Abstract

This simulation study explores and compares the potential benefits of three work-in-process inventory drive systems and their associated inventory buffer characteristics. The three inventory drives are a push, a pull and a hybrid push-pull system. While these systems have some aspects in common, their buffer management systems vary. The statistical analysis associated with the study was based on data gathered from three computer simulated flow shop assembly line environments. Hypotheses concerning the production performance measurements were established. The independent variables were controlled and manipulated for each of the models. From the statistical analysis, a conclusion was drawn as to which system would afford the operation optimum results. While inventory has traditionally been considered and shown as an asset from an accounting point of view, it is obvious from the findings of this study, that excess WIP inventory, above the minimal requirements for production, will have a negative effect on the production measurements evaluated in this study.

Introduction

Purpose of the Research

The purpose of this research was to explore and compare the potential benefits of three work-in-process (WIP) inventory drives and their associated buffer management systems through the use of computer simulation. The three types of drive systems under study are a push system, a pull system and a hybrid push-pull system. These inventory drive systems were examined in a computer simulated typical flow shop assembly line environment. For the purpose of this paper, an inventory drive system is defined as the type and direction of pressure that is supplied to WIP inventory to facilitate its movement from raw material to a finished product. Also, a typical flow shop will be defined as a form of manufacturing assembly line in which operations assemble a standard uninterrupted flow of materials.

The statistical analysis associated with the study is based on data gathered in a comparison of three separate computer simulations. These simulations are identical in design except for the WIP inventory drive methods and the protective capacity buffers that operate in support.

Through the development of these models and the comparative analyses of the statistical data, the three drive systems are studied. From this study, decisions can be made to help determine which system would best meet the current and future needs of the typical flow shop assembly line environment. The contribution of the study is to reduce the amount of time and cost of making an operational choice.

Importance of the Research

Aggarwal (1985) once stated: “A revolution is occurring in operations management - three important approaches--material requirements planning (MRP), kanban (JIT), and optimized production technology
(OPT and later known as the Theory Of Constraints (TOC))--have invaded operations planning and control in quick succession. Each new system has challenged old assumptions and ways of doing things. These innovative methods are completely changing not only manufacturing processes but also operations management. Factory managers must decide which approach to adopt to meet current and future needs. Installing any one requires several years to train company personnel and millions of dollars of investment.” He goes on to state: "During the early part of the next (century), managers will likely be faced with the question of which one to choose to run their factories.”

Goldratt and Fox (1986) report: “The Western manager is challenged to solve a very fundamental problem from this alphabet soup of solutions. To understand each of these new technologies can, by itself, be a time-consuming challenge. Deciding which is best is a formidable task. Figuring out how to put them all together seems beyond our reach. Since we don't have the time, resources or funds to do everything, everywhere, we had better be convinced that we are taking the actions that will leapfrog us back into the race. There is no longer margin for error and no time for risky experiments.” Kee (1995) writes: “One of the questions confronting many managers today is that of deciding which paradigm to select for production-related decisions. Spencer and Cox (1995) state that interest has increased in WIP scheduling applications. Thorne and Smith (1997) noticed readers have a confusing conflict between the proponents of various manufacturing acronyms: TQM, OPT, JIT, and MRP to name a few.

Each of the operating systems listed above operates with a different WIP inventory drive system. Hug and Hug (1995) have concluded that variations in the inventory drive systems and the introduction of raw material will have an effect on the level of WIP inventory in the system. It will be of significant importance to the practitioner to discern the relative differences and the associated considerations that evolve around the choice of one inventory drive method over another. This study had the goal of minimizing the investment of time and capital required in choosing an appropriate method to drive WIP inventory.

Statement of the Problem

McClure (1997) has stated we no longer attempt to maximize production, but rather attempt to optimize it. Orlicky (1975) and Fogarty, Blackstone, and Hoffman (1990) note that variation between the master production schedule (MPS) and actual production will emanate even when the schedule is not embellished. This disparity is brought on by a miscellany of unplanned events that transcend typical manufacturing operations. The development of production control systems would be simple except for the existence of these unplanned events.

