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Abstract

Low inventory, or just-in-time (JIT) manufacturing systems, enjoy increasing application worldwide, yet the behavioral effects of such systems remain largely unexplored. Operations Research (OR) models of low inventory systems typically make a simplifying assumption that individual worker processing times are independent random variables. This leads to predictions that low-inventory systems will exhibit production interruptions. Yet empirical results suggest that low-inventory systems do not exhibit the predicted productivity losses. This paper develops a model integrating feedback, goal-setting, group cohesiveness, task norms, and peer pressure to predict how individual behavior may adjust to alleviate production interruptions in low-inventory systems. In doing so we integrate previous research on the development of task norms. Findings suggest that low-inventory systems induce individual and group responses that cause behavioral changes that mitigate production interruptions.

Keywords

low inventory, inventory, just-in-time, systems, production, JIT, manufacturing, model

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Working Paper 97 - 17



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This paper has not undergone formal review or approval of the faculty of the ILR School. It is intended to make results of Center research available to others interested in preliminary form to encourage discussion and suggestions.

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Abstract

Low inventory, or just-in-time (JIT) manufacturing systems, enjoy increasing application worldwide, yet the behavioral effects of such systems remain largely unexplored. Operations Research (OR) models of low inventory systems typically make a simplifying assumption that individual worker processing times are independent random variables. This leads to predictions that low-inventory systems will exhibit production interruptions. Yet empirical results suggest that low-inventory systems do not exhibit the predicted productivity losses. This paper develops a model integrating feedback, goal-setting, group cohesiveness, task norms, and peer pressure to predict how individual behavior may adjust to alleviate production interruptions in low-inventory systems. In doing so we integrate previous research on the development of task norms. Findings suggest that low-inventory systems induce individual and group responses that cause behavioral changes that mitigate production interruptions.

The Effects of JIT on the Development of Productivity Norms

One technique commonly used to improve manufacturing competitiveness is the reduction of inventory within the manufacturing process, often referred to as just-in-time manufacturing or JIT. Current Operations Research (OR) models suggest that reductions in inventory lower inventory costs, but also increase interference within the manufacturing line. This interference causes idle time which reduces line efficiency and productivity. Yet many firms have experienced increases in profit when changing to low-inventory systems. Proponents of JIT argue that this apparent contradiction is explained by savings elsewhere in the system (e.g., lower holding or obsolescence costs) and improvements in production quality and response time.

We propose that this is only part of the story. There are behavioral benefits to low-inventory systems which, when ignored, would cause OR models to consistently overstate the amount of interference and idle time in certain circumstances. Fully understanding these systems is important to manufacturers who are constantly trying to balance the benefits of lower inventory with the costs of increased idle time. Moreover, such understanding requires research that integrates behavioral theory from applied psychology with OR models.

There appears to be a gap between the literature in the fields of Operations Research and Industrial/Organizational Psychology (I/O). Operations Research literature generally assumes that changes made in the amount of inventory in a manufacturing line do not affect the behavior of the workers on that line. Almost all of the literature uses the assumption of independent machine processing times. For example, the speed of a co-worker and the amount of inventory in the system do not affect an individual's work speed. Socio-Technical-Systems Theory however, suggests that any large change in the technology used, such as the inventory policy, will lead to changes in the social, political or cultural systems (see, for example, Tichy, 1983). Goal theory suggests that increased feedback, such as that available in low-inventory systems, can lead to increased goal achievement (Latham & Locke, 1991). The increased interdependence among workers, which accompanies the reduction of inventory, can also have consequences for the dynamics of groups and the motivation of group members (Guzzo & Shea, 1992). We intend to address this gap, by integrating behavioral theory with operations research models to improve our understanding of OR and to extend behavioral theory.

The goals of this paper are twofold. First, we use I/O theory to contrast the effects different inventory policies have on the behavior of manufacturing workers. Second, we experimentally compare different inventory policies to test propositions from the theory. We start by examining the fundamental differences between low- and high-inventory systems and use

behavioral theory to explain the possible effects of these differences on worker motivation and group dynamics. We then describe an experiment to gather processing time and survey data to test our predictions. The results of our experiment are used to explore the interrelationships among work interdependence, feedback, group cohesion, group norms and productivity to further refine both OR and behavioral theory.

Definition of Terms

This paper is concerned with the dynamics of serial production lines, so a common vocabulary is required. These systems usually can be thought of as a series of machines or workstations with one worker at each machine. Work flows "downstream" from the first machine to the last, being processed once on each machine in the series. Management tries to "balance" the line by making the processing times on every machine equal, on average. If the line is not balanced then there is a "bottleneck" at the machine having the longest average processing time. In the long run, no serial line can produce any faster than its slowest machine, the bottleneck.

Between every two machines, and at the beginning and end of the line, are locations to store inventory until it is needed for the next machine. These inventory storage locations are called "buffers" because both the inventory and the unoccupied storage space provide a buffer that prevents randomness and longer processing times in one part of the line from immediately affecting other parts. If work flows from left to right, the buffer to the left of a machine (upstream) would be that machine's input buffer while the one to the right (downstream) would be its output buffer and the input buffer of the next machine in the series. A machine will become idle when a task is complete and its input buffer is empty; it is "starved." Similarly, it will also become idle when the output buffer is full, because there is no place to put the finished items; it is "blocked." Blocking and starving are considered equivalent problems on manufacturing lines as both lead to idle time and loss of labor and machine efficiency.

All serial lines are constrained, in the long run, by the slowest process. Any machine working faster than that will eventually be idle. Those downstream of the bottleneck will be starved, while those upstream will continue to produce unfinished inventory until they are eventually blocked. Idle time due to imbalance in average processing time is referred to as "balance delay." The difference between high- and low-inventory situations is the time period over which this occurs. With larger buffers the faster machines can work longer before becoming idle. Management has greater opportunity to correct or work around the problem. They might, for instance, add overtime to the bottleneck machine or temporarily reassign people

from the faster machines to other work. When the bottleneck machine is working alone it can rebuild the downstream inventory and empty the upstream buffers. In low-inventory systems management does not have this luxury because reaction times are much shorter. Since there is little inventory in the system, if other machines were to be shut down temporarily then the bottleneck machine would quickly become blocked or starved itself.

Another source of idle time can be referred to as "variance delay." Balance delay is caused by differences in the average processing times among machines. Variance delay is caused by the variance of processing times causing a temporary bottleneck. For instance, if one machine had a series of shorter than average processing times and exhausted the available inventory in its input buffer, it would be starved and become idle. This is less likely to happen with larger buffers. In fact, while balance delay cannot be prevented by large buffers, only postponed, variance delay can be prevented by buffers large enough to allow processing times to average out. Variance delay can also be reduced by bottlenecks. Since the other machines are faster, on the average, their variance will merely redistribute their balance delay without increasing the total amount of idle time.

