Pull Systems: Implementation Experience in American Manufacturing

JIT Manufacturing/Lean Production

In the 1990s lean manufacturing became a common phrase in business literature. The underlying principles of lean manufacturing are well founded in operations management; however, lean is usually described as a collection of best practices. Among these best practices is a production and inventory control technique known as pull. There is a surprising dearth of information about pull system implementation. Some researchers even suggest that "many manufacturers will never be able to implement pull." To the contrary, when implemented properly we have found pull systems to be a readily accepted lean practice that provides immediate and remarkable improvements in business performance.

Charles Standard and Dale Davis

Maya Productivity Plus, Inc.
The First National Bank Building
7722 State Road 544 East, Suite 215
Winter Haven, Florida 33881
dale@lean-mfg.com

Proceedings of the Twelfth Annual Conference of the Production and Operations Management Society, POMS-2001, March 30-April 2, 2001, Orlando, FL

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Introduction:

Lean production is gaining widespread acceptance among American manufacturing managers. Although it has only recently become popular, the concepts are far from new. Lean incorporates some ideals from earlier periods of American manufacturing such as the American System (1850), Mass Production (1920), and the Training Within Industry (TWI) effort during World War II (1940-1945). On this foundation lean production developed as an independent way of *thinking* about manufacturing. In the late 1980s it was recognized as a distinct system of manufacturing production.

Lean production is an integrated philosophy of operations management that can be used to develop sound manufacturing decisions. Lean seeks to minimize unnecessary time, materials, and effort throughout the manufacturing organization. Central principles include a profound respect for people and a fervent pursuit of perfection through continual, iterative improvement. One of the most important features of lean manufacturing is the focus on reducing variability and streamlining the flow of production material throughout the entire operation including the supply and distribution systems. In fact, virtually all of the techniques commonly associated with lean manufacturing are intended to reduce some form of variability (Crawford and Cox, 1991). Reducing variability and streamlining flow minimizes cycle time and the squared coefficient of variation (*scv*) of cycle time leading directly to better operational performance.

In spite of its holistic perspective, lean manufacturing is often characterized as a collection of best practices, and there are countless books and articles explaining how to use the common lean techniques. This has expanded the general awareness of lean manufacturing, its practices, and its potential benefits, but it has also led to "piecemeal" applications of the tools and techniques. Such improvement efforts usually provide little or no benefit, and many manufacturing professionals have understandably become disillusioned (Milligan, 1999). Inconsistent and unpredictable results have spawned an ongoing debate about whether implementing lean manufacturing actually improves operational performance.

Nomenclature

Many researchers use the term just-in-time (JIT) to mean an overall philosophy of manufacturing comparable to lean manufacturing but without necessarily inferring the total quality management (TQM) aspects. Others use JIT to mean specific time-based practices that help a manufacturer produce or deliver items "just in time" for use by a subsequent operation or customer. Except where ambiguity or confusion might occur, we defer to the popular usage of JIT as a management philosophy. We include the word "practices" to indicate those specific practices that support the overarching lean or JIT philosophy.

Effectiveness of lean manufacturing

To examine its effectiveness and ability to improve manufacturing performance, several operations researchers have turned their attention to lean manufacturing and the closely related JIT philosophy. Their studies include theoretical analyses, simulations, case studies, anecdotes, and empirical research of the type more commonly associated with the quantitative social sciences. The resulting body of knowledge provides important insight into the essence of lean manufacturing, how it should be applied, and why it works. These studies also provide a framework of understanding about lean manufacturing that promotes appropriate implementations in industry. This, in turn, leads to more consistent and predictable operations improvement. A sampling of recent empirical research is reviewed here.

Many empirical research studies have found a statistically significant relationship between lean manufacturing and operational performance. White *et al*. (1999) used a sample of 454 large and small U.S. manufacturers from several different industries and geographic regions. They found that the most frequent benefits of JIT adoption are shorter cycle time (throughput time), lower inventory, improved internal quality, and higher labor productivity. Huson and Nanda (1995) linked a variety of business performance improvements to JIT adoption. These include increased firm value, increased earnings and earnings per share (EPS), lower inventory, and increased labor productivity. They also found that JIT firms were better able to maintain their profit margins than were their non-JIT competitors.

