SIMULATION OF A MULTI-STAGE MANUFACTURING PROCESS

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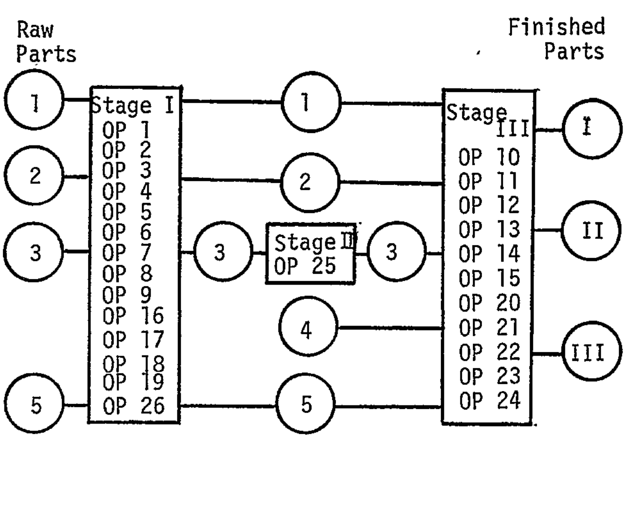
Introduction

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:



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 concentrated study of available simulators was undertaken resulting in the construction of a specific multi-stage 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 1710 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 figures for the process was also questioned. Inclusion of the 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, $\bar{x}$, compared so as to arrange the machines in a heirarchy of dependability. This data, when converted to cummulative 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).

b. Flow Chart of the Actual Process.

c. Flow Chart of the Simulated Process.

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:

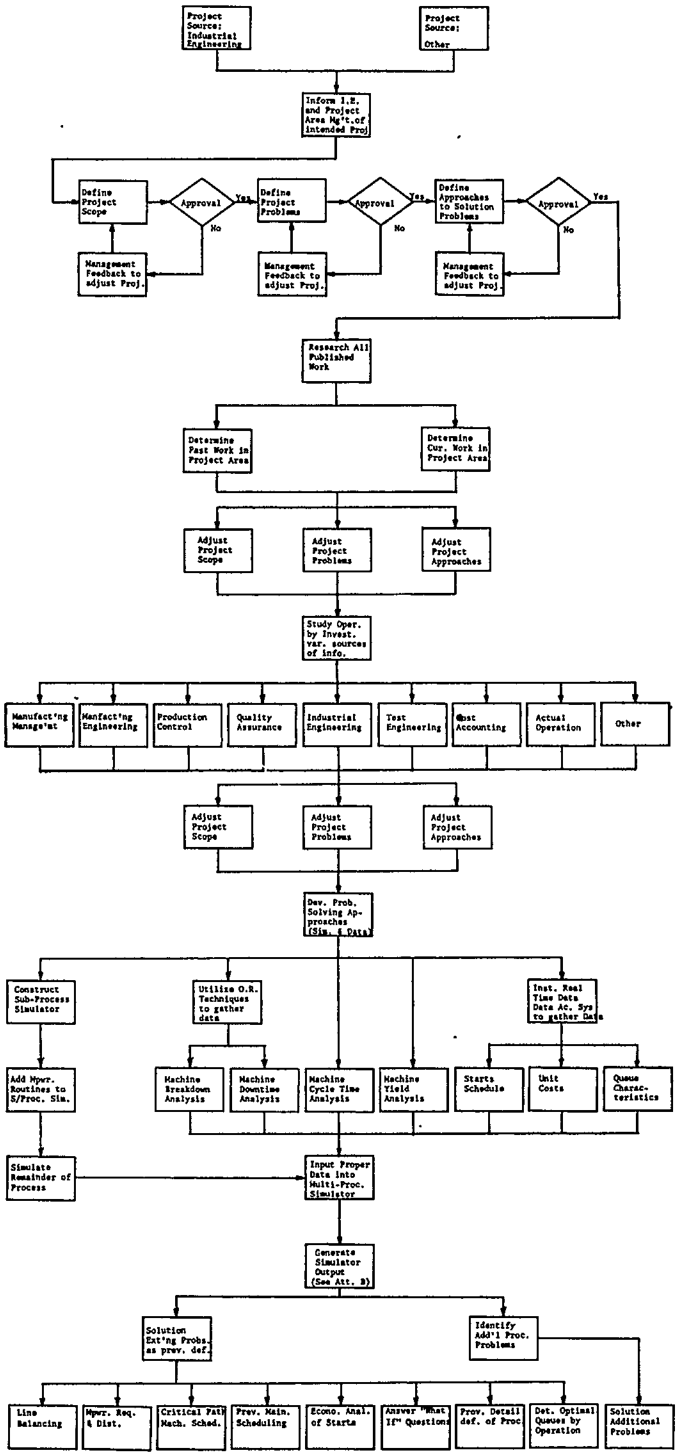
    (1) Total parts started
    (2) Total good parts
    (3) Total reject parts
    (4) Total cost of parts worked
    (5) Total cost of good parts
    (6) Total cost of reject parts
    (7) Total in process inventory
    (8) Current inventory cost
    (9) Average inventory cost
    (10) Maximum inventory cost
    (11) Total process yield

