A GENERALIZED MANUFACTURING LINE SIMULATOR SYSTEM FOR PRODUCTION, EQUIPMENT AND MANPOWER PLANNING

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Abstract

The simulation model written in GPSS/360 is designed to provide a general frame work to simulate the flow of jobs through a manufacturing line using the specified resources of machines and manpower for a specified number of periods.

The model does not have to be altered to simulate each individual production facility. The data, which in effect creates the model of a production facility, comes from a data bank and can be changed from period to period. The model uses GPSS Help Blocks to abstract data from the data bank, store results of simulation performance into the bank and maintain logical consistency of simulation from one period to the next.

The model has a production scheduling algorithm with two optionally monitors the line periodically and releases jobs into the line, or it will implement an externally imposed job release policy.

The model permits study and measurement of the performance of the production line under a given set of operating rules and their stochastic interaction. By extending the length of simulation to several periods integrated production, equipment and manpower plans can easily be obtained.

1. INTRODUCTION

Solid state component manufacture is a dynamic field because new products and processes constantly and rapidly move from the research and development stage to the manufacturing line. Relatively few techniques are available to develop integrated plans for production, equipment and manpower.

Because of the lack of a central technique, manufacturing planning is usually done in a serial fashion. Periodically, standard component forecasts are issued and used to generate production schedules. From these tooling plans are generated and become the base of direct manpower plans. The usual result is that completed plans become available just prior to the issuance of a new standard component forecast. Thus plans are in a constant state of updating with relatively little time for implementation of current plans.

Since there is no central source of information about the data elements needed to develop a manufacturing plan, each plan cycle cannot be initiated until all data elements are completely regenerated. There is a need for a mechanism which will provide two things: a central data source whose elements are easily updated; a technique that will quickly convert proposed changes in operating requirements into a totally integrated manufacturing plan.

The Simulation technique is chosen because of its ability to represent the dynamic activities of the manufacturing line and their complex stochastic interactions in time. The objectives of the simulation model are to provide an impact analysis technique with which to measure and evaluate proposed changes in:

(1) Standard Component Forecasts
(2) Yield Forecasts
(3) Equipment Plans
(4) Manpower Plans
(5) New Product Plans
(6) Release Schedules
(7) Inventory Policies

as they affect the manufacturing line in terms of:

(1) Work In-process
(2) Direct Work Load
(3) Equipment Utilization
(4) Manpower Utilization
(5) Ship Performance
(6) Capacity of the Line

The Simulation model itself will not be altered with each individual production facility. It is designed to provide a general frame work for simulating the flow of jobs through a manufacturing line using the specified resources of machines and manpower for a specified number of periods.

This paper will describe the structure of the simulation model, basic inputs and outputs, and how it is used as manufacturing planning tool.

2. STRUCTURE OF THE SIMULATION SYSTEM

The manufacturing line simulation model written in GPSS/360 is an integral part of TRACE 1 (Total Resource Allocation & Cost Estimating) system developed by the Advanced Industrial Engineering group. As such it represents a central part of the manufacturing planning capability of the Trace 1 system.

The power and flexibility of the model is derived from its capability to abstract data from a general manufacturing facility data bank. Its relationship to the data bank is shown in Fig. 1.

The data bank contains period by period specifications for each factor describing the line. The period numbers P_1 thru P_{22} represent the partitioning of the data by period. These are part number routings, yields machine characteristics, etc. The period can vary from one day to one year. At the beginning of each period, the relevant line specifications are transferred to the simulator; and at the end of each period, simulation performance is reported back to the bank. The simulation is carried out starting and ending at any period.

The communication between the bank and the simulator is carried out by GPSS Help Blocks as shown in Fig. 2.

The basic functions that the Help Blocks perform are:

(1) Reading and storing data.
(2) Memory space saving:
    a. by redimensioning the GPSS matrices at execution time to suit the problem to be simulated.
    b. by packing data into the input matrices.
(3) Provide flexibility to model users by automatically initializing the input matrices.
(4) Save GPSS time by performing iterative scanning and computations when called upon.
(5) Maintain logical consistency of simulation from one period to next when parts, tools and operations are added or deleted from simulation.

