AN EVALUATION OF MULTIPLE JOB SHOP SEQUENCING POLICIES

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of the
requirements for
the Degree of
DOCTOR OF PHILOSOPHY
July, 1972

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PREFACE

A number of digital simulation investigations have been concerned with the effect of various sequencing policies on job shop performance. Research has been restricted, however, to the general application of one sequencing discipline to all waiting jobs. In many job shop applications, this procedure is inappropriate or even infeasible. Job shop sequencing invariably involves an attempt to minimize job flow time, the number of machine setups, and the lateness of critical jobs. These objectives are frequently achieved by the simultaneous application of several sequencing rules. The primary purpose of this investigation is to evaluate the effect of switching between sequencing rules. It is hoped that the contribution made by this dissertation will aid job shop managers in deciding upon the suitable combination of sequencing rules for particular applications.

The author wishes to express his appreciation to his major adviser, Dr. Earl J. Ferguson, for his guidance and assistance during this investigation. Through his efforts, the author learned that the rewards of a research endeavor will be evident with patience and faith in one's ability. Appreciation is also expressed to the other committee members: Dr. Hamed K. Eldin, for his encouragement and

insistance on high professional standards; Professor Frederick M. Black, who initially stimulated the author's interest in simulation; and Dr. Carl B. Estes, for his moral and professional support.

The author also wishes to express deep appreciation to Miss Velda Davis for her assistance in typing the initial and final drafts of the manuscript.

Finally, special gratitude is expressed to my wife, Bonita, for her understanding, encouragement, and many sacrifices during the two years of schooling and research that became five.

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CHAPTER I

INTRODUCTION

Computer simulation has long been recognized as the most feasible method of analyzing the scheduling problems associated with complex job shop production systems. Researchers have demonstrated through a variety of simulation experiments that the order in which jobs are processed can significantly affect the operation of a job shop with respect to various performance criteria. Consequently, numerous sequencing rules have been developed and evaluated. Moore and Wilson (1) list 23 of the more common rules which are far from exhaustive. The total number is limited only by the imagination of the researcher, scheduler, or job shop manager.

Sequencing rules may be classified as local or global depending upon the extent of the information required for their implementation. A local rule is based only on the attributes of jobs competing for service at a particular machine; whereas, the global rule requires additional information about jobs or machine states at other machine centers or queues. Since global rules depend upon an effective and possibly costly management information system, they have not been very popular with researchers and job shop managers.

The local rules can be further categorized as simple or compound. Simple rules consider one job attribute to determine the sequence priority. The shortest process time rule, favored by many researchers, is typical of this category. This rule recognizes the setup and service time for the succeeding operation and selects the job with the shortest total process time to run first. In contrast, a compound rule calculates a priority assignment from a combination of two or more job attributes. For example, a rule may dictate that jobs are processed in ascending process time order; and within each process time class, all jobs of a particular size or color are run first. By applying various weighting factors to each attribute, many variations of the rule could be constructed.

Considering the number of rules in each category, identification of the preferred rule in a particular application may appear to be an interminable process. Actual job shop conditions and managerial objectives, however, would eliminate a number of rules from consideration. A select few, probably no more than five or six, would be evident for potential implementation. Researchers have identified the rules which best fulfill designated performance criteria. Some of the more significant rules are discussed in Chapter II.

Previous research has been restricted to the application of one sequencing rule to all waiting jobs in a job shop system. It is conceivable, however, that different rules could be applied simultaneously to various queues.

As Moore and Wilson (1, p. 9) observed, "A scheduler may, in practice, use a mixture of sequencing rules. Yet, the effect of switching between rules has received little attention." Would some combination of rules improve the operation of a job shop? It is theorized at this time that if applied in a valid manner to an appropriate job shop, a proper set of sequencing rules will surpass the effects of one rule.

The proposed investigation will attempt to explore the above mentioned effects through computer simulation. Since the combinatorial possibilities in such an investigation could become quite numerous, it will not attempt to be all encompassing. Instead, it will concentrate on rules which are logically admissible in an actual job shop. The selected set of rules will be evaluated against a recognized standard single rule and against the sequencing procedure currently implemented in the shop.

Research Objectives

The primary objective of this research is to extend job shop scheduling theory by investigating the application of multiple sequencing rules. This objective is accomplished through the development of a computer simulation model of an actual job shop system. More specifically, four sequentially dependent processes in a job shop typical of those found in the hose manufacturing industry are simulated in which six sets of unique sequencing combinations are analyzed. In each of the six combinations a specific, but possibly different, sequencing rule is applied to each process. The shortest process time rule applied to each of the four stages is established as the standard against which the other rule combinations are compared. The six rule sets, along with the reasoning behind their selection, the performance criteria with which they were evaluated, and the model assumptions are presented in Chapter IV after a description of the job shop system.

Another objective is to develop a realistic job shop model employing the General Purpose Simulation System/360. The model incorporates the effects of machine downtime by shift due to normal breakdowns, job setups, and labor force variations. Shop operating data including downtime, production by process, and job routing is obtained from actual shift status reports. Machine running time, a random variable dependent upon various job characteristics, is established from standard time data.

A third objective is to evaluate the effect of setup priority rules on the operation of the job shop. Three sets of sequencing rules are expressly designed to group jobs of common characteristics in order to minimize downtime attributable to machine setups.

A fourth objective is to evaluate the six sets of sequencing rules against the sequencing policy currently implemented in the job shop. This highly flexible policy, which incorporates expediting, is primarily directed towards the completion of jobs on a predetermined date. The results of this evaluation constitute a set of alternatives for consideration by management. It is recognized that any solution to a job shop scheduling problem involves a compromise in satisfying various performance criteria; management is ultimately required to select the sequencing policy which best fulfills its needs.

The fifth and final objective is to develop a practical procedure for validating the computer model. The procedure is designed to show that the model is a reasonably acceptable representation of the reference system from which inferences about the reference system may be drawn.

Stages of the Investigation

The investigation took place in three distinct stages. The first stage consisted of data acquisition and job shop orientation. Job shop literature particularly concerned with computer simulation was reviewed. The researcher gained an insight into the operation of the reference job shop through interviews with the resident industrial engineer and schedulers and by reviewing operational data. Where germane data was unavailable, preliminary estimates and hypotheses were formulated. Where necessary, data was converted to a form suitable for computer simulation.

Model construction and validation, the second stage, was by far the most time consuming. After flow-charting and assembling the model in the General Purpose Simulation

System (GPSS), the model was simulated in the IBM 360/65 computer. Using the Wilcoxin rank-sum test for identical populations, the model was statistically demonstrated to be a valid representation of the reference job shop.

The third stage was a simulation and evaluation of the five sets of sequencing rules. The results were analyzed with consideration to the designated performance criteria. The assumptions used in constructing the model were re-evaluated to gain some insight towards future research.

Before proceeding into a description of the job shop system, a brief review of the literature will be presented.

CHAPTER II

LITERATURE REVIEW

This chapter summarizes the results of several digital computer models which are representative of the work that has been accomplished in the past fifteen years. The particular references herein described are intended to provide a greater insight into the job shop scheduling problem and were used as guidelines for the present research. Unless otherwise noted, all are based upon, but not necessarily limited to, the following assumptions:

(1) Machines do not break down and are never unable to perform their designated tasks for lack of an operator, tool, or material.

(2) No machine may process more than one job at a time and no job splitting is allowed.

(3) Each job, once started, must be performed to completion.

(4) Jobs move instantaneously from one machine to another.

(5) All process times are considered to be random variables obtained from a common distribution.

(6) Setup time is independent of the sequence in which the jobs are performed.

A considerable amount of research has been concerned with the development of optimal local priority rules. The shortest process time (SPT) rule, probably the most widely referenced, was investigated by Conway and Maxwell (2) in an experiment in which the number of machines in operation, and the level of work in process, were controlled variables. When compared to a rule which selected jobs on a random basis, variations of the SPT rule more effectively minimized average and total flow time, the average number of jobs in process, average waiting time, and average job lateness. Although the resulting variation in flow time was especially high, Conway and Maxwell hypothesized that the SPT rule was the optimal local priority rule.

In later research, Conway (3) evaluated a series of local priority rules, both simple and compound, using a larger computer and an expressly designed simulation language. Although no single rule exhibited the best performance simultaneously for all evaluation criteria, the SPT rule warranted the highest overall valuation. It was an important component of every compound rule that minimized some performance measure and as a simple rule it clearly dominated all the other rules tested. In contrast with the previous experiment, the flow time variance with the SPT rule was smallest except for a rule which was specifically directed to this objective. Conway also studied the performance degradation of the SPT rule with progressively poorer estimates of processing time. In practice, the process time may not be known with absolute certainty. Consequently, some selections with this rule would not represent the shortest processing time of the jobs in queue, with the worst situation occurring when the estimates were completely exorbitant. When the error in process time estimation was less than ten per cent, there was no detectable degradation in performance; when the error in estimation was one hundred per cent, SPT lost only approximately ten per cent of its advantage over the random rule. Considering the overall performance of the SPT rule, Conway (3, pp. 129-130) concluded:

> It surely should be considered the 'standard' in scheduling research, against which candidate procedures must demonstrate their virtue.... There are many ways of modifying the shortest processing time priority rule and of combining it with other rules. The 'SPT influence' seems to be always beneficial. This should be considered an important building block in any scheduling procedure. It should at least be used to break ties, and resolve indifferences -- all other things being equal (or immaterial), select the job with the shortest processing time.

Rejecting the sequence - independent setup assumption as an over-simplification, Baker (4) compared the results from setup time oriented rules with the SPT, first to arrive in queue is served first, and shortest service time rules. The average flow time by completed jobs was selected as the measure of performance. Using mean setup and mean service times of 0.2 and 1.25 time units, respectively, Baker found that the rules which disregarded setups fared better than the setup oriented rules. A rule which processed all jobs of a given class before proceeding to another class in a fixed class sequence (FIXSEQ) did perform well, however, with respect to both mean and maximum flow times. Moreover, when the mean setup time was doubled, this rule proved to be markedly superior to the other rules.

In a similar study, Wilbrecht and Prescott (4) investigated the SIMSET rule which assigns the highest priority to the job with the smallest setup time regardless of its run time. Their simulation model randomly assigned setup values of 1, 2, 3, or 4 time units and service time values between 1 and 20 time units. When compared with the random rule and five service time oriented rules, SIMSET gave the best overall performance result. It was the only rule, for example, that completed a number of jobs per week statistically different from the random rule. These two experiments are particularly interesting since they both indicate that setup times play a crucial role in job shop performance. Future research may establish the job shop conditions and critical setup-service time ratio which would warrant the use of setup oriented rules over service oriented rules.

The effect of compound priority rules has also been the subject of intense research. Typical of this research is the work of Maxwell and Mehra (6) who studied the relationship between job shop performance and priority rule complexity in an assembly structured environment. The job shop model consisted of eight machines and the measures of performance were the mean flow time, mean tardiness, and the per cent of jobs tardy. The investigation started with simple rules and progressed methodically to complex composite rules which included both local and global factors. The investigators found that for assembly structured jobs an operational slack factor (OSF) rule which assigned the highest priorities to jobs with the lowest slack value exhibited the best performance. In their context, slack is defined as the job due date minus the time at which a selection from queue is to be made minus the remaining processing time. The SPT rule was second best and both rules were considerably more effective than the remaining simple rules. If the simple rules could give good results, Maxwell and Mehra reasoned that more complex rules should perform even better since the sequencing policy would be based on more information. Consequently, simple rules were assigned various weights, combined, and evaluated. The results, however, only partially fulfilled expectations. Many composite rules improved the performance, but the improvement was not significant enough considering the increase in information content needed to implement the rule. This was especially evident when global information was provided. However, one composite rule which gave a relatively high weight to an SPT factor proved to be uniformly superior with regards to all the measures of performance. The rule, a composite of three simple rules, is written in notational form as: OSF(0.25) + SPT(0.25) + OUF(0.50), where the numbers in parentheses are weighting factors and OUF is a factor which gives a high priority to jobs which require more extensive processing and with tighter due dates. Maxwell and Mehra concluded that for assembly structured job shops, the value of the information in a local priority rule is significant. The simple rule will perform relatively poorly when compared to compound rules. However, the inclusion of global status information does not show a significant improvement in performance.

One more reference to be discussed is representative of the limited research performed in conjunction with an actual job shop using real-world data. Earl LeGrande (7) simulated the El Segundo fabrication shop of the Hughes Aircraft Company. The shop consisted of approximately 1000 machines and work stations and a labor force of 400 divided into five interacting sections: machine shop, sheet metal shop, metal processing, waveguide manufacturing, and tool manufacturing. For simulation purposes, the shop was organized into 115 machine groups and 47 labor classes. Each machine group was capable of performing a given operation and each labor class was assigned to one or more specific machine groups. Numerous paths for work in progress through the machine groups were possible because of the variable product mix and physical arrangement of equipment. Routing information for the simulated jobs was derived from a transition probability matrix and the processing time was obtained by sampling from a negative exponential distribution with a mean equal to the mean processing time for the particular machine group. LeGrande was forced to reduce the actual job load in the simulation by 25 per cent because of computer capacity limitations; consequently, the statistical validity of his model has been questioned. But since the only model condition allowed to vary during the course of the investigation was the priority rule under evaluation, he felt that his results would be valid; and changes in model performance would be attributable to the manner in which the jobs were sequenced through the shop. Six simple priority rules were evaluated. Under the assumption that each of ten performance criteria was of equal importance, the SPT rule gave the best results. This rule produced the greatest number of completed jobs, the lowest average number of jobs waiting in the shop, and the highest utilization of labor and equipment.

CHAPTER III

JOB SHOP DESCRIPTION

In the early stages of research involving job shop simulation, the researcher is invariably confronted with a model development problem. Should the model be constructed around a hypothetical job shop with fictitious data or around an actual job shop with real-world data?

Modeling activity is always subject to time and cost restraints. Therefore, it would be advantageous to develop the simplest possible model which is capable of fulfilling the research objectives. The hypothetical model is relatively easy to design since the sequential logic and parameter values can be arbitrarily determined. Moreover, previous research has indicated that the results from such models may be extended with reasonable confidence to real applications. An additional effort is required to model an actual job shop, but many more practical benefits may be realized. Priority rules may be compared with both a recognized standard rule and actual sequencing policies which may be based on human experience without reference to any specified rule. The model would also be capable of evaluating changes in machinery, staffing, shop layout, and job characteristics. The latter approach was selected for this research.

The job shop consists of four processes commonly used in the manufacture of rubber hose for industrial and commercial applications. The shop is capable of manufacturing a wide variety of hoses consistent with technical and physical specifications. Production is primarily directed towards the replenishment of fast-moving inventory stock, but the fabrication of special non-inventory customer orders is also common. In the latter case, however, an extended due date is specified. Shop operation is normally scheduled on a continuous basis, five days a week, to keep pace with customer demand. The number of operational machines changes over each of the three daily work shifts due to preordained variations in the work force and normal breakdowns.

Regardless of specification, each hose consists of three common elements. As is shown in Figure 1, the innermost element is the rubber tube whose function is to retain the fluids transported by the hose. The chemical composition, inside diameter, and thickness of the tube are expressly designed to provide the physical properties necessary for anticipated service conditions. The reinforcement, composed of textile fibers or yarn, enables the hose to withstand internal pressure or external forces. The design strength is determined by the type of weave, the number of plies, and the composition of the yarn. The cover is the outermost element and protects the reinforcement from

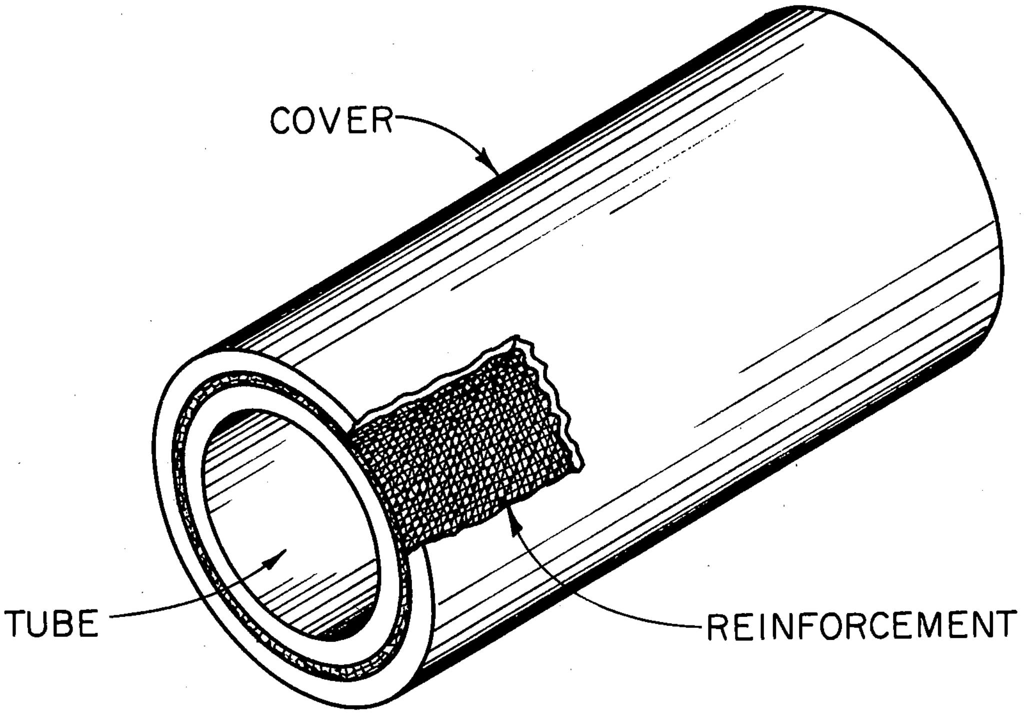


Figure 1. Hose Construction

outside damage or abuse. Cover composition, color, and thickness may also be varied in conformance with particular specifications.

Three job shop processes are involved with the physical construction of the hose and the fourth process is a preliminary operation for vulcanization. The tube is formed to a specified inside diameter and wall thickness in the first process by one of three continuous extrusion machines. Two machines are referred to as 4.5 inch tubers and the third as a 6 inch tuber. Each tuber is designed to process tube stock of specified inside diameters. The 4.5 inch and 6 inch tubers produce tube stock of 0.250 to 0.700 and 0.701 to 1.500 inches, respectively. The rate at which tube is fabricated is primarily dependent upon its inside diameter and chemical composition. Machine setups of approximately twenty minutes duration are required whenever the rubber composition of the tube is changed. After extrusion, the tube is stored and transported on a circular tray called a pan, which is also the generally accepted term for a job unit of hose. Depending upon the outside diameter of the tube, each pan can accommodate tube lengths of 600 to 1050 feet. Job lots up to 100 pans are not uncommon. Since a considerable amount of heat is generated during the extrusion process, a minimum cooling time of eight hours must elapse before the tube is allowed to proceed through the shop.

