1981 Winter Simulation Conference Proceedings
T.I. Ören, C.M. Delfosse, C.M. Shub (Eds.)



# SIMULATION OF A NETWORK MANUFACTURING PROCESS

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A GPSS model was developed to simulate the flow of parts through the stages of a network manufacturing process. The general network consists of M sequential stages, with a variable number of machines per stage. Parts can be processed on any of the $N_i$ machines at stage i, and different types of parts may be mixed within a single machine. The simulator is used to evaluate scheduling policies proposed for each stage of the process. Scheduling policies to be considered are first in-first out (FIFO), last in-first out (LIFO), minimum process time, maximum process time, random, and priority.

## 1. INTRODUCTION

A primary responsibility of a manufacturing process is meeting scheduled delivery dates for the manufactured parts. An important step in meeting the schedule is the assignment of jobs to facilities in an efficient manner. This assignment procedure becomes very complex when the flow of parts through the stages of the process forms a network; therefore it is desirable to implement the policy that yields the most efficient production of parts. The problem then is selecting the most efficient scheduling policy. A simulation model was developed to evaluate several strategies for one such manufacturing process.

The model, written in GPSS V, simulates the flow of parts through the stages of the process of a given network configuration. The network consists of M stages, with each stage consisting of a set of similar machines. Machines within a stage perform identical operations; although each machine may have a unique capacity. Each part must pass through each stage in a sequential fashion (once per stage); however, the parts may be processed on any available machine within a given stage. The flow of parts then describes a manufacturing network, as shown in Figure 1. In general, each stage is a batch process - parts are loaded into a selected machine and processed for a fixed amount of time, and then removed. No parts may be added once the machine processing begins, and each part must remain in the process until completion. Manual labor is involved between stages for the loading and unloading of parts. The parts are transported through the system via a standard transport mechanism (e.g. tray or basket).

## 2. SCHEDULING POLICIES

### 2.1 Policy Definition

The model was developed to test various scheduling policies as applied to a network described above. As the machines become available at each stage, the next job or set of jobs (each tray or basket is an independent job) to be processed must be selected. The scheduling policies to be tested by the simulator therefore consist of the set of rules used in making these selections. A separate selection policy may be applied at each of the process stages. A selection policy must also be established for determining the order in which the manual labor tasks (machine loading and unloading) are to be performed.

### 2.2 Selection Rules

First In-First Out (FIFO): Jobs are selected in the order at which they arrive at the stage being considered. Manual labor tasks can also be processed FIFO.

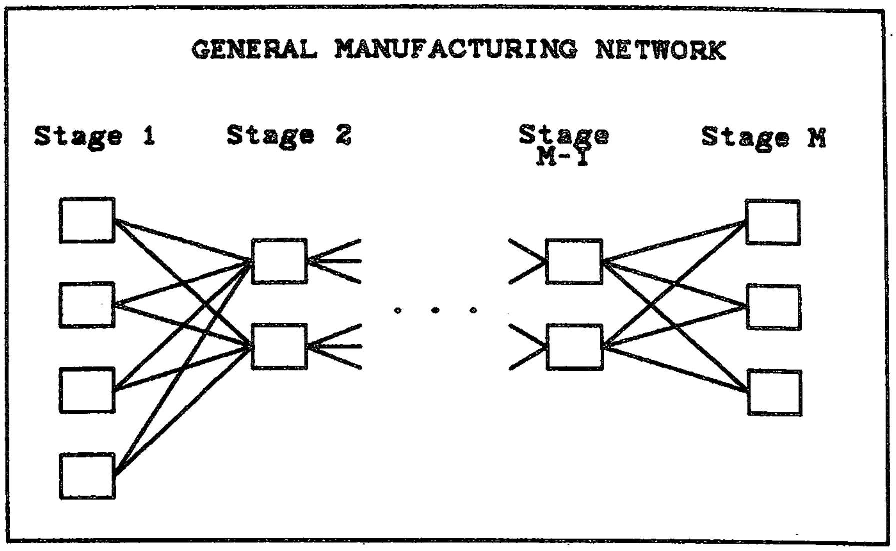


FIGURE 1

Last In-First Out (LIFO): Jobs are selected in an order opposite to that in which they arrive. Manual labor tasks can also be processed LIFO.

Random: Jobs are selected in a random order. The random selection can be done in two ways: jobs are assigned one random number for each stage, and retain that number until selected; or jobs are assigned a random number for their current stage each time a machine at that stage begins its selection.

Minimum Process Time: Jobs with the shortest processing time at each stage are selected first.

Maximum Process Time: Jobs with the longest processing time at each stage are selected first.

Priority: A set of job parameters is used to calculate a priority for each job at each stage. The parameters may include due date, processing time, quantity, or a special part number priority factor. If due date is used, the priority will increase with time.

