A Simulation Study on Protective WIP Inventory and its Effect on Throughput and Lead-Time Requirements

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Abstract

This research compared the variables of throughput and lead-time requirements based on the WIP inventory control systems of three different management philosophies through computer simulation. The philosophies were examined in typical assembly line environments and based on WIP inventory control systems of

- Part buffers and a push system – MRP;
- Kanbans and a pull system – JIT;
- Time buffers and a hybrid push-pull system – TOC.

The analysis was based on data gathered in three separate simulations that were identical in design except for the WIP inventory control methods and their buffers. In both performance measurements the WIP inventory control methods of the TOC management philosophy exceeded the outcomes of the MRP and JIT models. Inventory, traditionally considered as an asset, over and above the minimal requirements for production, will have a negative effect on the performance measurements.

Introduction

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. Taylor (1999) states that this disparity is brought on by a miscellany of unplanned events that transcend typical manufacturing operations. He goes on to state the development of production control systems would be simple except for the existence of these unplanned events.

These unplanned events consist of (but not limited to) machine breakdowns, tool breakages, worker absenteeism, lack of material, scrap, rework, customers who change their minds on timing and quality, etc., and the fact that operations are interdependent. Development of random fluctuations and dependent events cannot be prevented, but they can, and should, be compensated.

Because of the two basic phenomena of random fluctuations and dependent events, which are indigenous to the manufacturing environment, 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. The question now is how much and where?

Sage (1984) states that inventory is the largest manageable asset, and yet the reasons for this investment are seldom thoroughly examined or challenged. Goldratt and Fox (1986), Tersine (1988), Taylor (1999), and Taylor (2000) have demonstrated how reducing work-in-process (WIP) inventory levels allows for quicker new product introduction, higher level of quality, higher margins, lower investments per unit, improved due date performance, and more accurate forecasts. Umble and Srikanth (1990) also agree that inventory reduction in manufacturing can be very beneficial. Lower levels of inventory mean the overall investment is less and return on investment greater.

Tersine (1988) notes that at some point the reduction of inventory will interfere with operating efficiency and customer service. Deming (1982) and Hendrick and Moore (1985) state that inventory control methods attempt to reach several objectives that are actually in direct conflict

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with each other. The production and sales functions would prefer rare stock-outs, while keeping as little cash as possible tied up in inventory, while simultaneously avoiding the high cost associated with excessive setups that are synonymous with small production runs.

This environmental set of circumstances leads to an enormously difficult task of optimizing the level of WIP inventory. 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. It is management's responsibility to overcome conflict.

Integrating the shop floor activities and various machining centers with protective capacity is an accumulation of the decisions results based upon a management philosophy. A modern assembly line often incorporates machine centers that are linked together by a material handling system. Different vendors with different levels of automation may manufacture each of these machine centers. The variation in the level of automation, along with the proper placement of WIP inventory, will serve as throughput protection.

When dealing with manufacturing work-in-process inventory control systems, a problem arises when the need to answer critical questions goes un-addressed, such as:

- Which WIP inventory control schemes to employ;
- How to assign protective WIP inventory to the associated work centers; and
- How to coordinate the WIP inventory required to assemble the products.

MRP WIP Inventory Control Methods

The WIP inventory control method used in Material Requirements Planning is based on buffer control. The APICS Dictionary (1992) defines a buffer as: "A quantity of materials awaiting further processing. It can refer to raw material, semi-finished stores or hold points, or a work backlog that is purposely maintained behind a work center." Because the WIP inventory control method for a MRP-based system is schedule oriented, the material is literally pushed through the process to assure adherence to the predetermined schedule. This push system will allow WIP inventory to build in areas where capacity is insufficient to handle the load. The APICS Dictionary (1992) defines a push system as: "The production of items at time required by a given schedule planned in advance. In material control, the issuing material according to a given schedule and/or issuing materials to a job order at its start time." A push system permits the advancement of additional WIP inventory regardless of current levels.