Consider a simplistic example with two machines and no buffers. The processing time on the first machine is 1 minute. The processing time on the second is either 8 or 10 minutes, for an average of 9. This line will produce one unit every 9 minutes, on the average. The first machine will have balance delay of 8 minutes per unit, average. Increasing the processing time (decreasing the speed) of the first machine, until it is 8 minutes per item, will have no effect on the productivity of the line. It will still be dominated by the bottleneck machine and average 1 unit every 9 minutes. Balance delay will be 0 half the time and 2 minutes otherwise, for an average 1 minute per unit. Therefore while average processing time has increased it has been offset by a corresponding decrease in balance delay and productivity remains unchanged. If the first machine is slowed to 9 minutes per unit the line will be balanced and balance delay eliminated. However, if no inventory is kept, productivity will fall to one unit every 9.5 minutes due to variance delay.

Both balance and variance delay are caused by variance, either inter or intra-machine variance. Inter-machine variance is difference in the mean processing times which causes balance delay. Intra-machine variance is variance in processing time of a machine which can cause variance delay. Since the bottleneck machine determines the output of the line, any changes to the line which do not increase the productivity of the bottleneck machine will not increase productivity of the line. For instance, increasing the processing speed on the fastest machine will increase balance delay on that machine equal to the increase in speed without

changing the number of pieces coming out the end of the line. Increasing the speed of the fastest machine can only increase productivity to the extent that it decreases interference, (variance delay) of the bottleneck machine. This effect is even more pronounced in low-inventory lines since variance delay occurs faster and idle time of workers at the faster machines cannot be used for any other useful purpose. Likewise, decreasing the speed of the fastest machine will have no effect on productivity until it begins to interfere with the bottleneck. On the other hand, increasing the speed of the slowest machine will immediately increase the productivity of the line up to the point where that machine ceases to be the bottleneck. Thus, if low-inventory causes slower workers to speed up and faster workers to slow down, as we subsequently predict, it is likely to result in an increase in productivity, even if the average processing time across workers does not change.

Just-In-Time (JIT) means many things to many people. However, at its most fundamental level, JIT refers to the reduction of inventory. In this paper we are concerned with the aspects of JIT related to the reduction of inventory within the processing line, the so-called work-in-process inventory (WIP). While recognizing that JIT can involve more than just low inventory (see Schonberger, 1982 for example) we use the terms JIT and "low-inventory system" interchangeably in this paper.

Literature Review and Hypothesis Development

Operations Research Literature

Operations Research models have been used to investigate the dynamics of serial production lines for over 40 years. The general conclusion is that low-inventory production lines, with machines in series and random processing times, will experience more variance delay than similar lines with higher inventory (Dallery & Gershwin, 1992). Compare two similar lines which differ only in the limits imposed on inventory. On line "A" all buffers are smaller than or equal to those for the corresponding buffer in line "B." Under the assumptions of the model, line A will have a production rate (e.g., units per hour) less than or equal to that of line B. That is, with smaller buffers there will be more blocking and starving, and hence a lower production rates. We will call this the "Theory of Smaller Buffers."

This theory, however, was derived using the assumption that processing times are independent. For example, the amount of time it takes a worker to process one item on a machine, excluding idle time between processes, is assumed to be independent of the amount of inventory in the system, and unaffected by the speed of neighboring machines. With this assumption, and others concerning the processing time distribution, it has been proven that the

rate of production of a manufacturing line is a non-decreasing function of the buffer capacity (for example see Shanthikumar & Yao, 1989). If buffer capacity is considered a resource then artificial limits on this resource should hurt, or at least not improve, the production rate of the line. While most modelers would quickly agree that these assumptions may not hold in some cases, no one has demonstrated a systemic error related to their use.

Despite this link between restraints on inventory and lower productivity, there are many examples of productivity increasing when inventory has been reduced. One apparel manufacturer produced exactly the same product at two different plants. The high-inventory plant had direct labor cost of \$6.50 per item. The labor cost at the plant using JIT was \$4.92 per item, a saving of 24% (Berg, Appelbaum, Bailey, & Kalleberg, 1996). A Montreal manufacturer of sports equipment switched production in its plant to Serial Worksharing, a JIT system, and increased productivity by up to 200% (Zavadlav, 1993). Fifty-two percent of HRM managers surveyed reported that JIT had increased labor productivity in their plant while only 13% reported a decrease (Golhar & Deshpande, 1993). An outside consultant predicted productivity increases up to 35% with the introduction of modular manufacturing, a JIT system (Gilbert, 1990). How do we explain these examples of increased productivity when OR models predict a decline?

The traditional explanation for the apparent contradiction is the reduction of labor "waste." Lower inventory allows quality problems to be noticed and corrected quickly, leading to less rework and reduced loss with JIT systems. It also reduces labor wasted in the production of damaged or obsolete inventory and in the physical handling of inventory (Bartholdi, Eisenstein, Jacobs-Blecha, & Ratliff, 1995). The argument states that while workers may have more idle time, when working they are less often producing scrap or poor quality items. This is a compelling explanation for increased productivity in JIT, but it maintains the assumption that worker speed is unchanged when new work systems are introduced, an assumption that contradicts much behavioral theory.

Relaxing this assumption has significant practical consequences. Schultz, Juran, Boudreau, McClain and Thomas (1997) used the processing times and other results from this study to show that an OR model which assumes processing times are the same across inventory conditions would have predicted 19% less output than was actually realized. If processing time distributions are the same in high- and low-inventory then workers in low-inventory would have been idle, on the average, 19% of the time, with most of the idle time due to balance delay. In fact they were idle only 9% of the time and, because average processing times were faster, the output of the two lines differed by only 0.7%. As we shall

show, and as Schultz, et al. (1997) noted, most of the increase in speed was seen in the slowest worker on each processing line where the benefit to productivity is highest. Left unanswered was why people act differently in low- versus high-inventory conditions.

This paper uses behavioral theory to predict how the underlying differences between high and low-inventory may cause the differences in worker behavior described in Schultz, et al. (1997). We will use these results not only to increase our understanding of low-inventory systems, but also to improve our theories of motivation in group settings.

Behavioral Theory and JIT

Very few researchers have used behavioral theory to explain the increased productivity associated with low inventory. Most of the behavioral research on JIT has focused either on the implementation of JIT systems (see, for example, Arogyaswamy & Simmons, 1991; Sevier, 1992) or recommendations for HRM practices (see, for example, Huber & Brown, 1991; Snell & Dean, 1992). These studies made little attempt to explain the effects of JIT on work behavior and productivity.

