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SIMULATION OF AN INJECTOR PLUNGER PRODUCTION LINE

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ABSTRACT

As part of the design of a new production system, simulation was used to evaluate four production cell design options for the manufacturer of fuel injector plungers. By simulating the proposed design options, Rochester Products was able to select the alternative that would provide the best performance. This paper describes the model used and provides details on the analysis performed.

Keywords: Manufacturing Simulation
Simulation Application
High Volume Batch Manufacturing
Discrete Event-Network Simulation

INTRODUCTION

Rochester Products is a high volume quality manufacturer of fuel injector plungers. Presently, the company would like to reduce the work-in-process inventory for one of its production lines. High inventories exist due to large lot sizes currently being produced. Large lot sizes are run because the time to changeover to different part types is large relative to processing time. To alleviate the situation, Rochester Products is considering a change in the current system to one of four proposed options. The advantage of the new system will be negligible setup and reduced processing times at the machines which in turn enable the company to reduce its lot size, and better respond to customer orders.

In order to evaluate the four proposed options, simulation was chosen as the method of analysis because it easily lends itself to incorporating the variety of details in the design options [1]. The simulation output results provide the information necessary to compare alternatives based on work-in-process inventory levels. Other performance measures were also used. For example, the daily throughput rate for each option determined whether that layout can meet the future production rates. Also, machine utilization and lead time statistics aided in determining the bottleneck station for each option. All of these factors played an important role in recommending a new system.

SYSTEM DESCRIPTION AND DESIGN ALTERNATIVES

Four alternate designs of the batch manufacturing system were simulated to determine system performance of each layout. Ninety-five unique part types are manufactured, belonging to four part families. One type of raw material, bar stock, is common to all four part families. A sequence of turning, heat treatment and grinding operations are performed on all part types, with the specific details of the operations and their sequence being dependent on the design option.

The point within the sequence at which the operation is set up for the specific part type within a family also differs with the design option. The process sequence for Option 4, which has exhibited the best performance, is shown in Figure 1. Bar stock for the product family arrives at the first operation, which is performed by a CNC Lathe. For Option 4, the part type is determined at this point. At each operation there are multiple machines that can perform the same operation. Upon completion of the turning operation, the part is transported to heat treatment. After heat treatment, parts are stored in in-process inventory. Parts are drawn from in-process inventory as orders are placed. They then proceed to a series of five different grinding operations. When the parts are finished with all the operations, they are placed in finished good inventory.

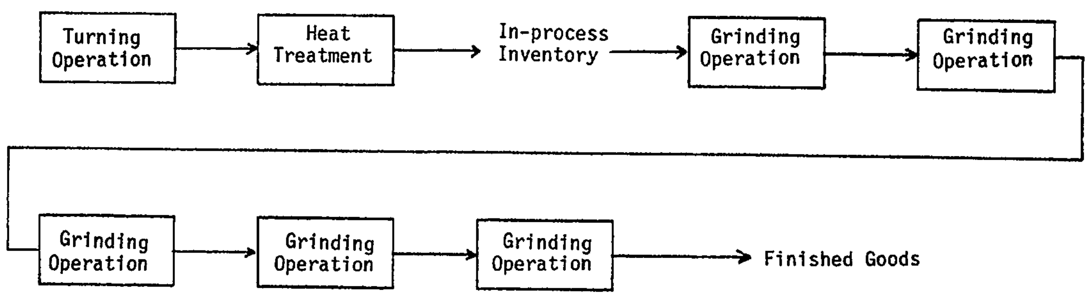

Figure 1. Option 4 Process Sequence.

The other layouts differ in the number and location of the in-process inventory points. The main differences in the alternatives are listed in Table 1. In options 1 and 2, the individual part types are determined late in the manufacturing process. Prior to those operations which generate unique part characteristics, they are grouped in one of four part families. The four options also differ in the number of operations and the number of machines at each operation.