Tersine (1988) states that the main idea behind WIP inventory control in MRP is based on the assumption that extra inventory of components with a dependent demand would normally serve no function; therefore it would not be needed. On the other hand, safety stock for components may be desirable to cushion uncertain lead times, scrap losses, and shrinkage. Tersine goes on to state that while independent demand for the end product may be variable, the dependent demand for components that make up the products deterministic and is dictated by the master production schedule.

JIT WIP Inventory Control Methods

Schonberger (1982), Hall (1984), Sage (1984), and Heard (1986) all state that JIT has several requirements, and one of which is a pull method of production. The WIP inventory control method used in the Just in Time management philosophy pull system is called kanban. The APICS Dictionary (1992) defines kanban as: "A method of Just in Time production that uses standard containers or lot sizes with a single card attached to each. It is a pull system in which work centers signal with a card that they wish to withdraw parts from a feeding operation or supplier." This kanban system must reduce the level of inventory and improve the synchronized movement of material through the plant. The APICS Dictionary (1992) 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."

As reported by Umble and Srikanth (1990), JIT kanbans are not without their limitations: JIT systems have at least four significant limitations. 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 is 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.

TOC WIP Inventory Control Methods

The WIP inventory control method used in the Theory of Constraints is based on buffer control. Buffer control 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. Goldratt and Cox (1992), Goldratt and Fox (1986), and Goldratt (1990) described DBR techniques in detail. Additional studies by Schragenheim and Ronen (1989) and Demmy and Petrini (1992a,b) also explain DBR in detail. The APICS Dictionary (1992) defines buffer as: "A quantity of materials awaiting further processing. It can refer to raw material, semi-finished stores or hold points, or a work backlog that is purposely maintained behind a work center."

The physical difference between the buffers used in MRP and the buffers used in TOC rest in the fact that the MRP buffers are based on a physical count or are limited by the amount of actual storage space, while the buffers of TOC 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 worth will fluctuate. Demmy and Petrini (1993) state that buffer management offers a powerful approach for improving productivity of shop floor operations.

MRP, JIT, and TOC Comparison Literature

Everdale (1984) reviewed the three management philosophies of MRP, JIT, and TOC. He resolves: that JIT proceeds one step further than TOC and does not synchronize operations and eliminates many `Murphy's' that TOC recognizes as constraints. However, TOC, like JIT does not address all the planning support activities of MRP. Two other studies, performed by Plenert and Best (1986) and Sohal and Howard (1987) support the same conclusions. They state in their studies that JIT and TOC are both more productive than MRP, and TOC is more complete than JIT. Fogarty, Blackstone, and Hoffman (1990) state the MRP approach to the problem of random fluctuations and dependent events is to eliminate dependence by holding large safety stocks at every workstation. They go on to state that the JIT approach is to eliminate the random problems by exposing them.

Both MRP and JIT believe that plants are balanced to the point that every work center has the same output potential. TOC approaches the problem by accepting the fact that balanced plants just do not exist. Some work centers will have more or less production potential and the one with the least will be the system constraint. In this event, TOC breaks dependencies by establishing material buffers only at constraints. Non-constraints will usually not have material buffers but will deal with the dependency through excess capacity. Fogarty, Blackstone, and Hoffman (1990) point out that to add inventory to a non-constraint will cause an increase in lead-time and cause WIP inventory to increase with little tangible benefit. On the other hand, buffering the constraint from the random problems of the non-constraints and allowing the constraint always to have material to process, is an asset and does add value to the production. Only problems that threaten constraint production are eliminated.

Research Methodology and Model Development

Overview

The flow shop assembly line environment used in this study was selected from one of several assembly lines of a Texas manufacturing company. The manufacturing 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 managers with similar assembly lines the same basic information.

