AN INTEGRATION ANALYSIS OF MATERIAL REQUIREMENTS PLANNING, JUST IN TIME, AND THE THEORY OF CONSTRAINTS

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ABSTRACT

This study will detail many strategic aspects of MRP, JIT, and TOC in the areas of planning, execution, and scheduling of production systems. Critical questions will be addressed such as which control schemes to employ, how and where to assign WIP inventory, how to coordinate WIP inventory, and how to introduce raw materials into the system. There are several components of the three strategies that actually complement each other and go hand in hand. Using certain aspects of these three philosophies will allow management to minimize WIP, which will transcend an outflow of positive benefits. The implications of using MRP as a planning tool, JIT as an execution tool, and TOC as a scheduling tool could be very advantageous when applied to the right application.

STATEMENT OF THE PROBLEM

Orlicky (1975) and Fogarty, Blackstone, and Hoffman (1990) note that variation between the master production schedule 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 events consist of (but are 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 for through strategic planning.

When dealing with manufacturing control systems, problems arise when the need to answer critical questions go un-addressed, such as:

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<td>1.</td>
<td>Which control schemes to employ,</td>
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<td>2.</td>
<td>How to assign protective WIP inventory to the associated work centers,</td>
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<td>3.</td>
<td>How to coordinate WIP inventory required for assembly of the products, and</td>
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<td>4.</td>
<td>How to introduce raw material into the system.</td>
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IMPORTANCE OF THE RESEARCH

Aggarwal (1985) states: A revolution is occurring in operations management. During the last few years, three important approaches--material requirements planning (MRP), kanban (JIT), and optimized production technology (OPT) (or TOC)--have invaded operations planning and control in quick succession, one after the other. 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 strategy to adopt to meet current and future needs. Installing any one requires several years to train company personal and millions of dollars of investment. Aggarwal goes on to state: During the remainder of this century and perhaps during the early part of the next, managers will 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 it self, 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.

It will be of significant importance to the practitioner to discern the relative differences and the associated considerations that evolve around the strategic choice of an inventory control method and management philosophy. This review had the goal of minimizing the investment of time and capital required in making that choice.

PURPOSE OF THE RESEARCH

The purpose of this research will be two fold. The first objective will be to detail the many positive and negative aspects of MRP, JIT, and TOC as they apply to a manufacturing system. The second objective will be to bring about and develop a new concept of an integrative model of MRP, JIT, and TOC. This new model actually considers the most positive strategic aspects of each management philosophy and ties them together in a usable format. The format should assist strategic management in the areas of planning, execution, and scheduling of its own production process.

MATERIAL REQUIREMENTS PLANNING LITERATURE REVIEW

Starting in the sixties and on into the seventies, the basic elements of an integrated production planning and control system known as MRP were established. Orlicky (1975) states: In some rudimentary form, it (MRP) has no doubt existed as long as manufacturing. It has been evolving gradually, moving onto successively higher plateaus with every enhancement in data-processing capability. Material requirements planning had its origin 'on the firing line' of a plant. Practicing inventory managers and inventory planners have painstakingly developed it into its present stage of relative perfection.
MRP is a planning system that performs calculations to determine the net gross requirements for a stated dependent demand. Through the bills of materials, MRP explodes the top level of part number demand. It then considers inventory currently on hand along with current orders and balances the net requirements for production. Tersine (1988) claims MRP enables manufacturing organizations to maintain minimum levels of dependent demand items, yet it assures that production schedules for the independent items can be met. By attempting to produce and manufacture on an as needed basis, MRP makes an effort to drive excess WIP inventories to zero.

Contrary to Tersine’s position, Fox’s (1980) report on Booze, Allen, and Hamilton’s survey, and a survey by Anderson, Schroeder, Tupy, and White (1982) have indicated that the majority of the firms that have attempted MRP implementation have had less than satisfactory results. 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 as usual. Additional surveys by LaForge and Sturr (1986) and Cerveny and Scott (1989) substantiate these findings.

