SIMULATION OF A MULTI-STAGE MANUFACTURING PROCESS

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Introduction

Providing management control of the multi-stage manufacturing processes found in industry today requires the engineer to apply more sophisticated methods of process definition and analysis. These statistical methods may be collectively called operations research of which simulation is a specific technique. The following paper describes the use of simulation to solve multi-stage process problems in terms of problem definition and analysis of the simulator output.

In order to provide complete engineering support for manufacturing activities, IBM has installed Advanced Industrial Engineering groups in many manufacturing facilities, both domestic and overseas. The primary responsibility of the groups is to apply mathematical modeling, simulation, linear programming, and other operations research techniques to manufacturing problems wherever possible and practical. The Advanced Industrial Engineering project described in this paper was concerned with investigation of a multi-stage manufacturing process.

The process was constructed to convert five basic raw parts into three finished goods. This was accomplished by passing the parts through twenty-six separate operations including over ninety machines which may be grouped into three separated areas or departments as shown below:

![Diagram of the multi-stage manufacturing process]

A particular part could skip some operations and go through others twice. Generally, the parts would have variable routings depending upon schedule requirements, particular process characteristics (such as queue lengths, yields, etc.), and time of introduction into the system.

At the inception of this project, the manufacturing process faced numerous problems. For example, the cost of production was increasing while the production and yield targets were not being met. In addition, the process was not well understood, and there was an inability to foresee the effects of one operation upon another. Finally, non-timely and invalid process data resulted in inaccurate cost accounting, non-traceability of causes of production fluctuations, a lack of machine utilization information, and a lack of process control.

The aim of Advanced Industrial Engineering was to eliminate the above mentioned process problems. The actual conduct of the project is shown on attachment 'A'; however, certain significant activities should be elaborated on. In the first place, it was assumed that a mathematical model of the process would provide solutions to the problems stated above. Secondly, all necessary data required for the model was assumed to be readily available.

As investigation of the operation proceeded, it became quite apparent that a mathematical model, if not impossible, would be very difficult to prepare since the process was too complicated and too large in terms of variables to model. At this discovery, it was decided to attempt to simulate the operation. To effect such an approach, a computer study was undertaken resulting in the construction of a specific multistage process simulator using GPSS/360 (General Purpose Systems Simulator). GPSS is a scientific computer language designed to build simulators using statements approximating the characteristics of the operation. For example, queue blocks are used for inventories, seize blocks for machine operations and so forth. Since the engineer assigned to the project had no previous knowledge of GPSS, a slow and cautious "learning" period followed. The process was simulated in "bits and pieces" until the parts were joined and debugged to produce the final model. While this activity was continuing, it became more
and more apparent that the second assumption, that of valid data being available, was also unfounded.

At this juncture, the manufacturing management requested AIE to propose and install a data gathering system. Acting upon this request, a real time data acquisition system (using IBM 370 computer) was proposed and installed. The data from the system would not only provide inputs to the simulator, but would also provide production and defect reporting for process control. During installation of this system, the reliability of the cost accounting system was also questioned. Inclusion of source data (quantity figures) for cost accounting was then provided for on the data acquisition system. In addition to work on data acquisition, the existing batch control methods were analyzed and changes proposed to reduce the production fluctuations. Finally, since the simulator had to reflect the machine failures which would occur randomly in the actual process, a significant effort in studying machine failures was begun. The results of this study provided machine breakdown and downtime distributions by machine and by operation for the process. In addition, the distributions were assumed poisson and the means, \( X \), compared so as to arrange the machines in a hierarchy of dependability. This data, when converted to cumulative distribution functions, was fed into the model to determine simulated failures.

As stated previously, the engineering effort expended on the project was divided between the actual simulator and the supportive data, with the latter requiring close to 70 percent of the total project time. The actual construction of the model by operation, however, was just as important as the validity of the data in insuring the success of the project.

The simulator structure may be broken into three parts: the inputs, the main simulation, and the outputs. (See attachment "B"). The input parameters were made up of arithmetic operations (variable statements), macros and subroutines, mathematical functions describing process characteristics (i.e. machine failures), and constants describing process characteristics (i.e. cycle times). All of these items are located at the beginning of the simulation to provide ease of alteration as the process idiosyncrasies vary.

