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Conventional Shop Control Procedures to Approximate JIT Inventory Performance in a Job Shop

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Abstract

A two-stage simulation analysis shows that for certain types of manufacturers it is more appropriate to adjust shop control procedures to approximate just-in-time (JIT) inventory rather than to incur a major overhaul in the production system. In the first stage, screening experiments are performed to select the best dispatching rule, allowance-setting rule, batch size, and cycle time. Next, the performance of the selected conventional shop control factors is compared with the kanban simulation results. The results indicate that there are conventional shop control procedures that perform better than JIT in a job shop. It is observed that, even with adequate capacity, bottleneck areas surface due to fluctuation in the shop load. JIT is not appropriate in such a situation. The paper concludes that all shop control approaches do not perform equally well in a good manufacturing environment.

Keywords: *Just in Time (JIT), Kanban, Allowance Setting Procedure, Dispatching Rule, Shop Control, Multiple Comparison Tests*

Introduction

The advantages of just-in-time (JIT) implementation are well documented.[1-4] The success story of JIT in infinite variations spans a disparate range of industries, such as Harley-Davidson, Black & Decker, Hewlett-Packard, IBM, Motorola, John Deere, GE, and Xerox, to name a few.[5] As a result, there has been an effort to emulate JIT; however, companies must realize that JIT is an approach to the design and management of a production facility, and moreover, JIT requires a particular type of manufacturing environment for its successful implementation. Therefore, firms that want to adopt JIT must incur a major overhaul in the control system of their production facility, and such an attempt will be costly. In the long run, any production system needs to consider a trade-off between the costs to implement the system and the savings from the system's operation. To properly evaluate such decisions, the "optimal" results attainable at each cost level must be known.

The question thus arises whether JIT inventory results can be achieved in a job shop with existing operating procedures. This is the question to be investigated in this research. In a job shop environment, MRP reduces inventory and provides better customer service.[6,7] However, Plenert and Best[8] claim that kanban is better than MRP in a job shop. These studies suggest that the selection of a production control system is situation-specific. Yet others[9-13] argue that kanban and MRP are complementary -kanban through better visible controls is good for daily operations, while MRP provides better control for intermediate-term planning and scheduling. In a new plant with a few standardized products, the benefits of implementing JIT may be enormous, but in an existing job-lot manufacturing system JIT may not even be feasible. It is hypothesized that in a good manufacturing environment[14] an optimal combination of allowance-setting, dispatching, batch sizing, and input-output control (shop loading cycle time) procedures will compare favorably with JIT inventory performance. In particular, the effect of cycle time, batch size, allowance-setting procedures, and sequencing rules on the levels of inventory is studied. Since this paper deals only with the shop control aspect of JIT, JIT will be referred to as a kanban system.

Krajewski et al.,[14,15] Lambrecht and Decaluwe,[16] Luss,[17] and Lee[18] have found evidence that the success of a manufacturing process depends on environmental factors. Based on a comparative analysis of the performance of JIT and reorder point (ROP) systems, Krajewski et al.[14] concluded that the critical environmental factors for improved manufacturing performance are no special orders, small batch sizes, no machine breakdowns, low scrap rates, and low setup times. This research incorporates the above characteristics of a good manufacturing environment. The basic question asked is: Do all combinations of conventional shop control procedures perform equally well in good manufacturing environments? If not, what is the best combination? How do they compare with kanban results if kanban is implemented in the same shop?

Contribution of the Research and Literature Review

This study extends past research on job shop control by including several major aspects of shop floor control. The bulk of the shop control research[19-21] reported in the literature deals only with a subset of the shop control problem, such as scheduling and sequencing, allowance setting, batch sizing, and loading of job shops. For overall improvement in performance, all of these must be included in the shop control problem. The focus of this research is on the justification of the attempts to implement an optimal combination of conventional shop control procedures as opposed to JIT in a job shop. The JIT philosophy implies pursuing a journey toward perfection, that is, zero defects, zero inventory, zero disturbance, and total standardization. JIT requires a commitment to improve the system performance continually, through problem solving, continual education, participatory management, and reduction of organizational slack. While most of the strategic decision factors, such as waste reduction, total quality control, continual improvement, transaction reduction, and many of the design and planning decision factors, such as a stable Master Production Schedule (MPS) in most cases, reliable vendors, multifunctional workers, and foolproof methods, can be implemented in a job shop, many shop-level control decision factors of JIT are difficult to implement in job shops. Miltenburg and Wijngaard,[22] Discenza and McFadden,[11] and Belt[23] support integrating or phasing in JIT with MRP.

The study compares conventional shop control results with those of kanban by implementing both in a job shop operating in a good manufacturing environment. The results of this analysis will help practitioners in determining the aptness of implementing JIT in a job shop. The analysis will also specify what conventional shop control procedures should be adopted for improved system performance. This research will reduce the gap, currently existing, between the shop floor control research domain and the perspectives held by practitioners.

Krajewski et al.[14] studied the replicability of the kanban system in the U.S. In addition, they studied the various factors that have the greatest impact on manufacturing performance. By utilizing simulation, they have shown that kanban, when implemented in an attractive environmental setting, does indeed perform very well; however, Krajewski et al. also show that other traditional systems perform equally well in such an environment. Their results show that in more difficult plant environments all systems perform much worse. Based on these findings, Krajewski et al. infer that the success of the production system is factor-dependent, and most of these factors are environmental factors. The observed factors that deter kanban implementation are plants having special orders, large lot sizes, high setup times, high scrap rates, and considerable equipment downtime. Overall, the study suggests that the selection of the production/inventory system is less critical than the manufacturing environment itself. In two earlier papers, Ritzman, King, and Krajewski[24] and Krajewski et al.[15] investigated the contribution of lot sizes, setup times, worker flexibility, and level utilization to manufacturing excellence. Both of these studies questioned the portability of JIT to the manufacturing environments found in the United States.

