Use of Simulation for Determining Appropriate Levels of Buffer Inventories in a JIT Environment: A New Perspective on Implementation of JIT

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ABSTRACT

Approaching zero inventory from the Japanese JIT perspective involves removing Kanbans until problems result and then addressing those problems. This paper uses simulation using key variables to arrive at an appropriate level of decoupling inventory based upon the current state of the process variables. The effects of further process improvements on optimal inventory levels can also be determined through simulation. The paper uses a hypothetical example to illustrate how simulation can be combined with a program of continuous improvement to implement JIT. The simulation strategy is shown to provide a means of implementing JIT without incurring the production downtime required using the traditional Japanese strategy.

1. INTRODUCTION

Of what value are advanced technologies if they are not applied? This question is equally applicable to systems technologies, for example Just-In-Time (JIT) and MRP-II, as to "hard" technologies, such as robotics and machine vision. Why has United States industry been so good at developing new technologies and so poor at implementing them (Gomery, 1989)? Statistical process control (SPC) and robotics were largely developed in the United States, but Japanese industry has successfully implemented these technologies to their competitive advantage while U.S. industry generally has not (Basadur, 1992). Japanese industry has shown the competitive value of JIT in the world market. Despite the incontrovertible evidence of the marketplace, U.S. industry has been very slow to implement JIT (Chapman, 1992).

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The purpose of this paper is to illustrate how simulation can be used as a tool to help U.S. industry manage the implementation of JIT. One underlying premise of this paper is that if there is a cultural barrier to JIT in U.S. industry it may well be directed more toward the approach to implementation than to the practice of JIT. Many North American managers who have failed in the attempt to implement new ideas which have been effective in Japanese industry have found it expedient to assume that some mysterious aspect of Japanese culture permits the ideas to work there (Basadur, 1992). This paper disputes that explanation, and offers the explanation that simply copying the Japanese approach may have resulted in an inappropriate implementation strategy for the U.S. firm. Short-term oriented North American managers fail to see the justification for changing their manufacturing lines from product output to research (i.e., removing inventory to identify production problems) (Barlas, 1991). Some North American managers feel threatened by the uncertainty associated with new ideas and sometimes covertly stymie new development (Hutchins, 1992). Implementation strategy must address these issues.

The use of simulation is proposed as part of a strategic approach to minimizing uncertainty during JIT implementation, as opposed to just a way to address an operational question of inventory level adjustment. This is a different approach to the JIT implementation strategy than that taken by the Japanese. By making the implementation process more predictable, simulation may make JIT more palatable to U.S. industry.

The second underlying premise of this paper is that work-in-progress (WIP) inventory reduction should be a result of the process of implementing JIT (this paper's approach) rather than a means of implementing JIT (the traditional Japanese approach). The goal of JIT is not to totally eliminate inventory but to reduce total waste and reduce total cost ("Strike at GM...," 1992). In fact, some failed JIT implementations can be traced to managers attempting to go from "a buffer of 15 days of raw material to hourly deliveries" practically overnight ("Strike at GM...," 1992). Considering inventory as one of the wastes to be minimized (result) is quite different from considering it the primary means of implementing JIT.

2. BACKGROUND

The use of simulation in studying JIT systems is not a new concept. Many researchers [Rees, et. al., 1987; Lee and Seid, 1988; Jordan, 1988; Fallon and Brown, 1988; Changchit and Kung, 1988; Lambrecht and Decaluwe, 1988; Sarkar, 1989; Gupta and Gupta, 1989; Kung and Changchit, 1989; Cadley, et. al., 1989; Sridharan, et. al., 1990; Chaturvedi and Golhar, 1991; Crandall and
Burwell, 1993] have used simulation to model JIT systems. These papers have focused primarily on the use of simulation to address JIT operational issues. This paper focuses on the use of simulation to address the strategic issue of how best to approach JIT implementation in United States manufacturing companies in order to increase the probability of success. Is it better to run inventory reduction experiments on-line to expose the problems for immediate attention (traditional approach) and risk failure when managers react inappropriately to the loss of production time, or is it better to conduct experiments using simulation to identify the problems that must be addressed before reducing inventory beyond a certain point?