The main body of the simulation (that area where actual parts are moved through the operations) was constructed in modular form by operation. That is, the logic is identical from operation to operation whenever possible to allow for the maximum use of macros and subroutines (attachment "C"). A typical operation begins with a part entering the queue for that operation. A search for a machine and a man is begun and continues until both are found. Upon securing the man and the machine, the part is cycled through both for a specified time. At the conclusion of the run time, both man and machine are released and the part continues to a test station where good parts are transferred to the next operation and reject parts are removed from the process. During the movement of parts various critical events are checked and recorded. First, the queue is examined to determine if the part enters an empty queue (machines starting to run) or leaves the queue empty (machines out of parts); secondly, the wait time to find a man to run the machine is recorded to see if idle machine time has been caused by manpower non-availability. Thirdly, the effects of coffee breaks, lunch breaks and shift interchange idleness is also recorded. Finally, based upon the cumulative downtime and breakdown distribution functions the machines of each operation are broken down and remain down according to the random breakdowns in the actual process. This information is also recorded as it occurs.

The last section of the simulator, the outputs, was approached with management usefulness and understanding in mind. For example, to tell management that a certain machine should run 38 percent of the time is somewhat meaningless when information about actual machine run times in terms of hours during the week compared with all other machines is obtainable.

The output phase of the simulator was aimed at solution of the process problems in terms of:

1. Line balancing.
2. Determining manpower requirements and optimal manpower distributions.
3. Critical path machine scheduling.
4. Preventative maintenance scheduling.
5. Economic analysis of raw parts starts.
6. Provide answers to "what if" questions, such as the addition and/or removal of machines and economical phasing of routing or engineering changes.
7. Presentation of a detailed definition of the process.
8. Determining optimal queues by operation to increase available space and decrease inventory cost.

The actual simulator outputs are outlined
below and some examples are shown in attachment "D").

a. Punched output of a real time data matrix representing actual machine utilization (the deck is passed through an 1130 program to produce a graphic scheduler).


d. Utilization of Operators for each Manufacturing department (graphical form).

e. Machine statistics (standard GPSS facility output) for each part type and each department.

f. Graphical representation of the machine utilization by operation.

g. Inventory Statistics by operation composed of:

   (1) Quantity In
   (2) Quantity Out
   (3) Quantity Reject
   (4) Yield
   (5) Current Queue Contents
   (6) Maximum Queue Contents
   (7) Average Queue Contents
   (8) Average Time per Part in Queue

h. Graph of the Average Queue Length.

i. Graph of the Maximum Queue Lengths.

j. Graph of the Average Waiting Time per Queue.

k. Cost Statistics by Operation Composed of:

   (1) Cost of worked parts
   (2) Cost of good parts
   (3) Cost of reject parts
   (4) Average inventory cost
   (5) Current inventory cost
   (6) Maximum inventory cost

l. Summary Cost statistics printed out weekly and accumulated monthly composed of:

   (1) Total parts started
   (2) Total good parts
   (3) Total reject parts
   (4) Total cost of parts worked
   (5) Total cost of good parts
   (6) Total cost of reject parts

With such output data the industrial engineer may suggest many things. For example, the quantity of start by raw type by day may be predetermined either by the process management, the industrial engineer, or generated by the simulator on a "most economical" basis. Also, the simulator could analyze proposed routing changes, machine additions or deletions, and major process reorganizations. In addition, the simulator could propose major process reorganizations.

The usefulness of the multi-stage process simulator is not limited to those benefits listed above. Indeed, the list is only limited by the imagination and definable questions either management or industrial engineering can provide. By simulating the highly complex and confusing process described above, an engineering and programming tool has been provided to answer questions and solve problems which previously were only partially solved or completely escaped solution. This approach provides still another method of solving the old problem of mixing of the factors of production, manpower, materials and equipment.
UTILIZATION OF THE OPERATORS FOR DEPARTMENT X

UTILIZATION

MAN NUMBER (FACILITY NUMBER IN SIMULATION)