Huang, Rees, and Taylor[25] and Sarker and Fitzsimmons[26] infer that the kanban process cannot automatically be applied to American production systems. If kanban is implemented without changing the operating conditions, the additional kanbans required make the Japanese system look more like an American push system. Rice and YoshiKawa[27] reveal that the JIT system has its roots in employee motivation, and without it the system is bound to fail. They give evidence of such failure in Japan. Sarker and Harris[28] studied the effect of imbalance in a JIT production system. Their analysis of a JIT system indicates that it creates unequal utilization of operators, fluctuation of production rates, creation of temporary inventory, and "blocking" and "starvation" of the line. Philipoom et al.[29] investigated the consequences of implementing JIT with kanban without the appropriate production environment to do so.

Shop Control Decisions

Shop Description

Based on a benchmark job shop, a hypothetical job shop model was developed to perform the comparative analysis. It should be mentioned that the most obvious differences between a hypothetical shop and an actual shop (for example, number of workcenters, number of machines, pattern of work flow, and so on) have been found to be of little consequence in determining the relative importance of different operating policies in the shop. Studies conducted by Conway and Maxwell,[30] Baker and Dzielinski,[31] Moore and Wilson,[20] and Ragatz and Mabert[32] support this conclusion. The benchmark shop has six workcenters with a total of 23 machines. A description of the workcenters and the type and number of machines in each workcenter is given in *Table 1*. There is a total of 23 employees in the direct labor force. Forty-two different parts are processed in this job-lot manufacturing environment. The processing requirements consist of cutting, shaping, boring, and welding of the raw pieces. The routing for each job is predetermined and fixed (there are no alternate routings). The number of operations in each job is also predetermined. A job can visit the same workcenter several times in its routing. Jobs arrive with a specified mean interarrival time. The arrival process in the benchmark shop follows the negative exponential distribution with a mean of 60 minutes and 20 to 100 jobs per batch. The actual job processing times at the various workstations also follow the negative exponential distribution. The collected shop data were used to run the simulation model.

Control Factors and the Performance Measures

(a) Conventional job-shop control: The conventional shop control system with infinite buffers is similar to the one suggested by Baker.[33] It controls the flow of jobs at three levels of detail. Arriving jobs are accumulated in a preshop file and are assigned a flow time based on a selected allowance-setting rule to determine their due dates. At the second stage, a selected batch of jobs is released to the shop floor. At this stage, it is assumed that all preshop activities are completed and material is available for processing of the batch of jobs. The period of time between release of jobs to the shop (henceforth referred to as cycle time) is based on the batch processing times at the various workstations and is consistent with the order review and release activities in a job shop. Based on batch processing times at the slower/bottleneck workstations, cycle times between in the range of 30 to 60 minutes were tested to find one that assures smooth flow in the shop. After a batch is released to the shop floor, its movement is controlled by the dispatching rule in force; this is the third level in the control system. After all processing has been completed on a batch of jobs, the batch leaves the system if its due date has been exceeded, or it is placed in the finished goods inventory until its due date. No early delivery is allowed in this control system. The due dates for jobs were kept static because the dispatching rules perform better if the due dates do not change by shop load.[34] *Table 2* outlines the tested conventional shop control factors and the performance measures collected. The inventory performance measures collected in this study are consistent with the dollar-weighted measure of Wilson and Mardis.[35]

Two of the most widely used rules of setting allowances are selected for testing. These are the total work content (TWK) and processing plus wait-

Table 1
Job Shop Used in the Analysis

Workcenter No.	Machine Types	No. of Machines
1	Laser press-turret-punch	4
2	Press-brake machines	5
3	Welding machines	4
4	Punch-press machines	5
5	Shearing machines	2
6	Bending-rolling machines	3
No. of Job Types Processed = 42		

Table 2
Control Variables for Conventional Shop Control and the Performance Measures Used in the Study

Control Variables	Performance Measures
Cycle time: How often should the shop be loaded?	A. Time-averaged inventory values of:
Batch size: How many units of a particular type should be released to the shop floor?	1. Work-in-Process Inventory
Which allowance-setting procedure?:	2. Total System Inventory
(1) Total Work Content (TWK): $D_i = r_i + A_i; A_i = K_1P_i$	
(2) Processing Plus Waiting (PPW): $D_i = r_i + A_i; A_i = P_i + K_2n_i$	B. Due date performance of jobs
where: D_i due date for *i*th job; P_i processing time for *i*th job; K_1 and K_2 = allowance factors; r_i *i*th job arrival time; n_i = number of operations in *i*th job	
Which Dispatching Rule?:	
(1) First Come First Served (FCFS): Random	
(2) Shortest Processing Time (SPT): Static	
(3) Earliest Due Date (EDD): Static	
(4) Minimum Slack (MINSLK): Dynamic	

ing (PPW) rules. Since the kanban system is a demand pull system, job flow times are estimated based on actual processing times at the workcenters; that is, they are based on total work content of the job. On the other hand, MRP systems use PPW, as exemplified in the IBM software implementations of CAPOSS and COPICS.

Batch size is a function of the MPS demand quantities and setup times. The simulation model uses the same MPS and setup times as for the benchmark study shop. For determining the best batch size, a weighted EOQ is used because the average batch size at the benchmark shop closely approximated the weighted EOQ, given by the following:

$$\text{Weighted } EOQ(\overline{EOQ}) = \sum_{i=1}^{n} p_i EOQ_i$$

where p_i = relative frequency of the ith item.

If the MPS quantities are less than the weighted EOQ, then

$$\text{Batch size} = \underset{i}{Min}\left[D_i, (\overline{EOQ})\right]$$

where D_i is the MPS production quantity for the selected ith item.

Job dispatching is the final control decision exercised by the decision maker. In selecting the dispatching rules, the recommendations of Melnyk, Vickery, and Carter[36] have been used. Based on practitioners' perspectives, they recommend that a rule be simple to use, be transparent and valid, and generate meaningful priorities that facilitate joint decision making and evaluation among planners, dispatchers, and operators. Four rules are tested to include all three major dispatching rule strategies, random, static, and dynamic. The FCFS rule is a random rule; it considers neither job nor shop information in determining a priority and is a simple, static, and non due date oriented rule used in kanban systems. The SPT and EDD rules are based on job information and do not change while the job is on the shop floor. The SPT rule is a static, non due date oriented rule that has been found to be effective in controlling both work-in-process inventory and tardiness. When applied to complex systems, the SPT rule has been shown to outperform many other sophisticated rules.[37] EDD is a static, due date oriented priority discipline. In this rule, the job chosen for processing is the one with the most imminent due date. This rule is known to be effective in reducing both early and late job completions. MINSLK is a dynamic rule; that is, in this rule the job priority is recalculated over time. It uses the job slack measure in priority determination. Job priority equals the minimum time remaining before the job due date minus all remaining processing time for the job. Observe that MINSLK is an operation-based rule whereas the first three rules are job-based rules.