The familiar representation of excessive levels of WIP inventory hiding operational problems can be used to illustrate the difference in emphasis between previous works and this paper. Figure 1a depicts the familiar analogy of high water levels (WIP) hiding rocks in the stream (operational problems). The traditional approach to JIT implementation (Figure 1b), successfully utilized in Japan (Schonberger, 1982), requires that water levels (WIP) be reduced to expose the rocks (operational problems) so that they can be addressed and removed. This approach views inventory reduction as a means of implementing JIT.

Even in the more advanced U.S. organizations there are frequently vestiges of the short-term perspective which rebel against creating short-term problems (e.g. downtime, missed due dates) in order to expose underlying operational problems. This cultural impediment to JIT may be addressed by simulating the current state of the process, using the data obtained to establish the appropriate level of WIP, and then using the model to predict the effect of various process improvements. This is analogous to using a diver to locate and mark the rocks for removal while maintaining a just-sufficient level of water to allow our ship to pass without hitting a rock (Figure 1c). After removal of the marked rocks, the water level can be safely lowered and the process repeated. This approach views inventory reduction as a result of JIT implementation.

3. THE JIT CONCEPT

Many U.S. firms overemphasize JIT’s inventory reduction and material control aspects (Blackburn, 1991). The real thrust of JIT is directed toward reduction of wasted time and wasted materials (Schonberger, 1982). Making a process ready for JIT involves analyzing that process to determine the sources of waste and reducing or eliminating them. There are many potential sources of waste in a process.
Figure 1a: Work-in-Progress and Hidden Problems

Figure 1b: Traditional Approach to JIT Implementation
Figure 1c: JIT Implementation Using Simulation to Mark the Rocks

Figure 2: Schematic of Simulated Process
One potential source of waste is variation in process times. The variation may be quantified by determining the distribution of process times and its mean value and dispersion about the mean. A line which is perfectly balanced based upon work station standard times may often be frequently out-of-balance if there is too much variation in the process times at each station. The excessive variation may result from a variety of causes including insufficient operator training, variable quality component parts, level of automation, and inadequate procedures. In order to insure that the excessive variation in one process does not shut down a downstream process, decoupling or buffer inventory is provided. Often the amount of this buffer inventory is relatively uncontrolled limited only by the amount of space available for its storage.

Another potential source of waste is unplanned maintenance of equipment (i.e. equipment breakdowns). Unscheduled maintenance can result from improperly selected equipment, improper methods, inadequate operator training, or poor or nonexistent preventative maintenance procedures. Unscheduled maintenance for a station may be characterized by its mean time between failures (MTBF). Buffer inventory serves to decouple downstream operations from stations undergoing breakdown maintenance.

A third potential source of waste is rejected product from the line. Rejected product can result from a variety of causes including lack of process control, low quality purchased parts, inadequate training, level of automation, inadequate or poorly maintained equipment, or inadequate procedures.

In traditional (non JIT) operations, finished product lot inspection is sometimes performed long after the lot is produced because of the large lot sizes. Where WIP inventory stocks are large, an out-of-control process upstream of the inspection operation can result in a build-up of defective products or subassemblies awaiting sorting and/or rework (Vonderembse and White, 1988). If the operators who produced the defective parts are required to do the rework, this reduces the operating time of the production line. Production costs are increased if the rework operation is accomplished on overtime or in a separate rework department. The result is waste in production downtime and/or time spent reworking (a non-value added process) the defective product.

4. THE SIMULATION

The example presented is a highly simplified representation of a real-life situation. The number of variables is intentionally small to facilitate the
understanding of the concept. With modern simulation systems, many variables are easily handled without any knowledge of a higher level programming language. The simulations in this paper were conducted using the XCELL+ software (Conway, et. al., 1990).

The variables considered in this simulation are:

Variation in Processing Time—All work centers are assumed to have the same mean processing time and the same processing distribution. A uniform distribution is used to simulate a process in which the products run are fairly standard. The mean processing time is held constant at 1.00 time units. Three minimum and maximum processing times are simulated (0.75, 1.25), (0.85, 1.15), and (0.95, 1.05).