By individually simulating each of these policies for a given process configuration and set of orders, the ability to meet the scheduled delivery dates can be determined. The policy which best meets the scheduled dates can then be selected as the policy to implement in the manufacturing process.

## 3. EXAMPLE NETWORK MODEL

A sample network to be considered is shown in Figure 2. The network consists of one unit processing stage (e.g. molding) and three successive batch operations, with a manual operation required between each stage. This sequence of processes produces finished parts from a uniform raw material. Mixing of parts at any of the batch stages is allowed, with the requirement that the processing time for the part mix is the maximum of the individual job process times. For example, different products may require different drying times, but extended drying does not affect the product quality.

Requests for parts arrive as orders consisting of a part number, quantity to be produced, and a due date. The model simulates the arrival of the orders to the initial stage, and assigns each order to a unit processor as the machines become available. The assignment is made according to the scheduling policy being tested (for this example, a scheduling policy is one selection rule applied at all stages). A request is made for a machine operator (one operator is required for the duration of the unit process), and the processor remains idle until the operator arrives. Set-up is performed, and the operation proceeds to completion. As the parts are produced, they are placed into baskets, and are transported to the first batch operation (Stage 2). After Stage 1, each order consists of several baskets of parts. The unit processor is then assigned another order, and the process is repeated (the operator may also be freed to perform other tasks if necessary).

After Stage 1, each basket of parts proceeds to the first of the three batch operations. At this point, each basket acts as a unique job, independent of the other baskets that comprise the order. As the machines become available at the first batch stage, baskets are assigned to the machines according to the current selection rule (multiple baskets are assigned to each machine up to the machine's capacity). After the baskets have been assigned, a request for manual labor is issued. When the operator arrives, the selected baskets are loaded into the machine and the process begins. The batch operation is automatic and no manual operation is required, therefore the operator is then freed to perform other tasks. When the process is complete, another request for manual labor is made, and the baskets are unloaded from the machine. The baskets are then transported to the next batch stage, the machine is assigned another set of baskets, and the operator is released. The two remaining batch processes are similar to the first in operation, and differ only in processing time. After completion of the last stage, the baskets are re-grouped into their original orders, and the completion date for the entire order (all baskets) is compared with its due date. The

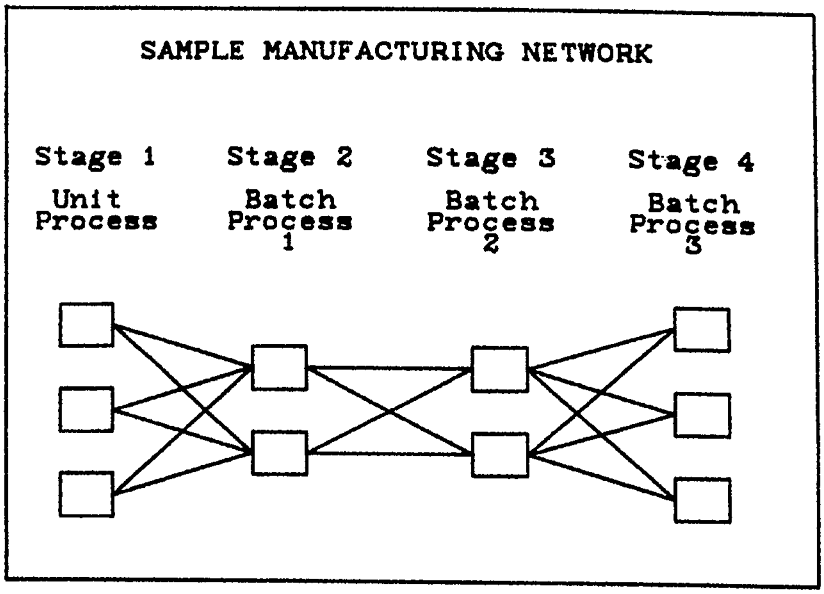


FIGURE 2

| STAGE | PROCESS TYPE | NUMBER MACHINES | MACHINE CAPACITY |
|---|---|---|---|
| 1 | UNIT | 3 | N/A |
| 2 | BATCH | 2 | 50 * |
| 3 | BATCH | 2 | 60 * |
| 4 | BATCH | 3 | 65 * |