In the second process, reinforcement, a textile cord is formed over the tube by braiding or knitting machines. A braided cord is generated by displacing yarn carriers in a weaving motion around the tube. Braiding machines are categorized as single or double deck and according to the number of carriers on each deck. Both single and double deck braiders with 20, 24, 36, 48, and 64 carriers are in use in the shop. Each deck applies a single ply of braid to the tube. By making multiple passes through the single deck machines, multiple braid hose may also be produced. The process time per pan is determined by both the type of weave and number of passes through the machine. Whenever a new yarn type is specified, a machine setup is performed, at which time each yarn carrier must be exchanged. Therefore, the setup time for a particular machine depends upon its yarn carrier configuration. Although not providing as much reinforcement strength to the tube, the knitted cord can be generated at a much faster rate. Process time and machine setups are contingent upon the knitted pattern desired and the yarn type, respectively. Knitting machines may have one or two decks of yarn carriers. Each deck accommodates four yarn carriers.

Since the reinforcement process is much slower with relation to the preceding and succeeding processes, many more machines are required to maintain the flow of pans through the shop. Hose reinforcement is performed by 137 machines and as many as 12 machines may be scheduled for each job lot. To further increase pan flow, the lots may be split into two smaller lots.

Twenty operational zones are designated with the reinforcement area. One operator is responsible for all the machines in a zone. Therefore, only one machine setup can be performed in a zone at a time. Moreover, when an operator is absent for a prolonged period, all the machines in a zone become unserviceable. Table I shows the designation and number of machines in each zone. For simulation purposes, the zones are numbered 3 through 23.

In the third process, a rubber cover is extruded over the reinforced tube. The process is performed by two machines generally referred to as 4.5 inch and 6 inch cover machines. Reinforced tubes with outside diameters between 0.300 and 0.900 inches and 0.851 to 2.000 inches are processed by the 4.5 inch and 6 inch covers, respectively. Either machine can accommodate the overlapping sizes. The outside diameter of the inflated reinforced hose and the composition of the cover determines the process time through the two machines. Machine setups occur when the chemical composition or color of the cover are changed. As in the first process, an 8-hour cooling period is required before further processing is permitted.

In the fourth process, three lead presses are used to form a continuous lead sheath over the hose preparatory to a vulcanization operation. Process time varies with the outside of the hose. One lead press, however, applies the lead sheath at a rate which is one-third faster than the other presses.

TABLE I

OPERATIONAL ZONE MACHINE ALLOCATION

Zone	Machine Designation*	Quantity
3	Braider, 64D	2
	Braider, 48D	2
4	Braider, 64D	2
	Braider, 48D	2
5	Braider, 48D	5
6	Braider, 48D	5
7	Braider, 36D	6
8	Braider, 36D	6
9	Braider, 36D	6
10	Braider, 36D	6
11	Braider, 36D	6
12	Table Braider (S)	10
13	Braider, 36S	6
14	Braider, 36S	6
15	Braider, 48S	10
16	Braider, 48S	5
	Braider, 36S	6
17	Table Braider (S)	4
	Table Braider (D)	6
18	Table Braider (S)	4
	Table Braider (D)	5
19	Wardwell Braider	5
20	Wardwell Braider	5
21	Wardwell Braider	5
22	Knitter (D)	1
	Knitter (S)	5
23	Knitter (S)	6

*Designation includes number of yarn carriers and deck classification, single or double.

Although setups are performed with the lead presses, the resulting non-productive time is quite small and will be considered as inconsequential.

In summary, the job shop consists of 147 machines. Numberous routes through the shop are possible depending upon the physical characteristics, reinforcement specification, and completion priority of the job lots. Due to the number of customer orders in process each shift, each order may be expected to compete for service on common machines. A sequencing policy is necessary to control the flow of pans through the shop. Under the current sequencing policy, approximately 2,500 pans of hose are produced weekly through each of the four processes. A conventional due date is not associated with a job lot since it may consist of a combination of customer orders, each having a different due date. In a looser sense, however, it is convenient to attach a weekly completion date to each lot. This date indicates the week in which completion of the lot is desired.

CHAPTER IV

MODEL CONSTRUCTION AND VALIDATION

The job shop model was constructed and simulated in the General Purpose Simulation System (GPSS). All the job shop characteristics which were discussed in the previous chapter are incorporated in the model. Simulations were performed in the IBM 360, model 65 computer with a core capacity of 300,000 bytes. Although this capacity is quite substantial considering previously reported simulations, it was necessary to limit the simulation runs to 15 working shifts or one week of production. Even so, 250,000 bytes of core were required for each validation run and an additional 40,000 bytes was necessary for the evaluation of each set of priority rules.

The records pertaining to an actual week of production were randomly selected from historical files to develop and simulate the model. The information extracted from these records includes the number and designation of each processed job lot, the scheduled routing through the shop, and the reported machine downtime. The mean process time through each process was derived from standard process time tables. Since fractional time units are not permitted in GPSS, productive and non-productive times are expressed in tenths of minutes. The data input, computer program listing, and logic flow charts are shown in Appendices I and II.

Since the model incorporates empirically derived data, it was possible to fully load the model with in-process inventory at the initiation of each simulation. A normal or steady state condition was attained almost immediately, and no provision was made for the conventional "warmup" period to attenuate initial transient effects.

Model Assumptions

A job shop model, by its very nature, does not include or consider all the factors which influence the flow of jobs through the actual system. Cause and effect relationships are rarely known with certainty which necessitates the development of simplifying assumptions to facilitate model development. The assumptions associated with this research are:

1. The randomly selected job lot sample is representative of the lots in process, both in number and mix, in a typical week of production.
2. Job lots which are provided with a routing through the fourth process are considered late if not completed during the simulated week; an incomplete routing indicates that the lot is scheduled for completion during the following week.
3. No machine may process more than one pan of

hose at a time; each job lot, once started, must be performed to completion.

4. The labor force varies in accordance with a predetermined schedule. Therefore, the staffing status of each machine is known in advance.
5. Twenty minutes are required to set up each machine in the first process; in the second process, setup time is taken as one minute per yarn carrier for the braiders and fifteen minutes for each knitter. Setup time in the remaining processes is insignificant and is not considered in the model.
6. Process time is normally distributed about a mean derived from standard time data. The standard deviation varies with each process.
7. Normal machine breakdowns occur in the first, third, and fourth processes. Downtime follows empirically derived discrete distributions. Downtime data for process 2 machines was nonexistent, therefore, these machines are not subject to breakdowns.
8. Job lots will never split into more than two lots during the reinforcement process. Lot splitting does not occur elsewhere in the shop.
9. A minimum delay time of eight hours will always elapse after the first and third processes.

10. Scrap is not generated in sufficient quantities to reduce job lot size.

Priority Rule Combinations

Six sets of priority rules were selected for evaluation. Each set consists of some combination of five rules; three rules are designed to minimize the non-productive time resulting from setups in the first two processes, and two rules are intended to maximize job flow. In the first process, setups may be minimized by sequencing job lots according to the rubber compound specified for the tube. This observation prompted the formulation of two rules:

1. Divide all job lots awaiting service into groups having the same specified rubber compound. Within each group, arrange the job lots in ascending process time order. Determine the total number of pans in each group and arrange the groups in order of descending pan quantity. Service the lot in the largest group and with the shortest process time first. This rule is designated as COMP-SPT, an abbreviation of Compound-Shortest Process Time.
2. Divide all the job lots into two classes. In one class, place all the lots which should be completed this week; in the other class, place the lots which may be completed in later

> periods. Within each class, assemble the lots into groups having the same specified rubber compound. Determine the total number of pans in each group and arrange the groups in order of descending pan quantity. Service the lot in the largest group in the class which must be completed this week first. Since this rule gives priority to lots with the same compound and with complete routing, it is designated as COMP-ROUT.

For the second process, a rule was developed which minimizes sets by sequencing job lots according to the reinforcement yarn specified. This rule, designated YARN, divides all job lots awaiting service on each type of reinforcement machine into groups having the same yarn type. All the lots with the same yarn class are serviced before another class is considered.

The remaining rules were designed to maximize the flow of job lots through the shop. The first is the familiar shortest process time (SPT) rule which arranges all the job lots awaiting service, in order of ascending process time per pan. The lot with the shortest process time is serviced first. The second rule, a variation of the SPT rule, gives priority to jobs which should finish this simulated week. The rule, designated SPT-ROUT, divides all job lots awaiting service into two groups. One group contains all the lots which are scheduled for completion this week; the other group contains all lots which may be completed in later periods. The lots in each group are arranged in ascending process time order. The lots scheduled for completion this week are scheduled first, beginning with the lot with the shortest process time.

Table II shows the six priority rule sets which were developed from the rules explained above. The rules in each set which were applied to the job lot queues associated with each process are indicated. The first set, which applies the SPT rule to each process also serves as a standard, along with the currently implemented sequencing policy, against which the remaining sets are compared.

Performance Criteria

The relative importance of a priority rule or set of rules must be referenced to some criteria with which the judgment is made. Most job shop research has used flow time or tardiness as the measure of performance. But in an actual job shop a number of other measures may be equally or more important. Based upon actual experience with the job shop, the effectiveness of each set of priority rules was evaluated by the following criteria:

1. The productivity of each process. Production statistics are maintained by working shift for every process.
2. Job lateness. Lateness is defined as the difference between the actual and desired completion

TABLE II

PRIORITY RULE SETS UNDER EVALUATION

Set Number	Process Applied	Rule Designation
1	1	SPT
	2	SPT
	3	SPT
	4	SPT
2	1	SPT-ROUT
	2	SPT
	3	SPT
	4	SPT
3	1	SPT-ROUT
	2	YARN
	3	SPT
	4	SPT
4	1	COMP-SPT
	2	SPT
	3	SPT
	4	SPT
5	1	COMP-ROUT
	2	SPT
	3	SPT
	4	SPT
6	1	COMP-ROUT
	2	YARN
	3	SPT
	4	SPT

times. The total productivity of the fourth process in the validated simulation is the standard for this criterion.

3. The amount of in-process inventory. Some in-process inventory is required after every process to provide a safety margin in the event of a prolonged machine breakdown. But it is desirable to reduce the inventory to the lowest practicable level.
4. Utilization of the fourth process machines. The capital investment in the three lead presses is quite substantial which necessitates the highest possible utilization of each machine.

It should be recognized, from previous research findings, that no set of priority rules is likely to optimize all performance criteria. Moreover, the criteria are rarely considered to have equal importance. Therefore, the job shop manager will ultimately be responsible for the selection of the priority rule sets which appear to be most beneficial to the job shop.

Job Lot Parameters

A total of 216 job lots were identified from the randomly selected, production records. For simulation purposes, eighteen parameters are associated with each lot. These parameters identify the lot and determine its characteristics, mean process times, and routing configuration through the shop. The parameters in numerical order are:

1. Primary job lot number. This number, from 1 through 216, identifies the job lot.
2. Initial routing code. The code is a number from 1 through 26 and indicates the queue which the lot will join initially. The queue coding is shown in Table III. The queues are associated with the machines or operational zones which they serve.
3. Lot quantity in pans.
4. Mean tuber process time. All process times are derived from standard time tables and are expressed in tenths of minutes.
5. Reinforcement routing code. If the lot has been processed through the first process and is scheduled for further processing, this code indicates the second process queue which will be entered. If the code is a zero, the lot becomes in-process inventory and will proceed no further.
6. Number of reinforcement machines scheduled for the lot. This number may range from 1 through 12 and indicates the number of machines which may service the lot.
7. Lowest reinforcement machine number. For

TABLE III

QUEUE CODING

Queue Name	Code
4.5 inch Tuber	1
6 inch Tuber	2
Operational Zone 3	3
Operational Zone 4	4
Operational Zone 5	5
Operational Zone 6	6
Operational Zone 7	7
Operational Zone 8	8
Operational Zone 9	9
Operational Zone 10	10
Operational Zone 11	11
Operational Zone 12	12
Operational Zone 13	13
Operational Zone 14	14
Operational Zone 15	15
Operational Zone 16	16
Operational Zone 17	17
Operational Zone 18	18
Operational Zone 19	19
Operational Zone 20	20
Operational Zone 21	21
Operational Zone 22	22
Operational Zone 23	23
4.5 inch Cover	24
6 inch Cover	25
Lead Press	26

simulation purposes, each machine in the shop is assigned a unique number. This parameter indicates the lowest numbered machine which can service the lot. The numerical code for each type of machine is shown in Table IV. Therefore, if parameters 6 and 7 had values of 3 and 50, respectively, the lots could only be serviced by machines 50, 51, and 52 in the second process time.

8. Mean reinforcement process time.
9. Cover routing code. If the lot has been processed through the second process and is scheduled for further processing, this code indicates the third process queue which will be entered. If the code is a zero, the lot becomes in-process inventory and will proceed no further this week.
10. Mean cover process time.
11. Mean lead press process time. If zero, the lot becomes in-process inventory and will proceed no further this week.
12. Division code. If the lot is scheduled to split into two smaller lots upon completion of the second process, this code indicates the number of pans which will be accumulated in the first of the lots before it is allowed to proceed further. The second lot will contain the original lot quantity minus the division code. If the

TABLE IV

MACHINE NUMERICAL DESIGNATION

Machine Type	Numerical Designation
4.5 inch Tuber	1-2
6 inch Tuber	3
Braider, 64D	25-28*
Braider, 48D	29-42
Braider, 36D	43-72
Table Braider (S)	73-82, 117-120, 127-130
Braider, 36S	83-94, 110-116
Braider, 48S	95-109
Table Braider (D)	121-126, 131-135
Wardwell Braider	136-151
Knitter (D)	152
Knitter (S)	153-163
4.5 inch Cover	164
6 inch Cover	165
Lead Press	166-168

*Numbers 4 through 24 are reserved for dummy machines which serve to maintain setup statistics in the second process.

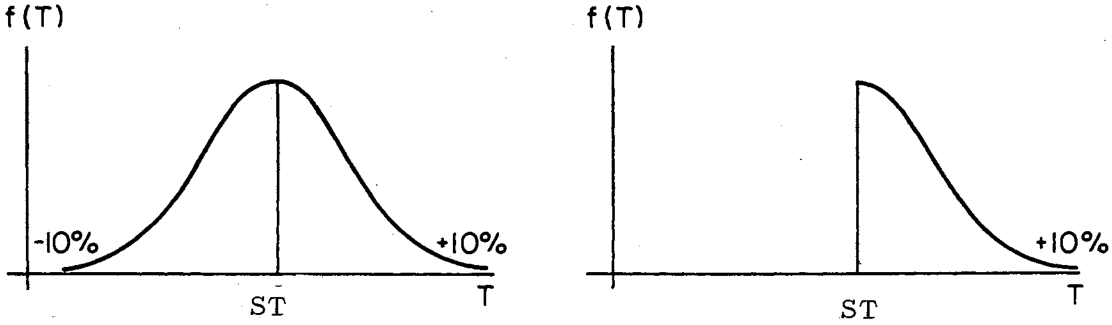
lot is not scheduled for division, the division code will have the same value as the original lot quantity.

13. Yarn type. This number indicates the yarn type specified for the lot and ranges in value from 1 through 21.
14. Release time. (Used only for model validation.) Time at which the lot may be released for processing.
15. Secondary job lot number. For simulation, two sets of job lot number are required. This number ranges from 171 to 386.
16. Ply code. This code indicates the number of additional passes which are required through the single deck reinforcement machines. If zero, only one pass is required; if 1, two passes are required.
17. Compound code. This code indicates the tube compound specified for the lot and ranges in value from 1 through 14.
18. Routing priority. This parameter provides an additional priority for lots which should be completed during the simulated week.

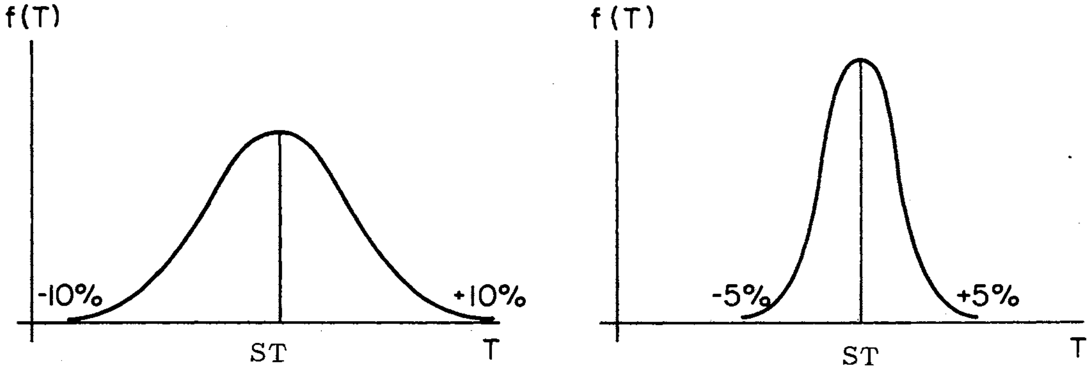
Probability Distributions

As was indicated previously, machine process time and downtime are assumed to be random variables which follow prescribed probability distributions. In a GPSS model, both continuous and discrete probability distributions may be specified by relating pairs of independent and dependent functional values, where the independent variable must be monotonically increasing in decimal values from 0 to, but excluding, 1.

The value of a random variable is determined by a Monte Carlo technique. A uniformly distributed psuedo random number within the interval 0 to 1 is generated by the computer. The corresponding dependent value is then determined from a specified distribution. The dependent value may itself be the random variable or it may be calculated by multiplying the dependent value by a standard mean value. In the model, process time is assumed to be normally distributed with the distribution mean for each job lot derived from standard time data. The variation in process time has been found, through historical records, to differ with each process. Figure 2 illustrates the process time distributions for each process. The maximum process time in each distribution occurs three standard deviations from the mean. In the first process, the process time can vary by as much as 10 per cent above or below the standard value. Therefore, to compute the process time for a particular pan of hose through this process, the standard process time for the pan is multiplied by a normally distributed number between 0.9 and 1.1. The standard time in the second process is known to be low and the actual process time varies upward by as



PROCESS 1 PROCESS 2



PROCESS 3 PROCESS 4

(ST represents the standard time per pan of hose through the reference process.

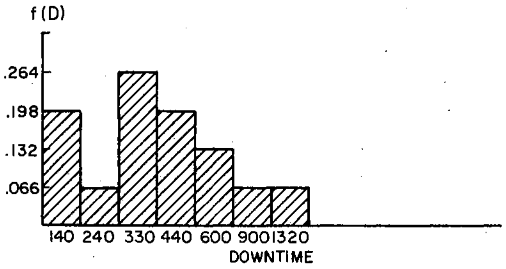
Figure 2. Process Time Distributions

much as 10 per cent. In the third and fourth processes, process times vary above and below the standard value by 10 and 5 per cent, respectively.

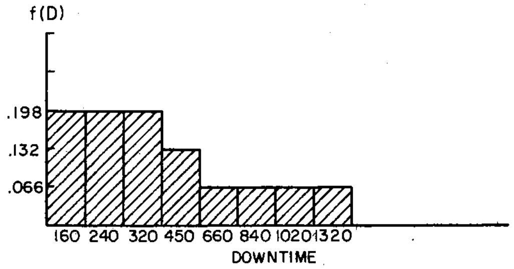
Reported downtime records were used to construct the probability distributions for each machine in the first, third, and fourth processes. By assumption, the second process machines do not break down. Since few downtime values were observed with each machine, downtime was assumed to be a discrete random variable. Figure 3 shows the empirically derived, discrete, downtime distributions for each indicated machine. All downtimes are expressed in tenths of minutes. For simulation purposes, each machine will be unserviceable at the beginning of each shift for a time determined by its downtime distribution.

