Use of Simulation for Determining Optimum Level of Buffer Inventories in a JIT Environment: A Strategic Perspective

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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 utilizes simulation using key variables to arrive at an optimal 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 the simulation technique.

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, and 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? 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. 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.

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. Simulation is proposed as a different approach to
implementation 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 is a result of the process of implementing JIT rather than a means of implementing JIT. The difference is significant. A misunderstanding of this premise could in part account for the relative lack of application of JIT in the U.S.

BACKGROUND

The use of simulation in studying JIT systems is not a new concept. Many researchers [Rees, et. al., 1987; Lee and Seah, 1988; Jordan, 1988; Fallon and Brown, 1988; Changchit and Kung, 1988; Lambrecht and Decaluwe, 1988; Sarker, 1989; Gupta and Gupta, 1989; Kung and Changchit, 1989; Cadley, et. al., 1989; Sridharan, et. al., 1990; Chaturvedi and Golhar, 1991] 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.

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.

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.

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.

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.
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
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 many traditional (non JIT) operations, finished product lot inspection is performed long after the lot is produced. In some cases several shifts or even several days may elapse between production and inspection of a lot. This can result in a build-up of defective lots awaiting sorting and/or rework. Frequently, in order to "punish" those responsible for the defects, the operators who produced the lot are required to rework the lot. The rework operations take away from the operating time of the production line. The result is waste in production downtime and time spent reworking (a non-value added process) the defective product.

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).

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 buffer between stations W1 and W2; B3 is a 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.
The hypothetical case addressed here involves planning the implementation of JIT for the existing process described above and whose initial state is described in Run 1 of Table 1. Data were collected from the hypothetical production line to describe the process time distribution, the process equipment MTBF, and the defect rate for the line. It is assumed that all defectives are recycled to and reworked by the station producing the defective.
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><strong>Process Time</strong></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><strong>Breakdown</strong></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><strong>Repair</strong></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><strong>Rejects</strong></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. 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.

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%.

**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 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 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 reductions in buffer WIP which can be achieved are a result of the improvements in the process.

RECOMMENDATIONS AND CONCLUSIONS

The purpose of this paper was to demonstrate with a simple example how simulation can be used as a tool 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. Until this point is reached, simulation can afford American
managers an opportunity to rationally manage their buffer inventories while implementing the process improvements necessary for the successful implementation of JIT.

WORKS CITED


