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MRP, JIT, AND OPT:
A COMPARISON ON THE PRODUCTION FLOOR

BY

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B.S., University of Central Florida, 1983

RESEARCH REPORT

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ABSTRACT

In order to compete in manufacturing, industry realizes it must work more efficiently with its resources. Three manufacturing techniques have been developed to assist industry in this challenge --MRP, JIT, and OPT. This paper compares these three techniques. It concentrates on the factors that affect production after vendor materials are in-house. A brief discussion of some of the implementation difficulties a company may face during the transition to a new philosophy is also addressed. Finally, a case study of a low volume, highly technical military project is evaluated and analyzed.

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INTRODUCTION

In order to compete in manufacturing, industry realizes it must work more efficiently with its resources. To accomplish this, a company must simultaneously increase throughput, reduce inventory, and cut operating expenses (Meleton 1986, 13). The U.S. sees a need for change in manufacturing methods in order to meet the foreign challenge. Three manufacturing techniques have been developed to assist industry in this challenge -- MRP (Manufacturing Resources Planning), JIT (Just In Time), and OPT (Optimized Production Technology) (Plenert and Best 1986, 27).

What Is MRP?

MRP is an approach for calculating material requirements not only to generate replenishment orders, but also to reschedule open orders and to meet changing requirements. It is thought of more as a scheduling technique than an inventory ordering technique. There are a wide range of computer packages available to facilitate implementation in any size company.

What is JIT?

JIT is an approach to achieving excellence in a manufacturing company based on the continuous elimination of waste and the consistent improvement in productivity. Waste is defined as those things that do not add value to the product. The production process side of JIT has five fundamental areas: multifunctional operators, workplace organization, preventive maintenance, standardized containers, and minimized setup times. JIT is not a software package. A wide range of companies offer training courses in its philosophy.

What is OPT?

OPT is a product of Creative Output Inc. (COI). The company is marketing OPT as more than just a software package. It provides a complete system for production planning, materials planning, and resource scheduling. COI believes that for users to be successful in using OPT, it is important that they adopt the entire OPT philosophy. Its main thrust centers around bottleneck resources. OPT emphasizes "an hour lost at a bottleneck is an hour lost for the total," whereas, "an hour saved at a non-bottleneck is just a mirage."

Research Emphasis

The purpose of this paper is to compare the principles of the three manufacturing techniques -- MRP, OPT, and JIT. It concentrates on the factors that affect production after vendor materials have arrived in-house. These factors include operator cross-training, process setups, lot sizes/work-in-process (WIP), quality, scheduling, bottlenecks, inventory, capacity, flexibility, data accuracy, cost, and production. Also addressed are the difficulties encountered while attempting to incorporate new manufacturing philosophies into an established manufacturing plant. After reaching conclusions from the research, a low volume, highly technical military project is evaluated and analyzed.

COMPARISON

Differences Between Countries

The history of the systems gives insight as to how and why each was developed. MRP was developed in the U.S., JIT in Japan, and OPT in Israel. The working environments in the U.S., Japan, and Israel are extremely different. For example, in the U.S. there is no land space restriction and factories tend to be very spread out. Land space is a problem in Israel and is extremely restrictive in Japan where it becomes a major constraint for production (Plenert and Best 1986, 22).

In the U.S. the major market for manufactured products is within the country. In Japan and Israel, the major markets for their products are outside of the country. Repairs or replacements to defective products are highlighted by the fact that they are thousands of miles away from their originating facility. In the U.S. , repairs are not that expensive and it is sometimes desirable to make a lower quality product so that replacement profits can be generated (Plenert and Best 1986, 22).

The U.S. has an abundance of product variability. The customers are offered as many options as possible in the design and development of their products. Japan, on the

other hand, restricts the product output to only a few selections. Product modifications are extremely difficult in the Japanese environment, and it is also more difficult to give efficient turnaround response time on customized products when they have to be shipped overseas. The Israeli system claims to be a compromise of these two methodologies, allowing more product variability than the Japanese system (Plenert and Best 1986, 22).

Because of these differences, the U.S. has developed a different methodology for production than Japan or Israel. U.S. factories are typically very large and spread out, which allows a large build-up of the inventory necessary to handle the product variability requirements (Lundrigan 1986, 23).