(b) Kanban shop control: The JIT inventory is estimated by implementing the kanban system in the study shop so that it is comparable with the conventional job-shop control procedure results. The kanban system has finite in-process inventory buffers and, therefore, station blocking. Buffer capacity is limited by the part containers in circulation between each pair of stations, the feeding station and the receiving station. The feeding station must remain idle until items are withdrawn from the container. This has the effect of reducing the average work-in-process inventory. The frequency of blocking can be reduced by increasing the buffer capacity, such as by having more containers. Material handling operation between a pair of workstations is performed instantaneously on completion of a container of parts. This is consistent with assembly operations where workstations are located close together (a requirement in a JIT system). Since it is a de facto single-card system, station blocking is done by part type. Only one container of part type j is allowed between a pair of stations. Station i cannot begin processing a container of part j if there is a container of part j in the following buffer. However, station i may process a container of another part j (j = 1, 2, ..., 42) if it is absent in its buffer. A station will be forced to remain idle only when it is blocked with respect to all part types. An item is produced only if there is a demand for it and if the workstation is not blocked, as opposed to the conventional shop control system where production takes place without blocking.

The benchmark job shop is basically a requirements-driven system; it is a dynamic batch manufacturing process where the product mix changes significantly from period to period. The gross requirements are generated by the MRP system based on average daily demand for the parent product. It is assumed that the lead times for setup and processing are known to the MRP system and that they do not change over the planning horizon. Container size was set to represent the average daily demand for the part as a means to control the number of kanbans to one. Supplier side issues are not taken into consideration in the model by assuming no raw material shortage. The environmental variables[14] are kept constant with no disruption with only three sources of uncertainty in the model, item demand and the processing and setup times.

The measures of performance used are the time-averaged inventory values for the studied systems. The time-averaged system inventory is given by the following:

$$\frac{\int_0^t \sum_i C_i P_i t\,dt}{t} + \frac{\int_0^t \sum_i \sum_j C_{ij} P_{ij} t\,dt}{t} + \frac{\int_0^t \sum_k C_k P_k t\,dt}{t}$$

where C_i is the initial cost of raw material for the ith item, C_k is the final value of the completed item, C_{ij} is the value added after jth processing of the ith product, and P_{ij} is the number of units of the ith product at the jth processing stage. In addition, data on the relevant service-level performance indicator—proportion of tardy jobs—are also collected. The reason for collecting the time-averaged inventory values is because the products are not equally valued, and the value added after each operation is different for each product. A simple sum of the number of units in inventory assumes equal product value, and it fails to take into account the product structures and multiplicities. Detailed product cost data was collected from the benchmark job shop for use as inputs to the simulation program. This approach is consistent with the dollar-weighted measure of Wilson and Mardis[35] and the stock-level performance indicator of Grunwald, StriekWold, and Weeda.[7] The time-averaged measure of inventory value coupled with forbidden early shipment captures many features of the just-in-time inventory philosophy. It incorporates a basic JIT principle of penalizing manufacturing systems that maintain high levels of expensive finished goods inventory.

Factor Levels and the Experimental Design

In the conventional shop control system, the effects of two methods of allowance setting (due date setting), four dispatching rules, batch size, and the cycle time are tested on inventory levels and due date performance. Both the allowance setting procedures, namely TWK and PPW, require the specification of one parameter to be implemented. These are the allowance factors used in assigning the flow times (the factors are K_1 and K_2 selected based on the weighted number of operations per job). Therefore, the treatment combinations will consist of the selected allowance-setting procedure with levels of either K_1 or K_2, one of the four dispatching rules, and the levels of cycle time and batch size.

In the first phase of the study, screening experiments are conducted to select the best allowance-setting and dispatching rules and the best cycle time for the model shop. The screening experiments are performed to decide which shop control procedures cause significant changes in the performance measures and, therefore, should become part of the shop control policy. The results of the screening experiments are tested statistically to establish the outcome. For comparing the dispatching rules, multiple comparisons are made using the Kruskal-Wallis test. Comparison of the TWK and PPW allowance-setting rules and the cycle times are carried out by constructing confidence intervals to test the significance of the difference between alternative systems. Investigations were made to see whether the assumptions of these tests are satisfied, and steady-state results were collected for analysis. The alternative conventional shop control policies were tested under similar experimental conditions. This ensured that any observed differences in shop performance were due to the differences in effectiveness of the shop control variables rather than due to the fluctuations of the experimental conditions.

The selected control factors from the screening experiments are used in the main experiments. In the main experiments, the results of the best conventional shop control combinations are compared with the kanban results. The JIT inventory levels are computed using the kanban simulation results. The simulated JIT inventory is regarded as the control, and the inventory performance of conventional shop control variables is compared with it. The statistical significance of the difference between the control and the inventory performance of conventional shop control variables is analyzed using the Dunnet's test.

Simulation Model

The study was carried out using a discrete-event simulation model of the job shop. The simulation program was written using the Simscript II.5 simulation language. It is a Fortran-based simulation language with subroutines for event timing, file handling, and statistical calculations.