Nakamura *et al*.(1998) identified a highly significant relationship (1% significance level) between JIT adoption and several performance measures including equipment effectiveness, internal quality, cycle time, lead-time, and inventory levels. Fullerton and McWatters (2001) also demonstrated a highly significant relationship (1% significance level) between JIT adoption and a wide spectrum of quality, time-based, and other operational performance measures. Specifically, they found that JIT adoption improves competitive performance by reducing inventory, lowering the cost of quality, reducing cycle time, improving equipment effectiveness, increasing flexibility, and improving profitability.

Fullerton and McWatters (2001) also attempted to determine which aspects of JIT were responsible for the observed improvement. They categorized several common JIT practices into three groups: manufacturing-related, quality-related, and unique JIT practices. The unique JIT category comprised only the practices of JIT purchasing and *kanban*. (*Kanban* is a specific mechanism for implementing pull production control using cards or bins to convey information about consumption. It is often used as a synonym for pull production control.) These unique JIT practices were found to be significantly related to ten of the fifteen performance measures used in the study.

The strong predictive power of the unique JIT variable can be explained by the observation that these practices are, indeed, unique to JIT and would likely be adopted only by firms that have fully committed to the overall lean manufacturing or JIT philosophy. Another interpretation is that these two JIT practices (JIT purchasing and *kanban*) are, themselves, highly correlated to manufacturing performance, and adopting them leads directly to significant operational gains. Research by Flynn *et al*. (1995) discussed below and our own implementation experience support this latter interpretation.

In an analysis of 80 electronics and automotive parts producers in Ontario, Canada, Callen *et al*. (2000) established a positive relationship between JIT adoption and business performance. The comparison statements presented here are in relation to traditionally managed (non-JIT) plants. Specifically, they found that JIT plants use significantly less work-in-process (WIP) and finished goods inventory, JIT plants have significantly lower variable and total cost, and JIT plants are significantly more profitable.

There is also strong evidence that lean manufacturing promotes successful organizational learning and provides a basis for continual operational improvement. For example, Callen *et al*. (2000) confirmed that the elapsed time from JIT adoption was a positive predictor of performance. In other words the performance of JIT plants continues to improve as they become more experienced with lean manufacturing. Huson and Nanda (1995) also found evidence of this cumulative learning effect observing that inventory turns and productivity improve steadily with elapsed time from JIT adoption.

Brox and Fader (1997) applied an empirical and analytical approach from economic theory to the question of lean manufacturing improvement in the Canadian electronics industry, and they were able to draw clear conclusions about its effectiveness. They found that the "JIT group" realized statistically significant operational benefits and is "distinct" from traditional (non-JIT) manufacturers. Specifically, they found that JIT users were more cost efficient, and this higher efficiency was enhanced by increased flexibility and improved quality; JIT plants were less wasteful in terms of labor and material consumption; and JIT users were more profitable generating six cents per dollar more output in gross profit compared to the traditional firms. In addition to the obvious competitive advantages associated with these improvements, these researchers concluded that *implementing lean manufacturing actually creates an entirely different manufacturing environment* (Brox and Fader, 1997:380).

One of the most important (and somewhat surprising) discoveries about lean manufacturing is that the techniques, themselves, do not appear to be correlated with improved operational performance. "There was not a significant relationship between the use of JIT practices, alone, and manufacturing performance" (Sakakibara *et al*., 1997:1246). These researchers concluded that the primary benefit of JIT practices is to build and support an excellent manufacturing infrastructure. It is this infrastructure that is responsible for improved operational performance (Flynn *et al*., 1995). (For the purpose of these studies, infrastructure variables include practices such as plant environment, management support, and supplier relationships, and unique JIT variables include practices such as pull systems (*kanban*), small-lot production, and JIT scheduling.)

Effects of Pull System Implementation

In spite of the weakness of the relationship between JIT practices and manufacturing performance, the addition of certain unique JIT practices does lead to further and statistically significant improvement beyond that explainable by infrastructure alone. Since our current investigation focuses on pull systems implementation in American manufacturing, it is of particular interest to understand how pull systems interact with infrastructure and performance variables. Flynn *et al*. (1995) found, for example, that management support and pull system implementation interact as a trade-off. This means that pull systems may not be a critical factor for improving operational performance, provided there is strong enough support among the top management. On the other hand, a pull system can serve as a counterbalance for weak or lacking management support, providing significant benefits to a manufacturing operation regardless of whether management supports the lean manufacturing effort overall.