These unplanned events consist of (but are not limited to) machine breakdowns, tool breakage, worker absenteeism, lack of material, scrap, rework, customers who change their minds on timing and quality, etc., and the fact that operations are interdependent. Random fluctuations and dependent events cannot be prevented, but they can, and should, be considered when choosing an inventory drive system.

Because of the phenomena of random fluctuations and dependent events, protective capacity must be supplied to ensure continuous operation. This protective capacity can be supplied through capital investment, but is most often offered in the form of additional WIP inventory. Brooking, Hailey, Parker, and Woodruff (1995) agree buffer inventory is required unless the production configuration needs are changed. Sage (1984) states that inventory is the largest manageable asset, and yet the reasons for this investment are seldom thoroughly examined or challenged. Tersine (1988) notes that at some point inventory levels will interfere with operating efficiency and customer service. Therefore, the chosen inventory drive systems should attempt to address both of those objectives. The problem is the objectives, operating efficiency and customer service are in direct conflict with each other. The production and sales functions would prefer no stock-outs, while keeping as little cash as possible tied up in WIP and finished inventory, and simultaneously avoiding the high cost associated with excessive setups that are synonymous with small production runs. In a buffer study
performed on serial manufacturing, Tayur (1990) states that buffer downsizing problems stem from the various sources of randomness. Attempting to remove all of the variability in the system would not be cost effective. So to combat the variability, buffer size is increased. This increase in buffer size will come at the expense of increasing WIP inventory. When WIP inventory is increased, required lead times are pushed back. Also, shorter response times will be imposed to correct quality problems. It is also known that some areas require more or less buffer protection than others. Therefore, the tradeoffs between balancing the benefits of buffering and the cost associated with the increased level of inventory must be dealt with.

Layden (1997) has listed three legitimate reasons to have WIP inventory in a manufacturing process. The first use is to cover process variability, the second reason is to compensate for a mismatch in process time and customer delivery demands, and the third reason is to allow for local re-sequencing without impact to the other workstations. These tradeoffs lead to an enormously difficult task of choosing and optimizing a WIP inventory drive system. This problem is compounded dramatically with the introduction of dynamic production requirements and the statistical fluctuations inherent in the stochastic nature of machines and their associated mechanical breakdowns.

Integrating the shop floor activities with a drive system is initiated through decisions based upon a management philosophy. A modern assembly line often incorporates machine centers that are linked together by a material handling system. Each of these machine centers may be manufactured by different vendors with differing levels of automation. The variation in the level of automation, along with the proper placement of WIP inventory buffers, will serve as throughput protection.

When selecting an inventory drive system the following questions should be addressed:

a. Which type inventory drive system should be employed
b. How and where should inventory buffers be assigned
c. At what size should the buffers be set

Increasing the body of knowledge in this area was the motivation for this research.

Push System Inventory Control Methods and Material Requirements Planning

The APICS Dictionary (APICS, p.40) defines a push system as: "The production of items at times required by a given schedule planned in advance. In material control, the issuing of material according to a given schedule and/or issuing of materials to a job order at its start time."

A push type WIP inventory drive system is used in Material Requirements Planning. Because the inventory control method for an MRP-based system is schedule oriented, the material is literally pushed through the process to assure adherence to the predetermined master production schedule. A push system would permit the advancement of additional WIP inventory regardless of the current level. This will force WIP inventory to build prior to areas where production capacity is insufficient to handle the load.