Those articles which have considered the motivational effects of JIT usually focus on management uses of JIT to coerce workers into higher levels of effort. Parker and Slaughter (1988) attributed the productivity increases to speedup and tighter management control. Sewell and Wilkinson (1992) likened JIT factories to optimally designed prisons. They argued that JIT regimes "both create and demand systems of surveillance which improve on those of the traditional bureaucracy in instilling discipline," thereby "consolidating central control and making it more efficient." Delbridge, Turnbull and Wilkinson (1992) thought that "JIT intensifies work as a result of increased surveillance and monitoring of workers' activities." Some mention was made in these papers of peer pressure, but no attempt was made to measure the effects, or to relate them to current theory. These papers made valuable insights and observations, but they were anecdotal and descriptive. In theoretical terms their argument was that JIT increases feedback which management uses coercively to decrease shirking, but they did not test this hypothesis.

Perceptions of the effects of low inventory were analyzed by Brown and Mitchell (1991). They surveyed direct labor employees at a manufacturing firm switching to a JIT system over a period of a year and a half. They were particularly interested in performance obstacles in JIT. They considered the concept of the interdependence of work in low-inventory settings and the possibility of slower workers restricting output. They found that JIT was associated with a significant increase in perceived problems in the areas of "Schedules and Assignments" and

"Reliance on Coworkers." Schedules and Assignments was a four-item measure including "There is too much pressure to do the job quickly." Reliance on coworkers was a five-item measure including "My coworkers work at a slow output rate" and "There is an inadequate match between coworkers' work speeds." The paper did not postulate any systematic change in worker behavior associated with low-inventory systems. It did demonstrate, however, the importance of worker interdependence and that workers in JIT perceive different sets of performance obstacles.

To our knowledge there is only one paper which experimentally examined differential behavior in a low-inventory setting. Doerr, Mitchell, Klastorin and Brown (1996) looked at the interaction of different types of goals and buffer sizes on productivity in a fish packing plant. They observed no significant difference in overall productivity between low- and high-inventory systems, despite higher levels of blocking and starving in the low-inventory systems. While spending more time idle, workers in JIT worked faster when work was available. Doerr et al. hypothesized that short breaks due to blocking and starving might allow increased effort during work periods. Unfortunately this was not the focus of their paper, and they were unable to test this hypothesis. Moreover they did not provide a theory-based framework to explain different behaviors in low-inventory systems. We now develop such a framework.

Differences Between Low- and High-Inventory Systems: Information and Interdependence

Low-inventory systems intrinsically provide more task-related information to workers than high-inventory systems. A change from two to three items in a buffer can be noticed with a glance while it takes more effort to notice a change from 2000 to 2001 items. Since JIT uses small inventories, usually placed on a marked grid or rack, it is easy to notice small changes in quantity. These changes provide immediate information on the worker's relative speed. If the inventory in the output buffer goes up, the worker is processing faster than the downstream worker. If it goes down (s)he is slower. Likewise inventory in the input buffer signals differences in speed with previous (upstream) workers. We have already discussed how this information can lead to greater management control. However, its use is not restricted to management alone. It is available to anyone who can see the buffer, most notably, the workers on the line.

The information available with low inventory has multiple implications. First, it is evaluative data -- the worker is processing items faster or slower than some standard. Second, it allows role comparisons -- the worker is processing faster or slower than a particular coworker. Third it has a direct interpersonal consequence -- a worker's processing speed may cause a co-worker to be idle (i.e., blocked or starved). Due to these multiple implications we

expect the information from JIT operations to have a greater impact than evaluative information alone.

Another fundamental difference between low- and high-inventory situations is the interdependence within work groups in JIT (Brown & Mitchell, 1991). With high inventory, people work essentially as individuals, independent of each other. The very reason for having inventory buffers between machines is to isolate the workstations. Due to strong interdependence, the situation is much different with low inventory. In any serial system the maximum work pace of the group is the work pace of the slowest individual, but with low inventory the time frame in which this is observed is much shorter, minutes or hours instead of days or weeks. Anyone working faster will be quickly blocked or starved. Also, with much less inventory, the work space becomes less cluttered and it is easier to see the entire work process. We propose to use behavioral theory to explore how these fundamental differences of information and interdependence can affect worker behavior in low-inventory manufacturing.

JIT Enhances Feedback and Goal Setting

The information available in low-inventory systems corresponds to the concept of feedback in goal theory. We adopt the definition of feedback that was first proposed by Wiener (1954), as performance-related information used to control a system. The effectiveness of goal setting increases with task related feedback (Erez, 1977) by allowing individuals to determine the gap between their performance and their goal. In general, the more dissatisfied they are with the gap the more effort they will exert to narrow it (Bandura & Cervone, 1983). Feedback which shows that performance is below the standard can increase the motivation to work harder. Feedback showing that performance is consistently above the level of one's peers can lead to the setting of lower goals (Bandura & Jourden's study as cited in Latham & Locke, 1991). Normally it is only the combination of both goals and feedback which leads to performance benefits (Erez, 1977). Feedback, not accompanied by goals, doesn't lead to improvements in performance unless it suggests self-setting improvement goals (Latham & Locke, 1991). Thus, if the feedback available in JIT is matched with, or suggestive of, task-related goals then JIT should affect productivity differently from high-inventory systems.

The information provided by the buffer contents in low-inventory systems has many of the qualities of good goal feedback. For the purposes of enhancing motivation through goal setting, the best feedback is specific, timely and frequent (Nadler, 1979). The feedback from JIT is specific as it relates exactly to the speed of the worker in reference to the speed of the rest of the line. It is timely, being immediately available upon the completion of any item. It is frequent

in that it provides feedback upon completion of every item, to each worker who can see the buffer. Finally, this information is necessary for the task, it contains social and role comparison information, and it is intrinsic to the work situation. All these qualities increase the impact of the feedback available in JIT, and, therefore, the behavioral differences between low- and high-inventory systems. From this comes the first research hypothesis:

H1: Subjects in a low-inventory work system will perceive more task feedback than those in a high-inventory system.

Feedback alone has little influence on performance, unless it is combined with goals. Goals work best when they are specific, difficult and encourage commitment (Latham & Locke, 1991). Goal commitment can increase when peers persuade, enforce norms, or serve as role models (Earley & Kanfer, 1985). Role models also help to influence goal behavior to the extent they increase co-workers' self efficacy, the belief that they are capable of achieving the goal (Bandura & Cervone, 1983). In experiments by Lichtman and Lane (1983) and Earley and Kanfer (1985) the performance of subjects was affected in the direction of the performance of a role model.

JIT feedback tells a worker when he or she is about to disrupt the flow of work or is about to be forced to stop work. Both may be undesirable outcomes which can lead to setting goals to avoid those situations. A worker who is the slowest in the group causes idle time, restricts the overall output of the group, and is demonstrated to be less capable than other group members. This person would feel incentives to speed up which, if they are a bottleneck, will increase the productivity of the line. A worker who is the fastest in the group spends the most amount of time stopped or about to be stopped. Their feedback is that they consistently outperform the goal which can lead to the setting of lower goals. They might gain the impression that they have worked harder than necessary and may be seen unfavorably by their coworkers. Therefore the incentive for the fast worker may be to slow down which will not affect productivity unless (s)he either becomes the bottleneck or causes variance delay of the bottleneck. JIT provides feedback to support and encourage goals of "don't cause idle time."

