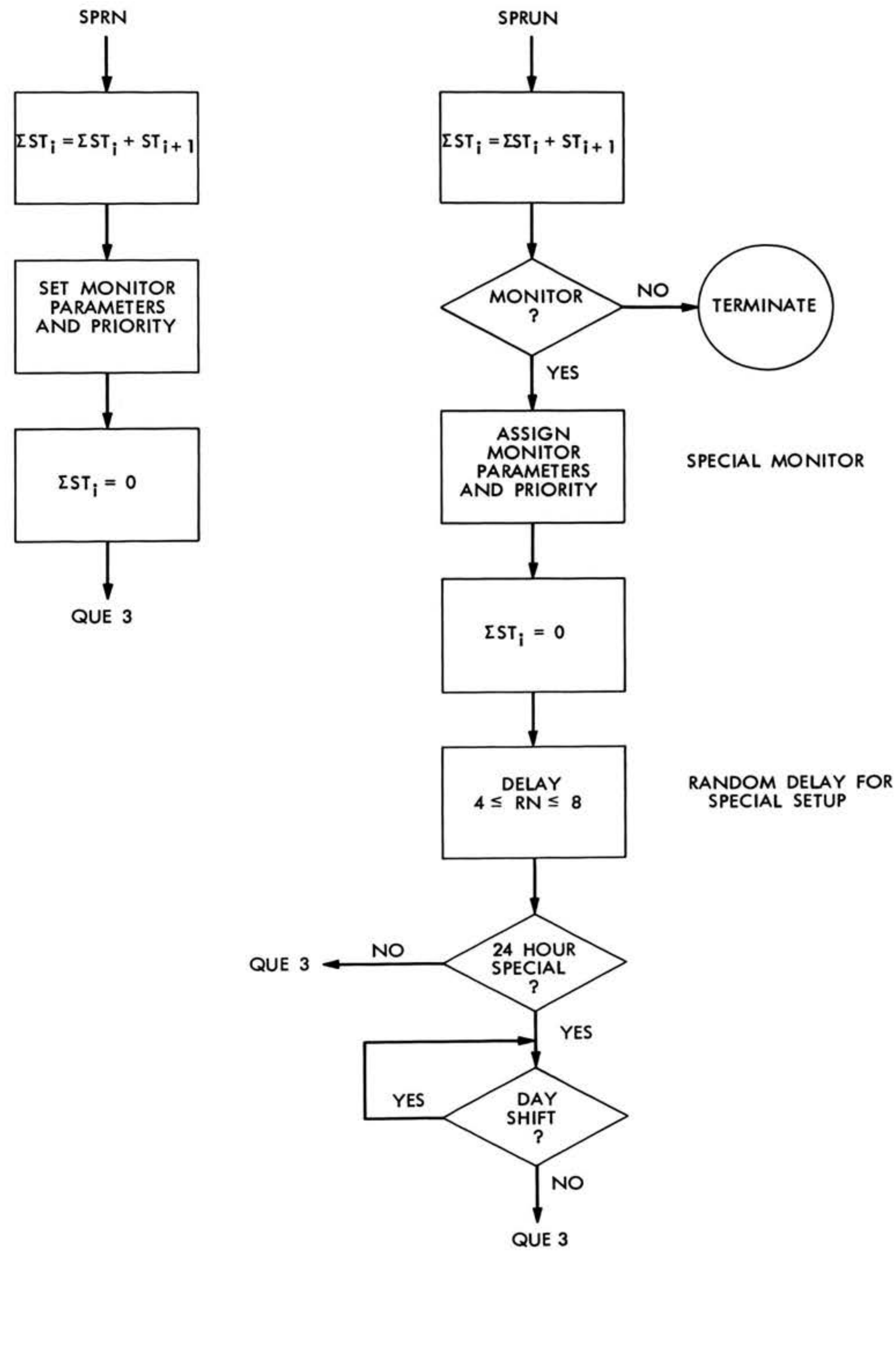
Once a realistic computer simulation model has been developed, the experimental potential is unlimited. If the decision maker accepts the concepts of modeling and simulation and he takes advantage of this potential, he may improve the quality (and the quantity) of his decisions.