Umble and Srikanth (1990, p.8) report: "MRP became a crusade that helped to shift the emphasis away from the traditional 'just-in-case' inventory mentality and toward a manufacturing control system based on actual need dates and quantities." Tersine (1988) claims MRP enables manufacturing organizations to maintain minimum levels of dependent inventory, yet it assures that production schedules for the independent items are pushed through the system. Wight (1984) states the impact of MRP on a manufacturing company can be profound. MRP is a key technique in production and inventory management. It is a workable, formal system that responds to the marketplace needs. It basically pushes inventory through the system and attempts to improve productivity. Clayton (August, 1997) claims the development of MRP was one of the milestones needed to convert informal systems into standard/universal formal systems.
Cox and Clark (1984) listed several technical problems with MRP systems in practice such as management of inventory levels. Whiteside and Arbose (1984) report that some critics believe that MRP is a $100 billion mistake. They go on to quote a study conducted at Chalmers University in Sweden that claims companies using MRP production and planning systems have preserved high levels of inventories. Many of the problems inherent to MRP can be based on the requirements that are placed on it. Ptak (1991), Knill (1995) and Lalsare and Sen (1995) all report that MRP is capacity insensitive. It is solely the processing logic to determine the requirements to fulfill this externally supplied plan (schedule). It does not check the feasibility of the master schedule. Gamboa (1996) feels MRP cannot track parts on a weekly basis let alone on a daily basis. The problem is its time insensitive. Sum, Ang, and Yeo (1997) have developed a list of critical success factors in the implementation of MRP and its push system of inventory control.

**Pull System Inventory Control Methods and Just-In-Time**

The first records of the JIT management philosophy stem from the efforts of Henry Ford and his assembly line operations. According to Vokurka and Davis (1996), Ford is considered the “grandfather” of JIT. The Japanese in general and Toyota specifically, have expanded the approach and concepts of Ford. The JIT philosophy has led to the development of systems that attempted to reduce the amount of required WIP inventory. The primary elements of zero inventories are to have only the required inventory when needed; to improve quality to zero defects; to reduce lead times by reducing setup times, queue lengths, and lot sizes; to incrementally revise the operations themselves; and to accomplish these things at minimum cost.

The APICS Dictionary (APICS, p.40) also defines a pull system as: "The production of items only as demanded for use, or to replace those taken for use. In material control, the withdrawal of inventory as demanded by the using operations. Material is not issued until a signal comes from the user." Keaton (1995) feels two conditions are required in a JIT system. First, output of a product must be level for a reasonably long time horizon, and second, mixed-model final assembly must be practiced. Ou and Jiang (1997) state that a pull method of production is one of the requirements of JIT. The inventory control method used in the Just-in-Time management philosophy pull system is called kanban. Kanban can be defined as a method of production that uses standard containers or lot sizes. Pull system work centers signal when they wish to withdraw parts from a feeding operation or supplier. This kanban system is designed to reduce the level of inventory and improve the synchronized movement of material through the plant. Dickey (1996) writes when considering a pull system and kanbans, appropriate levels of WIP inventory come into question.

As reported by Umble and Srikanth (1990), “JIT kanbans are not without their limitations: JIT systems have at least four significant limitations that should be mentioned. First, the number of processes to which JIT logistical systems such as kanban may be successfully applied is limited. Second, the effects of disruptions to the product flow under a kanban system can be disastrous to current throughput. Third, the implementation period required for JIT/kanban systems are often lengthy and difficult. Fourth, the process of continuous improvement inherent in the JIT approach is system wide and therefore does not focus on the critical constraints, where the greatest gain is possible.” Conti (1996) concurs that problems with implementation and operations will exist when employee attendance is a problem.

Crawford, Blackstone and Cox (1988) surveyed companies that have implemented JIT and have identified benefits and problems associated with the implementation. This survey showed an average company-wide reduction of 41% in WIP inventory, with reductions in manufacturing cost of 17% and reductions of lead-time by an average amount of 40%. The problems that were reported fell into several categories; resistance to change, lack of resources, lack of commitment, and lack of a solid base of
performance measurements. They also listed as problems interfacing with existing MRP systems and line balancing. Wrennall and Markey (1995), Epps (1995), and Wiersema (1997) concur in general with these findings.