The opportunity for peer and role-based influence is also higher in low-inventory situations. Because of the availability of feedback with low inventory, role models are more easily observed in JIT situations. The slowest worker in a group notices others who are working faster, and may be influenced to work faster themselves. The fastest worker on each team will be exposed to peer models who are performing slower and might, therefore, be influenced to slow down. However, as discussed previously, speeding up the slowest person is likely to

increase the productivity of the line while slowing down the fastest person is less likely to have any overall effect.

The feedback available in JIT may also influence social loafing. "Social Loafing refers to the reduction of individual effort exerted when people work in groups compared to when they work alone" (Williams, Harkins and Latane, 1981, p. 303). It may be diminished by the increasing identifiability of individual output in the short term provided by the feedback available in JIT. Further, to the extent that social loafing is tied to worker's desire for equitable division of labor (Jackson and Harkins, 1985), we would expect slower workers to speed up and faster workers to slow down. As noted previously, this would most likely increase the output of the line. Thus,

H2: Slower workers will work faster under low-inventory than high-inventory systems.

H3: Faster workers will work slower under low-inventory than high-inventory systems.

JIT Increases Cohesiveness

Group cohesiveness is defined as the attraction of a group for its members (Back, 1951). It can be thought of as a measure of the commitment of group members to the group task (Goodman, Ravlin & Schminke, 1987). While there is no direct relationship between cohesiveness and productivity, cohesiveness can increase the ability of groups to enforce group norms, reducing the variance of performance to a narrower band around the group norm (Guzzo & Shea, 1992). Therefore the overall effect of cohesiveness on average work speed depends entirely upon the norms chosen by the group. Cohesiveness reflects the amount of effort members will allocate to the group, while norms identify the direction of that effort (Goodman, Ravlin & Schminke, 1987). If the group norm encourages a certain level of productivity then cohesion will help enforce group norms and decrease imbalance on the line (Seashore, 1954). Back (1951) divides group cohesiveness into three types: that based on group attraction, on prestige or on task.

Hackman (1992) argues that groups whose cohesiveness is based on tasks are more likely to develop task-related norms. We therefore expect the most productivity benefit from group cohesiveness when cohesiveness is high, when it is task based, and when it is matched with task norms.

Many factors can increase group cohesiveness. Zander (1979) suggested that these include the size of the group, the size of the work area, the attractiveness of other group members, the success of the group, and gender. The factor most affected by low inventory is task interdependence. Deutsch (1949) showed that cooperatively interdependent tasks build a

sense of unity. The extent to which the group task requires active participation from all members has also been cited as a source of cohesiveness (Cartwright & Zander, 1968; Couch & French, 1948). As we have noted, JIT increases interdependence and may increase participation due to the vivid cues provided by low-inventory buffers. We therefore expect that the interdependence of low inventory will lead to greater cohesiveness.

H4: Participants in low-inventory systems will report greater group cohesiveness than those in high-inventory systems.

JIT Encourages the Development of Group Task norms

Group norms are defined as group expectations of member behavior sanctioned by the group (Goodman, Ravlin & Schminke, 1987). They are relevant in the workplace because of their potential to produce very high levels of motivation. Motivation to achieve group goals can often overwhelm the motivation for individual goals (Zander, 1979). Behavioral experimentation has demonstrated that, under certain conditions, task interdependence and task related feedback encourage the development of task norms. Task norms, if enforced, will decrease inter-machine variance. To the extent they increase the speed of the bottleneck machine without increasing the variance delay of the bottleneck, norms will increase the long run productivity of the line.

We argue that the task interdependence associated with low inventory encourages the development of productivity related norms. Feldman (1984) argued that norms are stronger when they make important behaviors predictable. The predictability of task behavior is more important to the group in low-inventory situations when the task is interdependent. Goodman, Ravlin and Schminke (1987) noted that, in groups that work interdependently, "It is easy to see why group standards emerge. Everyone is doing the same task and output is visible." Wageman (1995) demonstrated a positive relationship between task interdependence and task related norms in a study involving 152 Xerox maintenance teams. No one has directly tested the type of interdependence found in low-inventory systems, but we should see the same type of relationship, for reasons noted earlier. We conclude that the greater task interdependence found in low-inventory situations should lead to stronger group task norms.

H5: Subjects working in a low-inventory situation will report stronger perceptions of task norms than those in high-inventory systems.

Task feedback, especially group task feedback, also encourages the development of task norms by providing information for the enforcement of those norms, and by increasing the group's focus on the task. The feedback available with low inventory allows a worker's speed to be known by his/her peers. This encourages norm development since, for norms to be effective,

deviation from those norms must be observable (Goodman, Ravlin & Schminke, 1987). Group feedback also helps to focus the group on the task. Pryer and Bass (1959) observed that, when compared to groups with feedback, groups without feedback exhibited more boredom, were more easily distracted, and discussed the task less frequently. In a different study, Berkowitz and Levy (1956) noted that discussions during break periods were more frequently related to the task when feedback was given on a group basis. Therefore we expect that the feedback available with low inventory will encourage the development of group task norms.

H6: Subjects experiencing greater feedback will develop stronger task norms.

To establish the presence of group norms, as we have defined them, it is important to demonstrate that they are beliefs held in common and that they are enforced by the group. Goodman Ravlin and Schminke (1987) argued that two of the important measures of a group norm are their distribution and enforcement. A belief by one member of the group that the others expect a certain level of output would not be considered a norm if the other members of the group do not share that impression. Likewise, norms do not exist without the threat of sanctions from the group for deviation from that norm. Therefore any measure of group norms should include not only measures of individual impressions of the existence and strength of the norm, but also evidence that those impressions are shared by other group members and evidence of the enforcement of that norm. We operationalize enforcement of group task norms as peer pressure on subjects who are performing worse than the norm to speed up. We expect peer pressure to speed up to have the greatest effect on productivity. We expect it to be stronger in groups with stronger group task norms.

H7: In groups with strong task norms, subjects who work slower than their teammates will experience more peer pressure to work faster than slower working subjects on teams without strong task norms.