Model Validation

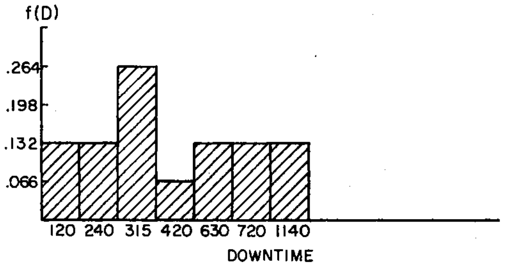
In order to draw inferences about the real job shop system, the model must undergo a validation process. In a strict sense, a model is considered valid if it is proven to be a true representation of the reference system. Under this definition, however, it would be virtually impossible to validate a model, since it implies that a universally acceptable set of criteria could be established to make this judgment. A more practical definition is offered: a valid model is one which serves its intended purpose. Using this definition, a model could be valid by some criteria and invalid by others. But various aspects of the real world are



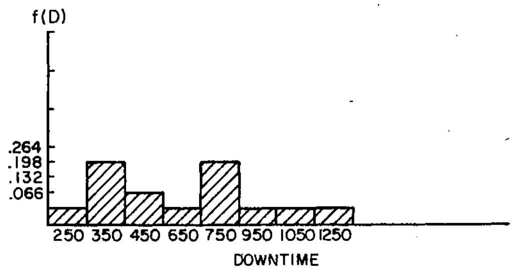
FIRST 4.5 INCH TUBER



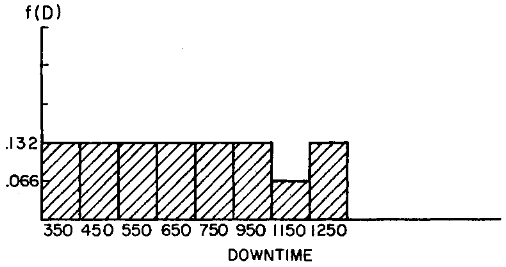
SECOND 4.5 INCH TUBER



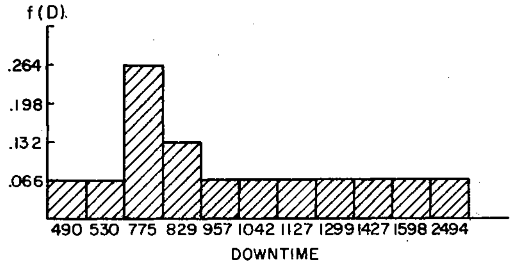
6 INCH TUBER



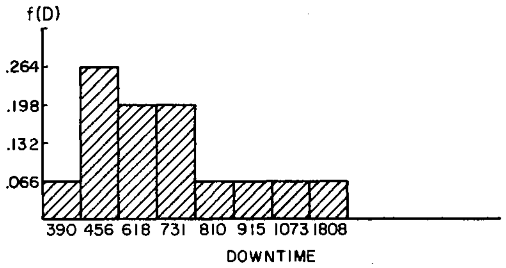
4.5 INCH COVER MACHINE



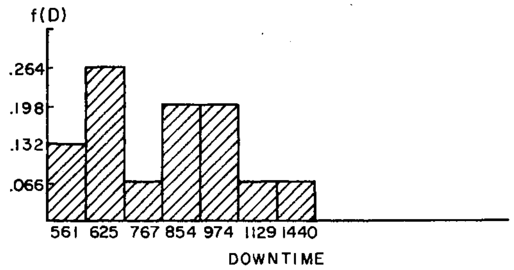
6 INCH COVER MACHINE



FIRST LEAD PRESS



SECOND LEAD PRESS



THIRD LEAD PRESS

(All downtime is expressed in tenths of minutes.)

Figure 3. Machine Downtime Distributions

invariably or deliberately omitted from a model to achieve the advantages of simplicity. Only those conditions which are deemed necessary to fulfill its intended purpose are included. Therefore, the validation criteria need only provide some assurance that this purpose can be achieved. Referring to the problem of validation, Conway et al. (8, p. 104) wrote:

> Some assurance of validity would be provided by a demonstration that for at least one alternative version of the simulated system and one set of conditions, the simulator produces results that are not inconsistent with the known performance of the system.

In this research, the purpose is to determine the effect of alternative sequencing policies on job shop performance by inference from a simulation model. The only performance criterion which was known for certain in the actual job shop, was the productivity of each process for each of 15 working shifts. Therefore, it was selected as the validation criterion. The productivity of the job shop and the model for each process are plotted in Figures 4 through 7. The model will be considered a valid representation of the actual job shop if it can be shown that the two populations are identical within an acceptable margin of error. A number of statistical tests are available to perform this function, but the Wilcoxin Rank-Sum Test was selected for its sensitivity, efficiency, and convenient application.

This distribution-free test is especially appropriate

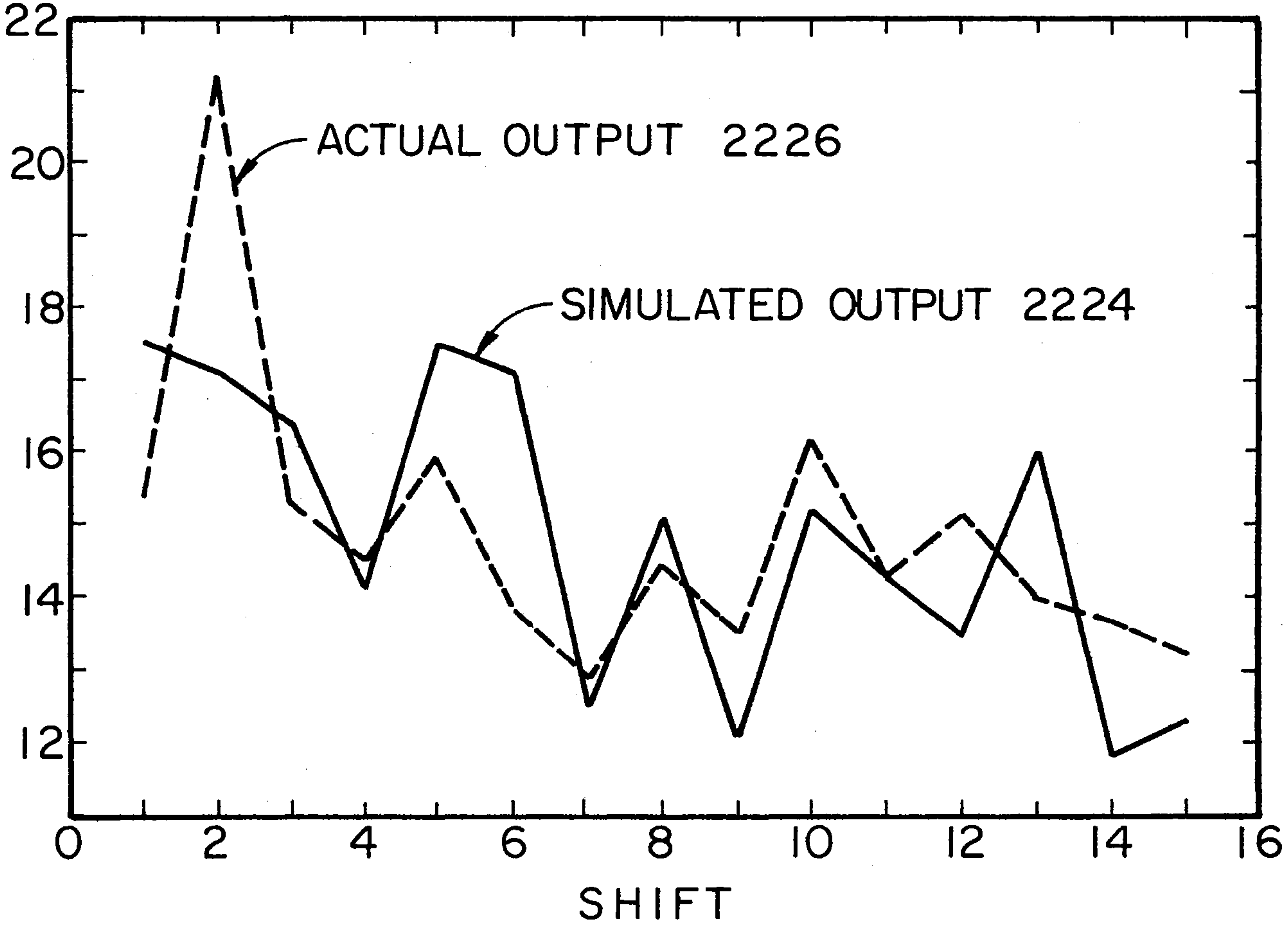


Figure 4. Process 1 Productivity of the Actual and Simulated Job Shops

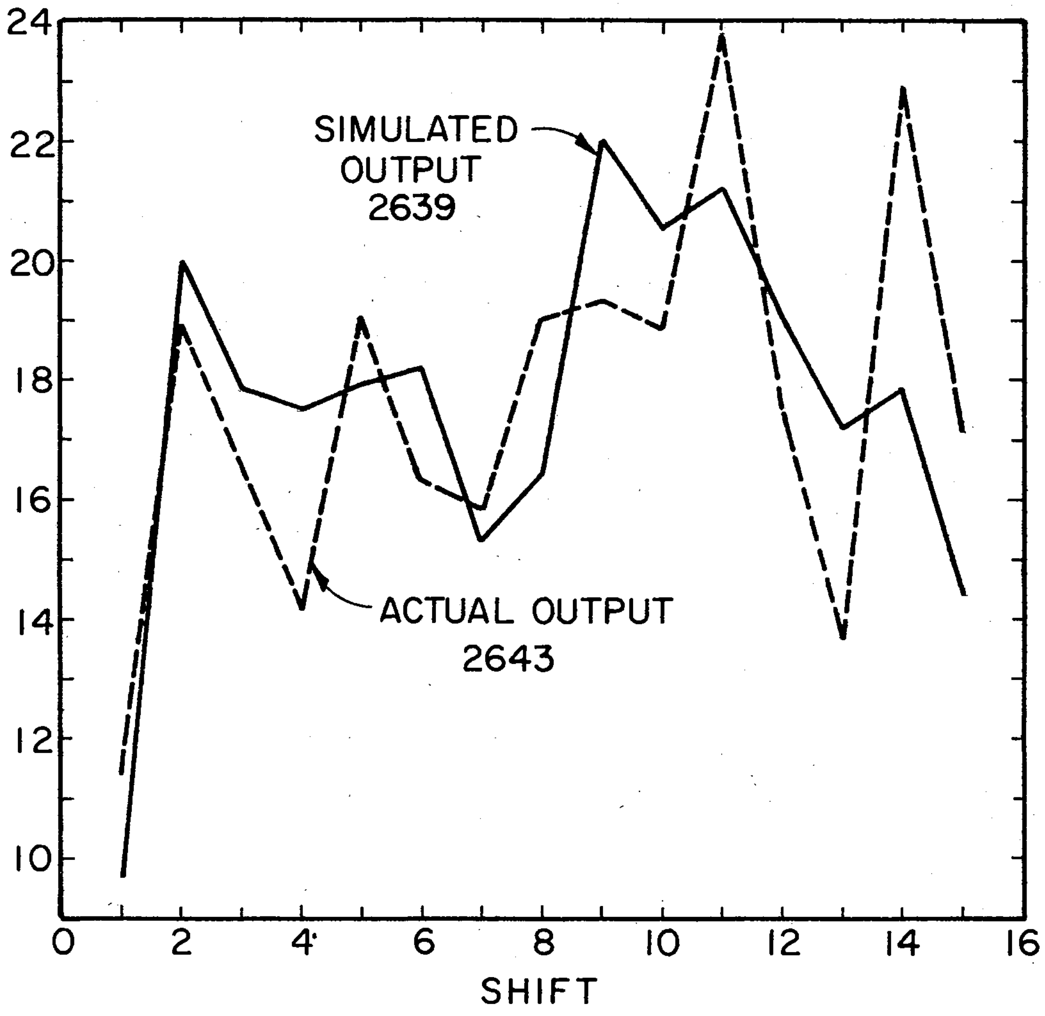


Figure 5. Process 2 Productivity of the Actual and Simulated Job Shops

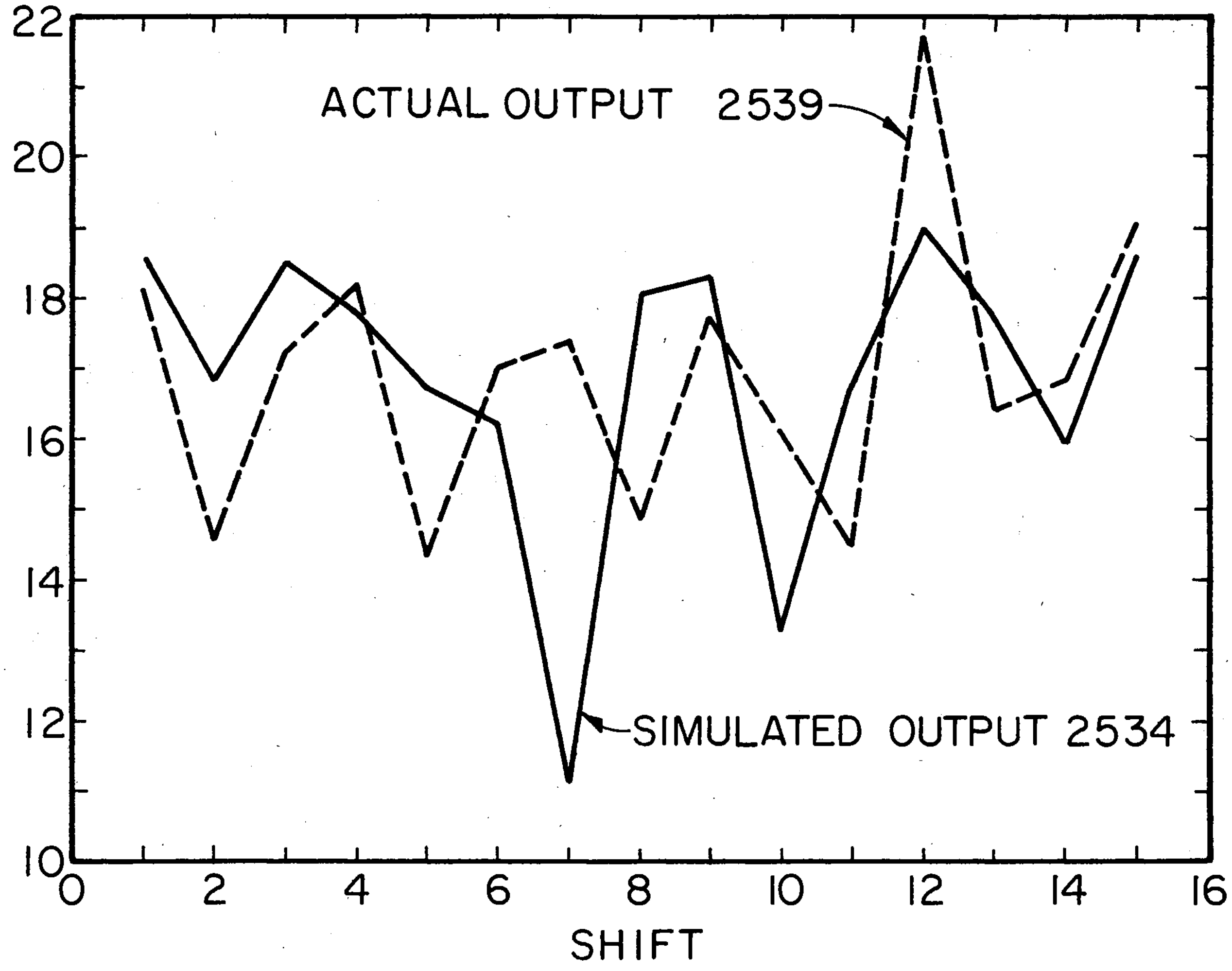


Figure 6. Process 3 Productivity of the Actual and Simulated Job Shops

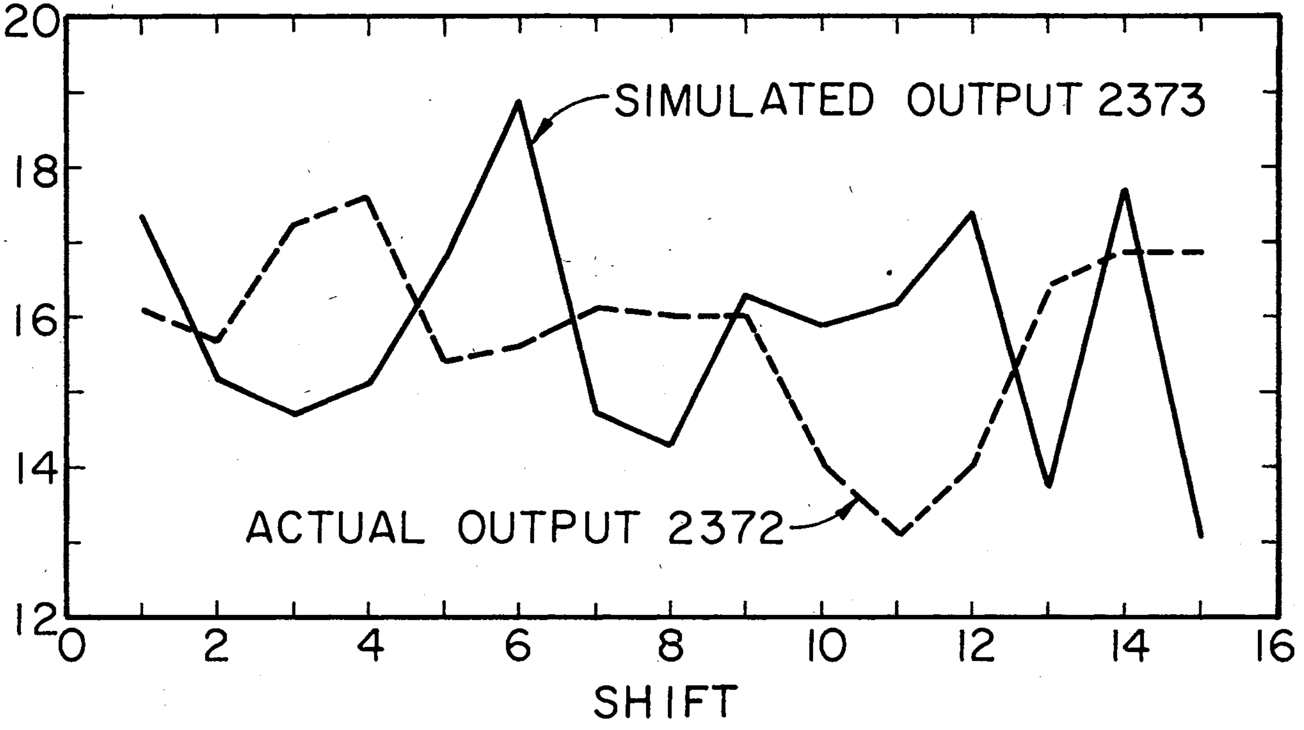


Figure 7. Process 4 Productivity of the Actual and Simulated Job Shops

for testing the hypothesis that two populations are identical against the alternative hypothesis that they are non-identical, and is especially likely to reject the hypothesis when the populations have unequal locations. Describing the efficiency of the test, Bradley (9, p. 109) states:

> In comparison with other distribution-free statistics, the Wilcoxin test typically ranks first or, when the set of tests being compared includes the optimum test for the conditions of the comparison (and the optimum test is not the Wilcoxin test itself), ranks a close second.