Many of the problems inherent to MRP can be based on the requirements that are placed on it. Ptak (1991) reports: MRP is not an execution tool. It only recommends actions that human planners must either ignore or carry out. Most importantly it is capacity insensitive. It does not check the feasibility of the master schedule. It is solely the processing logic to determine the requirements to fulfill this externally supplied plan (schedule). Chang and Yih (1994) and Spearman (1992) agree, due to capacity constraints (in MRP) lead times are over estimated and WIP inventory levels are further increased.

JUST IN TIME LITERATURE REVIEW

The first records of the JIT management philosophy stem from the efforts of Henry Ford and his assembly line operations. The Japanese in general and Toyota specifically have taken the approach and concepts of Ford and expounded on them. The JIT philosophy has led to the development of systems that intended to reduce the amount of required WIP inventory, and thus to remain competitive in the market.

The elimination of waste is the fundamental driving force of the JIT philosophy. Waste is considered to be anything beyond the absolute minimum resources of manpower, materials, or machinery required to add value to the product. Value is added to the product only with the effort of direct labor. Indirect labor adds cost but not value. Cost without value, is considered to be waste and should be minimized if not eliminated. Because of the limited natural resources of Japan, this philosophy is a natural strategic fit for the Japanese society.

After World War II, the United States began to lose ground on its competitive advantage. The first reaction was to copy the JIT management philosophy of Japan. The problem with this was the JIT philosophy is not just a software package that could be bought off the shelf and implemented. The JIT philosophy is considered to be a relentless never-ending crusade for the total
elimination of waste, and increasing respect for people. This idea cannot be limited to manufacturing alone, but must be extended throughout the entire organization.

Burnaham (1987) points out that JIT implementation has been successful in the United States when effectively implemented. The success can be attributed to an emphasis on learning new ways to train employees, on improving cooperation, and on determining role change needs. He also states there are a few major barriers to implementation such as the fear of change, the misplaced focus on labor savings, the use of efficiencies, and the lack of human relations development as a method of improvement. Another study conducted by Im and Lee (1989) revealed benefits based on the implementation of JIT. They summarize the possible improvements to production planning, shop floor control, master production scheduling, and material requirement planning.

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 problems as interfacing with existing MRP systems and line balancing.

Bartezzaghi and Turco (1989) reported on the impact of JIT as it applied to production performance. 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.

Schonberger (1982) and Schonberger and Gilbert (1983) have reported that major drawbacks exist in the implementation of JIT because they require a long time to implement successfully. Even though the system is relatively simple, implementation, which involves education, training, improved supplier relationships, etc., can be arduous.

THEORY OF CONSTRAINTS LITERATURE REVIEW

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 established in 1979. 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.

Goldratt and Cox (1992), authors of the book "The Goal," demonstrate how methods of management in several areas of manufacturing can be improved. These areas have historically been managed by decisions based on traditional managerial cost accounting assumptions. They go on to state that since people have sufficient brainpower, they just need to look at reality logically. Challenging present assumptions is essential to strategic breakthroughs, yet few challenge these assumptions. In a study by Frazier and Reyes (2000), they describe how one manufacture, in a three-month implementation period, reduced WIP inventory to 1/3 of its original value, reduced raw material inventory by 30%, and on-time completion of projects increased by more than 20%. Umble and Umble (2001) report similar findings with reductions of 60% in WIP, on time deliveries at an
astounding 94.6% with sales increasing by 15%. Miller (2000) adds that with TOC, companies are more flexible, robust, and responsive than ever before.

The Theory of Constraints is based on a combination of logic and intuition directed toward the purpose of continuous improvement. The intuition required is based on an educated sense that is developed through experience. The logic is derived through utilizing Effect-Cause-Effect analysis with features that check accuracy, logic, and the actual existence of the cause and effects and their associated relationships.

According to Rack and Rack (1993): TOC is a thinking process used to analyze problems, create or choose appropriate solutions and get buy-in to achieve successful results. Although it is demonstrably very powerful, it is not difficult to understand. Because the process utilizes how man was designed to think, it works for almost everyone interested in tapping into his/her own abilities. The appropriate use of the thinking process significantly impacts the goal and is intrinsically rewarding to the one(s) using it.