To conduct this research, three separate simulation models of a 29-station flow shop assembly line were developed. Several independent variables for each workstation were manipulated to observe their impact on the two dependent variables, of throughput and lead-time requirements. To determine which inventory control method and the associated management philosophy would afford the manager the greatest benefits, the following two research questions were addressed. They were based on the performance measurements listed above and asked the question, what affect if any did the management philosophy have on the operational performance measurement of throughput and the production performance measurement of lead times

The Simulation Models

To create the simulations in this proposal, the simulation package SIMFACTORY 6.1 was employed. SIMFACTORY performs what is called discrete event simulation (CACI 1993). Discrete event simulation is system modelling by taking the continuous processes that happen in the real world and breaking them down into key events that occur (CACI 1993). In an assembly operation, parts move from one work center to the next, with a process operation taking place while at that operation. 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 modelled. The most important aspect of modelling these operations was to represent accurately the operation's processing time by simulating the statistical distribution. Each of the three simulations was based on the separate work-in-process inventory management philosophies of MRP, JIT, and TOC. Although these three management philosophies have several aspects in common, they operate with different WIP inventory control methods for throughput protection. The parameters of the models are detailed below and compared in Table1.

MRP-Based Model

In the MRP-based model, the input to the assembly line was represented by the work being released by the master production schedule. The flow of these orders was not limited to the current rate of production at the time of order release. They were released according to production requirements that would keep material flowing at all workstations. The WIP inventory was pushed through the system to meet the production demands.

Orders should not be released prematurely because planned components and purchased parts may not be available at the time of requirement. Holding back on orders that the system is trying to release might cause a backlog of following orders that will become late before they are ever started into the system. With MRP, it is important that orders are released with the correct priority and sequence. When there is a call for the MPS to undergo a major change, the MRP system may unload a large amount of orders onto an already overloaded production system. As long as the capacity of the work centers and the number of products on order is still valid, the MRP system should be allowed to run its course without interference at the order release point.

The MRP WIP inventory control method is based on buffers of parts that are located in front of every production work center. Because MRP assumes infinite capacity, there is normally no pre-established basis of control other than the checks and balance procedures of the MRP system and the physical storage capacity of the storage area. When order release 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 output of new orders, then the level of WIP inventory will decrease. With MRP it is important to ensure all of the buffers contain parts to ensure operations protected from lost throughput. Maintaining the arrival pattern of raw material and the amount of future work required to meet the schedule makes this assurance.

WIP inventory was regulated not to exceed 10 pieces of work in any of the queues. The down stream WIP inventory level was allowed to increase to the maximum capacity at every queue and conveyor before the feeding operation ceases to produce. This rule was be in effect at every operation but the last. All operations were allowed to fill the queues and conveyors to the maximum level at any time of the production process.

JIT-Based Model

In the JIT-based model, the input to the assembly line was also represented by the work being released by the Master Production Schedule. The flow of these orders was limited by the current rate of production at the time of order release. They were released as demand required. The WIP inventory is pulled through the system to meet the production demands. The JIT WIP inventory control method uses what are referred to as kanbans. The kanbans consisted of parts measured in units of containers that 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. Holding back orders that the system is trying to release might cause a hole in the production process. This lack of work calls for the entire production process momentarily to shut down until the kanban was filled.

For the final operation to meet its production requirements, it drew parts from the previous work center as required. The work center that fed the final operation only made parts enough to replace inventory that the final operation consumed. Each work center of the assembly line operation followed the procedure of replacing only what was taken by the next operation. This sequence continued all the way up-stream until it reached the first operation.

Because the number of containers and the size of the containers can be varied, a question may arise as to the appropriate process batch size and transfer batch size. Whatever the choice, it is important to ensure that the kanbans are present and that they provide an adequate level of WIP inventory to protect throughput at all operations. Kanban placement was based on the number of given work centers in the assembly line process and the fixed number of parts required to fill the kanbans at each of the work centers. 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 fill the kanbans to the level of one part any time a part was transferred to the next position.

TOC-Based Model

In the TOC-based model, the input to the assembly line was slightly faster than the time represented by the production time requirements of the drumbeat. The drumbeat was the rate in which orders are being produced by the system's constraint. The flow of these orders was slightly faster than the current rate of production at the constraint to ensure the constraint operation that it would not be starved for material to process.