Processing Machine Breakdown Frequency (MTBF)—Machine failures can significantly affect the performance of the system and should be incorporated in models used to simulate the system (Buzacott, and Shanthikumar, 1993). The MTBF is assumed to be the same for all the work centers. An exponential distribution is used to simulate the frequency of machine failures for the simulation with means of 50, 100, and 300 time units. The processing machine repair time (MTTR) is simulated using an exponential distribution with a constant mean of 5 time units for all the simulation runs.

Defect Rate—The defect rate at each work center is assumed to be the same with defective products reprocessed at the work center that produced them. Three constant reject rates are simulated (10%), (7%), and (2%).

A very simple sequential manufacturing process was designed using XCELL+ as represented in Figure 2. There is a single product produced on the line which consists of three work centers (W1, W2, and W3). R is a receiving area which supplies the line with an infinite amount of material for use in the process. B2 is a finite buffer between stations W1 and W2; B3 is a finite buffer between stations W2 and W3. S is a shipping area which receives the finished product from the line. M1 is a maintenance facility consisting of one technician who repairs work stations which experience unscheduled maintenance downtime.

Kanbans are used in a JIT system to both control material flow and levels of inventory. By reducing the number of Kanbans in a system, inventory
levels are reduced. Kanbans, traditionally, are cards. However, the amount of space designated for WIP can be used as a Kanban. When a WIP storage space is open between one station and the next, the first station has the authority to produce a part to fill the space. The simulated process uses designated WIP storage areas (finite buffers) between stations as Kanbans. Stations are blocked after producing a unit when the downstream buffer is full. The number of units (capacity) each WIP storage area can hold corresponds to the number of Kanbans in that part of the process.

The hypothetical case addressed involves planning the implementation of JIT for the existing process described above and whose initial state is described in Run 1 of Table 1. It is assumed that all defectives are recycled to and reworked by the station producing the defective unit.

### Table 1: State of Process Variables for Simulation Runs

<table>
<thead>
<tr>
<th>Variable</th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>Uniform</td>
<td>Uniform</td>
<td>Uniform</td>
</tr>
<tr>
<td>Mean</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.75</td>
<td>0.85</td>
<td>0.95</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.25</td>
<td>1.15</td>
<td>1.05</td>
</tr>
<tr>
<td>Breakdown</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>Exponential</td>
<td>Exponential</td>
<td>Exponential</td>
</tr>
<tr>
<td>MTBF</td>
<td>50</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>Repair</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>Exponential</td>
<td>Exponential</td>
<td>Exponential</td>
</tr>
<tr>
<td>MTTR</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Rejects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate</td>
<td>10%</td>
<td>7%</td>
<td>2%</td>
</tr>
<tr>
<td>Disposition</td>
<td>Recycle</td>
<td>Recycle</td>
<td>Recycle</td>
</tr>
<tr>
<td>Initialization</td>
<td>1000 hrs.</td>
<td>1000 hrs.</td>
<td>1000 hrs.</td>
</tr>
</tbody>
</table>

The data collected were used to conduct 2000 hour simulations of the process after allowing the model to achieve steady-state (1000 simulated hours). The simulation was repeated while the buffer capacities were incrementally increased (i.e., the number of Kanbans in the system was
increased). The throughput (in units) of the line was chosen as the measurement variable to determine the state of the process. Since the simulation time was constant at 2000 hours for all runs, throughput is a meaningful measure of productivity (output per 2000 hours). Productivity could then be assessed as a function of the buffer capacities. The appropriate buffer capacity could be selected on the basis of the marginal contribution to productivity of each additional unit of buffer capacity. To achieve an economic optimum, buffer capacity would be increased until the marginal cost of an added unit of buffer capacity equaled the marginal return obtained.

Run 2 (Table 1) represents a repeat of the simulation series after improvements have been made to the process. The process time variation has been reduced from +/- 0.25 hours to +/- 0.15 hours perhaps by improved operator training, increased automation or replacement of obsolete equipment. Work station MTBF has been increased from 50 hours to 100 hours perhaps by scheduling preventative maintenance during scheduled idle time or on off shifts. The reject rate has been reduced from 10% to 7% perhaps by improved operator training, increased automation, better quality purchased parts, implementation of statistical process control (SPC), or the installation of better equipment. The actual approaches to improving the process would be determined after the root problems have been identified and the different alternatives evaluated from both a technical and an economic perspective. For example, the cost of implementing a preventative maintenance program to increase MTBF could be weighed against the costs of conducting breakdown maintenance only. With simulation, the inventory carrying costs and throughput aspects of this decision could be better evaluated.