With such output data the industrial engineer may suggest many things. For example, the quantity of starts 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 usefullness 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 solutioning the old problem of mixing of the factors of production, manpower, materials and equipment.

ATTACHMENT - A

MULTI - STAGE PROCESS SIMULATION - PROJECT FLOW CHART



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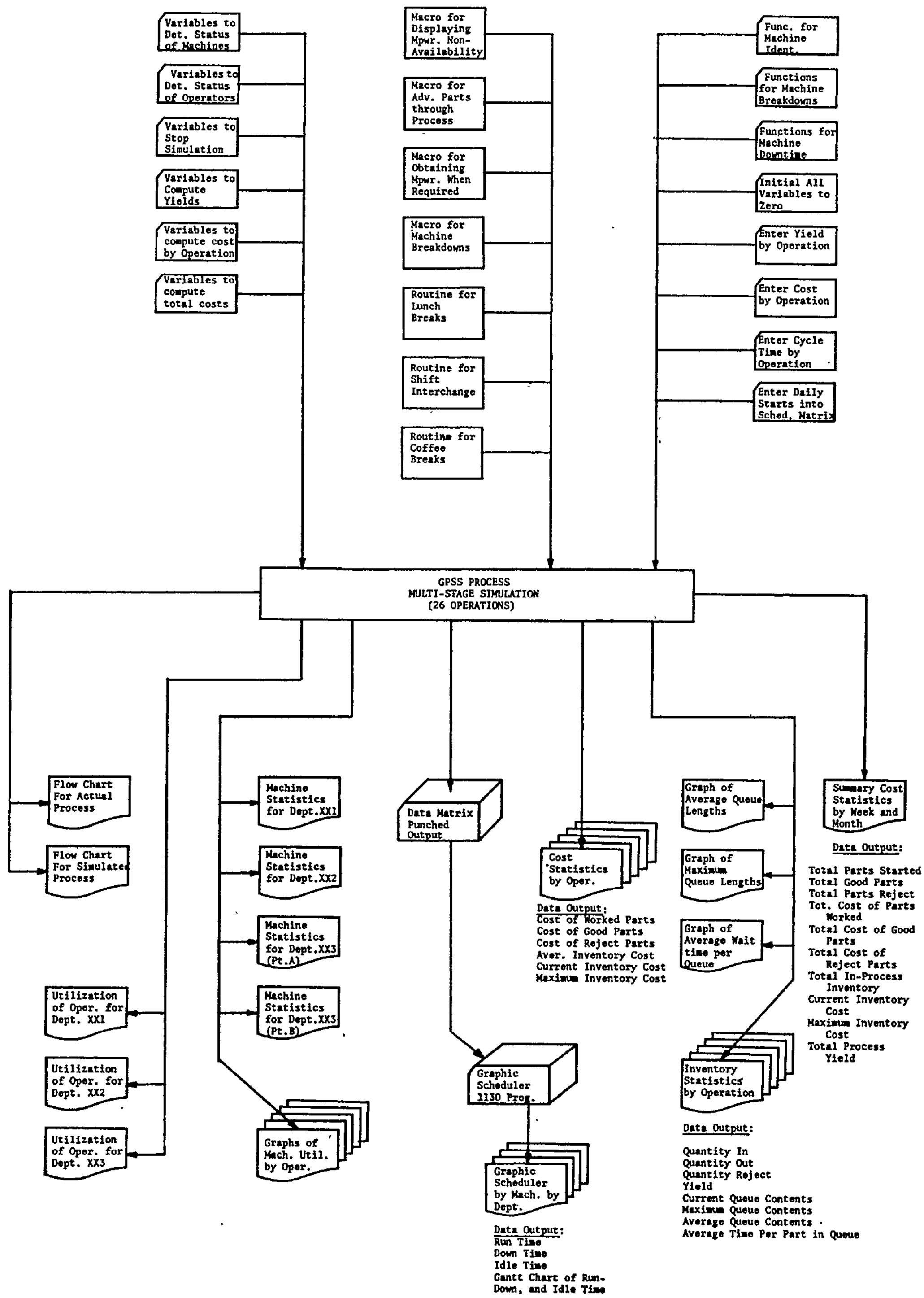
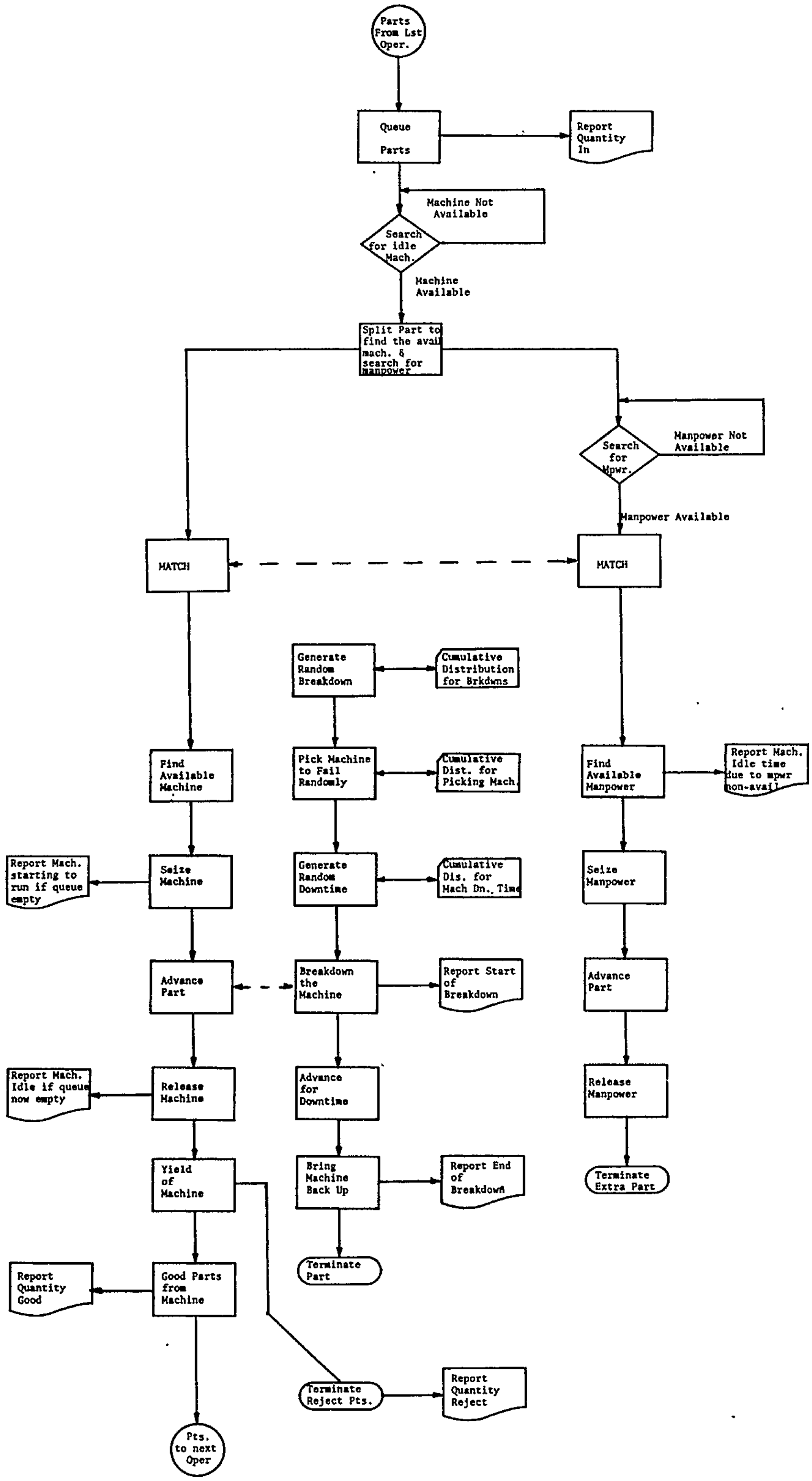
ATTACHMENT B