2.1 GROUND RULES AND SPECIFICATIONS OF THE SIMULATOR

The generality of the Simulation Model and the class of problems for which it can be used is determined by the set of ground rules and specifications under which it operates. To realistically simulate a manufacturing line, each part number, operation and tool must be individually characterized.

Each part can have its own schedule, job size, routing, yields, inventory levels, ship schedules, etc. Correspondingly each operation can have its own schedule, manpower pool and tools. It also may be encountered with the routing of any number of parts and can appear more than once in any particular part.

Each tool can be characterized by its own schedule, speeds, capacity, labor rates, maintenance schedule, mean time to failure with its statistical distribution, and mean time to repair with its statistical distribution, etc.

A large number of manufacturing line interactions exist due to variety of jobs, variable processing time, machine breakdown, preventive maintenance schedules and machine schedules. In the simulator the job release schedule can be derived during simulation or imposed by the user.

The machine may be in any one of the following states:

Unscheduled	Shift Teardown
Shift Set-up	Idle
Job Loading	
Job Running	
Job Unloading	
Unscheduled Maintenance	
Scheduled Maintenance	

2.2 JOB FLOW

The simulation model represents the flow of jobs through the manufacturing line using the routing specifies the sequence of steps a job has to follow starting from the point of release to the final stock point. At each step, because of its process yields and distribution, only a certain number of pieces of the job get through as accepted pieces and the remaining are classified as rejects. The rejected pieces may have to go through a rework path before rejoining the path of the accepts. An example of a simillified rounta is shown in Fig. 3.

Each step carries with it the operation number it represents for this part. It also carries a pointer specifying the path that both accepts and rejects will follow from the step. An operation can appear in more than one step, and therefore can have different step yield specification. Operation 10 in Fig. 3 exemplifies this. The information at the step such as the operation number, and the path that accepts and rejects will take is contained in one full word cell of the routing matrix.

It must be stressed here that the simulator illustrates the dynamics of the manufacturing line situation. In contrast to a scheduling procedure the simulator does not use some assumed wait-time at an operation, but rather uses the characteristics of the operation, machine, and the job at hand to determine the length of time a job will take for various elements of the operation. The operation types that can be represented are:

(1) Manufacturing
(2) Sampling Operation
(3) Quality Control Operation
(4) Multiplier Operation
(5) Downsort Operation

and machine types can be:

(1) Variable Cycle Machine
(2) Fixed Cycle Machine
(3) Manual Tool

giving rise to several different operation - tool type combinations.

Figure 4 illustrates the operational elements through which the job will flow. The specifications that are listed along side of the functions shown in the blocks are used to perform those functions. The specifications shown for Job Load, Run and Unload are not just a function of machine but a function of both machine and part number. Thus a machine can have different speeds, labor rates, etc. depending upon the part number being processed.

A job attempts to use the faster available machine on which that it can be run. If unable to use a machine at an operation, it will then wait in a user chain until one is available. It is not assumed here that a part can use any machine at a machine group (operation). Rather, it has a list of machines that it can use at the operation.

During the running of the job a machine can breakdown randomly. Statistical distributions can be specified for mean time between failure for each individual machine, and several repair time distributions can also be specified.

At the end of each of the function elements shown, the machine and manpower activity is updated in GPSS matrix savevalues. At the end of the routing the job is terminated and production figures are updated.

2.3 MACHINE ACTIVITY

The activity of a machine is illustrated in Fig. 5. Each individual tool can have its own scheduled maintenance policy, and shift setup and teardown schedules. At the end of shift setup, the machine attempts to unlink the appropriate job from the user chain. If unable to find the appropriate job it will remain idle, but available, for processing jobs. As soon as a job that can use this machine arrives at the operation it can begin processing. The job processing can be interrupted either by end of shift, by machine breakdown, or by shift teardown. At this time, the job will be removed from the machine. When the machine becomes re-available for jobs it will attempt to first process the job that was interrupted.