In the simulation model, the process approach[38] has been used. The process describes the life cycle of a batch/container of jobs through the manufacturing facility. The process approach is useful for calculating the time-averaged inventory values. The machines in the job shop have been modeled as resources required by process entities (batch/container of jobs) for their processing requirements. Simscript II.5 library routines are used to represent the arrival rates and the processing time distributions. For comparison purposes, the JIT inventory level is estimated by modifying the simulation program to implement kanban in the study job shop. For details of the simulation logic, the reader is referred to Huq[39] and Huq and Bernardo.[40] In the kanban simulations, a level schedule is used for releasing jobs to the shop, and the same set of jobs was processed so that similar machine and shop utilization is achieved. The container size is determined based on the total number of jobs, such that the system processes exactly the same type and the same number of jobs completed by the conventional control procedures as specified by the master production schedule (MPS). This was done in an optimistic manner that favors JIT results. Therefore, the performance measures obtained from these simulations provide a lower bound for JIT inventory. To reduce the variation in the simulation output, four methods are employed. The first of these is the identification and use of simulation lengths at which the system approximates steady-state behavior. A second method of variance reduction is the use of different seed values for the random number streams associated with each of the stochastic variables within the simulation. The third method of variance reduction is the determination and use of the appropriate number of replications. Finally, common random numbers are used across comparisons to eliminate the effects of the experimental conditions. The shop capacity has been kept constant.

Results of Screening Experiments

Tests based on Huq[39] show that the steady-state condition is reached when the program is run for about 30 simulated days. All analysis of the simulation output is based on the steady-state results. Except for two control factor combinations, all steady-state simulation output tested normal (Shapiro-Wilk's < .90). To determine the sample size, that is, the number of replications, the relative half confidence interval[41] is used, as discussed in Huq.[39] Based on an allowable 15% variation in the relative half confidence interval, and a desired 95% confidence, 20 replications of each simulation are performed.

Best Dispatching Rule

From *Figures 1* and *2*, it is obvious that MINSLK outperforms all other dispatching rules both in terms of inventory and due date performance. The dispatching rules were tested with two variations of batch size and two variations of allowance-setting procedures, namely PPW and TWK. The variations of the batch size used are 70 and 50, with 70 being the weighted EOQ for the items processed.

The value of the system inventory when MINSLK is used is only about 50% compared to the next-best rule. From these results, it is clear that static dispatching rules—SPT and EDD—are not pragmatic in this particular shop environment. This is consistent with the results found by Kanet and Hayya[42] and Gee and Smith[43] that operation-based rules are superior to job-based rules. The results also support the reported results obtained by Christy and Kanet[44] and Berkley[45] that SPT, which was found to be a superior rule under different conditions, is the worst rule among those studied in these experiments. The increased variability of the exponential distribution is one reason why SPT performs worst; with normal processing times, SPT is actually better than FCFS.[45] Also, SPT yields very poor results in job shops with forbidden early shipment assumptions.[44] The mix of jobs processed by the study shop is not uniform; there are jobs in the job mix with disproportionately high processing times and inventory values. The results establish that, in such a case, some kind of dynamic rule must be used. The inventory results are statistically verified using the Kruskal-Wallis test,[46] in which the test statistics came out significantly different [shop control combinations with MINSLK had the lowest rank sum (R_i)]. The Kruskal-Wallis test is used because the simulation output with dispatching rules SPT and EDD did not test normal. This confirms the earlier findings by Baker[47] that when job processing times vary considerably a

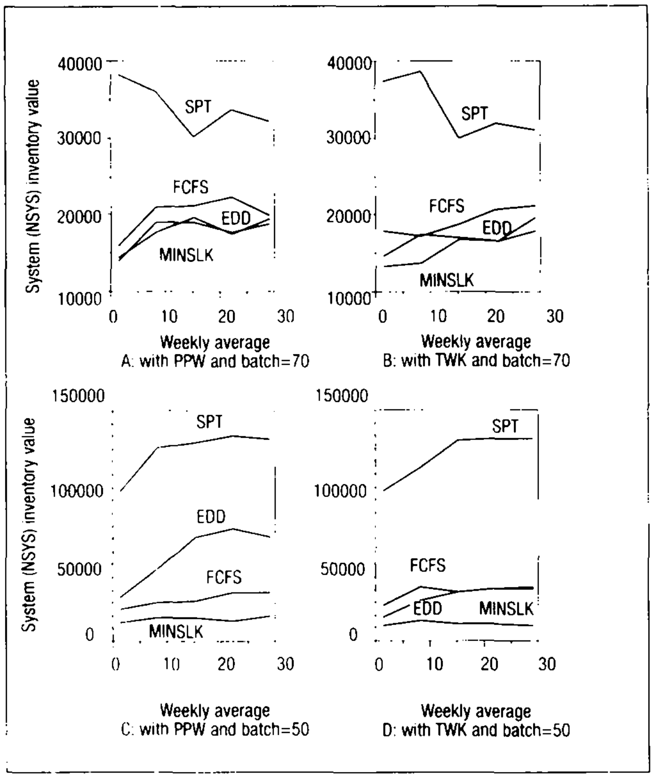

Figure 1
Comparison of Dispatching Rules

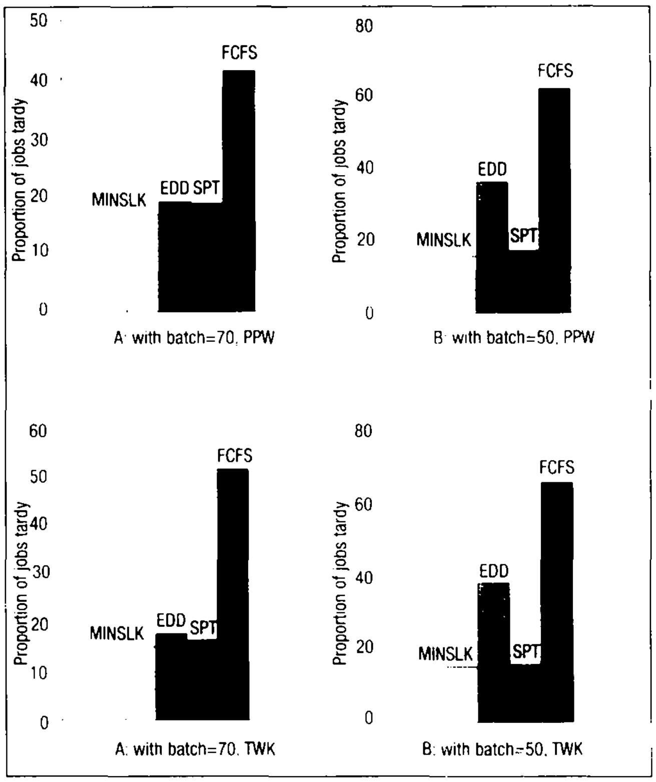

Figure 2
Comparison of Due Date Performance of Dispatching Rules

dynamic dispatching rule performs better. In all subsequent experiments, MINSLK is used as the dispatching rule.