The Role of Group Incentive Pay

There is no consensus in the literature or in practice on the value of using group incentive plans in conjunction with low inventory. The authors do not know of any researcher who has addressed the theoretical issue of whether JIT systems in particular should, or should not, be linked with group incentive programs. DeMatteo, Eby, & Sundstrom (1995), in a review of team reward systems independent of production system, noted the increasing use of team rewards and attribute it to the increasing interdependence among jobs. However, they found that "the underlying assumption that individuals who work in groups and receive group-level, rather than individually-based, rewards will be more motivated, more cooperative and more productive remains equivocal." (DeMatteo et al. 1995, p. 9). A review of low-inventory situations

in the literature also shows no clear consensus (Berg et al., 1996; Dunlop & Weil, 1996; Golhar & Deshpande, 1993; Parker & Slaughter, 1988; Zavadlav, 1993). Without a clear recommendation from the literature or practice, we feel it is important to study the effects of group incentive pay on low-inventory situations.

While the effects of group outcomes on productivity in groups may be equivocal, there is evidence to suggest that when groups have interdependent tasks then group pay may increase motivation. Hackman's theory of group effectiveness (1992) encourages "an organizational context that ... recognizes and reinforces the accomplishments of the group." Guzzo and Shea's theory (1992) stressed the importance of matching an interdependent task with interdependent pay. These theories are supported by the experimental work by Miller and Hamblin (1963). Drawing on 24 previous studies plus their own experiment, they showed that, with interdependent tasks, productivity increased with interdependent outcomes. They also showed no effect, or a very weak negative effect, when interdependent outcomes were used with independent tasks. There is clearly an expectation that interdependence of tasks, such as that found with low-inventory systems, when coupled with group incentives, should lead to productivity benefits.

While the literature on group processes does link group incentives to productivity with interdependent tasks, the mechanisms by which this contribution is made are less clear. Miller and Hamblin (1963) explained the effect with the concept of "blocking behavior." With high interdependence and competitive rewards workers have the opportunity to block, or even sabotage, the efforts of their coworkers. This motivation disappears with outcome interdependence. Guzzo and Shea (1992) pointed to a concept of "facilitating behavior." They believe that outcome interdependence provides an incentive for workers to help their coworkers and that the opportunity to do so is greater with task interdependence. Rosenbaum et al. (1980) found that, with interdependent tasks, feelings of personal attraction for other group members were higher with interdependent rewards. Berkowitz (1957) showed how group incentives increased group expectations of group member effort.

These alternative explanations can be integrated within a theory of group processes which includes the concepts of group cohesiveness, and group norms. The blocking behavior in the absence of group incentives (Miller & Hamblin, 1963) can be interpreted as a lack of enforced task norms. The facilitating behavior noted by Guzzo and Shea (1992) can be interpreted as the enforcement of task norms, as can the increased expectation of group member effort in Berkowitz's work (1957). Finally, the feelings of personal attraction noted by Rosenbaum et al. (1980) demonstrates an increase in group cohesiveness. The equivocal link

between group incentive pay and productivity, as noted by DeMatteo et al. (1995), may be explained by the observation that, in practice, task norms do not always lead to increased productivity. The bank wiring room in the Hawthorne studies had clear norms concerning productivity that were based on a "fair day's work" not on maximizing output (Roethlisberger & Dickson, 1939). Group pay also serves to legitimize the intervention of one worker in the processing speed of another, for example through advice or peer pressure. All of these theories and observations fit within a theory that links group incentive pay with increases in group cohesiveness and group task norms. While we expect the incentive part of group incentive pay to increase productivity, we expect the group part to affect the cohesiveness and norms of the group.

H8: Subjects receiving group incentive pay will report greater group cohesiveness.

H9: Subjects receiving group incentive pay will report stronger group task norms.

H10: Subjects receiving group incentive pay will work faster than subjects who receive no incentive pay.

Method

Participants

Subjects were 99 high school students from two central New York High Schools. Students were recruited with the help of faculty in the Science and Physical Education Departments, and students, and through advertisements and flyers. Ages ranged from 14 to 19 with 96% of the subjects between 14 and 17 years old. Fifty-five percent of the subjects were female. They were randomly assigned to treatments based on the number who showed up for any particular session and to keep the number of runs per treatment level over time. Each subject participated in only one run.

Tasks

Subjects were allowed to choose a computer terminal before the experiment began. Based on their selection they were assigned to teams of three each. Treatments were then randomly assigned to teams. Each subject had the task of entering data from a paper form into a computer. The forms allegedly contained order information for an electronics parts supplier. Each page of data consisted of an eight digit order number and either four or seven lines of parts information. Using a first-in-first-out criterion, subjects selected a booklet of three pages from an input buffer to their left. Turning to the page appropriate for their workstation they used

the mouse to select a "begin page" button on the screen. They typed in the order number and selected another button to begin entering the parts data. Each part line had three elements, a part name, a size and a quantity. The words on each line were slightly different at each of the three workstations, but the form, length, and process were the same. Using the mouse they selected the correct part name from a list of eight, the correct size from a list of six and then typed in the correct quantity. Upon completion of each line they selected another button on the screen to move on to the next line of data. When they had completed all items on the page another button on the screen was selected to go to the next order, and they placed the current booklet in an output buffer to their right and began on the next booklet. Workers did an average of 95 pages during an average 90 minutes of work. A Hypercard application was written to record the processing time for each individual for each repetition of each element of the task described above.

Treatments

Experimental treatments were conducted in a three (inventory policy) by two (pay scheme) factorial design. The three inventory treatments consisted of: (a) high inventory (HI), (b) high inventory with feedback (HIF), and (c) low inventory (JIT). The two pay treatments consisted of: (a) straight pay, and (b) group pay. Twenty-seven subjects were run with group pay and six with straight pay for each of the three inventory treatments. The data from one subject was lost (group pay, HIF treatment).

In the high-inventory treatment buffers were not shared. That is, the output buffer for one machine was separate from the input buffer for the next machine. Although the subjects were instructed that each booklet would eventually go to each machine in the series, the transfer of inventory was not done during the course of the experiment. Therefore, each person worked independently using their own stack of papers from their own input buffer and placed their output into their own output buffer. Input buffers began with more work than could be possibly finished during the experiment. Output buffers started with a modest pile of booklets so that workers could not easily gauge their progress by the amount of inventory in the output buffer.

The only difference between the low-inventory (JIT) and the HI treatment was the size of the intermediate buffers. In the JIT treatment, only the buffers before the first and after last workstation were essentially infinite. Both intermediate buffers were limited to a size of two with blocking after service. That is, a machine was blocked upon completion of the third item. In this configuration only the middle of the three workers could be both blocked or starved. The first worker could be blocked, if the output buffer was full, but could never be starved, as there was

an infinite supply in front of the first workstation. Similarly the last worker could be starved, but not blocked.

The High Inventory Feedback (HIF) treatment was designed to look at the components of feedback intrinsic to the low-inventory situation. It was exactly the same as the HI treatment with the addition of some feedback. The feedback provided was designed to resemble the evaluative content of the information available with low inventory, without the social element or consequences. Workers were given an outside reference as to how fast they were working. A box was added to the screen of each computer which showed the worker the difference between a standard rate and how many orders they had actually completed. If they worked faster than the standard rate the feedback box showed positive numbers of increasing magnitude. If they worked slower, the box showed negative numbers. The standard rate was selected from the average rate of the pretest of the experiment.