Goldratt (1990) states that if you focus on everything under the realm of your responsibility you in fact focus on nothing. Therefore he states that you should focus only on a small portion of it; spreading attention equally to all portions of the area means no concentration whatsoever, no focusing. With this thought in mind, there must be areas that would require concentrated efforts. Those areas of needed concentration should be the areas that make up the weak link in the operation.

The main force behind TOC is based on a desire of continuous performance improvement by maintaining a process of ongoing improvement. The improvement is always concentrated on and stems from Goldratt's (1990) five steps of constraint management, which are as follows:

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<tr>
<th>Step</th>
<th>Description</th>
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<td>1.</td>
<td>Identify the system's constraint(s).</td>
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<tr>
<td>2.</td>
<td>Decide how to exploit the system's constraints.</td>
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<tr>
<td>3.</td>
<td>Subordinate everything else to the above decision.</td>
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<tr>
<td>4.</td>
<td>Elevate the system's constraint(s).</td>
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<td>5.</td>
<td>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.</td>
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These five steps are a simple framework for the 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. An integral part of TOC consists of the following framework:

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<th>What to Change?</th>
<th>Description</th>
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<td>What to Change to?</td>
<td>Devise simple, practical solutions.</td>
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<tr>
<td>How to Cause the Change?</td>
<td>Cause others to invent or discover the ideas.</td>
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The three elements of change are techniques for verbalizing our intuition so we can check its soundness and communicate it clearly to others. Because formal education has been based on
the Aristotelian rather than the Socratic approach, one's logic skills are often not well developed in
the above areas.

MRP, JIT, AND TOC COMPARISON LITERATURE REVIEW

The three management philosophies of MRP, JIT, and TOC were reviewed by Everdale (1984) based on his experiences in operations management. He resolves: "Suffice it to say that JIT proceeds one step further than OPT and does not synchronize operations and eliminates many 'Murphy's' that OPT recognizes as constraints. However, OPT, like JIT does not address all the planning support activities of MRP, since OPT focuses primarily on Master Scheduling, Material Requirements Planning, and Capacity Planning, integrating these to a far greater degree.

Two other studies, evaluating the three management philosophies, performed by Plenert and Best (1986) and Sohal and Howard (1987) support the same conclusions. They state in their studies that JIT and OPT are both more productive than MRP, and OPT is more complete than JIT. Fogarty, Blackstone, and Hoffman (1990) have stated that the MRP approach to the problem of random fluctuations and dependent events is to eliminate the dependence by holding large amounts of safety stock at every work station. They go on to state that the JIT approach is to eliminate the random problems by exposing the problem and eliminating it. Both MRP and JIT believe that the ideal plant is 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 (Goldratt 1991). In this case, 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 the constraints. Non-constraints will usually not have material buffers but will deal with the dependency through excess capacity buffers. Fogarty, Blackstone, and Hoffman (1990) point out that to add inventory at a non-constraint will cause an increase in lead-time and cause WIP inventory to increase with little tangible benefit.

Cook (1994) and Lambrecht and Segaert (1990) conclude that DBR (TOC) leads to significantly higher level of throughput when compared to the same system under a JIT/Kanban control system. Lockamy and Cox (1994) and Ronen and Spector (1992) state that TOC can be used to aid in focusing on system improvements and adoption of JIT. Thuannadee (2000) states that scheduling material flow from the bottleneck in some form of JIT style has the greatest effect on lowering WIP inventory levels. Miltenburg (1997) expounds on the various elements on MRP, JIT, and TOC and how they can be successfully embedded into each other.