Which Allowance-Setting Rule—TWK or PPW?

From *Figure 1*, it is clear that TWK is better than PPW in inventory performance. As shown in *Figure 2*, the due date performance of both the procedures is almost similar, with TWK performing somewhat better. Compared to TWK, PPW maintains an average of \$3027 more inventory in the system. Moreover, the standard deviation of system inventory when PPW is used is much higher. To test the hypothesis that there is a significant difference between the two rules, a confidence interval on the difference in population means of system inventory is constructed as follows. The confidence interval (CI) is constructed from the differences in sample means. Depending on the position of this confidence interval relative to zero, there can be three possible conclusions. Given that $\overline{Y}_1$ is the mean system inventory with the PPW rule and $\overline{Y}_2$ is the mean system inventory with the TWK rule, the hypothesis under test (H_0) is no significant difference between $\overline{Y}_1$ and $\overline{Y}_2$. The possible conclusions are as follows:

1. The CI for $\overline{Y}_1 - \overline{Y}_2$ is entirely to the right of zero: $\overline{Y}_2$(TWK) is superior to $\overline{Y}_1$(PPW).
2. The CI for $\overline{Y}_1 - \overline{Y}_2$ contains zero: there is no significant difference between TWK and PPW.
3. The CI for $\overline{Y}_1 - \overline{Y}_2$ is entirely to the left of zero: $\overline{Y}_1$(PPW) is superior to $\overline{Y}_2$(TWK).

Since the same set of jobs is used to test TWK and PPW, the samples are correlated, which results in a tighter confidence interval for the difference in system inventory and thus a more-sensitive hypothesis test. Since there is a large difference between the sample standard deviations, they are assumed to have come from populations with unequal variances ($\sigma_1^2 \neq \sigma_2^2$). The calculations for constructing the confidence interval are as follows:

The difference between the sample means = $\overline{Y}_1 - \overline{Y}_2 = 3027$

Std. Dev. $(\overline{Y}_1 - \overline{Y}_2)$ =

$$\sqrt{\frac{s_1^2 + s_2^2}{n} - 2r_{12}s_1s_2/n} = 1334.36 \qquad (1)$$

The degrees of freedom for the **t** distribution, as given by Natrella,[48] are approximately

$$\upsilon = \frac{\left(\left(s_1^{\,2} + s_2^{\,2}\right)/n\right)^2}{\left(\left[s_1^{\,2}/n\right]^2 + \left[s_2^{\,2}/n\right]^2\right)/(n+1)} - 2 \tag{2}$$

$= 38.54$

$t_{38,.975} = 2.025$

Therefore, the 95% confidence interval for the difference between the means of system inventory $\overline{Y}_1$(PPW) and $\overline{Y}_2$(TWK) is

$(\overline{Y}_1 - \overline{Y}_2) \pm t_{38,.975}$ Std. Dev. $(\overline{Y}_1 - \overline{Y}_2)$

$= 324.92$ to 5729.00

Since the 95% confidence interval does not include zero, the null hypothesis H_0 of no difference between the system inventory means must be rejected. Indeed, the entire confidence interval is to the right of zero, which suggests that the policy with allowance-setting rule PPW yields a significantly larger mean system inventory than the policy that uses the TWK rule. Therefore, allowance-setting rule TWK is superior to PPW. The result also supports the conclusions drawn by Baker,[47] Kanet and Christy,[49] and Christy and Kanet[44] that TWK dominates PPW both in terms of tardiness and inventory performance. Raghu and Rajendran[50] found that TWK is superior to CON.

Selection of the Best Cycle Time

In this section, the appropriate cycle time, that is, the frequency of shop loading, is determined. An appropriate cycle time prevents work-in-process inventory buildup and assures smooth flow in the shop. If the shop is loaded more often than the slower workstations can handle, work-in-process inventory will rise. Therefore, the appropriate cycle time is determined based on the batch processing times at the slower workstations. The batch size and the allowance-setting procedure, that is, weighted EOQ = 70 and TWK, respectively, were selected earlier, and these are used in this experiment. From some test runs, it is observed that if the cycle time is less than 30 minutes (such as 20-25 min.) then the work-in-process inventory increases excessively, and if it is more than 60 minutes (65-70 min.), then backlog increases excessively. The four cycle times tested range between 30 and 60 minutes; these are based on average batch processing time at the slower workstations. *Figure 3* summarizes the results of these screening experiments. Observe that the inventory performance of the tested cycle times appears to be similar (*Figure 3*) and is true for both work-in-process and total system inventory. The due date performance for the tested cycle times also had similar results, with 30 minutes being slightly better in terms of proportion of tardy jobs (*Figure 4*).