The two pay treatments are straight pay and group incentive pay. All subjects in the straight pay treatment were paid \$25 for their participation. Participants in the group incentive pay treatment were paid a rate per page completed by the group, multiplied by the product of the percentage correct for each team member. Percentage correct was measured by the computer by comparing data entered against the master list. The rate per page was selected, based on pretest data, to produce an average incentive pay of \$25. Actual average incentive pay was \$29 per subject.

Procedure

Each run of the experiment consisted of four stages over four hours. Stage one consisted of welcoming, paperwork and initial training to familiarize subjects with the task and the computer. Training was conducted from a prepared text with the use of flip chart diagrams. This section ended with individual practice on ten pages. The next stage was treatment practice. Subjects were trained in inventory handling and, for the HEF treatment, the meaning of the feedback box. This section ended with a practice session and a 15 minute break. The third part consisted of the experimental run. Subjects worked for two periods of approximately 40 minutes each with a 15 minute break in the middle. The last part consisted of an exit questionnaire and payment. Subjects were told the number of pages they had entered correctly at the end of the individual practice, after the treatment practice and again after the experimental run.

Measures

Processing times were measured by the computers on which the data were entered. Elapsed time between critical events was measured in 60ths of a second (times in this paper are shown in seconds). Critical events included the beginning of each new line of data and the beginning of the order number entry. Two dependent measures of processing time are used, "Order # Time" and "Line Time." Order # Time is the time to enter the eight digit order number at the beginning of each page. Line Time is the amount of time required to enter each line on the order. There were either four or seven lines on each order. Together, these two measures account for most of the work in the experiment. The only time not included in these measures is "end time" and "between time." End time is a very short period between clicking the button to signal the end of the last line on the page and clicking the button to go to the next order. Between time includes idle time due to blocking and starving and the time required to pick up the next booklet. By using only Line Times and Order # Times as dependent measures we avoid confounding the speed of entering data with the idle time between orders.

Other concepts of interest were measured using a survey questionnaire given immediately following task performance. Each item was measured using five point Likert scale questions. Feedback was measured using three questions relating to the value to task performance of the information provided to the subject. The measurement of Group Cohesion used four questions modified from a measure developed by Dailey (1979) which measured personal attraction and belonging to the group. Group Task norms was measured using three questions relating to impressions of how much people cared about how hard co-workers were working and included one question from Peer Leadership Measure by Taylor and Bowers (1972). A measure of Peer Pressure was developed using three questions to determine if co-workers had proactively encouraged subjects to work harder. It also included a question from the "Peer Leadership Measure" (Taylor & Bowers, 1972). Finally, a measure of friendship prior to the experiment was computed using two questions. A full description of all items is available in the first author's Ph.D. thesis (Schultz, 1997).

Analyses

Analysis began by testing the internal reliability of the survey items. Initial analysis was done using correlation analysis and comparison of means as appropriate. Hierarchical analysis of covariance was used when multiple constructs were hypothesized to simultaneously affect an individual construct. The shared nature of group norms and group cohesion required that our analysis include the covariance of individual measures of norms and cohesion with other

members of the same work group. If this covariance effect is significant we argue that it supports the group nature of these constructs.

Results

Analysis of Correlations

Overall means, correlations and internal reliabilities (coefficients alpha) are shown in Table 1. The JIT and group pay columns show correlations due to treatment effects. Negative correlations with Item and Order # times reflect a decrease in processing times equivalent to an increase in processing speed. Internal reliabilities are on the diagonal. Correlations predicted by model hypotheses are in bold type. Since hypotheses 2, 3 and 7 relate only to certain segments of the subject population, correlations of processing time variables with JIT and Peer Pressure are not in bold type. Measures using Likert scale questions were reduced to two items each to achieve acceptable internal consistency levels.

The correlation among the two measures of processing time, average Item Times and average Order # Times is high, as would be expected. However, at a correlation of .52, separation of these two constructs is warranted.

The first two columns, JIT and Group Pay, are treatment effects and will be discussed fully in the following sections, Analysis of Mean Differences and Multivariate Analysis. We note here that the three significant correlations in the JIT column give partial support to hypotheses 1, 4, and 5, dealing with the influence of JIT on Feedback (.26), Group Cohesiveness (.18), and Task norms (.20). Hypotheses 8 and 9, dealing with the relationship of Group Pay with Group Cohesiveness (.31) and Task norms (.39), are also supported. Although the signs are in the correct direction, the magnitude of the correlations do not support hypothesis 10 concerning the influence of Group Incentive Pay on processing time (Item Times -.14, Order # Times -.06). Support for hypothesis 6 is also provided by the correlation of Task norms with Feedback (.37).

Peer Pressure is significantly correlated with Group Cohesiveness (.23), Feedback (.24), Task norms (.31), Item Times (.17) and Order # Times (.26). Of these, the correlation with Task norms is related to, but not a direct test of, hypothesis 7, which predicts such a relationship for slower workers. The significant correlations with Cohesiveness and Feedback are consistent with their indirect relationship hypothesized through Norms to Peer Pressure. The relationships with processing time variables, Item and Order # Times, are consistent with hypothesis 2 if peer pressure is considered as part of the motivation for slower workers to work faster.

The correlation of Task norms with Group Cohesiveness (.51) is higher than would have been expected given this set of hypotheses. While we predicted that both these constructs

would be positively correlated with JIT and, therefore, some positive correlation was expected, the result of .51 is higher than the correlation of JIT with either Norms or Cohesiveness. One possibility is that Group Cohesiveness predicts or directly influences the development of Task norms. We note this possibility now, and discuss it more fully later.

Table 1
Mean Responses, Correlations of Variables and Internal Reliabilities

Variable	Mean	JIT	Group Pay	Group				
				1	2	3	4	5
1 Cohesiveness	6.30	0.18	0.31	0.81				
2 Feedback	7.57	0.26	(0.07)	0.08	0.43			
3 Norms	6.81	0.20	0.39	0.51	0.37	0.79		
4 Peer Pressure	5.07	0.05	0.01	0.23	0.24	0.31	0.77	
5 Item Times	9.13	(0.14)	(0.14)	0.05	(0.12)	(0.12)	0.17	NA
6 Order # Times	10.00	(0.10)	(0.06)	0.04	(0.06)	(0.00)	0.26	0.52

Note. n=98. Correlations are significant (one tailed) at alpha =.01 if over .25, at .05 if over .19, and at .10 if over .16

Analysis of Mean Differences

Means and standard deviations are shown in Table 2. The effects of the feedback given in the HIF treatment are negligible. We tested for discrimination of the two treatments, HI versus HIF, on all dependent variables using Hotelling's T^2 test. Although the relationships of all constructs, except peer pressure, are in the predicted directions the overall effect is not significant ($F(6,58) = .36$). Differences in variable means were also tested individually using t tests assuming unequal variance which failed to show significant differences (at alpha = 0.1) for any variable. For this reason it was decided to combine HI and HIF into one treatment, which we refer to as the Large Buffer (LB) treatment.