OPTION	PART PRODUCTION	NUMBER OF IN-PROCESS STORAGE AREAS	TOTAL NUMBER OF MACHINES
1	PART TYPE DETERMINED LATER IN MFG. PROCESS	2	63
2	PART TYPE DETERMINED LATER IN MFG. PROCESS	2	56
3	PART TYPE DETERMINED EARLIER IN MFG. PROCESS	1	51
4	PART TYPE DETERMINED EARLIER IN MFG. PROCESS	1	55

Table 1. Option Characteristics.

The production control logic is shown in Figure 2. As the diagram shows the system can be viewed as two distinct manufacturing processes. Manufacturing process 1 is from raw materials to work-in-process inventory, while manufacturing process 2 is from work-in-process to finished goods. The schedule for the second manufacturing process is driven by customer orders. When an order is placed, items are removed from finished goods and delivered to final assembly. The inventory positions are evaluated every week, and the order quantity that is scheduled for production is determined by taking the difference of a predefined amount from the current inventory level. This type of inventory control is referred to as a (T, S) policy [2] where T is the time between orders and S is the desired inventory level at review time. In this study, S is set to be equal to the minimum amount of inventory so that no shortages exist between review periods. The inventory control logic for manufacturing system 1 is identical to 2, except its schedule is driven by the production of manufacturing system 2.

MODEL FORMULATION

The SLAM II® simulation language [3] was used to develop a model of the four proposed options. SLAM II was selected because of its many advantages. These advantages include:

1. The network capability enables the user to build a representable model quickly and easily;
2. User written code can be inserted into the model to give the user the ability to have complicated scheduling rules; and
3. The source code is portable.

A combined network-discrete event model was developed. The network portion is used to model the operations, and the discrete event portion is used to schedule part arrival to the system. Initially, the entities are the production requirements for one week for each of the individual part types. The attributes of these entities are shown in Table 2. The first two attributes define the part and family type that the entity belongs to, and the other attributes are used to store information about the pallet.

VARIABLE	DEFINITION
ATRIB(1)	Part Type.
ATRIB(2)	Family Type.
ATRIB(3)	Counter to indicate whether pallet is the last pallet of the weeks lot.
ATRIB(4)	Time of completion.
ATRIB(5)	Weeks production requirements for each part type.

Table 2. Definitions of Variables in the ATRIB Buffer Array

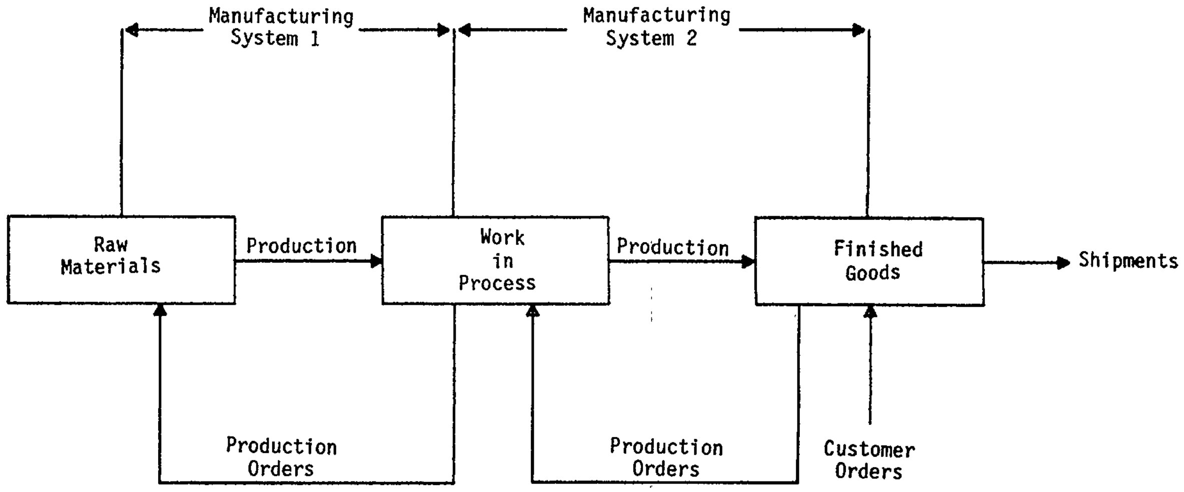

Figure 2. Production Control Logic.