Gilbert (1990) randomly selected and surveyed a total of 250 U.S. manufacturing firms to determine the extent of JIT implementation. This study found there was a significant reduction in the investment of inventory associated with the implementation of JIT. Chakravorty, and Atwater (1995) conclude the JIT solution is of little value to managers that are operating with high levels of system variability that cannot be reduced quickly.

Hybrid Push-Pull Inventory Control Methods and The Theory of Constraints

The hybrid push-pull inventory control method used in the Theory of Constraints is based on buffer management. Buffer management is achieved through what is referred to as Drum-Buffer-Rope (DBR). Goldratt developed the DBR approach in the 1970's in conjunction with the OPT software. DBR techniques are described in detail by Goldratt and Fox (1986), Goldratt (1990), Goldratt and Cox (1992). Additional studies by Schragenheim and Ronen (1989), Demmy and Petrini (1992a,b), and Betz (1996) also explain DBR in detail.

The physical difference between the buffers used in MRP and JIT and the buffers used in TOC rest in the fact that the MRP and JIT buffers are based on a physical count or are limited by the amount of actual storage space, while TOC buffers are measured in units of production time. Umble and Srikanth (1990) define a time buffer as inventory: “Designed to protect the throughput of the system from the internal disruptions that continually occur in manufacturing environments. When measured in units of production time the actual number of pieces in the buffer and the actual dollar amount of buffer’s worth will fluctuate.” Demmy and Petrini (1993) state that buffer management closes the loop in a DBR scheduling system and provides information needed to set buffer sizes. They also state that buffer management offers a powerful approach for improving productivity of shop floor operations.

The Theory of Constraints was developed through the efforts of a physicist, Eliyahu Moshe Goldratt. The original name for the Theory of Constraints was Optimized Production Timetables, which was introduced in 1979. The main idea behind OPT was a computerized mathematical scheduling system that was developed to assist in the production and assembly of manufactured products. The schedule enabled the producer to increase their production with the same number of workers. In 1982 the name was changed to Optimized Production Technology, again in 1984 to Synchronous Manufacturing, and finally in 1987 to Theory of Constraints. In this study OPT and TOC will be used synonymously.

Dugdale and Jones (1995) and Ruhl (1997) report the Theory of Constraints is an intuitive framework for managing an organization. The main force behind TOC is a desire for continuous performance improvement. The improvement is always concentrated on, and stems from, Goldratt’s (1990) five steps of constraint management, which are as follows:

1. Identify the System's Constraint(s).
2. Decide How to Exploit the System's Constraints.
3. Subordinate Everything Else to the Above Decision.
4. Elevate the System's Constraint(s).
5. If, in the Previous Steps, a Constraint Has Been Broken, Go Back to Step One, but Do Not Allow Inertia to Become the System's Constraint.

These steps are simply a framework for directing the efforts of a thinking process. Using the concept that a constraint is anything that limits the organization from achieving its goal, the steps to improve performance can be easily defined.
Research Methodology and Model Development

The assembly line environment used in this study was selected from a Fortune 500 manufacturing company. The company has requested that it remain anonymous due to the privileged information released for this study. This particular assembly line was chosen in order to study the basic parameters that exist in most typical assembly line environments. With this in mind, the findings would not only be applicable to this study, but would provide the same basic information to managers with similar assembly lines.

To conduct this research, three separate simulation models of a 29-station assembly line were developed. Several independent variables for each workstation were manipulated to observe their impact on the production performance measurements, lead times, dollar days of inventory and cost of goods sold. To determine which inventory drive system would afford the greatest benefits, production measurements were evaluated. For each of the simulations, the WIP inventory drive and buffer management system was employed and the question “What is the effect of the WIP inventory drive system technique on production measurements?” was evaluated.