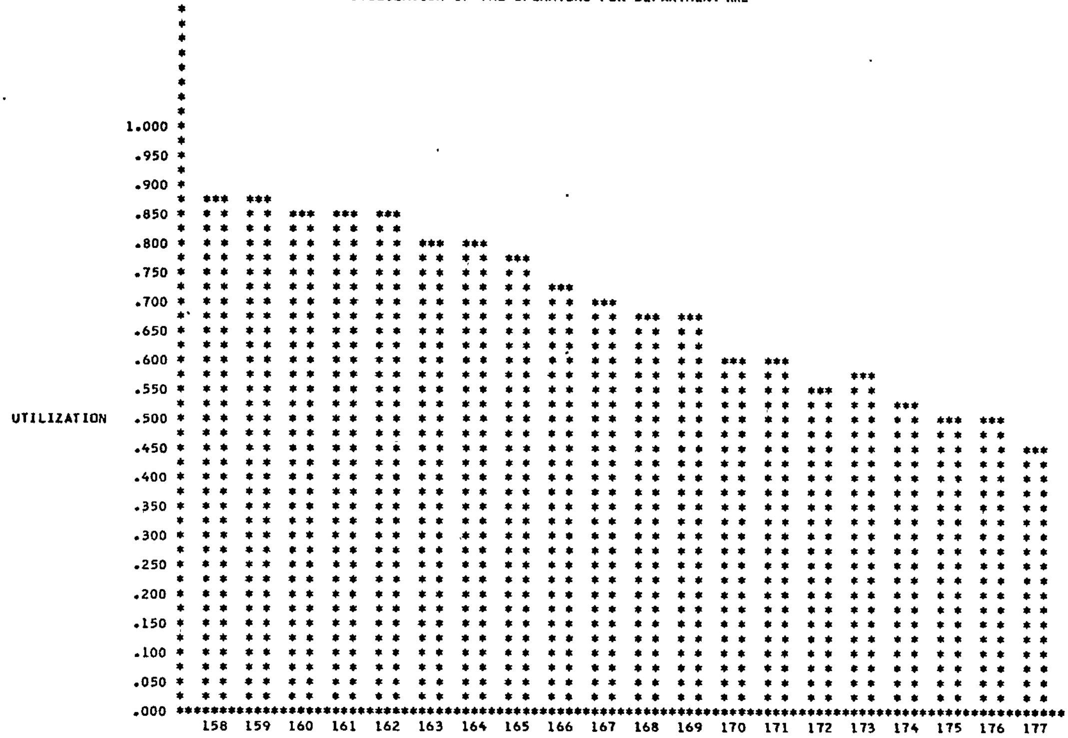
MULTI STAGE PROCESS SIMULATION - INPUT/OUTPUT