The only assumptions associated with the test are that the populations are continuous, the observations are randomly sampled, and the observations are independent.

Hose production at each process is a continuous random variable. It is theoretically possible, therefore, to observe a wide range of production values at the end of each working shift. The actual observations would be limited only by the precision of the measurement instrument. Production could be measured, for example, in inches or feet. For convenience, however, only whole pans of hose are reported in the actual job shop. The simulation, in like manner, records production in whole pans. The manner in which the observations are made in the actual shop and the simulation model are assumed to be sufficiently similar to satisfy the randomness requirement. That is, the differences in production between the actual shop and the model are assumed to be attributable to differences between the sampled populations and not to the manner in which the observations were made. The final requirement of independence is also satisfied since it is assumed that the production of a particular shift is not influenced by the production of previous shifts.

To perform the test, the lowest value in the combined production observations is assigned a rank of 1 and each successively, higher valued observation is assigned a sequentially higher rank. Observations which are equal in value (ties) across both actual and simulated samples, receive no rank and are not included in the calculations. The ranks of the observation in each sample are then summed. A table is entered and depending upon the number of untied observations in each sample and the rank-sums, a statement which rejects or fails to reject the null hypothesis can be made. The data and calculations required to perform the test for each of the four processes are shown in Tables V through VIII. Since in each process there was no reason to reject the hypothesis that the populations were identical, at the 95 per cent confidence level, the model was assumed to be validated.

TABLE V

PROCESS 1 VALIDATION CALCULATIONS

Shift	Actual Production (Pans)	Rank	Simulated Production (Pans)	Rank
1	154	10	175	2
2	213	1	171	4
3	153	11	164	6
4	145	12	141	14
5	159	9	175	3
6	139	16	171	5
7	129	20	125	21
8	145	13	151	TIE
9	135	18	121	24
10	162	7	152	12
11	143	TIE	143	TIE
12	151	TIE	134	19
13	140	15	160	8
14	137	17	118	24
15	122	23	123	22
Total Production	2226		2224	
Sum of Ranks		172		164
Number of Untied Observations	13		13	

The critical tabular value for two sets of 13 observations which would reject a hypothesis of similar populations at the 95 per cent confidence level is 142. Since both rank sums exceed this value, there is no reason to reject the hypothesis that the actual and simulated production distributions in the first process are identical.

TABLE VI

PROCESS 2 VALIDATION CALCULATIONS

Shift	Actual Production (Pans)	Rank	Simulated Production (Pans)	Rank
1	113	25	97	26
2	190	TIE	200	6
3	166	16	178	11
4	142	23	165	17
5	190	TIE	179	10
6	163	19	182	9
7	158	20	153	21
8	190	TIE	164	18
9	193	7	220	3
10	188	8	205	5
11	238	1	212	4
12	175	13	190	TIE
13	137	24	172	14
14	229	2	178	12
15	171	15	144	22
Total Production	2643		2639	
Sum of Ranks		173		178
Number of Untied Observations	12		14	

The critical tabular value for sets of 11 and 14 observations which would reject a hypothesis of similar populations at the 95 per cent confidence level is 129. Since both rank sums exceed this value, there is no reason to reject the hypothesis that the actual and simulated production distributions in the second process are identical.

TABLE VII

PROCESS 3 VALIDATION CALCULATIONS

Shift	Actual Production (Pans)	Rank	Simulated Production (Pans)	Rank
1	182	8	186	4
2	145	17	168	TIE
3	172	11	185	6
4	181	TIE	178	9
5	143	19	167	13
6	170	12	162	TIE
7	174	10	111	21
8	148	16	181	TIE
9	177	TIE	183	7
10	162	TIE	133	20
11	144	18	168	TIE
12	217	1	190	3
13	164	14	177	TIE
14	168	TIE	159	15
15	192	2	186	5
Total Production	2539		2534	
Sum of Ranks		128		103
Number of Untied Observations		11		10

The critical tabular value for sets of 11 and 10 observations which would reject a hypothesis of similar populations at the 95 per cent confidence level is 86. Since both rank sums exceed this value, there is no reason to reject the hypothesis that the actual and simulated production distributions in the third process are identical.

TABLE VIII

PROCESS 4 VALIDATION CALCULATIONS

Shift	Actual Production (Pans)	Rank	Simulated Production (Pans)	Rank
1	161	13	174	4
2	157	18	152	21
3	172	6	147	23
4	176	3	151	22
5	154	20	168	9
6	156	19	189	1
7	161	14	147	24
8	160	15	143	25
9	160	16	163	11
10	141	26	159	17
11	131	29	162	12
12	141	27	174	5
13	164	10	137	28
14	169	7	177	2
15	169	8	130	30
Total Production	2372		2373	
Sum of Ranks		231		234
Number of Untied Observations		15		15

The critical tabular value for two sets of 15 observations which would reject a hypothesis of similar populations at the 95 per cent confidence level is 192. Since both rank sums exceed this value, there is no reason to reject the hypothesis that the actual and simulated production distributions in the fourth process are identical.

CHAPTER V

RESULTS AND CONCLUSIONS

Initial Conditions

The simulations were conducted under as close to identical conditions as possible. In no case was the number of job lots or the parameter list of a lot altered. The lots contained the same number of pan units, required the same mean process times, and followed the same routes through the shop. The initial shop conditions, in-process inventory, and the number of serviceable machines were also identical in each simulation. Only the logic required to implement the various sequencing rules was changed. Therefore, any differences in job shop performance is attributable to the order in which the lots were processed.

Results

Selected performance and utilization statistics from each simulation are shown in Table IX. The data indicates the performance of the job shop under the various sequencing policies over a period of fifteen 8-hour shifts. The average in-process inventory is the simple average of the in-process inventory accumulated at each indicated process after the completion of each shift. Lead press utilization

TABLE IX

SIMULATION RESULTS

Simulation	Total Production in Pans				Average In-Process Inventory in Pans			Average Lead Press Utilization in Per Cent
	Process 1	Process 2	Process 3	Process 4	Process 1	Process 2	Process 3	
Current Policy	2224	2639	2534	2373	843.6	690.4	650.0	100
Rule Set 1	2232	2510	2396	2326	922.2	973.7	649.1	98.0
Rule Set 2	2232	2555	2500	2360	882.2	675.5	646.7	99.3
Rule Set 3	2232	2579	2500	2373	892.9	654.0	650.9	99.5
Rule Set 4	2232	2597	2516	2324	695.1	760.8	645.6	98.0
Rule Set 5	2232	2616	2504	2278	717.1	768.9	652.5	95.8
Rule Set 6	2232	2638	2514	2341	712.4	741.1	650.3	98.3

represents the percentage of the time that the three lead presses were either down for maintenace or processing job lots. The lead presses were idle during the remaining time since job lots were not available for processing. The first two sets of data are the standards against which the other sequencing policies are compared. The first set of statistics is the simulated performance of the shop with the currently implemented sequencing policy; the second set was obtained from the application of the Shortest Process Time rule for each process.

Analysis of Results

It is apparent that no one sequencing policy optimizes all the performance criteria. If the criteria were weighted equally, however, the current policy would probably remain in effect. Except for the first process, it provides the highest overall productivity and cannot be surpassed in lead press utilization. Sequencing rules do not appear to be as responsive as skilled schedulers who can plan ahead and make appropriate decisions as sequencing problems arise. Although more responsive, the current policy requires the constant attention and experienced judgment of several schedulers. Rule set 3 performs nearly as well and could be implemented by relatively inexperienced personnel. Because of the relative complexity of the SPT-ROUT rule, schedulers would be required to determine job lot sequencing through the first process. Afterwards, the remaining rules could be readily implemented by machine operators.

Rule set 1, the general application of the SPT rule, makes a relatively poor showing. With reference to the second performance criterion, it would result in 47 late pans. It also produces the highest average in-process inventories and ranks low in lead press utilization. Every other multiple-rule sequencing policy, with the possible exception of rule set 5, provide an improvement in shop performance over rule set 1. Even rule set 2, in which a modification of the SPT rule is used in the first process, appears to be superior to the rule generally applied in its simple form.

Other results are quite consistent with previous research findings. Rule sets 4, 5, and 6 which are designed to minimize setups in the first process are the least productive through process 4. This result is not too surprising with consideration to Baker's (3) study. The setup-process time ratio through the first process is extremely small. Setups are only performed when the rubber compound for a new lot is changed. Several lots could be processed over an extensive period before a 20-minute setup is required. Therefore, machine idle time due to setups in the first process is of little consequence. The reduction in idle time due to the COMP-SPT and COMP-ROUT rules is completely offset by forcing lots with early completion dates to wait until lower priority lots are completed. No benefits are realized by minimizing the number of machine setups. The SPT-ROUT rule which considers both process time and completion date considerably improves shop performance. In contrast, the YARN rule, which minimizes machine setups in the second process performs very well. Up to 128 minutes may be required for each machine setup and as many as 10 machines may be scheduled for a lot in an operator area. Since setups must be performed sequentially, a machine could remain idle for as long as 512 minutes. Therefore, it is advantageous to minimize the number of setups in the second process. Since the SPT-ROUT rule performed so well in the first process, there is some indication that a modification of the YARN rule, which would incorporate process time and completion date, would provide additional performance improvements.

Conclusions

Based upon the results of this study, there is a strong indication that an application of a proper set of sequencing rules may be superior to a single rule applied to all queues in a job shop system. The shortest process time rule, for example, which has received considerable attention in job shop literature, gives no assurance of improving shop performance when machine setup time is significant. Conversely, a rule which minimizes setups may not always be effective. Switching between such rules, however, may combine the desired features of both rules. It appears that the best set of rules for the simulated shop would:

1. Give priority to some combination of process time and completion date in the first process. No performance improvements are realized by sequencing lots by tube compound.
2. Minimize machine setups in the second process by ordering lots by yarn type with additional priority given to process time and completion date.
3. Order lots through the remaining processes by some variation of the SPT rule.

Employing the GPSS computer language and the capabilities of a large capacity computer system, it is possible to simulate a relatively large and complex job shop system. A realistic simulation model can be constructed which incorporates the effects of machine downtime by working shift due to normal breakdowns, job setups, and labor force variations. Moreover, the logic required to simulate a number of complex sequencing rules can be readily implemented.

Further evidence supports Wilbrecht and Prescott's (5) contention that setup time plays a critical role in job shop performance. When the setup-service time ratio is small, it is not advantageous to sequence job lots in order to minimize machine setups. Consequently, other sequencing schemes should be investigated. Above some critical, but as yet undetermined, ratio, machine idle time adversely affects productivity. Sequencing rules should be developed, under these conditions, which incorporate a setup reduction capability.

Model validation of an actual job shop system, although difficult, is possible provided the validation criteria is related to the intended purpose of the simulation. The validation process need only demonstrate that the model is an acceptable representation of the actual system within a tenable level of confidence. The Wilconxin rank-sum test is but one of a number of statistical tests which measures the difference between a reference system and a postulated model.

Finally, no multiple sequencing rule set was found which could supersede the experience and judgment of qualified schedulers. This fact, in itself, should not result in the abandonment of further investigations. Although schedulers may be on call constantly through all working shifts, occasions will invariably arise when machine operators will be faced with a job sequencing decision. Implementation of some "rule of thumb" would be beneficial during such occasions to improve shop performance.

Topics for Continued Related Research

The results from this investigation are based on a single simulation of six multiple rule sets. It was felt that sufficient evidence was obtained by this procedure to indicate the advantage of multiple sequencing rule policies in a particular job shop application. Obviously, additional simulations will be required to statistically support the preceding conclusions. It would also be desirable to extend the simulation period beyond fifteen 8-hour shifts. Such simulations would require a computer system with a core capacity in excess of 300,000 bytes. For the simulated job shop, additional rule sets warrant further investigation. It would be interesting to determine the effects of the SPT-ROUT rule implemented in the first three processes and the SPT rule in the fourth process. Although some performance degradation may be expected in the second process from machine setups, this rule should provide the minimum flow time for the fastest lots with the earliest completion dates. As suggested previously, the YARN rule could also be modified to improve the flow time for critical lots through the second process. Within each yarn class, lots could be arranged in order of ascending process time. This rule would process the fastest lots within each yarn class first. A second modification could be developed by dividing the waiting lots into two classes. The first class consists of lots which are due this week; the second class would consist of jobs which are due in succeeding weeks. within each class, the lots are grouped by common yarn specifications. The lot with the earliest competion date and the lowest arbitrary yarn specification in the first class would receive the highest sequence priority. Two additional sequence rule sets are, therefore, suggested for evaluation. The sets would include one of the previously described rules in process 2, the SPT-ROUT rule in processes 1 and 3, and the SPT rule in process 4.

The determination of the critical setup-process time ratio would be a significant contribution to job shop scheduling theory. When this ratio exceeds an as yet undetermined value, job shop performance will be adversely affected unless a sequencing rule is implemented which would minimize machine setups. The present investigation illustrates the important relationship between setup time and service time. A sequencing rule which is designed to minimize setups in the first process tends to degrade shop performance; whereas, a similar rule applied in the second process improves shop performance. Further investigations are needed to determine when a setup minimizing rule should be implemented.

The investigation of multiple sequencing rules cannot be considered complete. This research has only demonstrated the advantage of switching between sequencing rules in a single job shop application. Although the simulated shop is considered to be fairly representative, more work must be done to draw a more complete picture of the behavior of multiple sequencing rules.