An example network for the CNC Lathe operation is shown in Figure 3. The resource block defines the resource's label, the initial capacity of the resources, and the Await node where parts may wait if all machines are busy. The resource is referenced by the label CNC. There are nine CNC lathes, and parts wait for the lathe at the Await Node.

At the Await Node, the pallets wait for the first available CNC Lathe. After capturing the lathe the pallets are processed for twenty minutes. Then, the resource is released at the Free Node to process another pallet if one is available. Upon completion at this operation, the pallets move to the next operation.

Figure 4 shows the network logic for the heat treatment operation. Pallets arrive and wait at the Await Node for the opening of the HEAT Gate. When the gate opens, all pallets currently in the Await Node are processed at the heat treatment activity. The service time for each entity is uniformly distributed with a minimum of 4000 minutes and a maximum of 5000 minutes. After completing this activity, statistics are collected for the entity, and because this is the last operation before the pallet is placed in inventory, the entity is destroyed by a terminate node.

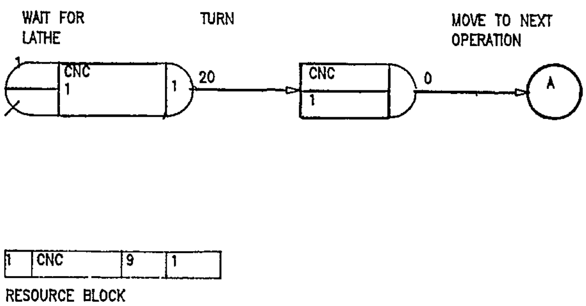

Figure 3. Network Model for the CNC Lathe Operation.

The gate block defines the gate's label, the initial state of the gate, and the Await Node it services. In this example, the gate is referenced by the label HEAT and is initially closed. Also, it services the Await Node. The opening and closing of the gate is done by a dummy entity which is created at time zero by the Create Node. Heat treatment is performed after every shift, and each shift is 400 minutes. Therefore, the gate is first opened after 400 minutes. Once the gate is open, and all entities waiting for the gate move by, it is immediately closed and scheduled to open again in 400 minutes. This process is repeated until the simulation is finished. The simulation ends when processing of the month's production schedule is completed.

ANALYSIS OF THE FOUR OPTIONS

One month's schedule was simulated which translated to a daily requirement of 4700 parts/day. Table 3 shows the throughput results for each of the four options. The results suggest that all four alternatives can

	OPTION			
	1	2	3	4
MEET MONTHLY REQUIREMENTS	YES	YES	YES	YES
AVG. DAILY PRODUCTION RATE	4780	4780	4786	5052
BOTTLENECK MACHINE	2ND GRINDER	2ND GRINDER	2ND GRINDER	1ST GRINDER
EFFICIENCY OF BOTTLENECK MACHINE	99.8%	99.8%	99.8%	43.8%
INCREASE PRODUCTION LOAD	NO	NO	NO	YES

Table 3. Throughput Results.

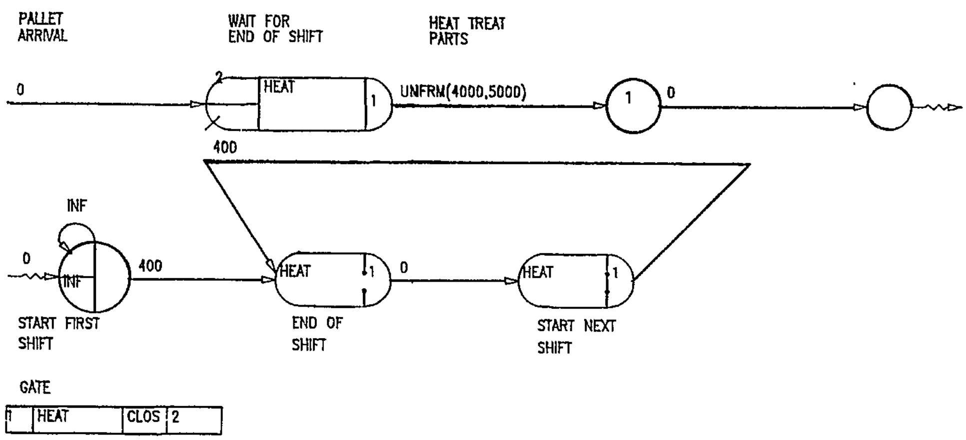

Figure 4. Network Model for the Heat Treatment Operation.