2.4 ADDITION AND DELETION OF PART NUMBERS, MACHINES AND OPERATIONS IN THE SIMULATOR

The ability to add, delete or modify data elements in any period in the bank although it provides data flexibility and efficient computer memory usage, gives rise to logical inconsistencies in facility description seen by simulation that must be corrected. As an example, when a part is deleted from simulation, the part numbers that are numerically following the deleted part will take on new internal numbers

on new internal numbers. The input matrices that are dimensioned by part number must be compressed to reflect the deletion. The jobs whose part numbers were affected by deletion and are currently at various operations in the simulator must be changed to correspond with the input matrix changes. The work in process jobs that belong to the part that was deleted must be terminated. Similar adjustments in GPSS entities must be performed in the case of machine and operation addition and deletions. The adjustments are done at the time of data change from one period to the next. The scanning of GPSS entities and adjustments are made possible by the Help routines.

2.5 JOB RELEASE SCHEDULES

At the beginning of simulation, jobs can be loaded into the model to reflect the actual in-process jobs that are present at various steps throughout the manufacturing line.

The part number, step number and the job size information of each individual job being loaded will be specified. At the start of simulation the final stock inventory for each part number and the average cycle time (time from the beginning of line to final stock) can also be specified. During simulation, jobs can be released into the manufacturing line in two ways;

(1) The model can implement an externally imposed release policy for any or all part numbers. The user can specify the number of jobs of each part number that must be released each day of the scheduling interval.

(2) The model can also optionally monitor the line periodically to determine the release policy of each number on the basis of ship requirements and the simulator performance.

Under the model generated release option, the release scheduler looks ahead for one cycle time and generates the policy for the next schedule interval using the following items of information:

a. Customer Ship Requirements
b. Current Work-in-process
c. Final Stock Inventory
d. Target Inventory
e. Part Number Yields at all steps of the routing
f. Part Number Cycle Time
g. Job Size

The scheduling interval is the period of time for which the release schedule is generated. At the end of this interval the line is again monitored and another release schedule is generated. This interval can be specified by the user and can range from one day to the number of days in the period. In cases where the cycle time of a part number exceeds the remaining time of the current period, the simulator looks at the future period's ship requirement to generate the release schedule (starts). It then attempts to smooth the daily starts by evenly distributing the part releases over the scheduling interval.

2.6 THE GPSS MODEL

The model contains approximately 1100 blocks, with 300 variables defined. The variables perform arithmetic computations and unpack the bits of packed information in GPSS matrices. There are approximately 35 full word and 25 half word matrices defined.

The simulation model can be run on an IBM System/360 Model 50 and upwards. The core requirement is 512K bytes and upwards depending upon the dimensions of the simulation matrices. The dimensions are a function of the following entities:

(1) Number of parts
(2) Number of tools
(3) Number of modes
(4) Number of operations
(5) Number of steps
(6) Number of jobs that can be in simulation at any one time.

The model is currently being used on an IBM System/360 Model 75 equipment with 1 million bytes of core using the actual manufacturing line data. The amount of computer time required to simulate a period of time depends a great deal upon the dimensions of the entities listed above. The computer time to simulate a full scale problem involving approximately 200 parts, 50 operations, 150 machines, 100 steps and 1500 active jobs for a period of one month required between 8 - 10 minutes.

The model is capable of accepting 255 routing steps and 225 operations. It is also established that the model can simultaniously accept up to 255 part numbers, 300 machines and 2000 modes. However an increase in the number of one entity can be compensated by a decrease in the remaining entities.

3. INPUTS TO SIMULATOR

While specific data for simulator usage is derived from a facility specification data bank, the information in the bank can be potential input to the simulator. An exhaustive list of information that can be stored in the bank is beyond the scope of this paper. Some of the basic input to the simulator can be listed as follows:

Part number oriented inputs:

a. Family
b. Parent or offspring part number
c. Ship requirements
d. Routing
e. Yields
f. Target Inventory
g. Beginning Inventory
h. Job Size
i. Job Release
j. Job Policies

Operation Oriented Inputs:

a. Operation type
b. Dept. of which it delongs
c. Schedules
d. Manpower pools

Machine Oriented Inputs:

a. Tool type
b. Operation to which it belongs
c. Machine schedule
d. Shift setup
e. Shift teardown information
f. Failure rate function
g. Repair time function
h. Crew size
i. Modes of operation

Under each Mode of Operation:

a. Machine speed
b. Job load, run an unload information
c. Labor rate information

The facility specification information can be exhibited using the report programs.