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APPENDIX A

GPSS SOURCE LISTING OF THE SIMULATED JOB SHOP

```
BLOCK
NUMBER  *LOC    OPERATION  A,B,C,D,E,F,G                 COMMENTS
                SIMULATE
        ********************************************************************
        *                      OKLAHOMA STATE UNIVERSITY                   *
        *                                                                  *
        *                           THESIS RESEARCH                        *
        *                            EDWIN W BULA                          *
        *         DEPARTMENT OF INDUSTRIAL ENGINEERING AND MANAGEMENT      *
        *                                                                  *
        ********************************************************************
        *INPUT - SEED RN GENERATORS
                RMULT       31,13,7,23,19,15,11,17
        *
        *INPUT - IDENTIFY INITIAL UNSERVICEABLE MACHINES,NO OPERATOR
                INITIAL     LS25-LS26/LS105-LS108/LS157-LS158/LS163
        *
        *INPUT - INITIALIZE COUNTERS
                INITIAL     X12,200/X13,170/X15,5000/X16,9800
        *
        *INPUT - INITIAL YARN SETUP IN PROCESS 2 MACHINES
                INITIAL     X29-X32,9/X33-X35,4/X40-X42,16/X43-X48,9/X49-X54,11
                INITIAL     X55-X58,9/X61-X66,4/X67-X72,1/X83-X94,1/X136-X143,3
                INITIAL     X146-X149,6/X150-X151,10/X152-X156,19/X159-X161,21
        *
        *INPUT - INITIAL IN-PROCESS INVENTORY
                INITIAL     X174,873/X175,850/X176,565
        *
        *INPUT - INITIALIZE SHIFT COUNTER
                INITIAL     XH1,-1
        *
        *INPUT - ESTABLISH SETUP TIME FOR PROCESS 2 MACHINES
                INITIAL     XH25-XH28,1280/XH29-XH42,960/XH43-XH72,720
                INITIAL     XH73-XH82,240/XH83-XH94,360/XH95-XH109,480
                INITIAL     XH110-XH115,360
                INITIAL     XH116-XH119,240/XH120-XH131,440/XH132-XH135,240
                INITIAL     XH136-XH151,240/XH152-XH163,150
        *
        *INPUT - CUMULATIVE PROCESS TIME DISTRIBUTION FOR PROCESSES 1 & 2
         1      FUNCTION    RN1,C21
        0,.9/.049,.9015/.099,.9046/.149,.91/.199,.9189/.249,.9317/.299,.9481
        .349,.9663/.399,.9833/.449,.9956/.499,1/.549,1.0044/.599,1.0167
        .649,1.0337/.699,1.0519/.749,1.0683/.799,1.0811/.849,1.09/.899,1.0954
        .949,1.0985/.999,1.1
        *
        *INPUT - INITIAL JOB LOT ROUTING
         2      FUNCTION    P1,L216
        1,1/2,1/3,2/4,02/5,2/6,1/7,1/8,20/9,7/10,3/11,19/12,11/13,25/14,5/15,7
        16,21/17,9/18,21/19,20/20,5/21,14/22,18/23,6/24,14/25,20/26,22/27,22
        28,23/29,24/30,24/31,25/32,25/33,25/34,26/35,26/36,26/37,26/38,26/39,1
        40,1/41,2/42,2/43,16/44,15/45,12/46,16/47,7/48,3/49,24/50,13/51,10
        52,24/53,24/54,25/55,25/56,25/57,26/58,26/59,26/60,26/61,26/62,1/63,1
        64,2/65,1/66,7/67,25/68,16/69,24/70,24/71,24/72,24/73,25/74,25/75,25
        76,26/77,26/78,1/79,25/80,1/81,23/82,2/83,24/84,24/85,9/86,25/87,26
        88,26/89,2/90,2/91,2/92,1/93,1/94,2/95,2/96,1/97,1/98,24/99,6/100,24
        101,24/102,24/103,25/104,25/105,25/106,25/107,26/108,1/109,1/110,1
```

```
111,1/112,24/113,24/114,24/115,24/116,24/117,25/118,1/119,1/120,1/121,2
122,1/123,24/124,24/125,26/126,1/127,1/128,1/129,2/130,24/131,26/132,25
133,2/134,1/135,18/136,1/137,2/138,24/139,1/140,25/141,24/142,20/143,1
144,1/145,1/146,1/147,25/148,1/149,26/150,2/151,2/152,24/153,1/154,1
155,1/156,1/157,2/158,2/159,18/160,16/161,21/162,2/163,2/164,1/165,2
166,25/167,1/168,24/169,1/170,1/171,1/172,1/173,2/174,3/175,1/176,22
177,24/178,2/179,2/180,24/181,24/182,7/183,22/184,23/185,23/186,11
187,25/188,26/189,24/190,24/191,19/192,26/193,25/194,25/195,26/196,24
197,26/198,5/199,25/200,25/201,26/202,26/203,25/204,25/205,26/206,26
207,26/208,26/209,26/210,26/211,25/212,26/213,26/214,26/215,26/216,24
*
*INPUT - JOB LOT QUANTITY (PANS)
 3      FUNCTION    P1,L216
1,22/2,35/3,10/4,40/5,12/6,39/7,30/8,60/9,17/10,18/11,98/12,39/13,26
14,18/15,13/16,6/17,10/18,4/19,30/20,29/21,3/22,13/23,9/24,7/25,16
26,20/27,78/28,33/29,14/30,60/31,72/32,23/33,19/34,120/35,37/36,33
37,20/38,22/39,43/40,76/41,32/42,76/43,3/44,30/45,27/46,15/47,22/48,15
49,24/50,34/51,2/52,7/53,42/54,47/55,31/56,35/57,17/58,23/59,36/60,22
61,24/62,35/63,62/64,4/65,35/66,16/67,17/68,15/69,14/70,4/71,18/72,26
73,39/74,19/75,14/76,30/77,26/78,46/79,118/80,35/81,81/82,16/83,15
84,14
85,17/86,11/87,28/88,21/89,9/90,21/91,36/92,15/93,24/94,25/95,100/96,30
97,13/98,11/99,2/100,5/101,19/102,12/103,7/104,2/105,5/106,9/107,25
108,59/109,5/110,29/111,13/112,19/113,2/114,4/115,14/116,15/117,9/118,8
119,20/120,14/121,41/122,52/123,8/124,20/125,6/126,32/127,25/128,25
129,40/130,18/131,23/132,26/133,50/134,16/135,12/136,24/137,20/138,23
139,40/140,8/141,28/142,76/143,24/144,10/145,42/146,15/147,17/148,30
149,12/150,8/151,34/152,38/153,26/154,21/155,40/156,11/157,32/158,4
159,9/160,1/161,7/162,13/163,43/164,50/165,36/166,7/167,55/168,30
169,9/170,21/171,45/172,13/173,81/174,12/175,86/176,48/177,20/178,41
179,8/180,7/181,10/182,12/183,35/184,100/185,50/186,25/187,100/188,17
189,6/190,4/191,50/192,30/193,6/194,68/195,148/196,19/197,10/198,19
199,24/200,31/201,20/202,24/203,21/204,36/205,28/206,21/207,26/208,20
209,15/210,30/211,30/212,40/213,25/214,30/215,11/216,5
*
*INPUT - MEAN PROCESS TIME PER PAN THROUGH PROCESS 1
 4      FUNCTION    P1,L216
1,62/2,77/3,73/4,71/5,84/6,77/7,66/8,0/9,0/10,0/11,62/12,0/13,0/14,0
15,0/16,0/17,0/18,0/19,0/20,0/21,0/22,0/23,0/24,0/25,0/26,0/27,0/28,0
29,0/30,0/31,0/32,0/33,0/34,0/35,0/36,0/37,0/38,0/39,75/40,62/41,59
42,73/43,0/44,0/45,0/46,0/47,0/48,0/49,0/50,0/51,0/52,0/53,0/54,0
55,0/56,0/57,0/58,0/59,0/60,0/61,0/62,84/63,111/64,49/65,66/66,0/67,0
68,0/69,0/70,0/71,0/72,0/73,0/74,0/75,0/76,0/77,0/78,104/79,104/80,84
81,0/82,49/83,0/84,0/85,0/86,0/87,0/88,0/89,71/90,71/91,71/92,62/93,62
94,65/95,73/96,62/97,62/98,0/99,0/100,0/101,0/102,0/103,0/104,0/105,0
106,0/107,0/108,66/109,90/110,111/111,111/112,0/113,0/114,0/115,0/116,0
117,0/118,111/119,90/120,105/121,59/122,102/123,0/124,0/125,0/126,84
127,102/128,102/129,71/130,0/131,0/132,71/133,65/134,62/135,0/136,66
137,81/138,0/139,71/140,0/141,0/142,71/143,62/144,77/145,62/146,90
147,0/148,75/149,0/150,84/151,84/152,0/153,75/154,111/155,111/156,111
157,98/158,71/159,0/160,0/161,0/162,73/163,73/164,62/165,84/166,0
167,71/168,71/169,84/170,84/171,111/172,84/173,65/174,0/175,102
176,102/177,84/178,59/179,65/180,0/181,0/182,0/183,0/184,0/185,0
186,0/187,0/188,0/189,0/190,0/191,0/192,0/193,0/194,0/195,0/196,0/197,0
198,0/199,0/200,0/201,0/202,0/203,0/204,0/205,0/206,0/207,0/208,0/209,0
210,0/211,0/212,0/213,0/214,0/215,0/216,0
*
```

```
*INPUT - PROCESS 2 ROUTING
 5      FUNCTION   P1,L216
1,18/2,9/3,23/4,3/5,0/6,0/7,0/8,20/9,7/10,3/11,19/12,11/13,9/14,5
15,7/16,21/17,9/18,21/19,20/20,5/21,14/22,18/23,6/24,14/25,20/26,22
27,22/28,23/29,0/30,0/31,0/32,0/33,0/34,0/35,0/36,0/37,0/38,0/39,13
40,19/41,22/42,23/43,16/44,15/45,12/46,16/47,7/48,3/49,0/50,13/51,10
52,0/53,0/54,0/55,0/56,0/57,0/58,0/59,0/60,0/61,0/62,9/63,22/64,6
65,18/66,7/67,7/68,16/69,0/70,0/71,0/72,0/73,0/74,0/75,0/76,0/77,0
78,23/79,23/80,0/81,23/82,0/83,0/84,0/85,9/86,0/87,0/88,0/89,16/90,16
91,5/92,20/93,0/94,0/95,0/96,21/97,21/98,0/99,6/100,0/101,0/102,0
103,0/104,0/105,0/106,0/107,0/108,0/109,0/110,22/111,22/112,0/113,0
114,0/115,0/116,0/117,0/118,22/119,7/120,22/121,9/122,22/123,0/124,0
125,0/126,7/127,22/128,22/129,3/130,0/131,0/132,3/133,0/134,0/135,18
136,0/137,5/138,00/139,0/140,0/141,0/142,20/143,0/144,0/145,0/146,0
147,0/148,0/149,0/150,3/151,0/152,0/153,13/154,22/155,22/156,22/157,0
158,0/159,18/160,16/161,21/162,5/163,0/164,0/165,0/166,0/167,0/168,20
169,7/170,0/171,0/172,0/173,0/174,3/175,0/176,22/177,0/178,9/179,0
180,11/181,0/182,7/183,22/184,23/185,23/186,11/187,0/188,0/189,0/190,0
191,19/192,0/193,0/194,0/195,0/196,0/197,0/198,5/199,0/200,0/201,0
202,0/203,0/204,0/205,0/206,0/207,0/208,0/209,0/210,0/211,0/212,0/213,0
214,0/215,0/216,0
*
*INPUT - REINFORCEMENT MACHINES SCHEDULED FOR LOT
 6      FUNCTION   P1,L216
1,4/2,6/3,3/4,4/5,6/6,6/7,4/8,7/9,6/10,3/11,8/12,5/13,6/14,3/15,6/16,2
17,3/18,4/19,8/20,3/21,3/22,4/23,2/24,1/25,8/26,1/27,6/28,3/29,0/30,0
31,0/32,0/33,0/34,0/35,0/36,0/37,0/38,0/39,12/40,8/41,1/42,3/43,1/44,3
45,10/46,4/47,4/48,2/49,0/50,8/51,2/52,0/53,0/54,0/55,0/56,0/57,0/58,0
59,0/60,0/61,0/62,5/63,6/64,3/65,6/66,6/67,5/68,3/69,0/70,0/71,0/72,0
73,0/74,0/75,0/76,0/77,0/78,3/79,3/80,1/81,5/82,0/83,0/84,0/85,5/86,0
87,0/88,0/89,3/90,3/91,4/92,4/93,0/94,0/95,4/96,4/97,4/98,4/99,2/100,0
101,0/102,0/103,0/104,0/105,0/106,0/107,0/108,6/109,0/110,6/111,6/112,0
113,0/114,0/115,0/116,0/117,0/118,6/119,6/120,6/121,6/122,6/123,0/124,0
125,0/126,6/127,6/128,6/129,8/130,0/131,0/132,8/133,5/134,0/135,6/136,0
137,3/138,0/139,4/140,0/141,0/142,4/143,0/144,0/145,0/146,0/147,0
148,0/149,0/150,4/151,0/152,0/153,12/154,6/155,6/156,6/157,0/158,0
159,6/160,1/161,2/162,7/163,0/164,8/165,0/166,0/167,4/168,4/169,6/170,0
171,0/172,0/173,5/174,4/175,6/176,11/177,0/178,6/179,0/180,6/181,0
182,3/183,1/184,4/185,5/186,6/187,0/188,0/189,0/190,0/191,8/192,0/193,0
194,0/195,0/196,0/197,0/198,4/199,0/200,0/201,0/202,0/203,0/204,0/205,0
206,0/207,0/208,0/209,0/210,0/211,0/212,0/213,0/214,0/215,0/216,0
*
*INPUT - LOWEST REINFORCEMENT MACHINE NUMBER FOR LOT
 7      FUNCTION   P1,L216
1,132/2,55/3,161/4,27/5,43/6,67/7,142/8,142/9,43/10,29/11,136/12,67
13,61/14,33/15,49/16,150/17,55/18,146/19,144/20,40/21,92/22,127/23,37
24,91/25,144/26,152/27,153/28,161/29,0/30,0/31,0/32,0/33,0/34,0/35,0
36,0/37,0/38,0/39,83/40,136/41,152/42,161/43,114/44,97/45,73/46,105
47,51/48,25/49,0/50,83/51,65/52,0/53,0/54,0/55,0/56,0/57,0/58,0/59,0
60,0/61,0/62,61/63,153/64,37/65,126/66,43/67,43/68,113/69,0/70,0/71,0
72,0/73,0/74,0/75,0/76,0/77,0/78,161/79,161/80,152/81,159/82,0/83,0
84,0/85,58/86,0/87,0/88,0/89,105/90,105/91,33/92,144/93,0/94,0/95,159
96,148/97,148/98,142/99,37/100,0/101,0/102,0/103,0/104,0/105,0/106,0
107,0/108,0/109,0/110,153/111,153/112,0/113,0/114,0/115,0/116,0/117,0
118,153/119,49/120,153/121,61/122,153/123,0/124,0/125,0/126,43/127,153
128,153/129,29/130,0/131,0/132,29/133,159/134,0/135,126/136,0/137,40
138,000/139,144/140,0/141,0/142,144/143,0/144,0/145,0/146,3/147,0/148,0
149,0/150,29/151,0/152,0/153,83/154,153/155,153/156,153/157,0/158,0
159,130/160,115/161,149/162,33/163,0/164,136/165,0/166,0/167,144
168,144/169,43/170,0/171,0/172,0/173,159/174,25/175,153/176,153/177,0
178,61/179,0/180,67/181,0/182,43/183,152/184,160/185,159/186,67/187,0
188,0/189,0/190,0/191,136/192,0/193,0/194,0/195,0/196,0/197,0/198,33
199,0/200,0/201,0/202,0/203,0/204,0/205,0/206,0/207,0/208,0/209,0/210,0
211,0/212,0/213,0/214,0/215,0/216,0
*
*INPUT - MEAN PROCESS TIME PER PAN THROUGH PROCESS 2
 8      FUNCTION   P1,L216
1,6440/2,6222/3,528/4,2379/5,3639/6,6222/7,1479/8,1479/9,3639/10,2379
11,1229/12,6222/13,3065/14,2379/15,5708/16,1167/17,6222/18,1167/19,1323
20,4026/21,5704/22,6440/23,2379/24,6764/25,1323/26,555/27,961/28,528
29,0/30,0/31,0/32,0/33,0/34,0/35,0/36,0/37,0/38,0/39,7181/40,1229
41,555/42,528/43,5704/44,3892/45,5817/46,2599/47,5704/48,2433/49,0
50,7181/51,6764/52,0/53,0/54,0/55,0/56,0/57,0/58,0/59,0/60,0/61,0
62,3065/63,961/64,3806/65,6440/66,3065/67,3065/68,6764/69,0/70,0/71,0
72,0/73,0/74,0/75,0/76,0/77,0/78,528/79,528/80,693/81,469/82,0/83,0
84,0/85,3065/86,0/87,0/88,0/89,2599/90,2599/91,2379/92,1323/93,0/94,0
95,422/96,1260/97,1260/98,1479/99,2379/100,0/101,0/102,0/103,0/104,0
105,0/106,0/107,0/108,0/109,0/110,961/111,961/112,0/113,0/114,0/115,0
116,0/117,0/118,961/119,5704/120,616/121,3065/122,601/123,0/124,0/125,0
126,3639/127,601/128,601/129,2379/130,0/131,0/132,2379/133,469/134,0
135,7108/136,0/137,2379/138,0000/139,1186/140,0/141,0/142,1186/143,0
144,0/145,0/146,0/147,0/148,0/149,0/150,3892/151,0/152,0/153,7181
154,961/155,961/156,961/157,0/158,0/159,6440/160,5704/161,1323/162,2447
163,0/164,1229/165,0/166,0/167,1186/168,1186/169,3639/170,0/171,0/172,0
173,469/174,3447/175,601/176,601/177,0/178,3065/179,0/180,6222/181,0
182,3639/183,693/184,422/185,469/186,6222/187,0/188,0/189,0/190,0
191,1229/192,0/193,0/194,0/195,0/196,0/197,0/198,2379/199,0/200,0/201,0
202,0/203,0/205,0/205,0/206,0/207,0/208,0/209,0/210,0/211,0/212,0/213,0
214,0/215,0/216,0
*
*INPUT - PROCESS 3 ROUTING
 9      FUNCTION   P1,L216
1,0/2,0/3,0/4,00/5,25/6,24/7,0/8,0/9,25/10,0/11,24/12,24/13,25
14,25/15,00/16,24/17,24/18,00/19,24/20,25/21,0/22,24/23,25/24,24/25,24
26,25/27,25/28,00/29,24/30,24/31,25/32,25/33,25/34,0/35,0/36,0/37,0
38,0/39,24/40,24/41,25/42,00/43,0/44,25/45,00/46,25/47,24/48,25/49,24
50,24/51,0/52,24/53,24/54,25/55,25/56,25/57,0/58,0/59,0/60,0/61,0/62,0
63,25/64,25/65,0/66,00/67,25/68,0/69,24/70,24/71,24/72,24/73,25/74,25
75,25/76,0/77,0/78,00/79,25/80,0/81,25/82,0/83,24/84,24/85,00/86,25
87,0/88,0/89,25/90,00/91,00/92,24/93,0/94,0/95,25/96,24/97,0/98,24/99,0
100,24/101,24/102,24/103,25/104,25/105,25/106,25/107,0/108,0/109,0
110,25/111,25/112,24/113,24/114,24/115,24/116,24/117,25/118,0/119,0
120,0/121,00/122,24/123,24/124,24/125,0/126,25/127,25/128,25/129,0
130,24/131,0/132,25/133,25/134,0/135,0/136,0/137,0/138,24/139,24/140,25
141,24/142,0/143,0/144,0/145,0/146,0/147,25/148,0/149,0/150,0/151,0
152,24/153,24/154,0/155,25/156,0/157,0/158,0/159,0/160,0/161,0/162,0
163,0/164,24/165,0/166,25/167,24/168,24/169,0/170,0/171,0/172,0/173,25
174,0/175,0/176,0/177,24/178,0/179,0/180,24/181,24/182,25/183,0/184,0
185,00/186,0/187,25/188,0/189,24/190,24/191,24/192,0/193,25/194,25
195,0/196,24/197,0/198,0/199,25/200,25/201,0/202,0/203,25/204,25/205,0
206,0/207,0/208,0/209,0/210,0/211,25/212,0/213,0/214,0/215,0/216,24
*
*INPUT - MEAN PROCESS TIME PER PAN THROUGH PROCESS 3
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 10      FUNCTION    P1,L216
1,45/2,57/3,52/4,62/5,45/6,57/7,0/8,45/9,45/10,49/11,51/12,57/13,45
14,49/15,62/16,54/17,57/18,54/19,49/20,43/21,0/22,49/23,53/24,54/25,49
26,45/27,48/28,52/29,59/30,62/31,49/32,42/33,45/34,0/35,0/36,0/37,0
38,0/39,52/40,51/41,45/42,52/43,0/44,42/45,45/46,43/47,62/48,83/49,45
50,52/51,0/52,57/53,45/54,48/55,53/56,53/57,0/58,0/59,0/60,0/61,0/62,45
63,48/64,43/65,0/66,45/67,45/68,0/69,54/70,54/71,57/72,51/73,45/74,43
75,43/76,0/77,0/78,52/79,52/80,0/81,46/82,0/83,57/84,49/85,00/86,48
87,0/88,0/89,43/90,0/91,49/92,49/93,0/94,0/95,49/96,49/97,0/98,57/99,0
100,57/101,45/102,54/103,49/104,49/105,44/106,45/107,0/108,0/109,0
110,48/111,48/112,54/113,57/114,49/115,54/116,62/117,45/118,0/119,0
120,0/121,45/122,62/123,53/124,57/125,0/126,45/127,48/128,48/129,49
130,60/131,0/132,49/133,46/134,0/135,0/136,0/137,0/138,45/139,51/140,83
141,45/142,51/143,0/144,0/145,0/146,0/147,49/148,0/149,0/150,0/151,0
152,51/153,52/154,0/155,48/156,0/157,0/158,0/159,0/160,0/161,0/162,0
163,0/164,51/165,0/166,53/167,51/168,51/169,0/170,0/171,0/172,0/173,46
174,0/175,0/176,0/177,49/178,0/179,0/180,57/181,72/182,45/183,0/184,49
185,46/186,0/187,49/188,0/189,54/190,54/191,51/192,0/193,52/194,52
195,0/196,45/197,0/198,0/199,49/200,49/201,0/202,0/203,49/204,49/205,0
206,0/207,0/208,0/209,0/210,0/211,45/212,0/213,0/214,0/215,0/216,62
*
*INPUT - MEAN PROCESS TIME PER PAN THROUGH PROCESS 4
 11      FUNCTION    P1,L216
1,0/2,0/3,97/4,93/5,0/6,0/7,0/8,72/9,00/10,87/11,72/12,80/13,00/14,81
15,93/16,78/17,78/18,0/19,00/20,84/21,0/22,72/23,87/24,00/25,0/26,83
27,96/28,97/29,0/30,93/31,91/32,54/33,149/34,93/35,72/36,93/37,98/38,72
39,00/40,72/41,83/42,97/43,0/44,0/45,72/46,76/47,93/48,129/49,72/50,73
51,0/52,83/53,72/54,93/55,87/56,93/57,129/58,72/59,83/60,75/61,91/62,83
63,96/64,76/65,0/66,83/67,0/68,0/69,78/70,78/71,84/72,72/73,00/74,75
75,84/76,72/77,72/78,97/79,0/80,0/81,0/82,0/83,78/84,72/85,00/86,96
87,72/88,80/89,76/90,0/91,81/92,0/93,0/94,0/95,91/96,0/97,0/98,0/99,0
100,80/101,72/102,75/103,81/104,87/105,78/106,00/107,93/108,0/109,0
110,96/111,0/112,0/113,0/114,0/115,75/116,00/117,83/118,0/119,0/120,0
121,83/122,93/123,73/124,0/125,72/126,0/127,93/128,0/129,0/130,91
131,88/132,0/133,0/134,0/135,0/136,0/137,0/138,0/139,72/140,129/141,0
142,72/143,0/144,0/145,0/146,0/147,0/148,0/149,91/150,0/151,0/152,0
153,0/154,0/155,0/156,0/157,0/158,0/159,0/160,0/161,0/162,0/163,0/164,0
165,0/166,0/167,0/168,72/169,0/170,0/171,0/172,0/173,0/174,0/175,0
176,0/177,0/178,0/179,0/180,0/181,0/182,0/183,0/184,91/185,0/186,0
187,91/188,91/189,78/190,0/191,0/192,72/193,0/194,0/195,97/196,0/197,72
198,0/199,0/200,0/201,81/202,81/203,0/204,0/205,87/206,87/207,83/208,75
209,93/210,72/211,0/212,83/213,83/214,83/215,83/216,93
*
*INPUT - LOT DIVISION CODE
 12      FUNCTION    P1,L216
1,3/2,11/3,10/4,5/5,12/6,25/7,0/8,60/9,17/10,18/11,34/12,15/13,26
14,18/15,13/16,6/17,6/18,4/19,30/20,9/21,3/22,13/23,9/24,7/25,16
26,20/27,78/28,37/29,14/30,60/31,72/32,23/33,19/34,120/35,37/36,33
37,20/38,22/39,3/40,23/41,32/42,27/43,3/44,30/45,27/46,4/47,22/48,15
49,24/50,34/51,2/52,7/53,42/54,47/55,31/56,35/57,17/58,23/59,36/60,22
61,24/62,30/63,62/64,4/65,35/66,16/67,17/68,15/69,14/70,4/71,18/72,26
73,39/74,19/75,14/76,30/77,26/78,46/79,118/80,35/81,10/82,0/83,15/84,14
85,00/86,11/87,28/88,21/89,9/90,21/91,23/92,15/93,0/94,0/95,100/96,30
97,13/98,11/99,2/100,5/101,19/102,12/103,7/104,2/105,5/106,9/107,25
108,0/109,0/110,29/111,13/112,19/113,2/114,4/115,14/116,15/117,9/118,8
119,20/120,14/121,25/122,13/123,8/124,20/125,23/126,32/127,25/128,25
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129,40/130,18/131,23/132,26/133,50/134,0/135,7/136,0/137,8/138,23
139,16/140,8/141,28/142,76/143,0/144,0/145,0/146,0/147,17/148,0/149,12
150,8/151,0/152,38/153,5/154,21/155,40/156,11/157,0/158,0/159,9/160,1
161,7/162,13/163,0/164,50/165,0/166,7/167,14/168,30/169,9/170,0/171,0
172,0/173,81/174,12/175,86/176,48/177,20/178,0/179,0/180,7/181,10
182,12/183,35/184,100/185,50/186,25/187,100/188,17/189,6/190,4/191,27
192,30/193,6/194,68/195,148/196,19/197,10/198,19/199,24/200,31/201,20
202,24/203,21/204,36/205,28/206,21/207,26/208,20/209,15/210,30/211,30
212,40/213,25/214,30/215,11/216,5
*
*INPUT - LOT YARN SPECIFICATION CODE
 13      FUNCTION    P1,L216
1,2/2,9/3,21/4,0/5,9/6,1/7,7/8,7/9,9/10,9/11,3/12,1/13,10/14,10/15,11
16,10/17,9/18,6/19,5/20,16/21,12/22,1/23,17/24,13/25,5/26,20/27,13
28,21/29,2/30,19/31,0/32,0/33,0/34,0/35,0/36,0/37,0/38,0/39,9/40,3
41,20/42,21/43,2/44,14/45,2/46,15/47,11/48,15/49,0/50,9/51,2/52,0/53,0
54,0/55,0/56,0/57,0/58,0/59,0/60,0/61,0/62,10/63,19/64,18/65,1/66,9
67,9/68,10/69,0/70,0/71,0/72,0/73,0/74,0/75,0/76,0/77,0/78,21/79,21
80,20/81,21/82,0/83,9/84,0/85,10/86,0/87,0/88,0/89,15/90,15/91,10/92,5
93,0/94,0/95,21/96,8/97,8/98,7/99,17/100,0/101,0/102,0/103,0/104,0
105,0/106,0/107,0/108,0/109,0/110,19/111,19/112,0/113,0/114,0/115,0
116,0/117,0/118,19/119,11/120,19/121,10/122,19/123,0/124,0/125,0/126,9
127,19/128,19/129,9/130,0/131,0/132,9/133,21/134,0/135,2/136,0/137,13
138,7/139,10/140,0/141,0/142,10/143,0/144,0/145,0/146,0/147,0/148,0
149,0/150,9/151,0/152,0/153,9/154,19/155,19/156,0/157,0/158,0/159,1
160,9/161,2/162,2/163,0/164,3/165,0/166,0/167,10/168,10/169,9/170,0
171,0/172,0/173,21/174,9/175,19/176,19/177,0/178,0/179,0/180,0/181,0
182,9/183,20/184,21/185,21/186,1/187,0/188,0/189,0/190,0/191,3/192,0
193,0/194,0/195,0/196,0/197,0/198,10/199,0/200,0/201,0/202,0/203,0
204,0/205,0/206,0/207,0/208,0/209,0/210,0/211,0/212,0/213,0/214,0/215,0
216,0
*
*INPUT - PROCESS RELEASE TIME
 14      FUNCTION    P1,L216
1,200/2,200/3,200/4,00200/5,200/6,200/7,200/8,19400/9,200/10,200/11,200
12,200/13,19400/14,200/15,200/16,200/17,200/18,200/19,2300/20,200
21,200/22,200/23,200/24,200/25,05000/26,200/27,200/28,200/29,200/30,200
31,200/32,200/33,200/34,200/35,200/36,200/37,200/38,200/39,5000/40,5000
41,5000/42,5000/43,200/44,5000/45,200/46,5000/47,200/48,5000/49,5000
50,200/51,200/52,5000/53,5000/54,5000/55,5000/56,5000/57,5000/58,5000
59,5000/60,5000/61,5000/62,9800/63,9800/64,9800/65,9800/66,9800
67,38600/68,5000/69,9800/70,9800/71,9800/72,9800/73,9800/74,9800
75,9800/76,9800
77,9800/78,14600/79,24200/80,14600/81,57800/82,9800/83,14600/84,14600
85,00200/86,14600/87,14600/88,14600/89,14600/90,14600/91,14600/92,19400
93,19400/94,19400/95,19400/96,19400/97,19400/98,43400/99,200
100,19400/101,19400/102,19400/103,19400/104,19400/105,19400/106,19400
107,19400/108,19400/109,24200/110,24200/111,24200/112,24200/113,24200
114,24200/115,24200/116,24200/117,24200/118,24200/119,24200/120,29000
121,29000/122,29000/123,33800/124,43400/125,33800/126,33800/127,33800
128,33800/129,33800/130,38600/131,38600/132,09800/133,33800/134,38600
135,48200/136,38600/137,38600/138,57800/139,43400/140,43400/141,33800
142,43400/143,43400/144,43400/145,43400/146,43400/147,48200/148,67400
149,48200/150,43400/151,43400/152,67400/153,48200/154,48200/155,48200
156,48200/157,48200/158,48200/159,57800/160,57800/161,62600/162,48200
163,48200/164,53000/165,53000/166,5000/167,57800/168,53000/169,57800
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170,57800/171,57800/172,57800/173,57800/174,53000/175,62600/176,62600
177,57800/178,67400/179,67400/180,67400/181,67400/182,24200/183,38600
184,38600/185,48200/186,29000/187,53000/188,62600/189,9800/190,19400
191,53000/192,53000/193,14600/194,43400/195,33800/196,19400/197,67400
198,200/199,38600/200,57800/201,48200/202,67400/203,33800/204,62600
205,33800/206,43400/207,33800/208,38600/209,43400/210,43400/211,53000
212,9800/213,48200/214,62600/215,48200/216,48200
*
*INPUT - CUMULATIVE PROCESS TIME DISTRIBUTION FOR PROCESS 2
 15     FUNCTION   RN2,C21
0,1/.049,1.0011/.099,1.0044/.149,1.0097/.199,1.0167/.249,1.0248
.299,1.0337/.349,1.0428/.399,1.0519/.449,1.0605/.499,1.0683/.549,1.0752
.599,1.0811/.649,1.0860/.699,1.09/.749,1.0931/.799,1.0954/.849,1.0972
.899,1.0985/.949,1.0994/.999,1.1
*INPUT - DATA FOR PROCESS 2 MACHINE - OPERATOR AREA ALLOCATION
 16     FUNCTION   P1,L24
1,1/2,24/3,24/4,28/5,32/6,37/7,42/8,48/9,54/10,60/11,66/12,72/13,82
14,88/15,94/16,104/17,115/18,125/19,135/20,140/21,145/22,151/23,157
24,163
*
*INPUT - YARN PLY SPECIFICATION
 17     FUNCTION   P1,L216
1,0/2,0/3,0/4,0/5,0/6,0/7,0/8,0/9,0/10,0/11,1/12,0/13,0/14,0/15,0/16,0
17,0/18,0/19,1/20,0/21,0/22,0/23,0/24,0/25,1/26,0/27,0/28,0/29,0/30,0
31,0/32,0/33,0/34,0/35,0/36,0/37,0/38,0/39,0/40,1/41,0/42,0/43,0/44,0
45,0/46,0/47,0/48,0/49,0/50,0/51,0/52,0/53,0/54,0/55,0/56,0/57,0/58,0
59,0/60,0/61,0/62,0/63,0/64,0/65,0/66,0/67,0/68,0/69,0/70,0/71,0/72,0
73,0/74,0/75,0/76,0/77,0/78,0/79,0/80,0/81,0/82,0/83,0/84,0/85,0/86,0
87,0/88,0/89,0/90,0/91,0/92,1/93,0/94,0/95,0/96,1/97,1/98,0/99,0/100,0
101,0/102,0/103,0/104,0/105,0/106,0/107,0/108,0/109,0/110,0/111,0/112,0
113,0/114,0/115,0/116,0/117,0/118,0/119,0/120,0/121,0/122,0/123,0/124,0
125,0/126,0/127,0/128,0/129,0/130,0/131,0/132,0/133,0/134,0/135,0/136,0
137,0/138,0/139,0/140,0/141,0/142,0/143,0/144,0/145,0/146,0/147,0/148,0
149,0/150,0/151,0/152,0/153,0/154,0/155,0/156,0/157,0/158,0/159,0/160,0
161,1/162,0/163,0/164,1/165,0/166,0/167,0/168,0/169,0/170,0/171,0/172,0
173,0/174,0/175,0/176,0/177,0/178,0/179,0/180,0/181,0/182,0/183,0
184,0/185,0/186,0/187,0/188,0/189,0/190,0/191,1/192,0/193,0/194,0/195,0
196,0/197,0/198,0/199,0/200,0/201,0/202,0/203,0/204,0/205,0/206,0/207,0
208,0/209,0/210,0/211,0/212,0/213,0/214,0/215,0/216,0
*
*INPUT - CUMULATIVE PROCESS TIME DISTRIBUTION FOR PROCESS 4
 18     FUNCTION   RN3,C11
0,.95/.099,.9523/.199,.9594/.299,.975/.399,.9916/.499,1/.599,1.0084
.699,1.026/.799,1.0406/.899,1.0477/.999,1.05
*
*INPUT - DISCRETE DOWNTIME DISTRIBUTION FOR 4.5 INCH COVER
 19     FUNCTION   RN4,D8
.066,250/.330,350/.462,450/.528,650/.792,750/.858,950/.924,1050
.999,1250
*
*INPUT - DISCRETE DOWNTIME DISTRIBUTION FOR 6 INCH COVER
 20     FUNCTION   RN5,D8
.132,350/.264,450/.396,550/.528,650/.660,750/.792,950/.858,1150
.999,1250
*
*INPUT - DISCRETE DOWNTIME DISTRIBUTION FOR FIRST LEAD PRESS
 21     FUNCTION   RN6,D11
.066,490/.132,530/.396,775/.528,829/.594,957/.660,1042/.726,1127
.792,1299/.858,1427/.924,1598/.999,2494
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*
*INPUT - DISCRETE DOWNTIME DISTRIBUTION FOR SECOND LEAD PRESS
 22     FUNCTION   RN7,D8
.066,390/.330,456/.528,618/.726,731/.792,810/.858,915/.924,1073
.999,1808
*
*INPUT - DISCRETE DOWNTIME DISTRIBUTION FOR THIRD LEAD PRESS
 23     FUNCTION   RN8,D7
.132,561/.396,625/.462,767/.660,854/.858,974/.924,1129/.999,1440
*
*INPUT - DISCRETE DOWNTIME DISTRIBUTION FOR FIRST 4.5 INCH TUBER
 24     FUNCTION   RN1,D7
.198,140/.264,240/.528,330/.726,440/.858,600/.924,900/.999,1320
*
*INPUT - DISCRETE DOWNTIME DISTRIBUTION FOR SECOND 4.5 INCH TUBER
 25     FUNCTION   RN2,D8
.198,160/.396,240/.594,320/.726,450/.792,660/.858,840/.924,1020
.999,1320
*
*INPUT - DISCRETE DOWNTIME DISTRIBUTION FOR 6 INCH TUBER
 26     FUNCTION   RN3,D7
.132,120/.264,240/.528,315/.594,420/.726,630/.858,720/.999,1140
*
*INPUT - TUBE COMPOUND CODE
 27     FUNCTION   P1,L179
1,1/2,2/3,3/4,4/5,4/6,5/7,4/8,0/9,0/10,0/11,0/12,0/13,0/14,0/15,0/16,0
17,0/18,0/19,0/20,0/21,0/22,0/23,0/24,0/25,0/26,0/27,0/28,0/29,0/30,0
31,0/32,0/33,0/34,0/35,0/36,0/37,0/38,0/39,6/40,4/41,4/42,3/43,0/44,0
45,0/46,0/47,0/48,0/49,0/50,0/51,0/52,0/53,0/54,0/55,0/56,0/57,0/58,0
59,0/60,0/61,0/62,5/63,7/64,8/65,9/66,0/67,0/68,0/69,0/70,0/71,0/72,0
73,0/74,0/75,0/76,0/77,0/78,3/79,0/80,4/81,0/82,8/83,0/84,0/85,0/86,0
87,0/88,0/89,5/90,5/91,5/92,10/93,4/94,4/95,4/96,5/97,5/98,0/99,0/100,0
101,0/102,0/103,0/104,0/105,0/106,0/107,0/108,11/109,5/110,7/111,7
112,0/113,0/114,0/115,0/116,0/117,0/118,7/119,5/120,12/121,5/122,4
123,0/124,0/125,0/126,4/127,4/128,4/129,4/130,0/131,0/132,0/133,7
134,13/135,0/136,2/137,9/138,0/139,4/140,0/141,0/142,0/143,2/144,4
145,13/146,5/147,0/148,6/149,0/150,11/151,11/152,0/153,6/154,3/155,3
156,3/157,11/158,4/159,0/160,0/161,0/162,4/163,4/164,4/165,11/166,0
167,4/168,0/169,4/170,4/171,3/172,14/173,7/174,3/175,4/176,0/177,0
178,5/179,4
*
*INPUT - REFER TO SPECIFIED MACHINES BY ABBREVIATED NAME
 TUBE1 EQU         1,F
 TUBE2 EQU         2,F
 TUBE3 EQU         3,F
 COVE1 EQU         164,F
 COVE2 EQU         165,F
 PRES1 EQU         166,F
 PRES2 EQU         167,F
 PRES3 EQU         168,F
*
*  VARIABLES USED IN THE MODEL
 1      VARIABLE   393+N$ULA
 2      VARIABLE   P1+165
 3      VARIABLE   P3+P16*P3-P6
 4      VARIABLE   P6-1
 5      VARIABLE   P5+1
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       6      VARIABLE    (P3-P12)+P16*(P3-P12)
       7      VARIABLE    P12-1
       8      VARIABLE    P9+140
       9      VARIABLE    2*P11/3
       10     VARIABLE    P11*P12
       11     BVARIABLE   FNU*7*LR*7
       12     VARIABLE    P*2-P*1
       13     VARIABLE    P15+208
       14     VARIABLE    P12+P16*P12
       15     VARIABLE    P3-P12
       16     VARIABLE    P15+416
       17     VARIABLE    P15+624
       18     VARIABLE    P7+P6-1
       19     VARIABLE    P1-222
       20     VARIABLE    P1-199
       21     VARIABLE    P3-1
       22     VARIABLE    X12+4800
       23     VARIABLE    P15+231
       24     VARIABLE    P9-1
       25     VARIABLE    P10*P12
       26     VARIABLE    P10-P10/7
       27     VARIABLE    FN11*11/10
       28     VARIABLE    P1-367
      *
      *  CREATE JOB LOTS
 1            GENERATE    1,,,216,,17,F
 2            SAVEVALUE   14+,1
      *
      *  ASSIGN JOB LOT PARAMETER LIST
 3            ASSIGN      1,X14
 4            ASSIGN      2,FN2
 5            ASSIGN      3,FN3
 6            ASSIGN      4,FN4
 7            ASSIGN      5,FN5
 8            ASSIGN      6,FN6
 9            ASSIGN      7,FN7
 10           ASSIGN      8,FN8
 11           ASSIGN      9,FN9
 12           ASSIGN      10,FN10
      *
      *  6 INCH COVER MACHINE MODIFICATION ALTERS STANDARD TIME DATA BY 15
      *  PER CENT
 13           TEST E      P9,25,MOD1
 14           ASSIGN      10,V26
 15      MOD1 ASSIGN      11,FN11
 16           ASSIGN      12,FN12
 17           ASSIGN      13,FN13
 18           ASSIGN      14,FN14
 19           SAVEVALUE   13+,1
 20           ASSIGN      15,X13
 21           ASSIGN      16,FN17
 22           TEST LE     P1,179,ROUTE
 23           ASSIGN      17,FN27
      *
      *  ENTER JOB LOTS IN INITIAL QUEUES IN SCHEDULED TIME ORDER
 24      ROUTE LINK       P2,P14
      *
```

```
      *  BEGIN PROCESS1 - SPLIT LOT INTO PAN UNITS
 25      PROC1 SPLIT      1,TIME1
               SPLIT      V21,TQUE
 27      SIZE  TRANSFER   P,2,SIZE
 28            TRANSFER   BOTH,TUBR1,TUBR2
 29            TRANSFER   ,TUBR3
      *
      *  CONVENIENT LOCATION FOR REQUIRED PROGRAM STATEMENTS
 30      WAIT  ADVANCE    30000
 31            TRANSFER   ,FINI
 32      CQUE  LINK       30,FIFO
 33      LPQUE LINK       31,FIFO
 34      RQUE  LINK       27,FIFO
 35      MACHN ASSIGN     7,X5
 36            LOGIC R    165
 37            TRANSFER   ,RUN
 38      GAREA ASSIGN     5+,1
 39            TRANSFER   ,SETUP
 40      TQUE  LINK       29,FIFO
      *
      *  FIRST 4.5 INCH TUBER
 41      TUBR1 GATE LR    1
 42            LOGIC S    1
 43      NEXT1 SEIZE      1
      *
      *  IS A SETUP REQUIRED?
 44            TEST NE    P17,XH2,NSET1
 45            ADVANCE    200
 46      NSET1 ADVANCE    P4,FN1
 47            RELEASE    1
      *
      *  RECORD COMPOUND IN USE
 48            SAVEVALUE  2,P17,H
      *
      *  START NEXT PAN IN LOT FROM TUBER QUEUE
 49            UNLINK     29,NEXT1,1,1,,MORE1
 50            TRANSFER   ,IPI1
      *
      *  WHEN LOT IS FINISHED,ALLOW NEXT LOT TO BEGIN PROCESSING
 51      MORE1 LOGIC R    1
 52            TRANSFER   ,IPI1
      *
      *  SECOND 4.5 INCH TUBER
 53      TUBR2 GATE LR    2
 54            LOGIC S    2
 55      NEXT2 SEIZE      2
 56            TEST NE    P17,XH3,NSET2
 57            ADVANCE    200
 58      NSET2 ADVANCE    P4,FN1
 59            RELEASE    2
 60            SAVEVALUE  3,P17,H
 61            UNLINK     29,NEXT2,1,1,,MORE2
 62            TRANSFER   ,IPI1
 63      MORE2 LOGIC R    2
 64            TRANSFER   ,IPI1
      *
      *  6 INCH TUBER
```

```
128            LOGIC R     165
        *
        *  DOES LOT CONTINUE THROUGH NEXT PROCESS? IF NOT, TERMINATE PAN TO
        *  IN-PROCESS INVENTORY
129      IPI2  TEST G      P9,0,FINI
        *
        *  DOES THE LOT SPLIT INTO TWO LOTS?
130            TEST G      XH*15,V14,REST
        *
        *  SPLIT INTO SPECIFIED LOT SIZES
131            ASSEMBLE    V6
132            ASSIGN      12,V15
133            TRANSFER    ,PROC3
134      REST  ASSEMBLE    V14
        *
        *  BEGIN PROCESS 3
        *
        *  PROCEED WHEN SPECIFIED MACHINE IS AVAILABLE
135      PROC3 GATE LR     V24
136            LOGIC S     V24
        *
        *  SPLIT LOT INTO PAN UNITS
137            SPLIT       1,TIME2
138            SPLIT       V7,CQUE
        *
        *  PROCESS PAN THROUGH MACHINE
139      COV1  SEIZE       V8
        *
        *  RECORD DEPARTURE FROM IN-PROCESS INVENTORY
140            SAVEVALUE   175-,1
141            ADVANCE     P10,FN1
142            RELEASE     V8
        *
        *  START THE NEXT PAN IN THE LOT
143            UNLINK      30,COV1,1,1,,FIN
144            TRANSFER    ,IPI3
        *
        *  IF LOT IS COMPLETED, START NEXT LOT
145      FIN   LOGIC R     V24
        *
        *  RECORD PRODUCTION AND IN-PROCESS INVENTORY
146      IPI3  SAVEVALUE   176+,1
147            SAVEVALUE   172+,1
148            GATE M      TIME2,FINI
149      TIME2 MATCH       TIME2
150            ASSEMBLE    2
        *
        *  WAIT 480 MINUTES FOR COOLING
151            ASSIGN      14,V22
        *
        *  DOES LOT CONTINUE THROUGH NEXT PROCESS? IF NOT, WAIT 3000 MINUTES
        *  AND TERMINATE LOT TO IN/PROCESS INVENTORY
152            TEST G      P11,0,WAIT
153            LINK        26,FIFO
        *
        *  BEGIN PROCESS 4
        *
```

```
        *  ROUTE LOT TO AN AVAILABLE MACHINE
154      PROC4 TRANSFER    ALL,LDP1,LDP3,11
        *
        *  LEAD PRESS 1
155      LDP1  GATE LR     4
156            LOGIC S     4
        *
        *  SPLIT LOT INTO PAN UNITS
157            SPLIT       V7,LPQUE
        *
        *  PROCESS PAN THROUGH MACHINE
158      LEAD1 SEIZE       166
        *
        *  RECORD DEPARTURE FROM IN-PROCESS INVENTORY
159            SAVEVALUE   176-,1
160            ADVANCE     V9,FN18
161            RELEASE     166
        *
        *  START NEXT PAN IN LOT; IF LOT IS COMPLETED, START NEXT LOT
162            UNLINK      31,LEAD1,1,1,,FIN1
163            TRANSFER    ,PROD
164      FIN1  LOGIC R     4
165            TRANSFER    ,PROD
        *
        *  LEAD PRESS 2
166      LDP2  GATE LR     5
167            LOGIC S     5
168            SPLIT       V7,LPQUE
169      LEAD2 SEIZE       167
170            SAVEVALUE   176-,1
171            ADVANCE     P11,FN18
172            RELEASE     167
173            UNLINK      31,LEAD2,1,1,,FIN2
174            TRANSFER    ,PROD
175      FIN2  LOGIC R     5
176            TRANSFER    ,PROD
        *
        *  LEAD PRESS 3
177      LDP3  GATE LR     6
178            LOGIC S     6
179            SPLIT       V7,LPQUE
180      LEAD3 SEIZE       168
181            SAVEVALUE   176-,1
182            ADVANCE     P11,FN18
183            RELEASE     168
184            UNLINK      31,LEAD3,1,1,,FIN3
185            TRANSFER    ,PROD
186      FIN3  LOGIC R     6
        *
        *  RECORD PRODUCTION
187      PROD  SAVEVALUE   173+,1
188      FINI  TERMINATE   0
        *
        *  ASSIGN PROCESS 2 MACHINES TO OPERATOR AREAS
189            GENERATE    1,,,1,,25,H
190            ASSIGN      25,24
191      AREA  ASSIGN      1+,1
```