Run 3 (Table 1) is a third simulation series performed after additional process improvements have been effected. The process time distribution has been reduced to +/- 0.05 hours, work station MTBF has been increased to 300 hours, and the defect rate has been reduced to 2%.

5. SIMULATION RESULTS

Figure 3 shows the results of the three simulation runs. In its initial state (Run 1) the process requires buffer capacities of about 20 (i.e. about 20 Kanbans) before the marginal contribution to throughput of an additional unit of buffer stock becomes relatively constant and small. A 50 per cent increase in each buffer’s capacity (from 20 to 30) increases throughput by only 0.2 per cent (3 units). The average level of buffer WIP during the simulation was 20 at buffer capacities of 20 and 34 at buffer capacities of 30. Because of the
diminishing marginal improvements in throughput, the recommended buffer capacity would be between 15 and 20 units.

After the first improvement stage (Run 2) the marginal effect of adding an additional unit of buffer stock becomes relatively constant and small after about 10 units of buffer capacity. A 20 per cent increase in each buffer’s capacity (from 10 to 12) increases throughput by only 0.3 percent (5 units). The average level of buffer WIP during the simulation was 11.5 at buffer capacities of 10 and 14 at buffer capacities of 12. The recommended buffer capacity at this stage would be about 10 units.

Figure 3: Throughput as a Function of Buffer Size for Three Process States
After the second improvement stage (Run 3) the marginal improvement in throughput of an additional unit of buffer stock becomes relatively constant and small after about 3 units of buffer capacity. A 67 per cent increase in each buffer's capacity (from 3 to 4) increases throughput by only 0.05 per cent (1 unit). The average level of buffer WIP during the simulation was 3 at buffer capacities of 3 and 6 at buffer capacities of 6. The recommended buffer capacity at this stage would be about 3 units.

Figure 3 clearly shows how the value of an additional unit of buffer WIP decreases as the process is improved. It is also clear that the substantial benefits in throughput are a result of the improvements in quality, MTBF, and process time variation. The process throughput with zero buffer WIP is almost 50 per cent higher at Run 3 than at Run 1. The reduction in buffer WIP which can be achieved is a result of the improvements in the process.

6. RECOMMENDATIONS AND CONCLUSIONS

The purpose of this paper was to demonstrate with a simple example how simulation can be used as a tool in conjunction with a program of continuous improvement to help manage the implementation of JIT. Simulation can be used to determine the appropriate level of buffer inventory based upon the state of key process variables. This appropriate level of inventory is just sufficient to sustain the production operation while attention is focused on improving the state of the key process variables. At some point during this continuous improvement process, the appropriate level of buffer WIP will approach zero. At this point simulation becomes unnecessary since no further reduction in buffer inventory is possible. Until this point is reached, simulation can afford American managers an opportunity to rationally manage their buffer inventories while identifying the process improvements necessary for the successful implementation of JIT.

A detailed discussion of the means for identifying the actions necessary to identify the appropriate process improvements is beyond the scope of this paper. However it should be noted that simulation must be used in conjunction with a program of continuous improvement which uses tools such as process capability analysis, statistical process control, quality circles, cause-and-effect charts, Pareto analysis in order to identify the root causes of the variations in the process. When these analyses result in an improvement in the process, simulation can be used to determine the new inventory levels most
appropriate for the process in its improved state as well as provide insight into which part of the process might be most fruitfully focused on next.

Previous research has determined many variables which must be included in the model to simulate real processes. It is unrealistic to expect that a single model can be developed incorporating variables which are universally applicable. Thus, the simulation model must be individually tailored to each application. However, by using simulation in conjunction with a program of continuous improvement, management can be provided with a more rational basis for making decisions about appropriate levels of WIP inventory as process improvements are effected. In addition, projections can be made about the effect on inventory levels and output rates of specific improvement activities. Those managers who are unwilling to create problems using the traditional JIT implementation method might find this approach acceptable. If so, this approach will make JIT available to an expanded universe of firms.

REFERENCES