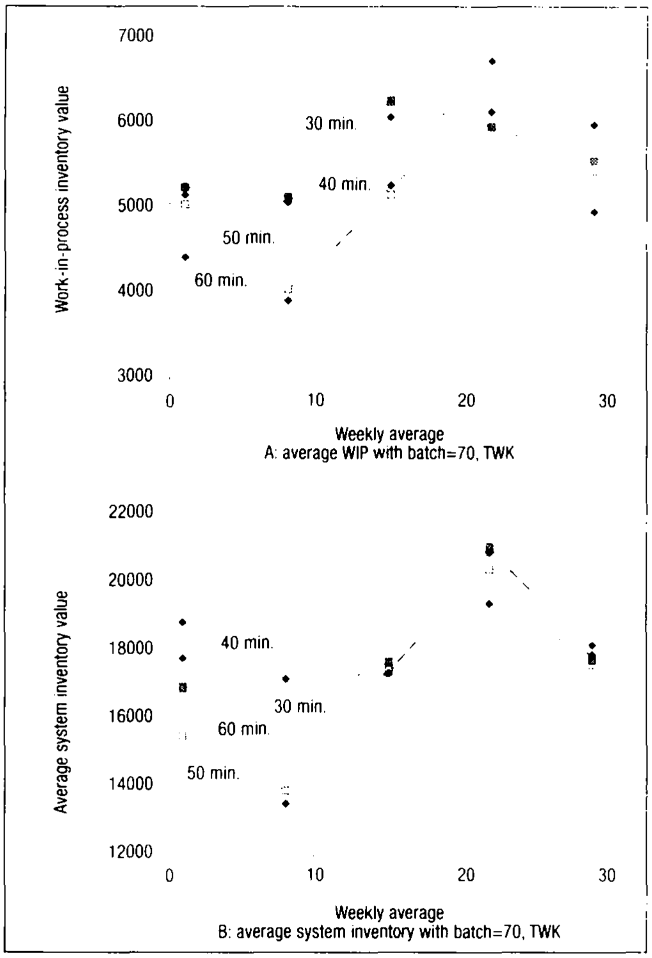

Figure 3
Inventory Performance of Cycle Times

Table 3 presents the statistical evidence of no difference in inventory performance among the tested cycle times. The analysis consists of constructing confidence intervals for the difference between the average inventory values and is similar to the procedure used for determining the best allowance-setting rule. Because 30 minutes came out slightly better in due date performance, its inventory performance is compared with the other cycle times. The comparison is carried out for both work-in-process and system inventories. It has been mentioned before that

Table 3
Confidence Interval for Differences in Weekly Average Inventory Values for Selected Cycle Times

Inventory category: Work-in-process
[MINSLK, batch size = 70; TWK (K_1 = 5)]
Assumption: Unequal population variances

Compared Cycle Times	Deg. of Freedom	$t_{.025,\,df}$	Confidence Interval Lower limit	Confidence Interval Upper limit
30 and 40 min.	7.70	2.306	-1142.9	1622.9
30 and 50 min.	9.88	2.228	-840.5	2266.9
30 and 60 min	8.88	2.262	-360.2	2519.9
Inventory category: System inventory				
30 and 40 min.	9.61	2.228	-2787.6	1799.6
30 and 50 min.	9.04	2.262	-1974.9	4047.7
30 and 60 min.	9.54	2.228	-1981.5	3587.5

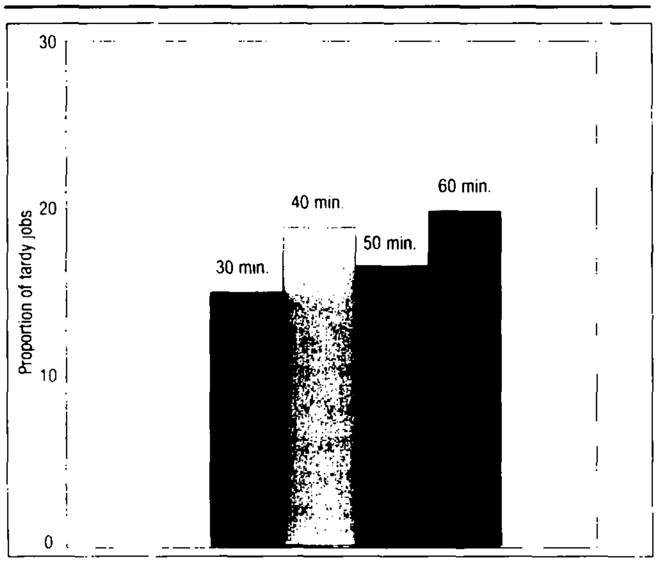

Figure 4
Due Date Performance of Tested Cycle Times

the simulation output of this model follows the normal distribution because the output of the model in fact represents the sampling distribution of $\bar{X}$. The degrees of freedom are calculated using Eq. (2). Observe that all these confidence intervals contain zero; therefore, the mean work-in-process and system inventory values for these cycle times are not significantly different. Consequently, based on due date performance, 30 minutes is chosen to be the best cycle time. These selected control factors are used in the main experiments.

Analysis and Implications of Selected Shop Control Factors

In a manufacturing system, if there is insufficient capacity then the system will not be able to decrease backlogs or improve delivery performance. However, even with less than capacity utilization of a system, some bottleneck areas, caused by fluctuations in peak load and disparateness of job mix, may exist. This is the type of environment where good shop control procedures make a maximum contribution to flow objectives. The following results apply to a job shop with bottleneck workstations processing a disparate mix of jobs.

The statistical analysis revealed that the dynamic dispatching rule MINSLK outperforms all other rules both in terms of inventory and due date performance. The results were the same under both allowance-setting rules TWK and PPW. From the results, it is clear that a dynamic dispatching rule is more appropriate in a shop where the job mix is not uniformly distributed. This is consistent with the findings by Baker.[47] This result is critical vis-a-vis the dispatching rules used by practitioners. The dispatching rule MINSLK should be used in all job shops with a disparate job mix.

Based on inventory and due date performance, it was shown that TWK is superior to PPW, for appropriate ranges of K_1 and K_2. The selected parameter values (K_1 and K_2) for these rules closely approximated the weighted number of operations per job. On average, the TWK rule maintained less inventory than did PPW. The due date performance of TWK was slightly better than PPW. These results are similar to the ones reported by Conway, Maxwell, and Miller.[51] For the practitioner, it implies that emphasis should be given to work measurement. To use the allowance-setting rule TWK effectively, standard time estimates for each task must be available. The standard time estimates must be developed through comprehensive time studies. Many MRP users do not emphasize work measurement, and as a result, use of the PPW rule has become standard among most MRP patrons. This concept is evidenced in the software implementations of CAPOSS (Capacity Planning and Operations Sequencing System) and COPICS (Communication Oriented Production Information and Control System) used by many large manufacturers. The discipline required to implement JIT helps set job allowances by the TWK method. Manufacturers who want to improve their system performance should use the TWK rule and create the condition for its application.

Cycle time depends on the batch size and the batch processing times at the workstations in its route. Determination of the appropriate cycle time makes the order review and release (ORR) process simple. In determining the best cycle time, the processing times at the slow workstations were considered. It was found that 30 minutes is the maximum processing time of a shop order at the slowest workstation. This demonstrates that the best cycle time can be determined by considering the batch processing times at the slow workstations. To the practitioner, this is very important because without a consistent shop loading procedure there will be no balance in the shop.