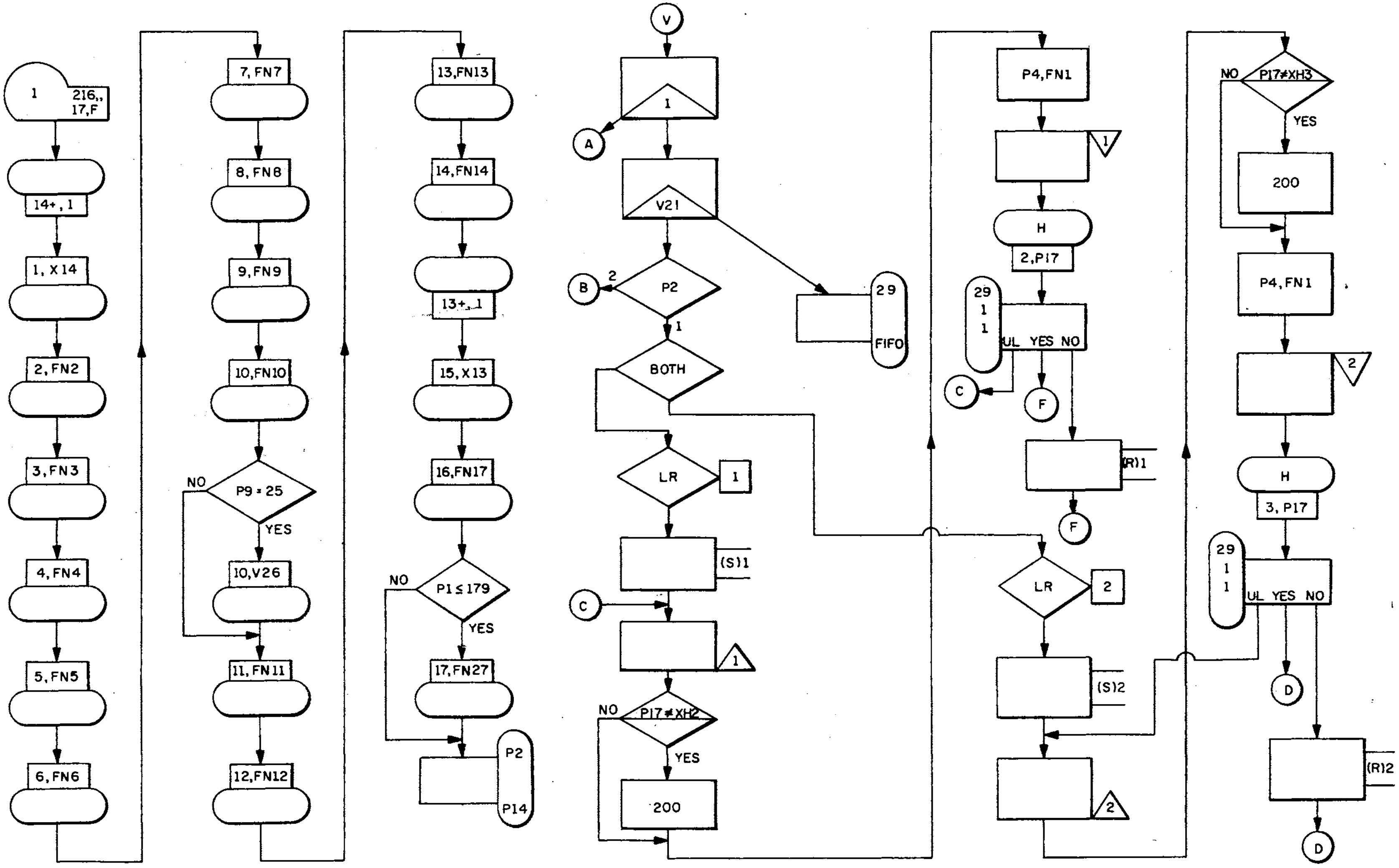
```
192             ASSIGN      *1,FN16
193             LOOP        25,AREA
194             ASSIGN      1,23
195       MACH  ASSIGN      25,V12
196             TRANSFER    ,ATION
197       ALLOC ASSIGN      *2-,1
198       ATION JOIN        P1,P*2
199             LOOP        25,ALLUC
200             ASSIGN      1-,1
201             ASSIGN      2-,1
202             TEST E      P1,2,MACH
203             REMOVE      3,,27
204             REMOVE      3,,28
205             JOIN        3,29
206             JOIN        3,30
207             REMOVE      4,,29
208             REMOVE      4,,30
209             JOIN        4,27
210             JOIN        4,28
211             REMOVE      5,,37
212             JOIN        6,37
213             REMOVE      6,,40
214             JOIN        5,40
215             REMOVE      7,,46
216             REMOVE      7,,47
217             REMOVE      7,,48
218             JOIN        7,49
219             JOIN        7,50
220             JOIN        7,51
221             REMOVE      8,,49
222             REMOVE      8,,50
223             REMOVE      8,,51
224             JOIN        8,46
225             JOIN        8,47
226             JOIN        8,48
227             REMOVE      9,,58
228             REMOVE      9,,59
229             REMOVE      9,,60
230             JOIN        9,61
231             JOIN        9,62
232             JOIN        9,63
233             REMOVE      10,,61
234             REMOVE      10,,62
235             REMOVE      10,,63
236             JOIN        10,58
237             JOIN        10,59
238             JOIN        10,60
239             TERMINATE   0
          *
          *     SIMULATE MACHINE DOWNTIME FOR PROCESSES 1,3,AND 4 MACHINES
240             GENERATE    4800,,220,16,,3,H
241             SAVEVALUE   1+,1,H
242             SPLIT       1,TIME
243             ASSIGN      1,385
244             SPLIT       4,DOWN,1
245       DOWN  ASSIGN      2,V28
246             ASSIGN      2,FN*2
```