Our own implementation experience provides strong support and a possible explanation for this finding. Pull production control systems reside primarily on the shop floor. They are often managed by production operators or material handlers, and they usually run well without the management intervention. They are self-governing and self-correcting, and they are highly insensitive to implementation errors (Spearman and Zazanis, 1992:530). Furthermore, pull systems tend to moderate the fluctuations that perturb any manufacturing system (Kimura and Terada, 1981). Because of these features, pull system implementation can provide significant benefits even without strong management support.

Pull systems strengthen the infrastructure that is critical to manufacturing excellence, but they also provide their own operational advantages. For example, in an empirical analysis of 244 firms, Koufteros (1999) found a significant relationship between pull system adoption and delivery dependability, an important measure of customer service. Other benefits include shorter lead times, lower variability, less inventory for a given level of throughput, greater production flexibility, and higher profits for a given level of capacity utilization (Spearman and Zazanis, 1992:524; Zipkin, 1995).

Pull systems defined

Part of the difficulty in assessing the effectiveness of pull production control systems is the lack of a common understanding for what the term “pull” actually means. “Pull” systems are frequently contrasted with push systems, an alternative approach to production control. However, in popular usage, the terms push and pull are generally not well defined (Grosfeld-Nir *et al*., 1994). The defining statements presented here are mutually compatible, consistent with the operations research literature, and should provide a conceptual understanding of push and pull production control systems.

(1) Pull production control is a consumption-based replenishment system. In a pull system, production (or material transfer) is authorized only to replenish material that has been consumed by a downstream operation or by an internal or external customer.
(2) Pull systems are not zero inventory systems. Since pull systems replenish what has been consumed, there must necessarily be some inventory present at all times.
(3) Pull systems provide a finite WIP cap. In a serial production routing, pull systems have finite buffers, while push systems have infinite buffers. In a push system material moves through the production routing without regard for the status of downstream buffers or operations.
(4) Pull systems control WIP, and throughput is an observed production parameter. In contrast,

push systems control throughput directly by controlling the release rate of orders or material; WIP is merely an observed production parameter (Spearman and Zazanis, 1992).

(5) Pull production control is not the same as make-to-order. Pull is not demand driven; it is consumption driven. Push systems, on the other hand, can be driven either by orders or forecasts.

(6) A pull system is a closed queuing network. Incoming material does not enter the system until outgoing material has exited.

The following analogy is useful for building intuition about push and pull production control systems. Does an automatic icemaker in a home refrigerator operate on a push or pull principle? Based on all 6 definitions listed above, we conclude that the icemaker operates on the principle of pull. In its steady state the icemaker has a finite buffer of ice cubes waiting in a tray. A mechanical sensing arm rests on top of the ice cubes. As ice cubes are removed from the tray (consumed), the arm senses a change in the buffer status. Eventually, as more ice cubes are consumed, the quantity in the buffer falls below some threshold, and more ice cubes are produced to replenish the buffer.

It is amusing to imagine an icemaker that operates on the principle of push. First, we would need to develop a computer algorithm that predicted when and how many ice cubes would be consumed throughout the day. Then, we would need to produce ice cubes according to this schedule. In theory this would work well, but, in practice, the system would be inherently inflexible. If ice cube consumption deviated from the predicted pattern for any reason (dinner guests or an unexpected weather change), the push system might incur a stockout of ice cubes or produce an overabundance. Certainly stochastic demand for ice cubes can be assuaged, perhaps with a larger buffer inventory of ice cubes. Nevertheless, the system would be needlessly complicated and unsatisfactory.

We have found this to be true of actual production control systems in manufacturing firms. The push approach to production control is often unwieldy and generally unsatisfactory. It allows stockouts of critical items and production overruns of other items causing disruption and congestion in the factory. Often, highly capable materials managers and production supervisors are forced to develop off-line (pull-type) procedures to work around these dysfunctional systems. The shortcomings of MRP-type production-scheduling systems are well documented in the literature (Anderson *et al*., 1982; Whiteside and Abrose, 1984; Deleersnyder *et al*., 1989; Blood, 1994).