4. BASIC OUTPUTS FROM THE SIMULATOR

To show the impact of proposed changes, the simulator will report:

Production Information = (part number by period)

Total Line

Releases, Quantity of stock, shipment from stock, finished goods inventory level.

For each Operation

Starts, thruput, cycle time, beginning and ending work in-process inventories, direct man-hours charged.

Manpower Information

Each Operation

Direct Manhours, direct charging indirece hours.

Each Dept.

Indirect labor hours.

Each Tool

Maintenance labor hours.

Equipment Information (Tool/Period)

Machine hours spent in each of the several possible machine states are reported.

The simulation performance is stored back into the bank period by period. At the end of simulation it is possible for the report programs to print out any or all of the output information from the performance part of the bank. There are more than 30 different reports which can be selectively executed providing various levels of output detail. Space will not permit the description of all of these output reports.

5. VERIFICATION OF THE SIMULATION MODEL

In any stochastic model of the size described in this paper the problem of verification is a very difficult one.

Several distribution-free simulation test problems of varying complexity have been designed and the exact answers were obtained by prior manual computations. This class of test problems was primarily implemented for checking the logic of the simulator and for correcting any possible program bugs. Tests were also conducted using statistical distributions where applicable. These test verified the accuracy of the computations and the logic of simulation.

Simulation results, using the manufacturing line specification data, were compared with the observed line performance using the following measures:

(1) Operational Starts & Thruputs
(2) Equipment utilization
(3) Direct Manpower used
(4) Average Cycle times.

These comparisons revealed that the model can represent the "real world" within reasonable degrees of accuracy.

6. HOW THE SIMULATOR CAN BE USED FOR PLANNING

The simulation model provides an impact analysis technique that can establish a set of plans under which the various factors of operating the manufacturing line can be optimized as much as possible. The availability of the central data bank and the ability to selectively modify specific data elements (without altering the existing data bank) provides a quick means by which alternate operating plans can be simulated.

A new set of operating plans are likely to show bottlenecks and overloaded areas of the line. After studying both the areas of bottlenecks and the excess capacity, decisions are made to correct the situation. These decisions could involve scheduling more machine time or more manpower; or varying the product mix, job sizes, inventory policies, release schedule or subcontract work.

About 2 to 3 simulation runs might be necessary to arrive at an acceptable plan. The resultant acceptable plan will then be a total manufacturing plan for production, equipment and manpower for the simulated period. The accepted plan can now be made part of the official data bank. Normally the length of the data and report intervals for the first year of the plan might be broken down into monthly units and the subsequent years can be partitioned into quarters, semiannual, and annual periods to provide a five year planning capability.

As new Component forecasts are issued periodically, the simulation model can be used to measure the adequacy of the existing plans to fulfill the new component forecast.

7. CONCLUSIONS

The Simulation System described in this paper can be used as an effective tool for developing integrated equipment, production and manpower plans in a manufacturing environment. The ability of the model to abstract data from a general data bank permits generality and a level of detail which would otherwise be impractical. The ability to add, delete or modify any data element in any period provides a quick and easy method of testing alternate operating plans without going through elaborate data preparation.