APPENDIX
ABBREVIATED FLOW DIAGRAM

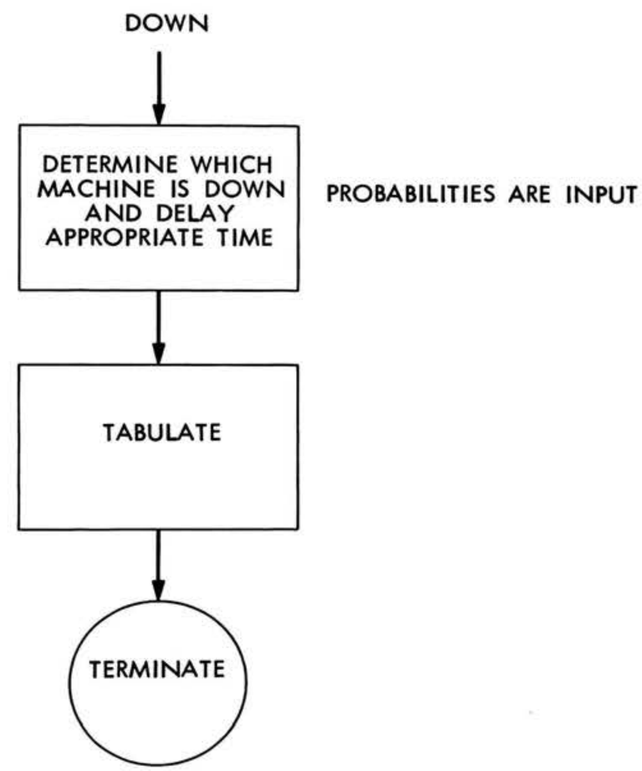


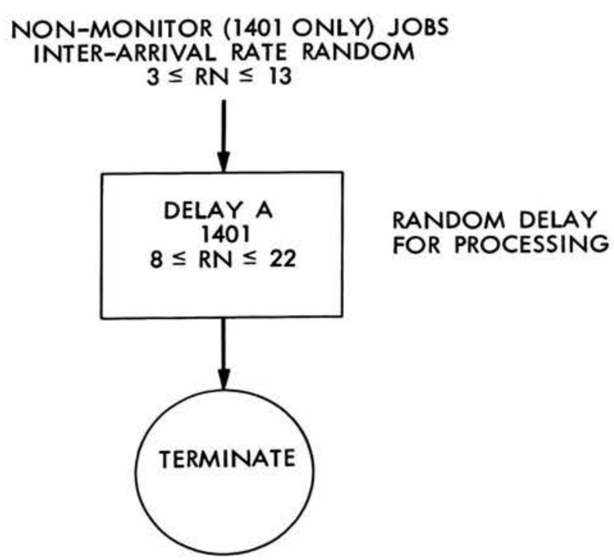

EXPRESS (LOCALS BUILT SIMILARLY)
YES
IND SET ?
NO
ΣTi = ΣTi + Ti+1
JOBS = JOB+1
COLLECT MONITOR PARAMETER VALUES
SET IND
ΣTi > 60 ?
JOBS ≧ RN
7 ≤ RN ≤ 12 ?
MONITOR ON NUMBER OF JOBS?
YES
ASSIGN MONITOR ID NUMBER
SET MONITOR PARAMETERS AND PRIORITY RESET IND
QUE 3
NO
MONITOR COMPLETED ?
YES
TABULATE TURNAROUND
TERMINATE


QUE 3
QUEUE 3
CARD-TO-TAPE
DELAY
5 ≤ RN ≤ 11
RANDOM DELAY FOR PROCESSING (TYPICAL FOR 4 1401'S)
QUEUE 4
7090'S
DELAY
ΣT
COMPILE AND COMPUTE DELAY (TYPICAL FOR 2 7090'S)
QUEUE 5
TAPE-TO-PRINT
DELAY
10 ≤ RN ≤ 60
RANDOM DELAY FOR PROCESSING (TYPICAL FOR 4 1401'S)
QUEUE 6
MONITOR
TEARDOWN
ROUTINE HANDLING
DELAY
4 MINUTES/JOB
IN MONITOR
TIME DELAY FOR TEARDOWN (TYPICAL FOR 5 PEOPLE)
CLASSIFY BY
MONITOR
TYPE AND
TABULATE
TERMINATE


SPRN
ΣST_i = ΣST_i + ST_i+1
SET MONITOR PARAMETERS AND PRIORITY
ΣST_i = 0
QUE 3
SPRUN
ΣST_i = ΣST_i + ST_i+1
MONITOR ?
NO
TERMINATE
YES
ASSIGN MONITOR PARAMETERS AND PRIORITY
SPECIAL MONITOR
ΣST_i = 0
DELAY 4 ≤ RN ≤ 8
RANDOM DELAY FOR SPECIAL SETUP
24 HOUR SPECIAL ?
NO
QUE 3
YES
DAY SHIFT ?
YES
NO
QUE 3

SHIFT CHANGES (SETUP PEOPLE)


DOWN
DETERMINE WHICH MACHINE IS DOWN AND DELAY APPROPRIATE TIME
PROBABILITIES ARE INPUT
TABULATE
TERMINATE


NON-MONITOR (1401 ONLY) JOBS
INTER-ARRIVAL RATE RANDOM
3 ≤ RN ≤ 13
DELAY A 1401
8 ≤ RN ≤ 22
RANDOM DELAY FOR PROCESSING
TERMINATE

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