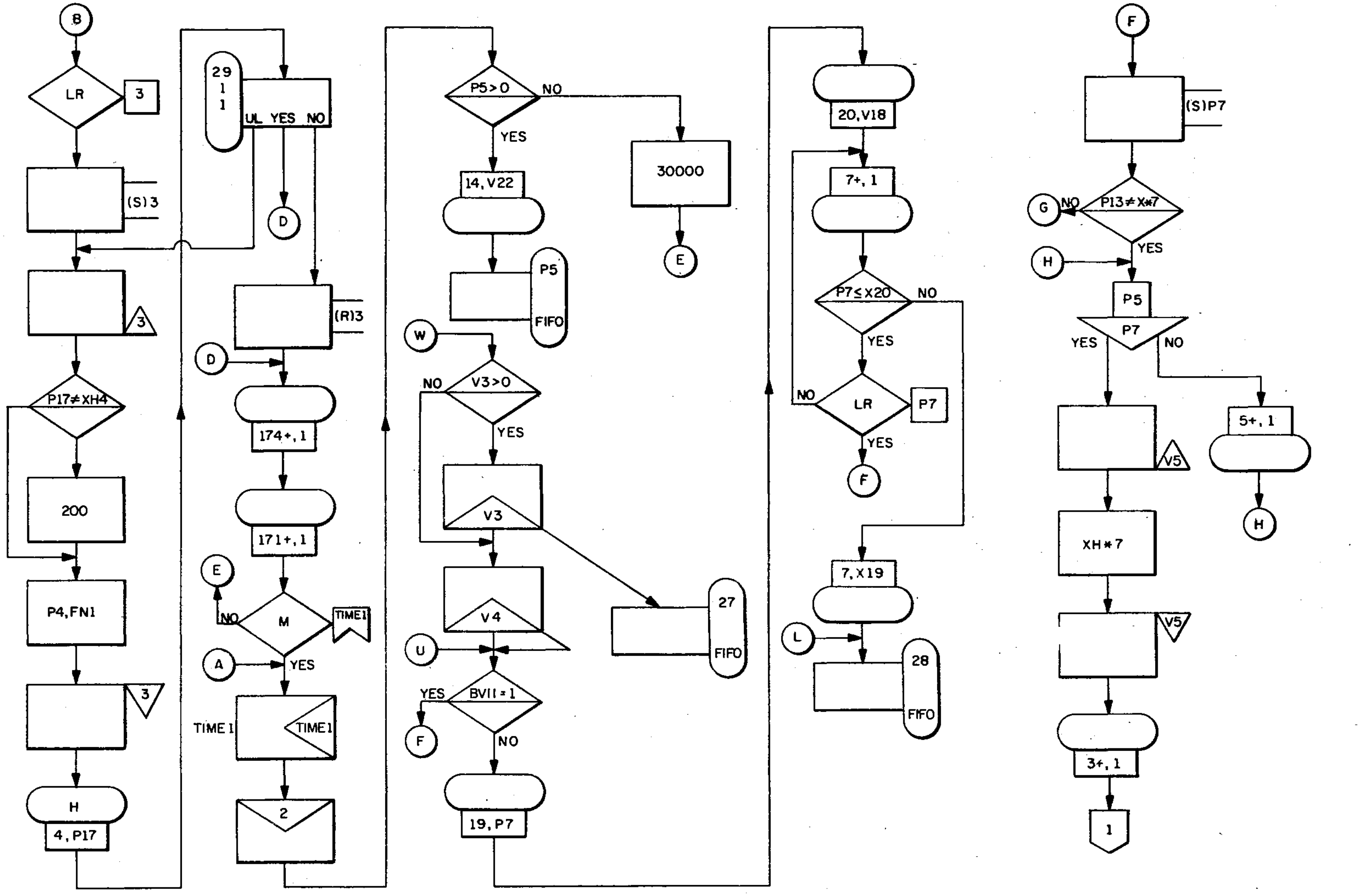
```
247             TRANSFER    ,TOR
248       TIME  ASSIGN      1,222
249       SIM   SPLIT       2,ULA,1
250       ULA   ASSIGN      2,V20
251             ASSIGN      2,FN*2
252       TCR   PREEMPT     V19
253             ADVANCE     P2
254             RETURN      V19
255             TERMINATE   0
          *
          *  RELEASE JOB LOTS FOR PROCESSING BY THE ACTUAL HISTORICAL SCHEDULE
256             GENERATE    150,,220,481,,4,F
257             UNLINK      28,AMACH,ALL
258             ASSIGN      2,2
259             ASSIGN      3,21
260             ASSIGN      4,2
261       SCH   ASSIGN      1+,1
262             UNLINK      *1,PROC1,ALL,14,X12
263             LOOP        2,SCH
264       EDU   ASSIGN      1+,1
265             UNLINK      *1,PROC2,ALL,14,X12
266             LOOP        3,EDU
267       LER   ASSIGN      1+,1
268             UNLINK      *1,PROC3,ALL,14,X12
269             LOOP        4,LER
270             ASSIGN      1+,1
271             UNLINK      *1,PROC4,ALL,14,X12
272             SAVEVALUE   12+,150
          *
          *  ESTABLISH MACHINE UNSERVICEABILITY DUE TO LABOR FORCE VARIATION
273             ASSIGN      1,14
274             SPLIT       1,SHIFT,1
275       SHIFT TEST E      X12,X*1,ZZZ
276             TEST E      P1,15,OTHER
277             LOGIC I     25
278             LOGIC I     26
279             LOGIC I     105
280             LOGIC I     106
281             LOGIC I     107
282             LOGIC I     108
283             LOGIC I     157
284             LOGIC I     158
285             LOGIC I     163
286             LOGIC I     15
287             TRANSFER    ,OVER
288       OTHER LOGIC I     37
289             LOGIC I     38
290             LOGIC I     73
291             LOGIC I     74
292             LOGIC I     75
293             LOGIC I     76
294             LOGIC I     77
295             LOGIC I     78
296             LOGIC I     79
297             LOGIC I     80
298             LOGIC I     81
299             LOGIC I     B2
```

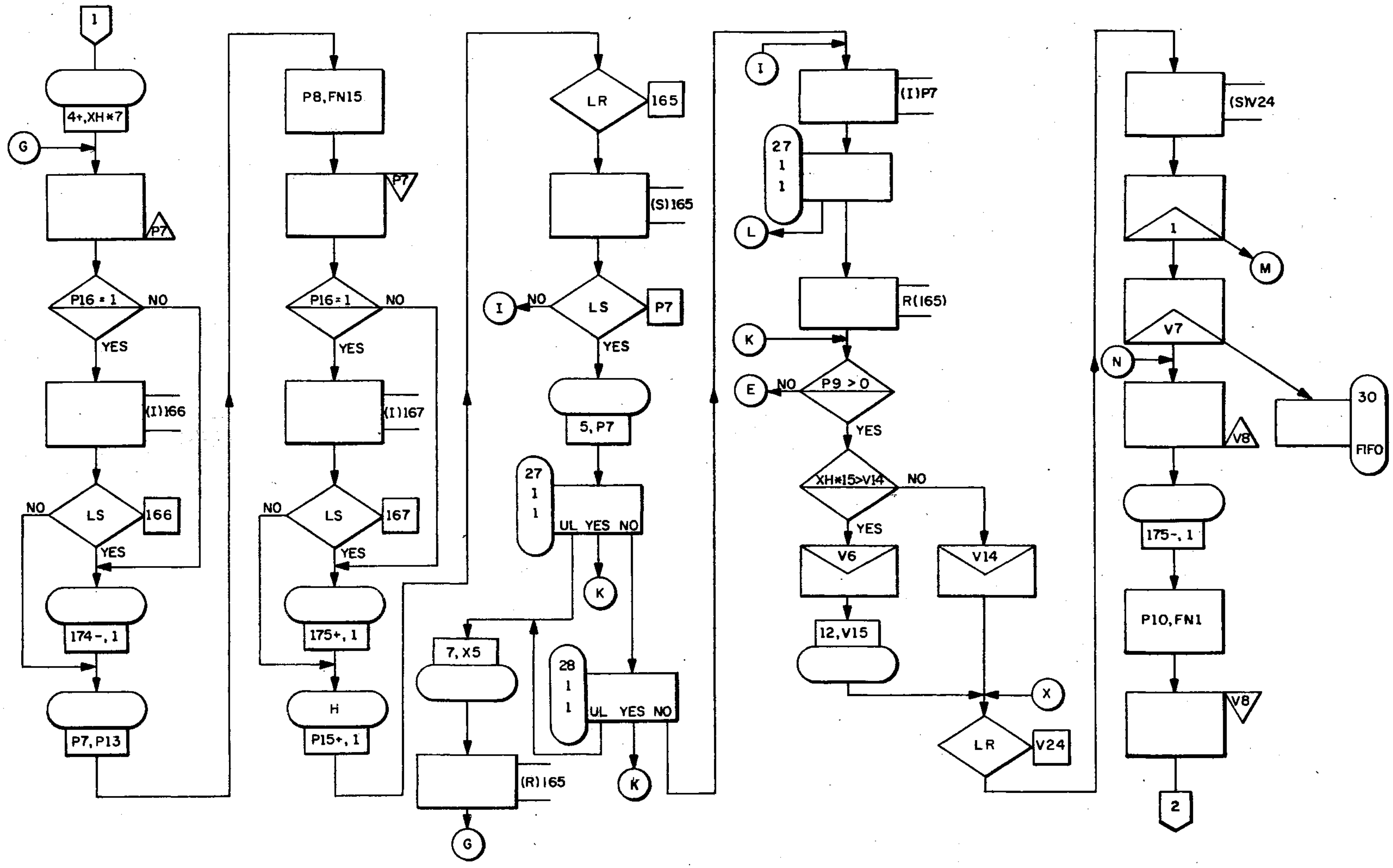
```
300             LOGIC I     16
301       OVER  GATE LS     P1,TWO
302             SAVEVALUE   P1+,4800
303             TRANSFER    ,ZZZ
304       TWO   SAVEVALUE   P1+,9600
305       ZZZ   ASSEMBLE    2
306             TERMINATE   1
                START       1
                REPORT
                TEXT        STATISTICS FOR SHIFT #XH1,2/XX#
                SPACE       2
          BLO   TITLE       ,
                SPACE       5
          CHA   TITLE       ,
                SPACE       5
          FAC   TITLE       ,STATISTICS FOR PROCESS 1 MACHINES--TUBE1 & TUBE2 INDI
         ICATE THE 4.5 INCH TUBERS, TUBE3 INDICATES THE 6 INCH TUBER
          FAC   INCLUDE     F$TUBE1-F$TUBE3/1,2,3,4,5
          FAC   TITLE       ,SETUP STATISTICS FOR PROCESS 2 MACHINES BY OPERATOR I
         CONTROL AREA
          FAC   INCLUDE     F4-F24/1,2,3,4,5
          FAC   TITLE       ,PRODUCTION STATISTICS FOR PROCESS 2 MACHINES
          FAC   INCLUDE     F25-F163/1,2,3,4,5
          FAC   TITLE       ,STATISTICS FOR PROCESS 3 MACHINES--COVE1 INDICATES  I
         THE 4.5 INCH COVER, COVE2 INDICATES THE 6 INCH COVER
          FAC   INCLUDE     F$COVE1-F$COVE2/1,2,3,4,5
          FAC   TITLE       ,STATISTICS FOR PROCESS 4 MACHINES--PRES INDICATES LEA
         AD PRESS
          FAC   INCLUDE     F$PRES1-F$PRES3/1,2,3,4,5
                SPACE       5
          SAV   TITLE       ,
                SPACE       5
          HSAV  TITLE       ,
                EJECT
                END
```