Deitz (1997) has reported that by applying simulation models, one can help speed up results or lower costs. He goes on to state that the immediate obstacle to simulation is the lack of simulationists that can model. Sly, Grajo, and Montreuil (1996) and Langnau (1997) state that with the software tools and methods now available, layout designs can be created in much less time and with greater reduction in material flow, WIP, and throughput time. Stylianides (1995) concludes that simulation can be used to evaluate proposals, assess the impact of proposals on existing manufacturing facilities, answer what if questions, and graphically animate in real time.

The Simulation Models

To create the simulations SIMFACTORY 6.1 was employed. SIMFACTORY performs what is called discrete event simulation (CACI 1993). Discrete event simulation is system modeling by taking continuous processes that happen in the real world and break them down into key events. (CACI 1993) Operations in the "real world" depend upon statistical fluctuations and not mean-value averages. Therefore, statistical distributions were employed to ensure that "real world" randomness was modeled accurately through appropriate simulation. Each of the three simulations was based on the separate WIP inventory drive systems of a push, pull and a hybrid push-pull system. Although these three systems have several aspects in common, they all operate with different WIP inventory control buffers for throughput protection. The basic parameters of the three simulation models are detailed and compared in Table 1.

Push System Model

In the push system model, the raw material input to the assembly line was determined by the master production schedule. The raw material input was not based on the current rate of production at the time of order release but was released according to master production schedule requirements that would keep material
flowing at all work stations. The WIP inventory was literally pushed through the system to meet the master production schedule demands.

The push system and buffer management method was based on part buffers that are located in front of each work center. Because MRP assumes infinite production capacity, there is normally no pre-established basis of WIP inventory control other than the checks and balance procedures of the MRP system and the physical storage capacity of the workstation buffer. When order release/raw material input exceeds the production output of the system, the level of WIP inventory will increase. On the other hand, when the output of production exceeds the input of new orders/raw materials, then the level of WIP inventory will decrease. With a push system and the parts buffer method of inventory control, it is important to ensure that all of the buffers contain parts. By assuring that all of the buffers contain parts, individual workstations are protected from lost production.

Pull System Model

In the pull system model, the raw material input to the assembly line was also determined by a master production schedule. The flow of these orders was limited by the rate of production at order release time. Orders were released no faster than demand required. Here WIP inventory is pulled through the system to meet production demands.

The pull system and buffer management of inventory control uses kanbans. The kanbans consisted of parts measured in units of containers and were drawn from preceding workstations only as needed. Production orders were not released prematurely because planned kanbans will not accept or require any additional parts when full. Yet holding back orders that the system is trying to release might create a hole in the production process. This hole in the production might call for the entire production process momentarily to shut down until the kanban was filled.

For the final operation to meet its production requirements, it draws parts from the inventory of the previous work center. The work center that fed the final operation only makes enough parts to replace inventory that the final operation consumed. Each work center of the assembly line operation follows the procedure of replacing only what was taken by the next operation. This sequence continues up-stream until it reaches the first operation.

Hybrid Push-Pull Model

In the hybrid push-pull model, the raw material input to the assembly line was introduced slightly faster than the time requirements of the drumbeat. The drumbeat is the production rate of the assembly line’s constraint. The flow of these orders was set slightly faster than the constraint rate of production to ensure it would never starve for material to process. The hybrid push-pull model mainly uses what is referred to as forward scheduling. Here the inventory is pulled through the system at every operation with the exception of the system constraint. At the system constraint, inventory is pushed to meet the master production schedule demands. With the push-pull system it is important that orders are released according to drum-buffer-rope priority and sequence.

Schonberger (1997) reports scheduling to a rate (such as the drum beat) simplifies planning and synchronizes production. The system's non-constraints are then scheduled to support the critical resources. They are scheduled backward to minimize the length of time the WIP inventory is held.