TOC uses what is referred to as forward scheduling because it focuses on the critical resources. The WIP inventory is pulled through the system at every operation with the exception of the operation that is considered to be the system constraint. At the system constraint, the WIP inventory is pushed to meet the production demands. With TOC, it is important that orders are released according to drum-buffer-rope priority and sequence. The system's non-constraints are then scheduled to support the critical resources and are scheduled backward to minimize the length of time WIP inventory is held.

The TOC WIP inventory 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. There is no need for additional WIP inventory (with the exception of the buffer inventory at the constraint). The WIP inventory control method associated with the TOC-based model was based on what is referred to as a hybrid push-pull system. The WIP inventory was controlled through buffers that were placed in front of the constraint. As the buffers were depleted of inventory, the work centers were allowed to replenish the inventory. All work centers were required to work when work was present, and sit idle when work was not present.

Performance Measurements

The following two measurements of throughput and lead-time requirements were used to study the results of the simulations and determine which method of WIP inventory control will afford the manager the greatest reward.

Throughput

Throughput is the level of sales that the business is producing not the level of production itself. The reason for this distinction is because production does not generate funds for the business until the product is sold. The APICS Dictionary (1992) defines throughput as follows: "The total volume of production through a facility (machine, work center, department, plant, or network of plants). In the Theory of Constraints, it is the rate at which the system generates money through sales." Throughput was calculated by deducting the cost of goods sold in the production of the product from the total sales revenue. Total sales were calculated by multiplying the number of parts to exit the last operation by the unit sales price. For the purpose of this study, there were no market constraints.

Everything produced was sold. This ensured that the system constraint remained within the assembly process itself. As shown in Table 1, TOC finished 1st, JIT finished 2nd, and MRP finished 3rd.

Table 1

Simulation Model Comparison

	MRP	JIT	TOC
Input to the assembly line will be represented by	Cost contents of MPS	Cost contents of MPS	Production time requirements of drumbeat
Flow of orders	Not limited to current rate of production	Limited to current rate of production	Limited to current rate of system constraint
Orders released according to	Required production lead times and due date performance	Assembly line demand	Constraint consumption
Scheduling	Backward off MPS	Backward off MPS	Forward off constraint
Pressure placed on WIP inventory	Pushed to meet MPS	Pulled to meet MPS	Pulled everywhere except for constraint where it's pushed
Buffer type	Parts buffer	Kanban containers	Time buffers
Buffer locations	Before every location	Before and after every location	Before and after constraint
Buffer size	Function of checks and balances system of MRP and physical storage capacity of area	Based on size and number of kanbans	Number and value of parts vary while processing time is held constant

Lead-Time Requirements

Lead-time requirements can be described as the total amount of time required to process, produce, or manufacture a product from the initial order conception to final transfer or delivery. The total amount of time might consist of order preparation, order transit, manufacturing and assembly, all transit times, and inspections. In some cases lead-time might even involve operations outside the organization. Lead-time is defined in the APICS Dictionary (1992) as: "A span of time required to perform a process (or a series of operations)." The makespan data output for the final operation was equal to lead-time. As shown in Table 2, TOC finished 1st, JIT and MRP tied 2nd.

Table 2

Dependent Variable Evaluation Results

MEASUREMENT	OBJECTIVE	MRP-PUSH	JIT-PULL	TOC-PUSH/PULL
THROUGHPUT (dollars)	MAXIMIZE	$18,006.90 (3)	$19,421.90 (2)	$19,988.60 (1)
LEAD TIME (minutes)	MINIMIZE	279.08 (2)	279.08 (2)	278.64 (1)

Conclusions

The purpose of this research was to evaluate the effects of inventory on throughput and lead-time requirements 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. In this study, it is important to point out just how the level of 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. The asset value reduction leads to lower carrying costs thus reducing the cost of goods sold. With a reduction in the cost of goods sold, increased throughput is possible.