Nevertheless, manufacturing firms continue to invest millions of dollars in push-based production control systems that promise to provide efficient flow of material throughout the enterprise. Unfortunately, with MRP imbedded in these systems, the investment is often accompanied by a degradation in the firm's performance as it allocates ever increasing resources to implementing and maintaining a fundamentally flawed system (Layden, 1998:51; Nahmias, 1997: 380). Recently, two of America's largest investment groups admitted (anonymously) that inappropriate ERP (enterprise resource planning) implementation is the primary reason for the failure of many of their portfolio manufacturing firms.

Evidence from American Manufacturing

Because of the stabilizing effects on production flow and many other related benefits, we consider pull production control to be an integral part of an overall lean manufacturing system. Therefore, it may seem reasonable to expect that pull systems are used frequently and implemented early in a lean transformation. Surprisingly, the empirical evidence does not support this conjecture. In fact, many manufacturing managers seem to consciously avoid implementing pull systems. Pull systems are often among the last practices instituted, and many manufacturers do not accept them at all (White *et al*., 1999).

Flynn and associates (1995) found that pull systems were the least frequently used of 12 essential JIT practices. Callen and associates (2000) found that global JIT users implemented pull systems less than half the time. Brox and Fader (1997) found that pull systems were used only occasionally, ranking 14^{th} out of 17 selected JIT practices. White *et al*. (1999) found that pull system implementation ranked 8^{th} out of ten common JIT practices, and among small manufacturing plants only JIT purchasing had been in place for a shorter time! Again, we point out that Fullerton and McWatters (2001) found the specific practices of JIT purchasing and pull production control to be significantly related to ten of the fifteen performance measures used in their study.

Why are manufacturing managers so reluctant to implement pull systems? One major reason is that pull system implementation requires managers to conceive of their operation in a totally new way. Consider a serial routing. If a downstream process were producing parts slower than normal (perhaps due to a maintenance problem), it would not be “consuming” components at the anticipated rate. This means that replenishment signals would arrive at the upstream process less frequently than expected. Fewer replenishment signals means less production output at the upstream process, which, in turn, means less absorbed overhead for the upstream department.

If the upstream process were operating under a push system, it would continued to produce parts at the normal rate, without regard for the downstream operation. This would allow the upstream department to achieve its production (and financial) targets at the expense of increased congestion, excessive accumulation of WIP, and longer cycle times. It is well established in the operations research literature that these factors increase production cost. So, by attempting to uphold the efficiency of a single department, the push system would cause the overall operation to incur greater production costs. Adopting pull production control requires managers to look beyond the efficiency of a single process or department and make decisions that are more profitable for the operation overall.

Another reason for the lack of pull system adoption in the American manufacturing community is the widespread conflicting information about when, how, and even *if* pull systems should be implemented at all. For example, some authors provide a litany of requisite improvements must be in place before a pull system can be attempted. These prerequisites include:

- elimination of waste and other fundamental improvements to the production system

(Shingo, 1989).

- improved process design, standardized operations, and level production schedules. (Monden, 1992)
- short setup time and lead-time, smooth production schedule, and small lot production. (Suzaki, 1987)
- low inventory, excellent quality, reliable processes, short cycle times, short setup times, cooperative workers, uniform demand, uniform production schedules (Nicholas, 1998)
- short setup time and lead-time, uniform demand, level production schedule, reduced process variability, small container (or batch) sizes, increased production capacity (Inman, 1999)

We emphasize that all of these improvements are worthwhile. Waste, for example, is defined as unnecessary time, material, or effort expended in the production process. If these resources are indeed being expended unnecessarily, the process should obviously be improved, thereby "eliminating" the waste. Reducing setup time can lead to significantly lower total cost, particularly if the associated production lot size is also reduced. Similarly, reducing container size (move batch size) reduces significantly the mean and *scv* of cycle time resulting in lower overall production cost. Improving process reliability leads immediately to lower capacity utilization, a lower mean and *scv* of cycle time, and, consequently, reduced production costs (Zipkin, 1995).

The above "prerequisites" are excellent general recommendations for operations improvement, and they offer significant benefits in their own right. Nevertheless, we emphasize that there is nothing about any of these improvements that uniquely prepares a factory for pull system implementation. By portraying these as prerequisites, we are actually discouraging manufacturing managers from pursuing pull systems at all, denying them the multiple, and in many cases immediate, benefits associated with implementation.