This systems buffer management control method uses what are referred to as time buffers. With this method of inventory control it is important to ensure that the time buffers in front of constraints are never
starved for material to process. Buffers and inventory control at non-constraints are not critical and were held to zero whenever possible. With the exception of the constraint, there is no need for buffered inventory.

Table 1

<table>
<thead>
<tr>
<th>Drive System</th>
<th>Push</th>
<th>Pull</th>
<th>Hybrid Push-Pull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Schedule</td>
<td>MPS</td>
<td>MPS</td>
<td>Drumbeat</td>
</tr>
<tr>
<td>Flow of Orders</td>
<td>No Limit</td>
<td>Limited Rate of Production</td>
<td>Limited Rate of Constraint</td>
</tr>
<tr>
<td>Orders Released Based On</td>
<td>Required Production</td>
<td>Assembly Line Demand</td>
<td>Constraint Consumption</td>
</tr>
<tr>
<td></td>
<td>Lead Time and Due Date</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scheduling</td>
<td>Backward Off MPS</td>
<td>Backward Off MPS</td>
<td>Forward Off Constraint</td>
</tr>
<tr>
<td>Buffer Type</td>
<td>Parts Buffer</td>
<td>Kanban Containers</td>
<td>Time Buffers</td>
</tr>
<tr>
<td>Buffer Location</td>
<td>Before Every Location</td>
<td>Before and After Every Location</td>
<td>Before and After Constraint Only</td>
</tr>
<tr>
<td>Buffer Size</td>
<td>Function of MRP and Storage Capacity</td>
<td>Based on Size and Number of Kanbans</td>
<td>Processing Time of Parts is Held Constant</td>
</tr>
</tbody>
</table>

Inventory Control Design Parameters

The three simulations used in this study were identical in design with the exception of the drive systems and buffer control methods used in support. The buffer control methods were based on the following criteria.

Push System Buffers

The first model, which was based on a push system, was regulated by buffer placement both before and after the workstation. Total inventory was not to exceed 10 pieces of work in any buffer. All down stream buffers were allowed to increase to the maximum capacity at every queue and conveyor before the feeding operation ceases to produce. This rule was in effect at every operation but the last. All operations were allowed to refill the queues and conveyors to the maximum level at any time of the production process.

Pull System Buffers

The second model, which was based on a pull system, used kanban placement based on the number of given work centers in the assembly line process and the fixed number of parts required to fill the kanbans. Here the kanbans were located just before and just after the workstations and were allowed to hold one part per kanban. Once the kanbans were full, the operations that feed the kanbans were not allowed to produce any
more of the product. All operations were allowed to refill the kanbans to the level of one part any time a part was transferred to the next position.

**Hybrid Push-Pull System Buffers**

The third model was based on a hybrid push-pull system. The WIP inventory was controlled through a single buffer of 50 parts was placed in front of the constraint. This protective capacity was required only at the system constraint. As the buffer was depleted of inventory, the work center in front of the constraint was allowed to replenish the inventory. All work centers were required to work when work was present, and sit idle when work was not present.

**Simulation Runs**

In research planning it is necessary to determine a specific statistical power for the appropriate sample size (n) in reference to a given level of significance, alpha (α) and effect size (ES). Cohen (1992) reports that statistical power analysis exploits the relationship among the four variables involved in statistical inference. He also reports that for any statistical model, these relationships are such that each is a function of the other three. Therefore, given three of the variables the fourth can be determined. For the purpose of this study, the sample size of 10 days and an alpha value of .05 were used in the one-way ANOVA's. The alpha value of .05 gives the single one-way ANOVA comparison a designed probability of making a type I error at .05.

**Production Measures Of Performance**

Lead times, dollar-days of inventory and cost of goods sold are the production measures of performance of the simulations and were used to determine which inventory drive and buffer management system will afford the manager optimum results. The performance measures are formulated and defined below.