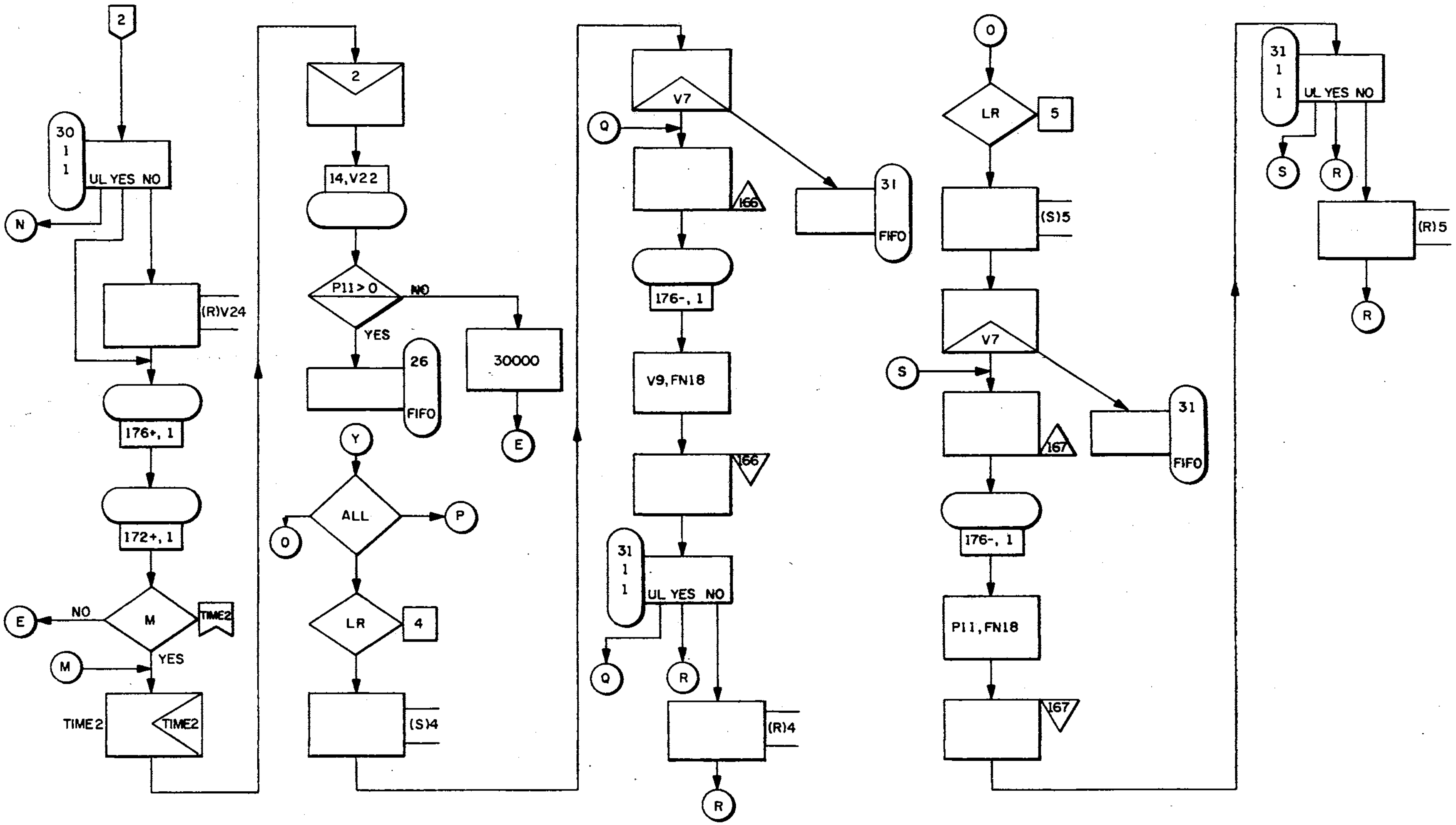
APPENDIX B

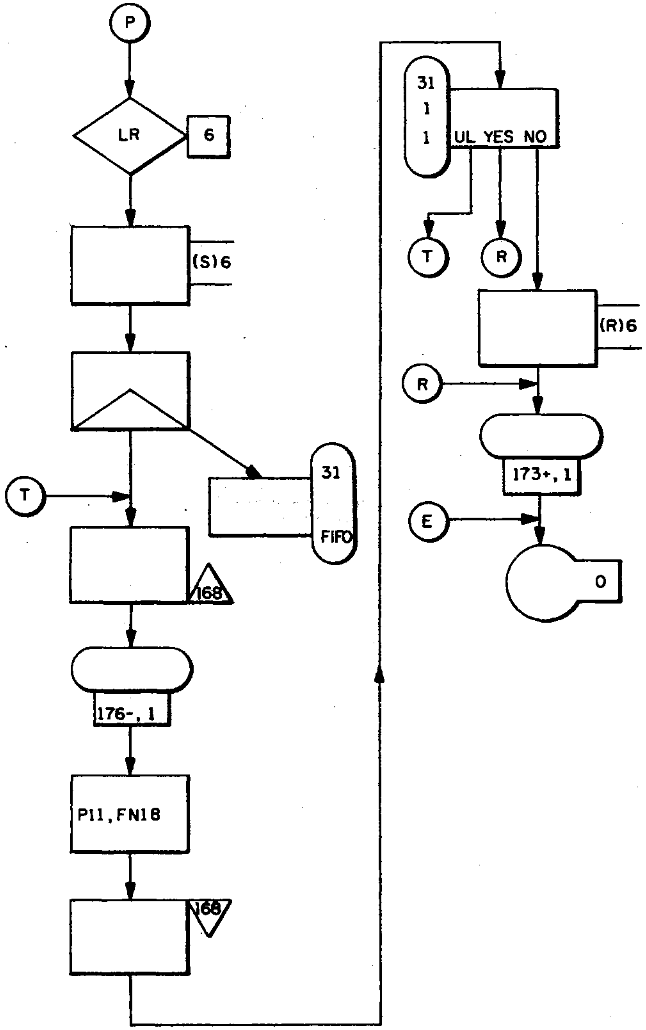
FLOW CHART REPRESENTATION OF THE SIMULATION MODEL

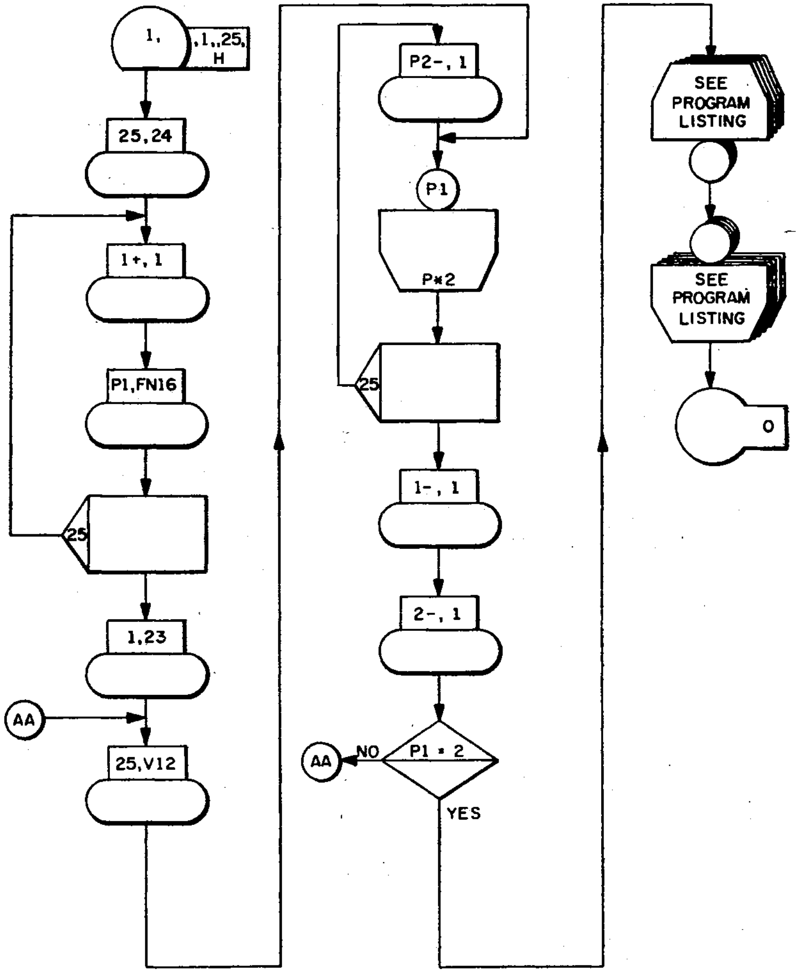

1
216,,
17,F
14+,1
1,X14
2,FN2
3,FN3
4,FN4
5,FN5
6,FN6
7,FN7
8,FN8
9,FN9
10,FN10
NO
P9 = 25
YES
10,V26
11,FN11
12,FN12
13,FN13
14,FN14
13+,1
15,X13
16,FN17
NO
P1≤179
YES
17,FN27
P2
P14
V
1
A
V21
B
2
P2
1
29
FIFO
BOTH
LR
1
(S)1
C
1
NO
P17≠XH2
YES
200
P4,FN1
1
H
2,P17
29
1
1
UL YES NO
C
F
(R)1
F
LR
2
(S)2
2
NO
P17≠XH3
YES
200
P4,FN1
2
H
3,P17
29
1
1
UL YES NO
D
(R)2
D

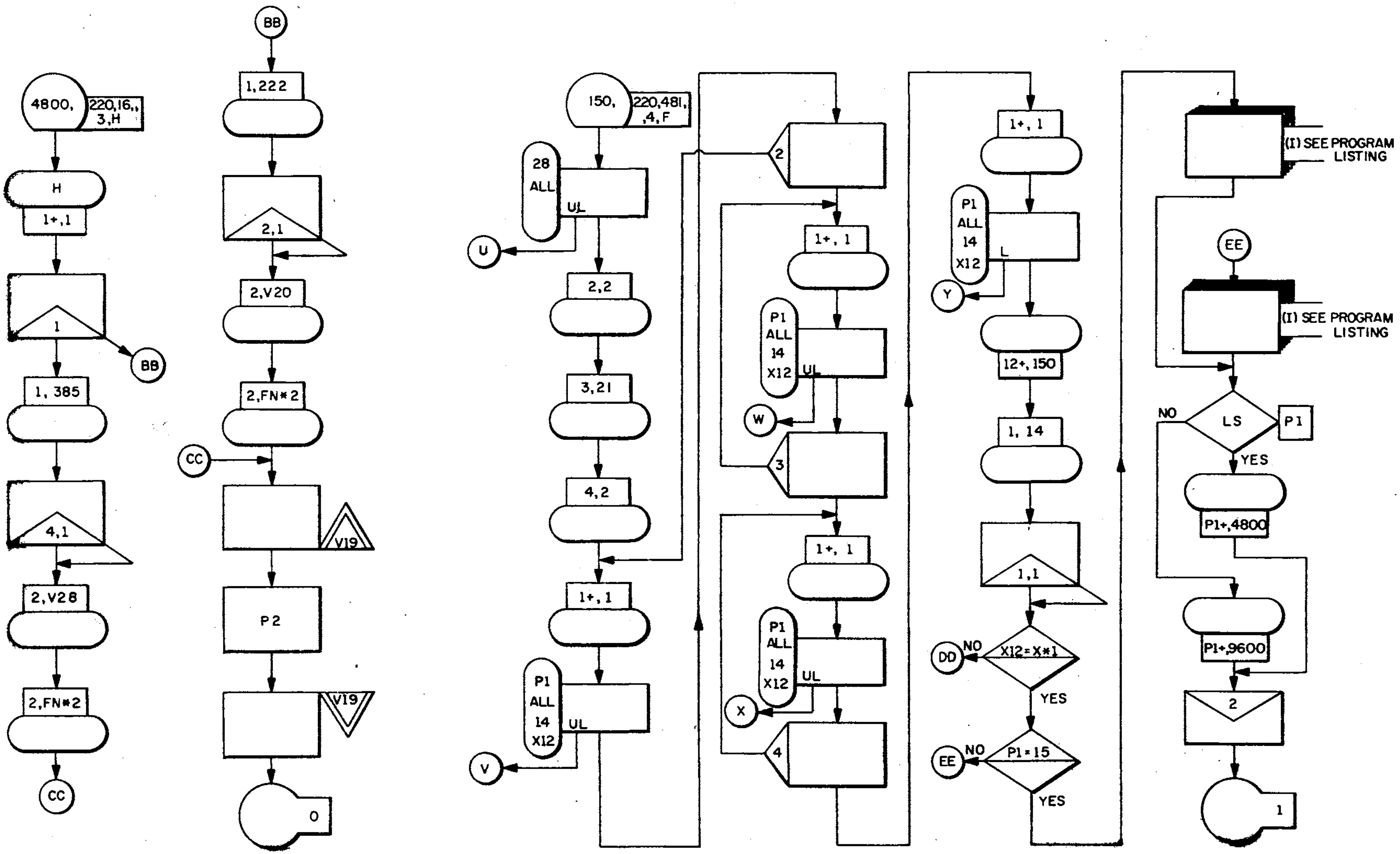

B
LR
3
(S)3
3
P17≠XH4
200
P4,FN1
3
H
4,P17
29
1
1
UL YES NO
D
(R)3
D
174+,1
171+,1
E
NO
M
TIME1
A
YES
TIME 1
TIME1
2
P5>0
NO
YES
14,V22
P5
FIFO
30000
E
W
NO
V3>0
YES
V3
V4
27
FIFO
U
YES
BV11=1
F
NO
19,P7
20,V18
7+,1
P7≤X20
NO
YES
NO
LR
P7
YES
F
7,X19
L
28
FIFO
F
(S)P7
G
NO
P13≠X*7
YES
H
P5
P7
YES
NO
V5
5+,1
H
XH*7
V5
3+,1
1


1
4+,XH*7
G
P7
P16 = 1
NO
YES
(I)166
NO
LS
166
YES
174-,1
P7,P13
P8,FN15
P7
P16=1
NO
YES
(I)167
NO
LS
167
YES
175+,1
H
P15+,1
LR
165
(S)165
I
NO
LS
P7
YES
5,P7
27
1
1
UL YES NO
K
7,X5
28
1
1
UL YES NO
(R)165
K
G
I
(I)P7
27
1
1
L
R(165)
K
E
NO
P9 > 0
YES
XH*15>V14
NO
YES
V6
V14
12,V15
X
LR
V24
(S)V24
1
M
V7
N
30
FIFO
V8
175-,1
P10,FN1
V8
2


2
30
1
1
UL YES NO
N
(R)V24
176+, 1
172+, 1
E
NO
M
TIME2
YES
M
TIME2
TIME2
2
14, V22
P11 > 0
NO
YES
26
FIFO
30000
E
Y
ALL
O
P
LR
4
(S)4
V7
Q
166
31
FIFO
176-, 1
V9, FN18
166
31
1
1
UL YES NO
Q
R
(R)4
R
O
LR
5
(S)5
V7
S
167
31
FIFO
176-, 1
P11, FN18
167
31
1
1
UL YES NO
S
R
(R)5
R


P
LR
6
(S)16
31
FIFO
T
168
176-, 1
P11, FN18
168
31
1
1
UL YES NO
T
R
(R)6
R
173+, 1
E
0


1,
,1,,25,
H
25,24
1+, 1
P1,FN16
25
1,23
AA
25,V12
P2-, 1
P1
P*2
25
1-, 1
2-, 1
AA
NO
P1 = 2
YES
SEE
PROGRAM
LISTING
SEE
PROGRAM
LISTING
0


4800,
220,16,,
3,H
H
1+,1
1
BB
1, 385
4,1
2,V28
2,FN*2
CC
BB
1,222
2,1
2,V20
2,FN*2
CC
V19
P2
V19
0
150,
220,481,
,4,F
28
ALL
UL
U
2,2
3,21
4,2
1+, 1
P1
ALL
14
X12
UL
V
2
1+, 1
P1
ALL
14
X12
UL
W
3
1+, 1
P1
ALL
14
X12
UL
X
4
1+, 1
P1
ALL
14
X12
L
Y
12+, 150
1, 14
1,1
DD
NO
X12=X*1
YES
EE
NO
P1=15
YES
(I) SEE PROGRAM LISTING
EE
(I) SEE PROGRAM LISTING
NO
LS
P1
YES
P1+,4800
P1+,9600
2
1

VITA

Edwin William Bula

Candidate for the Degree of

Doctor of Philosophy

Thesis: AN EVALUATION OF MULTIPLE JOB SHOP SEQUENCING POLICIES

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