In this study, material was released into all of the models at a steady rate. The rates were sufficient to allow for an inventory build-up at all buffers. The inventory level that was allowed at the constraint buffer in the TOC model was actually larger than that was required for protection and lengthened the makespan. If material had been released according to traditional TOC drum-buffer-rope methods, the amount of WIP inventory contained in the constraint buffer could have been maintained at a lower level. This lower inventory level would have allowed the parts to move through the constraint buffer at a faster rate, thus shortening the lead time requirements.

It is also important to point out that the average final daily assembly production of all three models in both weeks was identical; achieving the theoretical maximum allowable production, with the exception of week one of the TOC model. The theoretical maximum daily assembly production of all models was 1,050 units per day based on a 100% utilization of the system constraint. The average daily production for week one of the TOC model fell short by one unit at 1,049 units. The cause for this shortfall was strictly due to the inventory level of the constraint buffer falling to zero early in the simulation and momentarily starving the constraint. The drop in inventory level was due to random fluctuations and the dependent events that preceded the constraint buffer. Had this week's production been maximized, the throughput measurements for the TOC model would have been greater.

As the level of WIP inventory is reduced, the production area becomes less cluttered and more orderly, and quality problems become evident at an earlier date. With lower makespans in the assembly process and quality problems becoming evident at an earlier date, final production orders will be produced in less time and lead time requirements will be reduced. If quality problems become more evident at an earlier date, there will be less scrap and rework to deal with. This is what is considered as a positive feedback loop and in turn will reduce the level of WIP inventory. These conclusions are diagramed in a future reality tree (Figure 1).

In both performance measurements the WIP inventory control methods of the TOC management philosophy exceeded the outcomes of the MRP and JIT models. 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 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 minimize the level of WIP inventory effectively, it can increase throughput and reduce lead-time requirements. These improvements would allow the company to become more competitive in world markets.

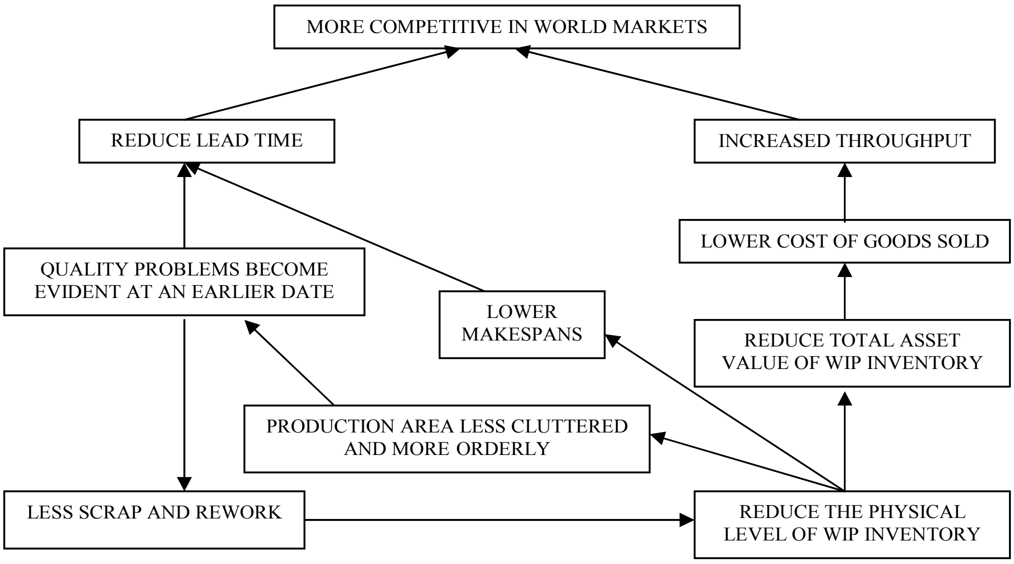

Fig. 1. Future Reality Tree

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