Lead time (LT) is the total time required to process, produce, or manufacture a product from the initial order conception to final transfer or delivery. The make span (MS) data output for the final operation was equal to lead time (LT).

\[ LT = MS \]

Dollar days of inventory (DDI) can be calculated by multiplying the average inventory level (IL) at each station by the make span or lead-time (LT) of each station times the cumulative raw material costs (CRMC).

\[ DDI = \sum (IL \times LT \times CRMC). \]

The total cost of goods sold (COGS) was determined through a summation of the average number to exit (NTE) at each workstation multiplied by the individual raw material costs (RMC) that are input at that workstation.

\[ COGS = \sum (NTE \times RMC) \]
Number to exit (NTE) is the count of parts that have left the final operation of the assembly process.

\[ NTE = TOTAL \ PRODUCTION \]

Average inventory level (IL) represents the average number of parts that are located at a station, queue or conveyor.

\[ IL = INVENTORY \ LEVEL \]

Raw material costs (RMC) is determined by the cost of the raw material that goes into each workstation.

\[ RMC = RAW \ MATERIAL \ COSTS \]

Cumulative raw material costs (CRMC) are determined by the cost of the raw material that goes into all workstations.

\[ CRMC = CUMULATIVE \ RAW \ MATERIAL \ COSTS \]

Research Objectives

The objective of the research was to determine which model would afford the manager optimum results. This determination was made through a statistical analysis of the dependent variables that were calculated from the computer-generated data. Each model was simulated for ten replications, which corresponds to two five-day workweeks. Each of the simulation replications was run for a warm-up period of 100 minutes allowing for a steady-state condition. After steady-state condition, data collection was initiated and collected over a replication period of 420 minutes. The 420-minute replication period represents 7 hours of production, which is an estimate of the amount of production time that one would expect in an 8-hour shift (with 30 minutes for lunch and two 15-minute breaks). Week 1 simulation was run with the first random number stream. Week 2 simulation was repeated with a different random number stream. Each of the daily data sets for the five-day workweeks was averaged together by the software package to produce individual simulation output data reports for each of the random number streams. Output data that was generated by the random number streams 1 and 2 were compiled by the SIMFACTORY software and reproduced through the report generator.

Limitations of Research

The output data simulated were limited in that they experimental and not drawn from experience in the current environment. Acquiring data from an actual, operating manufacturing facility would have imposed its own limitations to the research. First, an actual manufacturing facility does not maintain more than one WIP inventory control method to manage one assembly operation. Second, it would require a facility that could reproduce identical independent variables that affect the dependent variable.
outcome each time it ran a test. This is why simulation was used. An alternative to one actual facility performing a trial more than once would be three manufacturing facilities operating concurrently under the identical circumstances and economic conditions, which is most unlikely.

The results of this study were also limited to the characteristics used and assumptions made in the simulations. The characteristics of the study, which consist of the simulation model resources, were held constant for each model while the inventory control design parameters were manipulated to simulate the associated WIP inventory control methods. The simulation model resources were separated into the four categories of free, stationary, moving, and conveyors. The inventory control design parameters were based on current knowledge of the management philosophy. The simulation software package itself was limited in the fact that the simulations behaved only as programmed. The random generation of independent statistical fluctuations is somewhat less appealing than real life in some areas, but overall it was more appealing than the alternatives.

**Simulation Results**

The data produced by the different random number streams were very similar yet distinct. ANOVA tests were used to determine if the differences in the measurements were significant. The hypothesis that these samples come from different populations with the same mean were tested under the following conditions:

1. Dependent variables were developed with randomly selected input data and are independent.
2. All populations from which the randomly selected input data were drawn were normally distributed.
3. All of the populations from which the randomly selected input data were drawn have the same variance.

For the purpose of this research, these conditions meant that the dependent variables under study were developed at random and the values of the dependent variables of one WIP inventory control method were not influenced by the values of the other WIP inventory control methods. In addition, the values of the dependent variables were homoscedastic and normally distributed. In each case significant differences between the mean values for each dependent variable were found.