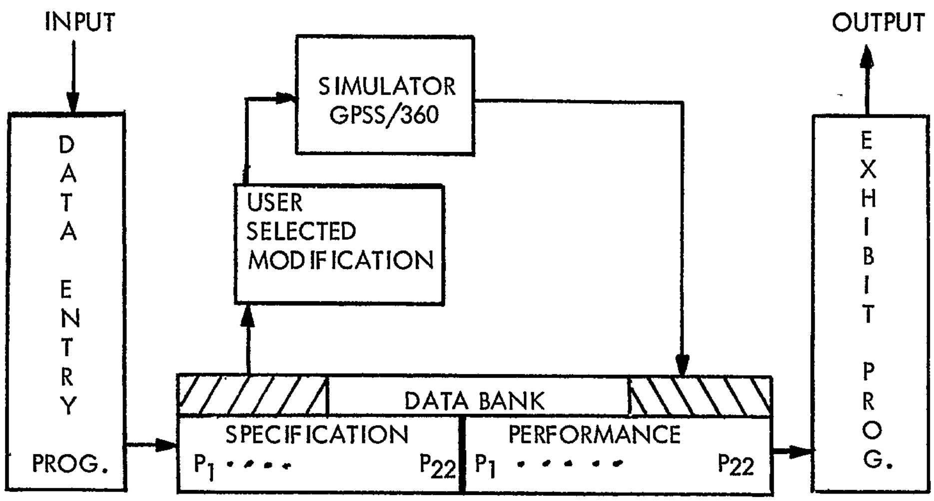
INPUT
OUTPUT
SIMULATOR
GPSS/360
USER
SELECTED
MODIFICATION
DATA
ENTRY
PROG.
DATA BANK
SPECIFICATION
PERFORMANCE
P_1 . . . . P_{22}
P_1 . . . . . P_{22}
EXHIBIT
PROG.

FIGURE 1

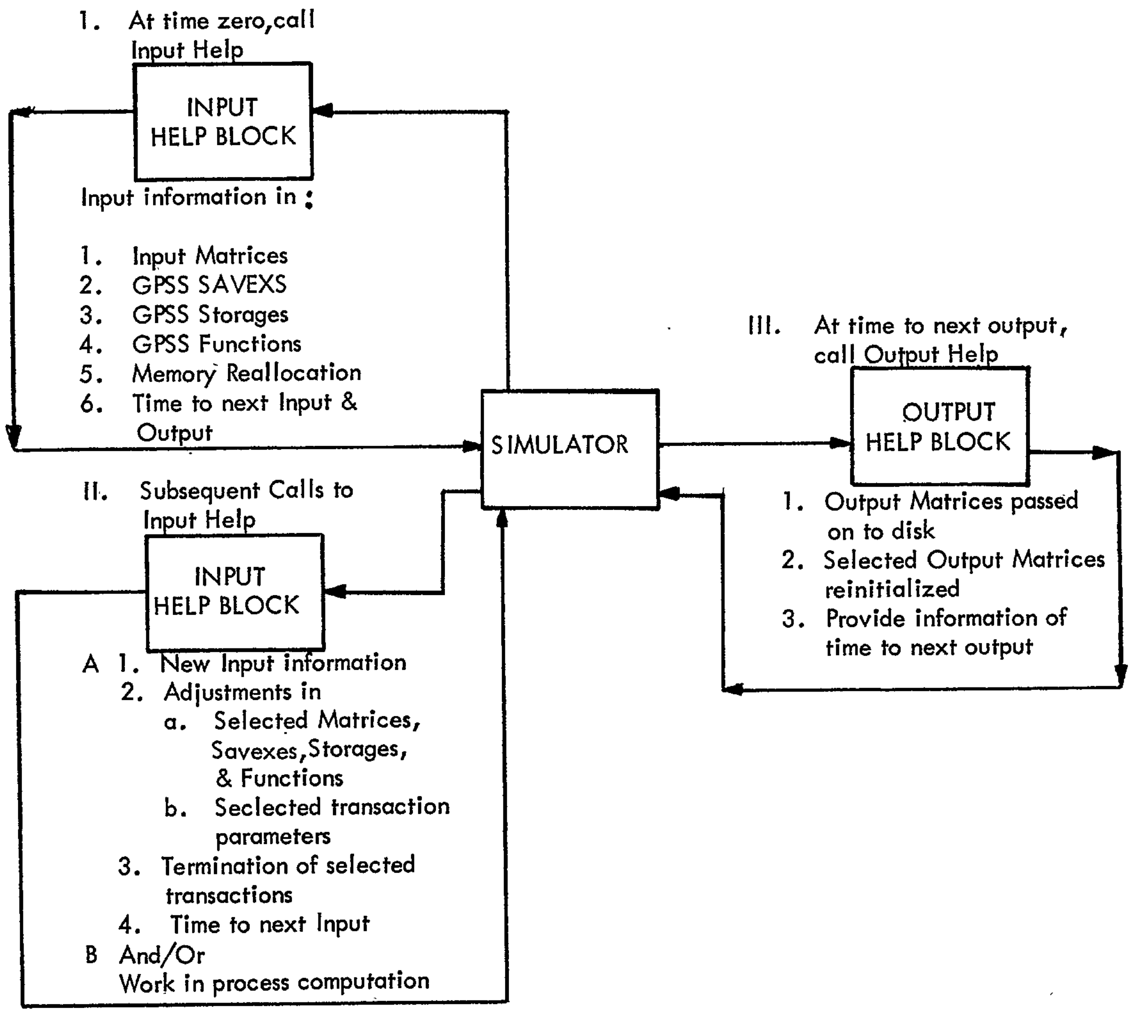
I. At time zero, call Input Help
INPUT HELP BLOCK
Input information in :
1. Input Matrices
2. GPSS SAVEXS
3. GPSS Storages
4. GPSS Functions
5. Memory Reallocation
6. Time to next Input & Output
SIMULATOR
III. At time to next output, call Output Help
OUTPUT HELP BLOCK
1. Output Matrices passed on to disk
2. Selected Output Matrices reinitialized
3. Provide information of time to next output
II. Subsequent Calls to Input Help
INPUT HELP BLOCK
A 1. New Input information
2. Adjustments in
a. Selected Matrices, Savexes, Storages, & Functions
b. Seclected transaction parameters
3. Termination of selected transactions
4. Time to next Input
B And/Or
Work in process computation