UTILIZATION OF MACHINES FOR OPERATION 181

MACHINE NUMBER (FACILITY NUMBER IN SIMULATION)
Utilization of Machines for Department XI

Inventory Statistics for the Multi-Stage Process

Operation 170
- Quantity In Is: 7300
- Quantity Out Is: 7500
- Quantity Reject Is: 100
- Yield Is: 98.63
- Current Queue Contents Are: 0
- Maximum Queue Contents Are: 1200
- Average Queue Contents Are: 193.72
- Average Time Per Part In Queue Is: 0.019109 Hours

Operation 6170
- Quantity In Is: 200
- Quantity Out Is: 1500
- Quantity Reject Is: 100
- Yield Is: 100.00
- Current Queue Contents Are: 500
- Maximum Queue Contents Are: 600
- Average Queue Contents Are: 272.20
- Average Time Per Part In Queue Is: 2.164526 Hours

Operation 181
- Quantity In Is: 2300
- Quantity Out Is: 2500
- Quantity Reject Is: 100
- Yield Is: 95.65
- Current Queue Contents Are: 0
- Maximum Queue Contents Are: 1300
- Average Queue Contents Are: 200.78
- Average Time Per Part In Queue Is: 0.128229 Hours

Operation 190
- Quantity In Is: 8800
- Quantity Out Is: 1200
- Quantity Reject Is: 100
- Yield Is: 96.66
- Current Queue Contents Are: 94800
- Maximum Queue Contents Are: 94000
- Average Queue Contents Are: 42482.90
- Average Time Per Part In Queue Is: 4.154859 Hours

Operation 191
- Quantity In Is: 3500
- Quantity Out Is: 2500
- Quantity Reject Is: 200
- Yield Is: 94.88
- Current Queue Contents Are: 21600
- Maximum Queue Contents Are: 21500
- Average Queue Contents Are: 9787.00
- Average Time Per Part In Queue Is: 2.075459 Hours
COST ANALYSIS FOR THE MULTI-STAGE PROCESS

OPERATION 220
AVERAGE INVENTORY COST $1200.00 COST OF PARTS FROM LAST OP $4800.00
CURRENT INVENTORY COST $200.00 COST OF GOOD PARTS $890.00
MAXIMUM INVENTORY COST $16400.00 COST OF REJECT PARTS $9400.00

OPERATION 231
AVERAGE INVENTORY COST $1600.00 COST OF PARTS FROM LAST OP $9600.00
CURRENT INVENTORY COST $4400.00 COST OF GOOD PARTS $10312.00
MAXIMUM INVENTORY COST $16400.00 COST OF REJECT PARTS $937.00

OPERATION 240
AVERAGE INVENTORY COST $1400.25 COST OF PARTS FROM LAST OP $19218.00
CURRENT INVENTORY COST $1880.20 COST OF GOOD PARTS $20682.00
MAXIMUM INVENTORY COST $18651.90 COST OF REJECT PARTS $940.00

OPERATION 241
AVERAGE INVENTORY COST $1400.25 COST OF PARTS FROM LAST OP $9375.00
CURRENT INVENTORY COST $10791.25 COST OF GOOD PARTS $10377.00
MAXIMUM INVENTORY COST $10791.25 COST OF REJECT PARTS $940.00

MULTI-STAGE PROCESS GRAPHIC SCHEDULER *** WEEK 2

SUNDAY MONDAY TUESDAY WEDNESDAY THURSDAY FRIDAY SATURDAY
AM PM AM PM AM PM AM PM AM PM AM PM AM PM AM PM AM PM
IN IN IN IN IN IN IN IN IN IN IN IN IN IN IN IN IN
MACHINE

TOOL NUMBER
A1
A2
B1
B2
B3
B4
B5
B6
B7
B8
B9
C1
C2
C3
C4
C5
C6
C7
C8
D1
D2
D3
D4
D5
D6
D7
D8
D9
E1
E2
E3
E4
E5
E6
E7
E8
E9
F1
F2
F3
F4
F5
F6
F7
F8
G1
G2
G3
G4
G5
G6

LEGEND:
ASTERISK......MACHINE RUNNING
LETTER 'B'......MACHINE BREAKDOWN
"BLANK"......MACHINE IDLE

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