* SAME CAPACITY FOR ALL MACHINES

FIGURE 3

| | | PROCESS TIME | | | |
|---|---|---|---|---|---|
| PART NUMBER | AVG ORDER QUANTITY | STAGE 1 (PARTS/HR) | STAGE 2 (HR) | STAGE 3 (HR) | STAGE 4 (HR) |
| 1 | 2000 | 290 | 45 | 48 | 56 |
| 2 | 5000 | 830 | 42 | 44 | 52 |
| 3 | 2800 | 280 | 47 | 52 | 62 |
| 4 | 2500 | 560 | 38 | 43 | 48 |
| 5 | 6000 | 630 | 42 | 45 | 50 |
| 6 | 1700 | 400 | 46 | 50 | 55 |
| 7 | 1800 | 330 | 43 | 49 | 57 |
| 8 | 2600 | 240 | 48 | 54 | 60 |
| 9 | 10000 | 900 | 36 | 39 | 46 |
| 10 | 3000 | 650 | 40 | 44 | 54 |

FIGURE 4

difference between the due date and completion date is the order's "earliness" (negative values imply tardiness). The effectiveness of the simulated scheduling policy is determined by analyzing the distribution of earliness and comparing it to distributions for other policies.

### 3.1 Input Data

3.1.1 Configuration: Figure 3 describes the sample network discussed above.

3.1.2 Process Data: The sample order data and process times are shown in Figure 4. The data presented are hypothetical order quantities and processing times for an arbitrary set of parts.

### 3.2 Model Results - Scheduling Policies

Each of the following selection rules was applied to the sample network:

1. First In-First Out (FIFO)
2. Last In-First Out (LIFO)
3. Random (RND)
4. Priority: based on due date (PRIO)
5. Maximum process time (MAX TIME)
6. Minimum process time (MIN TIME)

Each rule was subjected to the same workload - a normal load is defined by the average order quantities in Figure 4. The quantity represents the number of parts for each part number to be produced during a twenty-day manufacturing period. The model was run with this normal load for each of the six selection rules. The earliness for each order was recorded, and the mean earliness for all orders was then calculated. Figure 5 shows the mean earliness for each selection rule under a normal load. The most efficient selection rule was the priority rule, where each job is assigned a priority based on its due date. This method yielded an average earliness of 8.75 days, with no late orders. Less efficient were the FIFO and minimum process time rules, with averages of 7.3 days and 7.8 days, followed by LIFO and maximum process time rules, with averages of 6.5 and 6.9 days respectively.

Random selection was the least effective, yielding a 4.2 day average.

3.2.1 Increasing Workload: The next step was to test the efficiency of each rule with an increasing workload. Of the six selection rules, PRIO and MIN TIME displayed the best distribution of earliness. Figures 6 and 7 display the cumulative distribution of earliness with increasing workload for PRIO and MIN TIME. These graphs clearly show the degradation of response when the system becomes heavily loaded, as well as the advantage of PRIO over MIN TIME for those conditions.

The data in Figure 8 summarizes the difference in performance of the priority and minimum process time methods. The two methods display similar effectiveness under a normal load, however MIN TIME degrades much faster with increasing workload then does PRIO. The priority scheme based on due date displays the best overall performance of the six selection rules tested.

### 3.3 Model Results - Applications

In addition to testing scheduling strategies and the impact of increasing workloads, the simulator can also determine the effect of: adding or removing machines at a given stage; changing the number of operators available; or varying process times.

Figure 9 emphasizes the sensitivity of selection rule performance to the process configuration. Three configurations were considered:

1. Base configuration shown in Figure 2.
2. Base configuration with one Stage 4 machine removed.
3. Base configuration with one Stage 2 machine removed.

Under a normal load, the removal of one Stage 4 machine is not critical; however, the loss of that machine degrades the system when workload increases. The removal of one Stage 2 machine immediately degrades turnaround, and under heavy loading, its absence produces catastrophic delays. This same situation would apply to a Stage 3 machine as well. The process configuration in these cases is a critical factor.