ATTACHMENT C



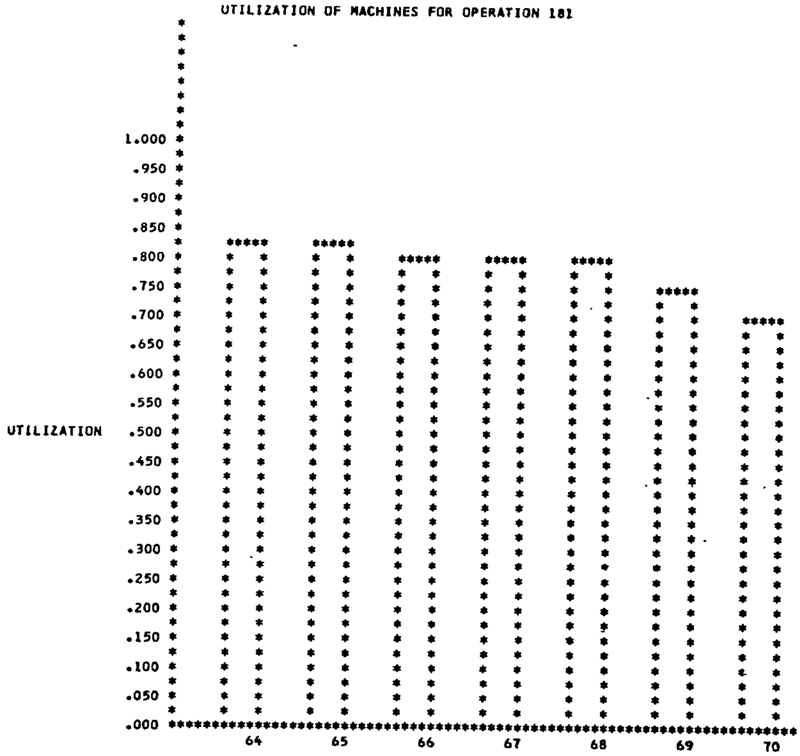
UTILIZATION OF THE OPERATORS FOR DEPARTMENT XX2



MAN NUMBER (FACILITY NUMBER IN SIMULATION)

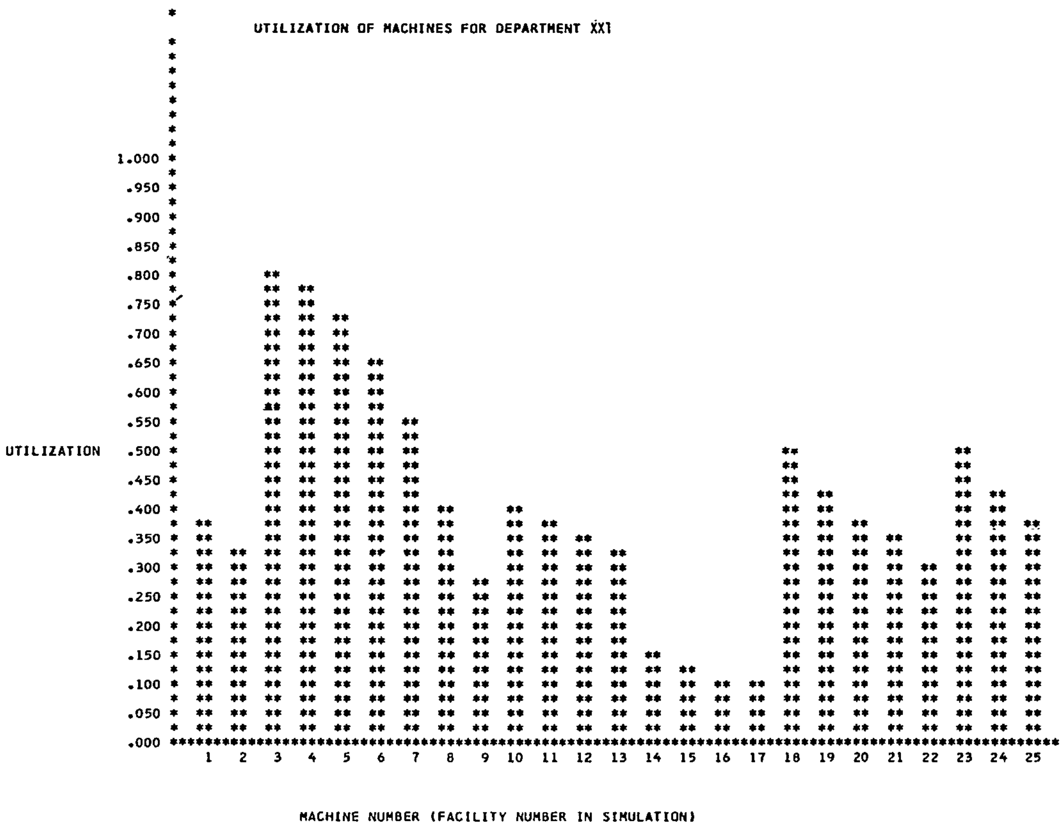
ATTACHMENT D-1

UTILIZATION OF MACHINES FOR OPERATION 181



MACHINE NUMBER (FACILITY NUMBER IN SIMULATION)