One example is the virtual elimination of stockouts that is realized immediately upon implementing a well-designed pull system. Without stockouts production flow is much smoother. This provides a lower mean and *scv* of cycle time, and inventory and lead-times can be reduced accordingly. These instantaneous benefits of pull system implementation are realized regardless of (and even in spite of) other operational issues that would otherwise hinder performance.

One of the greatest strengths of pull production control is its robustness and insensitivity to implementation errors and unsatisfied assumptions. Pull systems work well in the presence of variability and uncertainty, and they provide many of the same benefits that are associated with the "prerequisites" listed above. Implementing pull production control is an excellent way for a manufacturer to realize those benefits while the more general operational improvements are being pursued in parallel. Our perspective is well-supported by Marine and Riley (1995) who makes a similar observation about organization improvement efforts in general.

Many contemporary change programs for Total Quality Management (TQM),

> Just-in-Time (JIT), (SQC), and so on, advocate a checklist or organizational prerequisites that must be met to ensure success. In most cases, if those prerequisites were met, the company would have already made significant progress toward the program objectives! As organizations, we do not typically have the luxury of time and foresight to prepare so completely before declaring war! The key is to assess the organizational strengths we have and deploy them with a strategy that can gain ground while the other prerequisites are addressed.

Case Experience

While pull system implementation gives some manufacturing managers consternation, we have found the benefits allay quickly any fears. In one aerospace electronics firm we discovered that chronic parts shortages were causing the assembly department to experience frequent and abrupt schedule changes and idle time. The disruption to the schedule meant that partially completed items were set aside on the shop floor while other products were produced. Processing these “new” jobs out of sequence consumed components that were needed for the first job thus lengthening further the waiting time as replacement components were ordered. The resulting congestion increased the cycle times and customer lead-times, and the average work-in-process (WIP) inventory was excessive. Productivity was poor because of the frequent shortages, and the customer service level was quite low. All of these difficulties can be traced to this companies earnest efforts to use their MRP-type production scheduling system to achieve “just-in-time” production.

Because of the long history of parts shortages and the long list of pull system prerequisites that are commonly listed in the popular literature, the manufacturing manager thought that pull systems would not work in their environment. Nevertheless, because of the persuasiveness of the authors (and our assurance that a pull system would perform “no worse than” the existing system) he reluctantly agreed to a trial. We chose a particular assembly operation that received its components from an internal fabrication process. Formerly, the fabrication process had been scheduled by the company’s MRP-type production scheduling system. When we implemented a simple two-bin pull system, the upstream fabrication process produced only the quantity and style that had been consumed by the assembly operation.

At our suggestion the understandably-skeptical assembly operator kept detailed records the inventory in her bins. After a month of record keeping, she found that the levels stayed consistently between the minimum and maximum levels we had specified. When the other workers realizes that this particular operation was no longer stocking out of components, they began to ask for bins as well. Eventually, hundreds of internally and externally-produced components were supplied to the assembly operation in this way. The company realized significant performance improvements in productivity, customer service, and a dramatic reduction in cycle time and lead time specifically as a result of pull system implementation. In our experience, this type of performance is the rule rather than the exception. In addition, we find that when workers see the benefits themselves, they are much more willing to embrace a new way of doing things.

Summary

There is strong empirical evidence that implementing lean manufacturing leads to significant improvements in manufacturing performance and immediate improvements in customer service. There is also strong evidence that the practices by themselves do not confer competitive advantage. The benefits come from a comprehensive adoption of lean manufacturing principles and the consequent development of a superior manufacturing infrastructure. One unique JIT practice that does seem to be correlated with improved operational performance is pull system implementation. Pull systems are robust and insensitive to implementation errors, and they provide remarkable improvements to manufacturing performance.

Many manufacturing managers are skeptical about pull production control, and there arguably cases where the push approach could actually perform better. These include situations where demand, lead-time, and processing times are known and fixed and cases where a serial production routing is extremely long and complicated. Nevertheless, in actual practice, we have found pull system implementation to be a prudent and successful way to increase productivity, customer service, and a host of other operational performance measures.

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