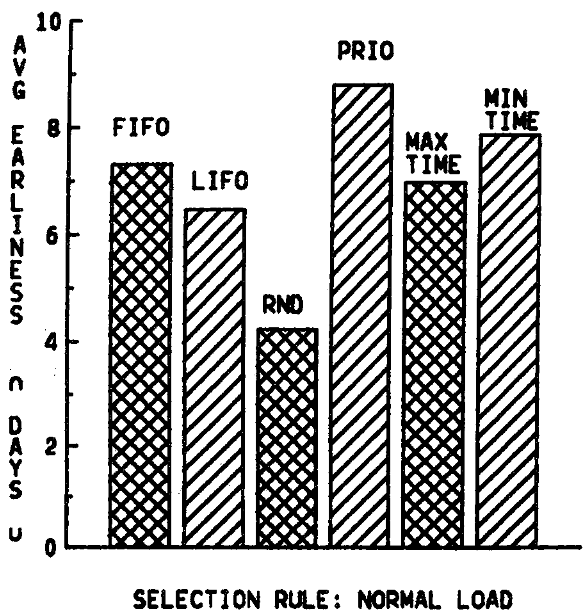


FIGURE 5

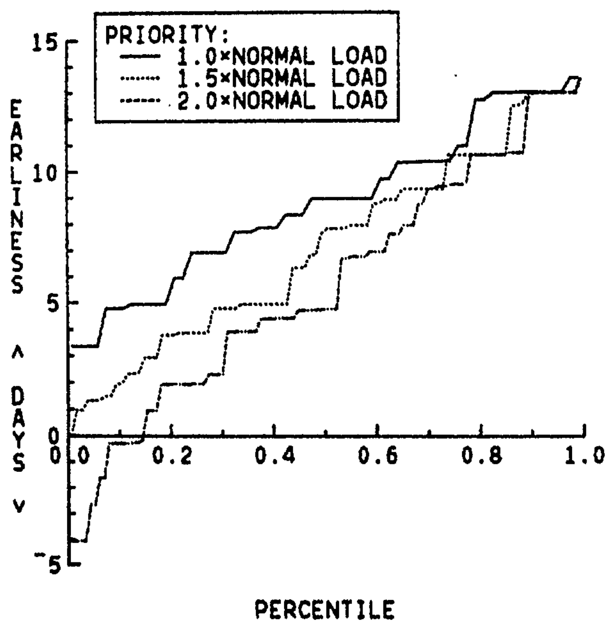


FIGURE 6

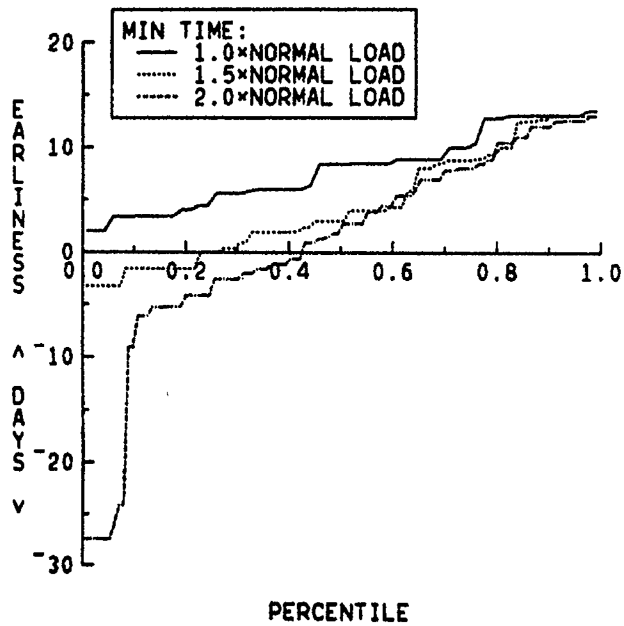


FIGURE 7

| | PRIORITY | | MIN PROCESS TIME | |
|---|---|---|---|---|
| LOAD (×NORMAL) | AVG EARLINESS (DAYS) | PERCENT LATE | AVG EARLINESS (DAYS) | PERCENT LATE |
| 1.0 | 8.75 | 0.0 | 7.82 | 0.0 |
| 1.5 | 7.10 | 1.1 | 4.35 | 26.7 |
| 2.0 | 5.65 | 14.8 | 0.83 | 42.6 |

FIGURE 8

## 4. CONCLUSIONS

The simulation model presented in this paper aided in evaluating scheduling policies and investigating process configuration alternatives for several general network manufacturing processes. For the general network, a priority selection rule based on the job's due date provides the best performance in terms of overall job earliness. The performance is sensitive to both the network configuration and the system loading.

Future work to be performed with the model includes:

1. Allowing different scheduling policies at each stage.
2. Dynamic selection of scheduling policies as the system load varies.
3. Additional due-date generation algorithms.
4. Application to additional network processes.

SELECTION RULE: PRIORITY

| LOAD (×NORMAL) | CONFIGURATION 1 AVG EARLINESS (DAYS) | CONFIGURATION 1 PERCENT LATE | CONFIGURATION 2 AVG EARLINESS (DAYS) | CONFIGURATION 2 PERCENT LATE | CONFIGURATION 3 AVG EARLINESS (DAYS) | CONFIGURATION 3 PERCENT LATE |
|---|---|---|---|---|---|---|
| 1.0 | 8.75 | 0.0 | 7.88 | 0.0 | 6.62 | 11.7 |
| 1.5 | 7.10 | 1.1 | 5.83 | 14.4 | 2.12 | 40.0 |
| 2.0 | 5.65 | 14.8 | 4.50 | 18.5 | -3.79 | 78.8 |

CONFIGURATION:
1: BASE (SEE FIGURE 3)
2: BASE WITH 1 STAGE 4 MACHINE REMOVED
3: BASE WITH 1 STAGE 2 MACHINE REMOVED

FIGURE 9

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