FIGURE 2

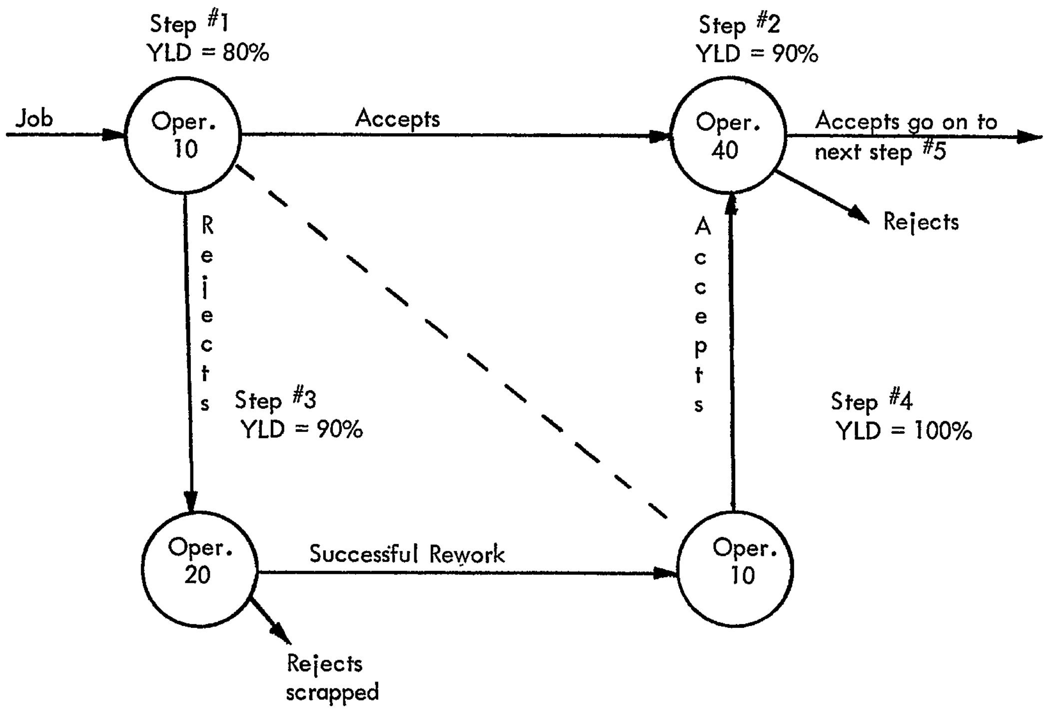
Step #1
YLD = 80%
Job
Oper.
10
Accepts
Step #2
YLD = 90%
Oper.
40
Accepts go on to
next step #5
Rejects
Rejects
Step #3
YLD = 90%
Accepts
Step #4
YLD = 100%
Oper.
20
Successful Rework
Oper.
10
Rejects
scrapped