Batch size is both an environmental and a control factor. It can be varied (controlled) to the extent of setup-time reductions. For the study shop, the best batch size was the minimum of weighted EOQ and D_i, where D_i is the Master Production Schedule (MPS) order size for the ith item.

Based on the above findings, the following guidelines are presented for selecting the appropriate conventional shop control parameters:

1. If bottlenecks exist, TWK is superior to PPW, for all ranges of K_1 and K_2.
2. The appropriate combination of shop control parameters is:
   (a) Cycle time = $\max_{ij} \{ \bar{Q} * p_{ij} \}$

   where $\bar{Q}$ is the average number of items in an order and p_{ij} is the processing time at the slowest workstation

   (b) K_1 = weighted average number of operations per job

   (c) Batch size = $\min_{i} [D_i, (\text{Weighted EOQ})]$

   (d) Dispatching rule: MINSLK

These conventional shop control factor combinations are used in the main experiments, and the results are compared with kanban performance.

Comparison of Shop Control with Kanban

In this section, the main experiment results are compared with the kanban (JIT) inventory levels for evidence in support of the hypothesis. For the conventional shop control system, the selected control factors from the screening experiments are used in the main experiments. Only the parameter (K_1) for the allowance-setting rule TWK is varied to determine the most desirable due date tightness levels. Based on the variations in the simulation output, the number of replications necessary was determined to be 30. The kanban simulation inventory is treated as the control. The experimental results are compared with the control using the Dunnet's test.[52]

Figure 5 gives the comparative due date performance of kanban and the conventional shop control combinations, and *Figures 6a* and *6b* represent the comparative work-in-process and system inventory values, respectively. Specifically, the performance of the work-in-process inventory value, and the proportion of tardy jobs are of interest. From the simulation results, it was clear that the value of inventory before any processing starts is less than 1% of the total system inventory for both shop control systems. Therefore, no separate tests are carried out to compare this category of inventory. On the other hand, the value of the finished goods inventory is a function of due date tightness. The kanban due date performance for the shop is 70-80% poorer as compared to the conventional shop control procedures, which resulted in lower finished goods inventory for kanban and thus lower system inventory. Therefore, for comparison purposes, only work-in-process inventory value and the proportion of jobs tardy are used.

From *Figure 5*, it is obvious that as the K_1 value is increased the tardiness performance improves; however, this comes at the cost of higher completed inventory (*Figure 6b*). From the results, it appears

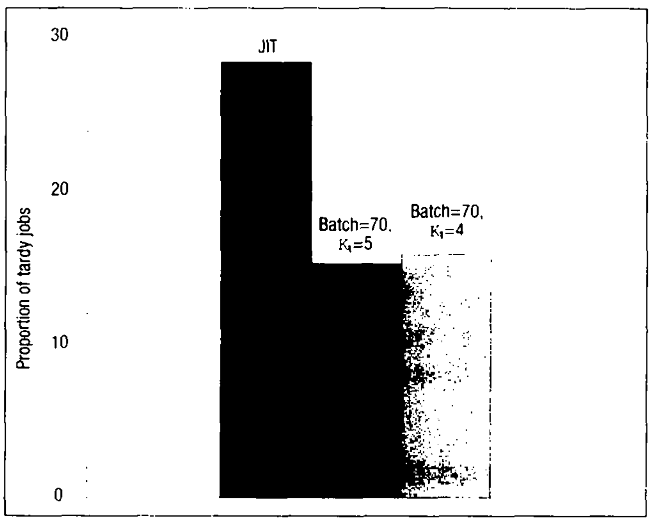

Figure 5
Comparison of Due Date Performance of JIT with Conventional Shop Control

that the dual objective of finding the best K_1 both in terms of tardiness performance and inventory performance is mutually unattainable. However, the due date performance of $K_1 = 5$ and $K_1 = 4$ are very close, whereas the corresponding increase in inventory for having a looser due date is quite high (*Figures 6a* and *6b*). Both of these K_1 combinations are compared with the kanban.

From *Figures 5* and *6a* and *6b*, it is clear that conventional shop control outperforms kanban in this study shop. The inventory results are statistically verified by performing analysis of variance and multiple comparison tests. To verify whether the marginal distributions follow the normal distribution, the Shapiro-Wilk's test (sample size = 30) is performed. The test statistic values demonstrated that none of the marginal distributions of the work-in-process inventory values follow the normal distribution (Shapiro-Wilk's > .90). It has been theoretically shown that data that are counts can often be made normal by taking their square roots.[53] Therefore, a square root transformation is applied to the work-in-process inventory value data; the transformed data tested normal (Shapiro-Wilk's < .90). The statistical tests are carried out using the transformed data.