INTEGRATION OF MRP-JIT-TOC

As stated in the introduction, one of the objectives was be to bring about and develop a new concept of an integrative model of MRP, JIT, and TOC. This new model actually considers the most positive strategic aspects of each management philosophy and ties them together in a very manageable format. The format should assist strategic management in the areas of planning, execution, and scheduling of its own production process.
There is no single method of management that best fits in all environments due to the many variations in production and the many positive and negative aspects of MRP, JIT, and TOC. Production variability in the 'real world' depends upon statistical fluctuations and not mean-value averages. Traditional MRP systems deal with the phenomenon of production variability by assigning inventory buffers and building excess inventory in front of all work centers. If an operation breaks down, final production is ensured by the protective capacity supplied by the excessive inventory buffers that were implemented at the down-stream locations. The problem with this is the amount of inventory that is required and the wide range of problems that are associated with excess inventory.

If the bill of materials and physical inventories were 100% accurate 100% of the time, MRP, through its checks and balances system, would no doubt be successful in driving duplicate and misplaced work-in-process inventories to zero. For this reason, an accurate and complete bill of materials and inventory database are two of the most significant MRP instruments available to the production manager in today's business environment. But because MRP itself is capacity insensitive, it would still do little to control the overall level of work-in-process inventory and the rate at which material was pushed into the system.

While MRP itself cannot execute a schedule, it can be an excellent mid- and long-range strategic planning tool. It can recommend quantitative production schedule requirements for a deterministic dependent demand based on an externally supplied independent demand. This independent demand is normally created and supplied by the market. The master production schedule used to produce the dependent demand must be produced by a finite scheduling system that takes into consideration demand capacity requirements and system process capacities at all resources. If the schedule does not consider production capacities, it runs the risk of prematurely releasing and advancing additional material, which will overload and bog the manufacturing process down; or it will starve the process by holding back the needed material that will ensure a continuous flow of production.

JIT deals with the phenomenon of production variability in a similar way. JIT still requires buffers, but also makes an attempt to eliminate the variability within the system by balancing the production process to the point where inventory buffer capacity requirements are near zero. It builds inventory at all work centers but holds the level of inventory to a minimum and allows the inventory to proceed only when there is a place for it to go. Spencer (1993) reports that if all of the inventory in a JIT system could be eliminated, it would outperform any other system. But until that can be achieved, the advantage of implementing protective capacity in the form of strategically positioned buffers is documental.

Attempting to remove all of the variability in the system is not cost effective. So to combat the variability in production, the protective buffer sizes are made positive in value to ensure continuous production. This increase in buffer size increases the level of WIP inventory. It is also a fact that some work centers will require more buffer protection than others, such as the system constraint or critical capacity resources (near constraints). If the constraint buffer is insufficient in size, and the constraint is starved for material to process, overall production will suffer and throughput will go down. If the size of the protective buffers at critical capacity resources are too small, and the resources operation is halted for a significant period of time, they may produce a
down-stream ripple effect and starve the constraint of needed inventory for production. Because these situations occur, the manager is faced with strategic decisions based on balancing the benefits of buffering; the cost associated with the increased level of inventory, and lost production.

On the other hand, TOC deals with the phenomenon of production variability by building protective capacity buffers only at the system constraint and possibly the critical capacity resources. It allows for the excessive production capacity of all other work centers to supply the protective capacity required to combat process variability. For this reason, protective capacity buffers are not required at non-constraints, and work-in-process inventories can be kept to a true minimum (or zero). TOC makes an attempt to reduce the process variability at the constraint, but does not concentrate much effort in eliminating variability at non-constraints. Here TOC makes an excellent contribution to the real-time scheduling requirements of the system constraint. In formulating a strategic integration of the three management philosophies, the following information would be required:

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<th>Current orders on hand and the sales forecasts. This information is essential in creating the independent demand.</th>
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<td>Accurate bill of materials, current engineering change notices, and new product introductions. This information is required to determine the dependent demand.</td>
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<tr>
<td>3</td>
<td>Current work-in-process inventories and the forecasted inventory receipts. This information creates the inventory database.</td>
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The above information would be essential in creating the demand capacity requirements of parts and subassemblies that correspond to the independent demand. Demand capacity requirements and system process capacities should be input into a finite scheduling system to create a realistic master production schedule based on the systems constraint production capabilities.