Tests of hypotheses using mean differences are shown in Table 3. Hypothesis 1 was supported; mean feedback under the JIT treatment (8.09) was significantly higher than mean feedback under LB (7.31). Hypothesis 2 was supported by Item Times and weakly supported by Order # Times (at an alpha of 0.10) as mean times of the slowest in each group were faster under JIT (Item = 9.5, Order # = 11.4) than LB (Item = 11.0, Order # = 12.9). Hypothesis 3 was not supported by either Item Times or Order # Times. Mean times of the fastest workers were not significantly slower for the JIT (Item = 8.0, Order # = 7.7) than the LB (Item = 7.9, Order # = 7.7) treatments. Hypothesis 10 was also not supported by either Item Times (Group Pay = 9.0, Straight Pay = 9.7) or Order # Times (Group Pay = 9.0, Straight Pay 10.3).

Table 2
Means and Standard Deviations of Measurements by Treatment

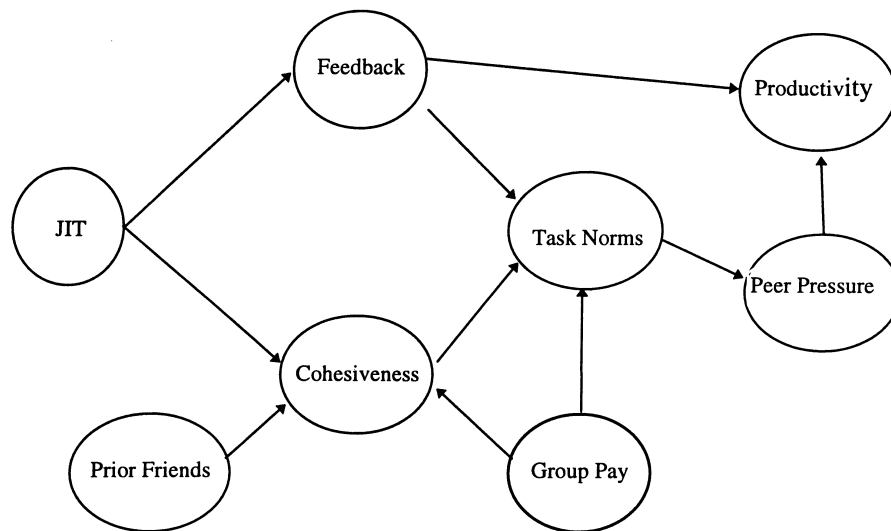
Variable	Measure	JIT	HI	HIF	LB
Feedback	Mean	8.09	7.30	7.31	7.31
	Std Dev	1.16	1.49	1.60	1.53
Group Cohesion	Mean	6.79	5.76	6.34	6.05
	Std Dev	2.06	1.87	1.99	1.94
Task norms	Mean	7.42	6.06	6.94	6.49
	Std Dev	2.02	2.15	2.27	2.24
Peer Pressure	Mean	5.24	4.73	5.25	4.98
	Std Dev	2.48	2.30	2.40	2.34
Order Times	Mean	9.59	10.22	10.21	10.21
	Std Dev	2.90	3.07	2.66	2.86
Item Times	Mean	8.71	9.70	9.00	9.36
	Std Dev	1.69	2.99	1.30	2.33

Table 3
Results of Mean Difference Tests

Hypothesis	Brief description	Test used	Test stat.	Sig level
H1	JIT increases Feedback	t-test	2.40	p=.01
H2	Slower workers work faster in JIT			
	Item Times, slowest workers	t-test	1.80	p=.04
	Order # Times, slowest workers	t-test	1.45	p=.08
H3	Faster workers work slower in JIT			
	Item Times, fastest workers	t-test	.20	p=.41
	Order # Times, fastest workers	t-test	.00	p=.49
H10	Faster work with Group Pay			
	Item Times	t-test	1.29	p=.11
	Order # Times	t-test	.50	p=.31

Note. All t-tests were one tailed, assuming unequal variance

Figure1. Model



Multivariate Analysis

Hierarchical analysis of covariance was used to test interrelationships among multiple hypotheses relating to Group Cohesiveness and Task norms. Team membership was coded from 1 to 33 for each work group in the experiment and entered as a covariate into the models before main effects.

The data supported hypotheses 4 and 8 which relate to the effects of the JIT treatment and Group Pay on the development of Group Cohesiveness. The model, including the team covariate, JIT, Group Pay and a control variable to account for friendships prior to the beginning of the experiment, was significant ($F=7.89$, $p=.00$). The team covariates, prior friendships, JIT treatment (H4) and Group Pay (H9) were all significant at $\alpha = 0.01$.

The data also supported hypotheses 5, 6, and 9 which relate to Task norms. Again the model used team membership as a covariate and Group Pay (H9), JIT Treatment (H5), and Feedback (H6) as predictors of the strength of Task norms. Due to the high correlation with Task norms noted before, Cohesiveness was also added as an independent variable. The overall model was significant ($F=4.89$, $p=.00$). As mentioned before, Goodman Ravlin and Schminke (1987) argued that opinions must be shared among group members before they can be classified as group norms. Our measure of norms is shared among group members as demonstrated by the significance of the covariance with team membership ($F=10.28$, $p=.00$). Group Pay (H9), Feedback (H6), and Group Cohesiveness were also significant at $\alpha = 0.00$. When all elements of this model are included the JIT treatment (H5) showed no significant direct impact on the strength of group norms at an alpha of 0.10. This supports the idea, first proposed

in the covariance analysis, that JIT does not directly increase Task norms, but rather works through Group Cohesiveness and Feedback.

The only remaining hypothesis to test is number 7, that slower workers will report more peer pressure in groups with stronger Task norms. This hypothesis was supported by a correlation of .43. Using a sample size of 33 (slowest worker on each team) this is significant at an alpha of .01.

Discussion

This research is the first to test the effects of low-inventory policies on the group dynamics of workers. It contributes to the understanding of group dynamics, as well as the interrelationships of work interdependence, feedback, group cohesion, group norms and productivity. Many of the hypotheses have been tested individually before, but they have not previously been integrated nor tested as a comprehensive theory. In testing the integration of these hypotheses we have used a contrast between high-and low-inventory production lines. This contrast is of particular importance as modern manufacturing becomes leaner. It also serves to demonstrate clearly the importance of behavioral considerations in manufacturing design decisions.