ATTACHMENT D-2



ATTACHMENT D-3

INVENTORY STATISTICS FOR THE MULTI-STAGE PROCESS

OPERATION 170

QUANTITY IN IS	7300	CURRENT QUEUE CONTENTS ARE	0.
QUANTITY OUT IS	7300	MAXIMUM QUEUE CONTENTS ARE	1200.
QUANTITY REJECT IS	100	AVERAGE QUEUE CONTENTS ARE	133.700
YIELD IS	98.63	AVERAGE TIME PER PART IN QUEUE IS	.019109 HOURS

OPERATION 6170

QUANTITY IN IS	200	CURRENT QUEUE CONTENTS ARE	500.
QUANTITY OUT IS	1500	MAXIMUM QUEUE CONTENTS ARE	600.
QUANTITY REJECT IS		AVERAGE QUEUE CONTENTS ARE	272.200
YIELD IS	100.00	AVERAGE TIME PER PART IN QUEUE IS	2.166526 HOURS

OPERATION 181

QUANTITY IN IS	2300	CURRENT QUEUE CONTENTS ARE	0.
QUANTITY OUT IS	2500	MAXIMUM QUEUE CONTENTS ARE	1300.
QUANTITY REJECT IS	100	AVERAGE QUEUE CONTENTS ARE	280.700
YIELD IS	95.65	AVERAGE TIME PER PART IN QUEUE IS	.128229 HOURS

OPERATION 190

QUANTITY IN IS	8800	CURRENT QUEUE CONTENTS ARE	94800.
QUANTITY OUT IS	1200	MAXIMUM QUEUE CONTENTS ARE	94800.
QUANTITY REJECT IS	100	AVERAGE QUEUE CONTENTS ARE	42482.900
YIELD IS	98.86	AVERAGE TIME PER PART IN QUEUE IS	4.154859 HOURS

OPERATION 191

QUANTITY IN IS	3500	CURRENT QUEUE CONTENTS ARE	21600.
QUANTITY OUT IS	2400	MAXIMUM QUEUE CONTENTS ARE	21600.
QUANTITY REJECT IS	200	AVERAGE QUEUE CONTENTS ARE	9787.000
YIELD IS	94.28	AVERAGE TIME PER PART IN QUEUE IS	2.075459 HOURS

ATTACHMENT D-4

COST ANALYSIS FOR THE MULTI-STAGE PROCESS

OPERATION 220

AVERAGE INVENTORY COST	$ 1200.00	COST OF PARTS FROM LAST OP	$	4800.0
CURRENT INVENTORY COST	$ .00	COST OF GOOD PARTS	$	8906.0
MAXIMUM INVENTORY COST	$ 16400.00	COST OF REJECT PARTS	$	.0

OPERATION 221

AVERAGE INVENTORY COST	$ 1600.00	COST OF PARTS FROM LAST OP	$	9600.0
CURRENT INVENTORY COST	$ 4400.00	COST OF GOOD PARTS	$	10312.0
MAXIMUM INVENTORY COST	$ 16400.00	COST OF REJECT PARTS	$	937.0

OPERATION 230

AVERAGE INVENTORY COST	$ 1406.25	COST OF PARTS FROM LAST OP	$	19218.0
CURRENT INVENTORY COST	$ .00	COST OF GOOD PARTS	$	20682.0
MAXIMUM INVENTORY COST	$ 12656.25	COST OF REJECT PARTS	$	940.0

OPERATION 240

AVERAGE INVENTORY COST	$ 1410.15	COST OF PARTS FROM LAST OP	$	11281.0
CURRENT INVENTORY COST	$ 1880.20	COST OF GOOD PARTS	$	25376.0
MAXIMUM INVENTORY COST	$ 17861.90	COST OF REJECT PARTS	$	.0

OPERATION 241

AVERAGE INVENTORY COST	$ 1406.25	COST OF PARTS FROM LAST OP	$	9375.0
CURRENT INVENTORY COST	$ .00	COST OF GOOD PARTS	$	10377.0
MAXIMUM INVENTORY COST	$ 10781.25	COST OF REJECT PARTS	$	.0