FIGURE 3

BASIC JOB FLOW

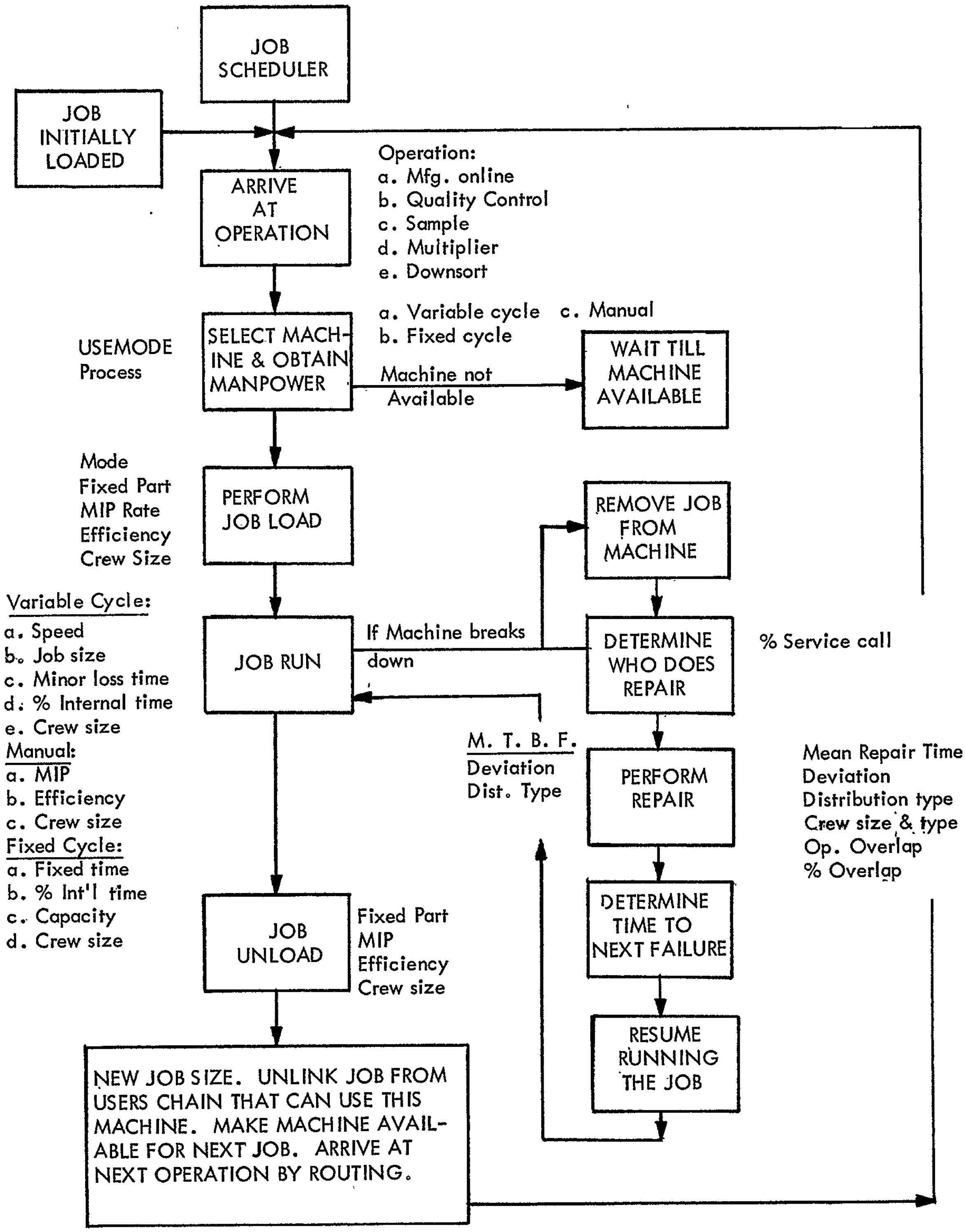

FIGURE 4