The summarized results of the production measures of performance and the rankings for each drive systems are shown in Table 2. In all of the cases the rankings are the same; the hybrid push-pull system finished first, the pull system finished second, and the push system finished last.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Objective</th>
<th>Push</th>
<th>Pull</th>
<th>Hybrid Push-Pull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Time (minutes)</td>
<td>Minimize</td>
<td>279.08 (2)</td>
<td>279.08 (2)</td>
<td>278.64 (1)</td>
</tr>
<tr>
<td>Dollar-Days Inventory</td>
<td>Minimize</td>
<td>$33,899 (3)</td>
<td>$20,165 (2)</td>
<td>$5,448 (1)</td>
</tr>
<tr>
<td>Cost of Goods Sold</td>
<td>Minimize</td>
<td>$23,993 (3)</td>
<td>$22,578 (2)</td>
<td>$21,991 (1)</td>
</tr>
</tbody>
</table>

Table 2
Research Summary

The purpose of this research was to explore and compare the potential benefits of the work-in-process inventory control systems of three different management philosophies through the use of computer simulation. The three management philosophies of Material Requirements Planning, Just-In-Time, and the Theory Of Constraints were studied in a typical flow shop assembly line process. A local manufacturing company that requested to remain anonymous supplied the assembly line process under study. The purpose of the study was to evaluate and compare the effects of inventory on the dependent variables that were used as performance measurements.

In this study, it’s important to point out how WIP inventory affects the outcome of the dependent variables. A reduction in the level of physical WIP inventory reduces the total asset value of WIP inventory within the system. This monetary value reduction leads to lower carrying costs and variable operating expense thus reducing the amount of total operating expense. A reduction in the total operating expense should increase cash flow.

A reduction of the physical WIP inventory level should lead to a lower cost of goods sold. With a reduction in the cost of goods sold, higher net profits are obtainable and increased throughput is possible.

The reduction in total operating expense in association with the reduction in the asset value of WIP inventory should yield a greater return on investment.

In this study, material was released into all of the models at a steady rate. The rate was sufficient to allow for an inventory build-up at all system buffers. As the physical level of WIP inventory is reduced, the production area becomes less cluttered and more orderly, and quality problems become evident at an earlier date. If quality problems become more evident at an earlier date there will be less scrap and rework to deal with. This is considered as a positive feedback loop and in turn will further reduce the level of physical WIP inventory.

In every performance measurement that was evaluated and compared, the WIP inventory control methods of the TOC management philosophy procedures exceeded the outcomes of the MRP and JIT models. In most cases, the performance measurement outcomes were significantly in favor of the TOC management philosophy.

Physical inventory has traditionally been considered and is currently shown as an asset from an accounting point of view. It is obvious from the findings in this study that excess work-in-process inventory, over and above the minimal requirements for production, will have a negative effect on the production performance measurements. TOC's management philosophy may hold tremendous improvement in all of the performance measurements, but the greatest accomplishment comes in reducing the amount of WIP inventory required to meet production goals.

In short, if management can learn to effectively minimize the level of WIP inventory, it can increase throughput and cash flow, allow for a greater return on investment, and return higher net profits. These improvements would allow the company to become more competitive in world markets.

Contributions of Research

The major contribution of the research is the broadening of the knowledge of protective WIP inventory control methods in a typical flow shop assembly line environment. The research should increase the knowledge base of manufacturing management philosophies. The examination and statistical
analysis of performance measurements gathered through the comparison of the three WIP inventory control methods achieves such an increase.

The increase in knowledge has come in the evaluation of WIP inventory methods of a production planning and control system and the effect of excess work-in-process inventory. The models also provided information that would help identify key characteristics that are expected to be present in similar typical environments. The results should be extendable to various other typical flow shop assembly environments.

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