meet the month's production requirements. However, the utilization of the bottleneck machine for the first three options is close to 100%; whereas in the fourth option, the efficiency of the most utilized machine is 43.8%. Therefore, only option 4 could sustain a significant increase in the production load.

Table 4 provides a summary of leadtime statistics. As shown in the table, the average production cycle, the time to process a part from the first to the last operation, for option 4 is the lowest, with a mean of 6.43 days. The reason the mean time to process a part from the last in-process inventory point to finished goods is longer for options 1, 2, and 3, than option 4 is because the bottleneck machine is located in that area. Also, as seen from the previous results, option 4's most utilized machine has much smaller utilization than the rest of the options. In addition, options 1 and 2 have the longest production cycle because their process plans consist of more operations.

	OPTION			
	1	2	3	4
MEAN TIME FROM RAW MATERIALS TO FIRST IN-PROCESS INVENTORY (days)	6.0	5.25	5	5.1
MEAN TIME FROM FIRST IN-PROCESS TO SECOND IN-PROCESS INVENTORY (days)	1.2	1.2	-	-
MEAN TIME FROM LAST IN-PROCESS INVENTORY TO FINISHED GOODS (days)	3.7	3.7	3.7	1.33
AVG. PRODUCTION CYCLE (days)	10.9	10.15	8.7	6.43

Table 4. Leadtime Results

Consistent with the other performance measures, option 4 has the smallest in-process inventory level of 2 production weeks for each part. The in-process inventory levels for the options are listed in Table 5. The in-process inventory levels for all alternatives are much smaller than the current system, which must maintain a 10 week buffer to satisfy customer demand fluctuations.

	OPTION			
	1	2	3	4
LEVEL OF INVENTORY IN-PROCESS 1 (weeks)	4	2	3	2
LEVEL OF INVENTORY AT IN-PROCESS 2 (weeks)	3	2	-	-
TOTAL IN-PROCESS LEVEL INVENTORY (weeks)	7	4	3	3

Table 5. In-Process Inventory Results.

In summary, option 4 had the shortest lead times, lowest in-process inventory level, and the best ability to meet increased order demand. Furthermore, option 4 was the cheapest to install and had the highest equipment reliability. Therefore, the recommended layout was option 4. The next section provides a sensitivity analysis of this option.

SENSITIVITY ANALYSIS FOR OPTION 4

In the previous analysis, it was found that option 4 was operating below capacity for the specified production requirements. To determine the option's capacity, other simulation runs were made at multiples of the base monthly requirements. This analysis is shown in Table 6. As the table shows, if the monthly requirements increased by 150%, the system would be producing 7574 parts/day and have a utilization of the bottleneck machine of 67%. This is still below capacity. On the other hand, trying to increase production by 250% would be beyond system capacity. However, the 200% level is attainable, and it yields a daily production rate of 10,092 parts/day.

	Outputs in Pieces/Day	Utilization of Bottleneck Machines
100% OF MONTHLY REQUIREMENT	5052	43.8%
150% OF MONTHLY REQUIREMENT	7574	67%
200% OF MONTHLY REQUIREMENT	10,092	87.5%
250% OF MONTHLY REQUIREMENT	BEYOND SYSTEM CAPACITY	

Table 6. Maximum Production Output.

CONCLUSION

In this study, simulation was used as an important tool in the analysis of a new production system. The study showed that one option clearly provided the best system performance. With that option, the level of in-process inventory could be reduced by 80% and a daily production rate of 10,000 parts/day is attainable. Rochester Products is currently reviewing that design for their production facility and moving toward its implementation.

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