The model presented, summarized in figure 1, is supported by the data. Despite idle time of 9% due to blocking and starving, JIT production equaled that of lines with higher inventory. The results supported several of our specific research hypotheses. Low-inventory manufacturing provides task feedback which can motivate performance. Interdependent work, as found in JIT, encourages the development of group cohesiveness. The combination of cohesiveness and interdependence with high quality feedback stimulates the development of task norms. These norms encourage coworkers to exert peer pressure, most strongly on the slowest member of each work team, to work harder. The data failed to support hypotheses that faster workers would slow down and that group incentive pay would cause faster processing times than straight pay.

We believe the effect of this model partially explains productivity increases with JIT. Stronger norms do not, by themselves, mean increased productivity. However, due to the goals suggested by the feedback, as well as social loafing and role theory, we suggest that slower workers will speed up and faster workers may slow down. The first reduces the bottleneck constraint on output while the second merely reduces the balance delay of the fastest workers, at least up to the point where variance delay becomes a dominant factor. Therefore idle time will be less, and productivity will be higher, than previously modeled.

The correlation analysis and the hierarchical covariance analysis suggest that the development of task norms is dependent upon group cohesiveness. It has been suggested that cohesiveness can be based on personal attraction, prestige or tasks (Back, 1951). It has also been shown that task cohesiveness leads to task performance (Zaccaro & Lowe, 1988). The idea tested here is that the connection between task cohesiveness and task performance is through task norms and peer pressure to enforce those norms. This connection has not, we believe, been demonstrated before. A certain level of task-based group cohesiveness appears to be necessary before task norms will be recognized or enforced. Because we did not predict this effect we do not offer this as a conclusion, but recommend the relationship of cohesiveness to the development of task norms as an area for further study.

We found no significant difference between the High Inventory and the High Inventory-Feedback treatments. This result agrees with previous findings that feedback, without goals, has little effect on productivity. It is also consistent with the idea that the evaluative data available in JIT, which was replicated in the HIF treatment, is not as important to the dynamics of the group as the social signals and personal consequences.

It has previously been established that group pay can increase productivity in interdependent work situations. Our data support the premise that the mechanism for this relationship may operate through the effects of group pay on the strength of cohesiveness and norms. The correlations from our experiment are .31 for group pay with cohesiveness and .39 for group pay with norms, both significant. The productivity incentives of this pay failed to show a significant direct effect on output. The overall effect was expressed well by one subject who, during a discussion after the experiment, stated that while he quickly forgot he was being paid a little bit more for each piece he completed, he never forgot that his teammates were. This would explain the difficulty in establishing direct links between group outcomes and group effectiveness since the relationship is indirect and may be dependent on the reinforcing nature of other aspects of the work environment. We conclude that the effectiveness of group incentives in interdependent work situations is due, at least in part, to the strengthening of task norms and cohesiveness.

Building on Hackman's (1992) theory of task-based cohesiveness we have established the beginnings of a theory on the development and effectiveness of task norms. Hackman (1992) argued that group effectiveness can be enhanced by cohesiveness when that cohesiveness is task based and emphasizes the value of feedback and knowledge of the work. We support the importance of job characteristics and argue that these conditions are available in JIT. Furthermore we propose that the link from task cohesiveness to effectiveness works

through task based norms and peer pressure. The establishment of these norms is encouraged by task interdependence which helps to form task cohesiveness and make cooperation, through the development of norms, an effective strategy for increasing group effectiveness. Task feedback, widely available, helps in the development of norms by encouraging task discussion and by allowing malfeasance to be noticed and punished. Interdependent outcomes increase the motivation for development and enforcement of task norms. Once formed, norms influence outcomes in part through the exertion of peer pressure on group members who fail to meet the standard.

The model of the effects of group dynamics on productivity presented here is also closely related to the model of Guzzo and Shea (1992). They proposed that group effectiveness is a consequence of outcome interdependence, task interdependence and potency. Task interdependence is provided by JIT work situations while outcome interdependence is provided by group incentive pay and potency is enhanced by task feedback. We contribute to this theory by showing how these factors interact through cohesiveness, norms and peer pressure. We also note that, in our example, group effectiveness is not as much an increase in output from HI to JIT, but rather attaining the same output with fewer resources. This is accomplished by increasing the speed of the slowest workers even if other workers may slow down. We would be interested in further research to test the power of these relationships in other work settings.

Conclusions

The group dynamics of low-inventory lines have their greatest effect on the slowest worker in each group. The slowest workers feel peer pressure to work faster and, in fact, do work faster in JIT than in high-inventory situations. This is consistent with the complaint that JIT's success is due to increased pressure. However it suggests that the source of the pressure may be as much from peers as from management. This is important to managers because it is the slowest process on any line that forms the bottleneck and determines the output of that line. By speeding up the pace of the slowest workers JIT decreases the imbalance of the line and improves productivity.

It is clear from this analysis that changing from high-to low-inventory work systems can have a profound effect on the way people perform their jobs. Yet these effects are typically not included in OR models when comparing different line designs or when modeling changes in buffer size. This omission could lead to decisions to increase inventory above optimal levels in order to reduce anticipated idle time. This could increase inventory cost without having any real effect on idle time.

Not all serial lines will display the dynamics shown here. Some processing times are not as readily influenced by worker motivation. Some factories will have other considerations which could completely overshadow the effects noted here. There is no guarantee that stronger task norms will lead to increased productivity. For instance, increased worker cohesiveness in plants with a history of labor-management strife could easily result in lower, not higher, output. As modelers we need to be careful in our designs and in applying our findings to work situations. Additionally managers responsible for low-inventory production should understand the underlying motivations and group dynamics of these situations in order to evaluate possible interventions to improve line effectiveness.

This research was conducted as a laboratory experiment with teenage subjects because of the exploratory nature of the study and because of limitations in time and funding. The next logical step would be to confirm this analysis with factory workers. While we know of no reason why reactions should be different by age group there are many other factors operating on the group dynamics of workers in a factory which, by design, were controlled in this study. The fact that cohesiveness, norms and peer pressure developed significant differences during two hours of production speaks to the strength of the underlying motivations at work in this study. Nonetheless it remains to be demonstrated that these effects are lasting and will continue to motivate behavior for long periods of time. The current study provides justification for future longitudinal field studies.

This research is also important to the understanding of group dynamics in the workplace and to the modeling and management of low-inventory systems. We have explored the interrelationships of feedback, cohesiveness, norms, peer pressure and interdependent outcomes on how work design affects group output. This expands the current state of knowledge about how groups perform. We have also demonstrated some of the behavioral effects of JIT systems and argued that the effects on variance are as least as important as the effects on overall average processing speed. By showing conditions under which common modeling assumptions are incorrect and by estimating the magnitude of the variance, we can improve those models and the implementation of their results. Finally, understanding of these systems is important to implementing and managing JIT production facilities. Further research is needed to test these findings in ongoing concerns and with different group tasks.

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