From this, inventory control reports can be produced and used as feedback for the current inventory level. Also lead-time requirements can be formulated to generate forecast inventory receipts. Due date performance can be regulated and controlled, and shipping dates can be quoted by the sales department with greater accuracy.

Raw material should be released into the system according to the master production schedule, which should be at a rate of material consumption at the constraint. (See Diagram 1) The rate of material consumption at the constraint is the production drumbeat. If raw material is released upstream from the constraint at a rate that is faster than current constraint consumption, inventory will build. Likewise, if raw material is released upstream from the constraint at a rate slower than current constraint consumption, the constraint will be starved for needed material and overall throughput will suffer.

Regardless of the rate of material consumption at the constraint and the rate of new material release, the buffer in front of the constraint should always contain an appropriate amount of protective production capacity that will ensure continuous operation. This is referred to as the production buffer. (See Diagram 1) The size of this buffer should be measured in units of
production time. Also a company-wide focus on total quality management and preventive maintenance is essential in protecting throughput at the constraint.

This rate of material consumption at the constraint should regulate the rate of new material release and that in turn will control the buffer that operates in support of the constraint. All operations between the system constraint and the initial release of raw material should work when material is present. The rule here would be to integrate a JIT kanban type system between these stations that would allow for a predetermined amount of inventory to build at all station queues that operate in front of the constraint.

These operations would continue to build small amounts of inventory that would attempt to ensure a smooth flow of material to the constraint but not build excess inventory through continuous operation. This is referred to as the production rope. (See Diagram 1) The operations that follow the constraint should be allowed to work when work is present and sit idle when it is not. There would be no need to purposely build any inventory at those locations because they have excess production capacity and would normally stay ahead of the constraint production.

TOC and JIT have many aspects that are similar. They both operate with a shared interest in continuous improvement, they both emphasize total quality management, and they strive for a reduction in WIP inventory. They do not strive for high efficiencies, as does MRP, since this only results in an increase in unnecessary WIP inventory.

No matter what the production situation, it would be virtually impossible for the total system to generate a finished product any faster than the slowest operation within that system. Because of this, releasing and pushing material into the system at a rate faster than constraint consumption only
serves to build unneeded and detrimental work-in-process inventory throughout the manufacturing process.

There are several components of the three strategies that actually complement each other. First, MRP is an excellent planning tool but does very little in the area of execution because it assumes infinite production capacity and will not deal with WIP inventory levels. MRP without JIT and TOC will never inject the appropriate level of raw material into the system. It will always be starved for or overloaded with material to process.

Second, JIT does not have the ability to plan a production schedule but it can and will control WIP inventory and keep it at a bare minimum at non-constraints. JIT cannot tell you what to make but it will tell you when to make it and how much to transfer to the next operation.

Third, TOC is the master scheduling tool. TOC used what is referred to as a drum-buffer-rope (DBR) scheduling operation. It recognizes the system constraint that limits production and schedules the introduction of raw materials into the system at the rate at which the constraint can consume them. The rope figuratively ties all of the work centers including the constraint together, and subordinates them to the constraint. This is where a true JIT pull system should be implemented. As the work center consumes a part from its buffer the JIT system will immediately replace it. And finally, a buffer needs to be assembled in front of the constraint to ensure production never stops.

CONCLUSION

This paper detailed many strategic aspects of MRP, JIT, and TOC in the areas of planning, execution, and scheduling of production systems. There were several critical questions addressed such as which control schemes to employ, how and where to assign WIP inventory, how to coordinate WIP inventory, and how to introduce raw materials into the system. It was demonstrated that there are several components of the separate management strategies that actually complement each other. Using the positive aspects of these three philosophies will allow management to minimize WIP, which will transcend an outflow of positive benefits.

The additional benefits of WIP inventory minimization include but are not limited to improvements to planning, control, and scheduling operations along with reduction in costs and lead time requirements. Additional benefits will consist of a higher rate of on time completions, increased sales, and processes that become more flexible, robust and responsive. The implications of using MRP as a planning tool, JIT as an execution tool, and TOC as a scheduling tool could be very advantageous when applied to the right application.
REFERENCES