ATTACHMENT D-5

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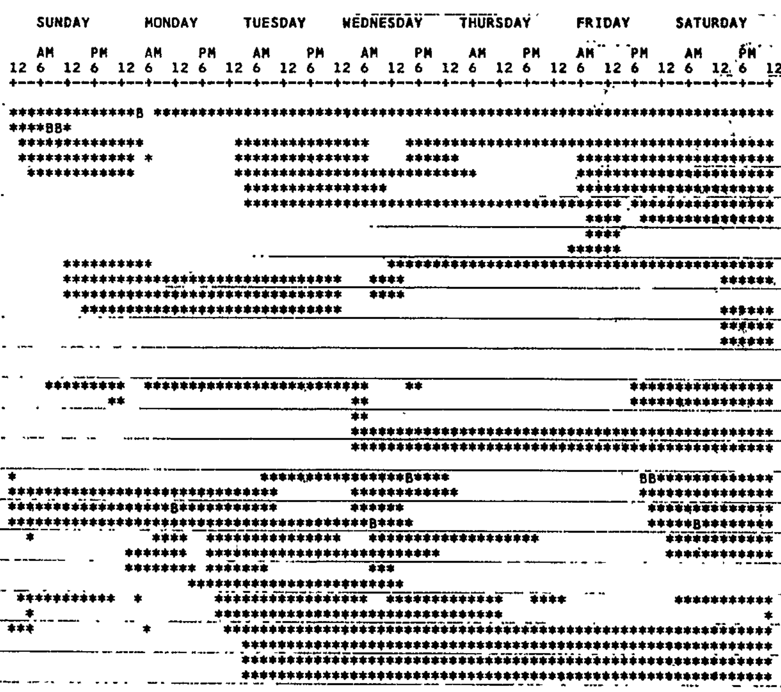
MULTI-STAGE PROCESS GRAPHIC SCHEDULER *** WEEK 2

DEPARTMENT XX2



MACHINE			RUN TIME IN HOUR	IDLE TIME IN HOUR	DOWN TIME IN HOUR
TOOL	NUMBER	A1	164.	2.	2.
TOOL	NUMBER	A2	19.	147.	2.
TOOL	NUMBER	B1	74.	93.	0.
TOOL	NUMBER	B2	46.	121.	0.
TOOL	NUMBER	B3	112.	55.	0.
TOOL	NUMBER	B4	70.	97.	0.
TOOL	NUMBER	B5	108.	59.	0.
TOOL	NUMBER	B6	31.	136.	0.
TOOL	NUMBER	B7	4.	163.	0.
TOOL	NUMBER	B8	9.	158.	0.
TOOL	NUMBER	C1	100.	67.	0.
TOOL	NUMBER	C2	75.	92.	0.
TOOL	NUMBER	C3	66.	101.	0.
TOOL	NUMBER	C4	64.	103.	0.
TOOL	NUMBER	C5	8.	159.	0.
TOOL	NUMBER	C6	8.	159.	0.
TOOL	NUMBER	C7	0.	168.	0.
TOOL	NUMBER	C8	0.	168.	0.
TOOL	NUMBER	D1	91.	76.	0.
TOOL	NUMBER	D2	31.	136.	0.
TOOL	NUMBER	D3	2.	165.	0.
TOOL	NUMBER	D4	90.	77.	0.
TOOL	NUMBER	D5	90.	77.	0.
TOOL	NUMBER	D6	0.	168.	0.
TOOL	NUMBER	E1	15.	146.	5.
TOOL	NUMBER	E2	104.	63.	0.
TOOL	NUMBER	E3	87.	77.	2.
TOOL	NUMBER	E4	106.	57.	4.
TOOL	NUMBER	F1	42.	125.	0.
TOOL	NUMBER	F2	78.	89.	0.
TOOL	NUMBER	F3	26.	141.	0.
TOOL	NUMBER	F4	45.	122.	0.
TOOL	NUMBER	G1	48.	119.	0.
TOOL	NUMBER	G2	33.	134.	0.
TOOL	NUMBER	G3	69.	98.	0.
TOOL	NUMBER	G4	114.	53.	0.
TOOL	NUMBER	G5	114.	53.	0.
TOOL	NUMBER	G6	114.	53.	0.

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

ATTACHMENT D-6