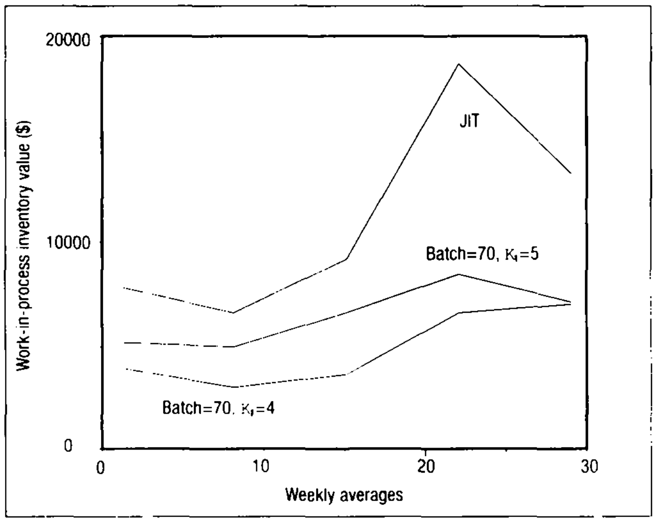

Figure 6a
Comparison of WIP for JIT with Shop Control

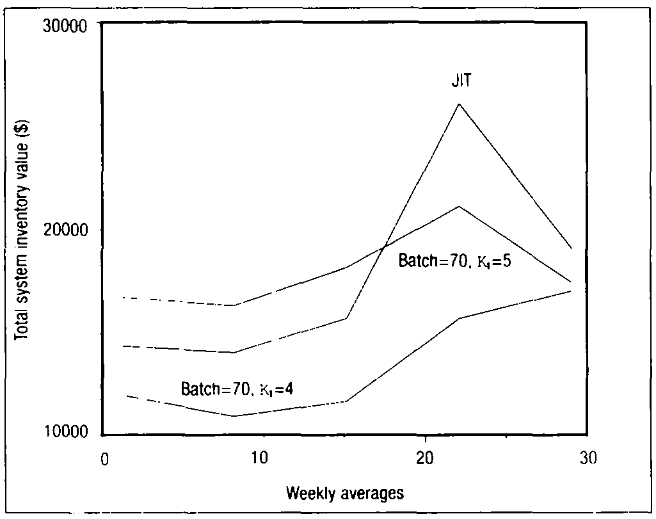

Figure 6b
Comparison of System Inventory for JIT with Conventional Shop Control

Multiple Comparison Tests

Table 4 gives the analysis of variance results for the average daily work-in-process inventory values for kanban and selected conventional shop control procedures. In particular, the selected shop control factors are TWK(K_1 = 4) and TWK(K_1 = 5), with MINSLK, batch = 70 (or D_i if D_i < 70), and cycle time = 30 minutes common to both procedures. The analysis is carried out using the transformed data. The F ratio indicates that the methods are significantly different; that is, when these control factor combinations are used, the resultant WIP inventory will be significantly different. Also, in *Table 4* the results of the Duncan's multiple range test are presented. Duncan's test put kanban WIP inventory values in a separate category, indicating that they are significantly different than the WIP inventory values generated by conventional shop control methods. As the mean WIP inventory value for kanban is highest, it is obvious that the conventional shop control procedures are superior to kanban. This conclusion is

Table 4
Analysis of Variance Results and Duncan's Multiple Range Test for Comparing JIT with Conventional Shop Control

Dependent Variable: Work-in-Process Inventory Value

Analysis of Variance

Source	Deg. of Freedom	Mean Square	F Value	Pr > F
Model	2	9273.034776	24.04	0.0001
Error	87	385.704525		

Duncan's Multiple Range Test

Number of means:	2	3
Critical range:	10.09	10.61

JIT	Batch = 70, K_1 = 4	Batch = 70, K_1 = 5
101.70	67.51	77.52

The underscore represents that these two shop control approaches are not significantly different.

supported by Dunnett's test carried out by comparing individual shop control treatment combinations with kanban.

Overall it appears that the conventional shop control procedures outperform the kanban system in this particular shop. The reason for this is attributable to the fact that during peak load periods two workstations become bottlenecks because of disparateness in the job mix. This is where better shop control procedures contributed maximally to the performance measures.

Conclusions and Comments

The research questions addressed in this study are as follows:

1. Given a good manufacturing environment, do all shop control procedures perform equally well?
2. If the shop control procedures do not perform equally well, are there combinations of procedures that approach JIT inventory and due date performance? If so, how well do they perform?

The summary of the findings will focus on these two research questions. This research has shown that all shop control procedures do not perform equally well in good manufacturing environments. Notwithstanding the good environment assumption, some combinations of the shop control variables perform better than others. Companies should try to find those procedures that help achieve the operations objectives.

MRP is an effective mechanism for global planning and scheduling function. The shop floor control system is necessary to interface the MRP system with the actual workstations. The shop floor control system becomes even more important in job shops where disparate job processing requirements render the throughput times less certain. For the success of the MRP system, it must receive feedbacks not only from the control system but also from the shop floor execution system. The tested execution system is simple, understandable, and easily visible; it is capable of improving shop floor performance.

From a human resource management point of view, kanban is easy to manage and implement. Workers know that they are responsible for making the kanban system work; therefore, when the system works they readily see improved performance, which provides a positive feedback for increased involvement. On the other hand, in an MRP system, workers are more detached from the decision-making process, and they fail to see how their work is contributing to system performance unless there is an effective, understandable, and easily visible execution system in place. An effective execution system will be able to provide the appropriate feedback to turn passive workers into active participants.

In a job shop, the variability in processing times and the inability to allocate tasks to various production stages equally creates imbalance in the shop. The kanban system is not designed to deal with such imbalances. As a result, the blocking mechanism creates huge work-in-process inventory in some production stages, causing longer throughput times and missed due dates for certain jobs. Sarker and Fitzsimmons[26] found that the efficiency of a kanban system decreases drastically at a nonlinear rate with a high coefficient of variation (CV) of processing time. The job processing time in the benchmark job shop follows the exponential distribution that introduces additional variation because of the increased variability of the exponential distribution.

With bottlenecks and the nonuniform distribution of the job mix, conventional shop control combinations outperformed kanban in terms of WIP inventory and proportion of tardy jobs. All selected conventional shop control combinations had consistently lower WIP inventory. The results indicate a significant difference between the control procedures. Companies that want to implement JIT should first evaluate whether they have the environment to do so. Based on the foregoing analysis, it is recommended that companies should not attempt to implement JIT in a job shop. Instead, they should look into the option of implementing better shop control procedures. Implementation of JIT in a job shop by overhauling the entire system will not be a cost-effective option. In addition, JIT in a job shop will perform poorly compared to a rigorous conventional shop control plan. Of course, the results and conclusions reported here are true only for the tested shop and should not necessarily be generalized.

Little research has been done combining the major aspects of shop control in job shop control systems. This study has narrowed that gap by proposing and testing several combinations of shop control methods for improving the performance of a job shop. Some insight has been gained regarding implementation of JIT in a job shop and what can be done to improve the performance of a job shop. Further research is needed to test other conventional shop control combinations because the tested rules are not exhaustive of the approaches that might be useful. A relatively small set of dispatching rules was tested in this study, and several others (for example, a truncated SPT and critical ratio) would be good candidates for inclusion in further studies. The job due dates were internally set. It would be interesting to find how the shop would perform if the due dates were externally set. It would also be important to understand how detailed shop information might affect the cycle time of releasing jobs to the shop. Finally, and perhaps more interesting, would be the investigation of how the selected shop control procedures would perform under a varying environmental setting. It would be interesting to determine the conditions under which a combination of conventional shop control variables that was found to perform optimally in a good environment becomes nonoptimal.

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