BASIC MACHINE ACTIVITY

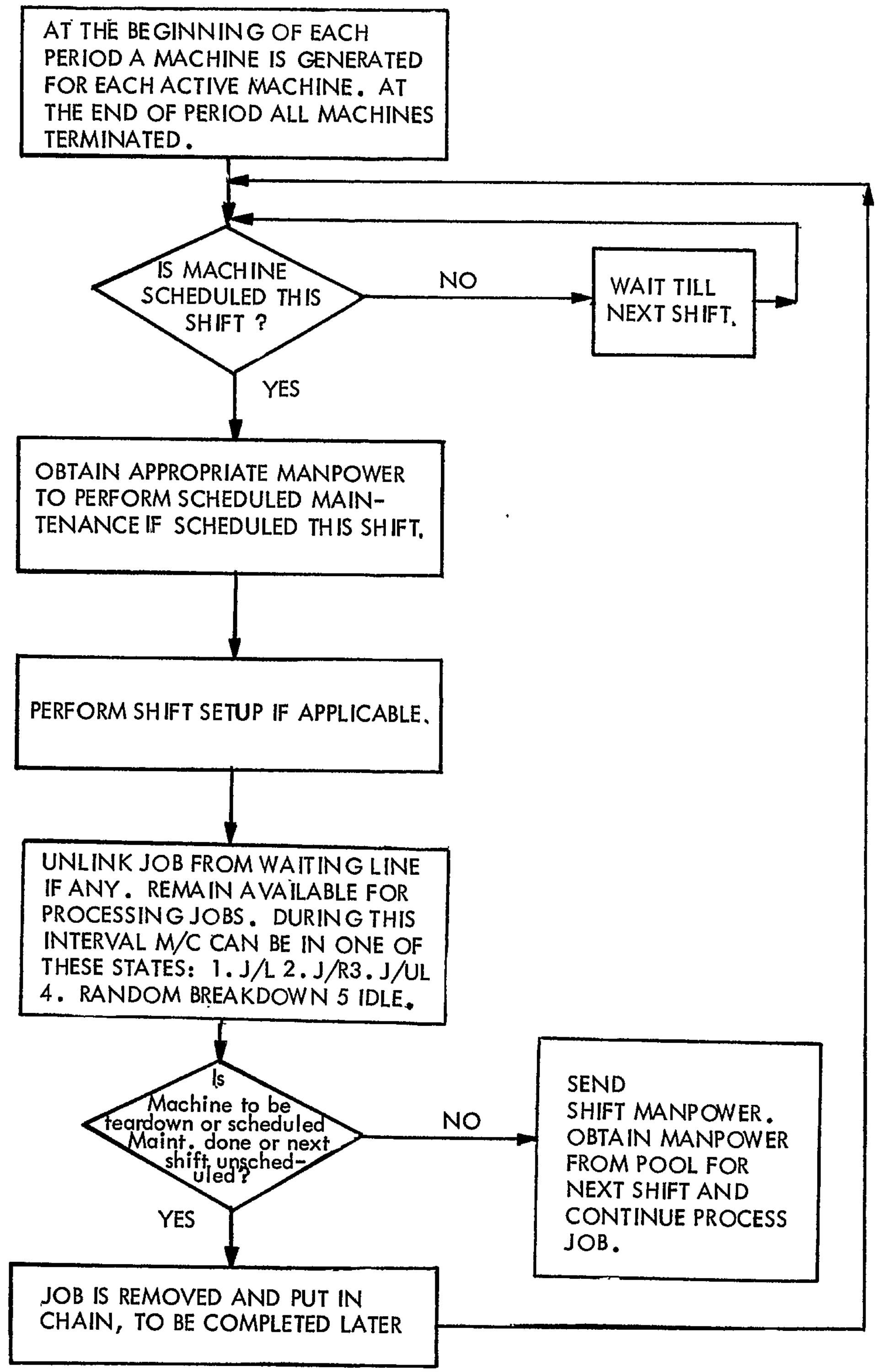

FIGURE 5