Employee Cross-Training

Cross-training allows for effective problem solving. A flexible worker can participate when problems arise at any point on the line, rather than just their particular operation (Goddard 1986, 53). U.S. industry has placed emphasis on the productivity of the individual operator, in contrast to the Japanese and Israeli philosophy of "team productivity," or of productivity of the facility as a whole. The difference can be seen in the job-costing techniques that the U.S. uses: pieces per hour for each individual operator. This puts the operator under a time

restraint to build products, whether or not they are needed, with a speed rather than a quality orientation (Plenert and Best 1986, 23). Task specialization tends to be preferred in U.S. repetitive processes (Rice and Yoshikawa 1982, 7). For JIT and OPT, total participation leads to flexibility on the part of the labor force -- workers being cross-trained in a variety of operations (Goddard 1986, 52).

In cellular manufacturing, which allows production to go up and down with demand, worker flexibility between operations is extremely important (Goddard 1986, 52). Cellular systems are more effective if operators are cross-trained and can move from one manufacturing process to another as the need demands. Cells can be arranged to produce different daily quantities by moving people in and out of each cell (Goddard 1986, 121).

One area of major concern when speaking about a flexible work force is the involvement of unions. Bringing the unions into the process in the beginning allows them to understand what the company is trying to accomplish (Goddard 1986, 52).

Setups

The objective of JIT is the elimination of waste. Every time the product is handled to move it, more is built than necessary, it is stored, or it is idle, then waste is being added. One area where this becomes clear is with large lot sizes and their basic cause --machine setup time (Goddard 1986, 19).

The JIT system is based on the assumption that setup and order costs are negligible. It requires great effort to force the real shop environment into being consistent with this assumption. The operators are responsible for pursuing this target. They spend much time and effort studying each operation to try to reduce setup times to zero. The task is not delegated to industrial engineers, but engineers may work with the operators (Rice and Yoshikawa 1982, 7).

Setup time cost is the factor in the economic production quantity (EPQ) equation that sets the lower limit on lot size, which is an important step in escaping from lot-oriented parts ordering and moving toward JIT (Schonberger 1983, 36). JIT supports the fact that as setup times approach zero, lot sizes can approach one. This would allow production to mirror the immediate requirements (Goddard 1986, 19). As JIT, zero inventory, and flexible manufacturing systems concepts begin to be more widely applied, setup time will become increasingly less of a driving issue

in American industry. The "best" algorithm for finite loading will have to reflect this (Vollmann 1986, 45).

Set-ups are an important factor in creating a flexible production environment. There are some steps involving internal and external setups that can be used to reduce these times. Internal setups require the machine be stopped, such as mounting and removing dies. These are items which will interrupt the run time. External setups are those activities that can take place while the machine is running, such as transporting dies between storage and machine. These items are external to the run time, and do not affect it. The steps to reducing or eliminating internal setups are as follows:

1. Separate the internal setup from the external setup.
2. Convert, where possible, internal setups to external setups.
3. Eliminate the adjustment process.
4. Eventually, eliminate setups altogether (Goddard 1986, 66).

Set-up time plays an important role in the OPT approach. It is a major factor in deciding lot sizes and in running larger lots through bottleneck work centers (Vollmann 1986, 45).

The OPT philosophy dictates that setups must be saved at all costs but only for bottleneck operations, which on the average number less than five. The lot sizing is established to schedule material arrival at bottlenecks for long, efficient runs (Meleton 1986, 14).

Lot Sizes/WIP

"The worst things that can happen in a manufacturing process are:

1. To produce bad product
2. To hide problems and inefficiencies with inventory, and
3. To interrupt the flow of product." (Goddard 1986, 82)

There are several disadvantages to large lot sizes: large WIP inventories, the need for extra storage space and increased storage costs, lower quality, a greater chance of obsolescence, increased material handling costs, and difficulty in leveling work on the shop floor (Goddard 1986, 65).

Large lot sizes also encourage poor work center scheduling. If work centers have overlapping functions, delays in the first work center will cause start-up delays in the second work center. If efficiency is being measured, the second work center will appear inefficient, whereas the first can make up its delays by speeding up processing near the end of its lot. The second work center, because of its delayed start-up, will not be able to recover time lost from these delays (Plenert and Best 1986, 24).

On the other end of the spectrum, there are several advantages to reducing lot sizes: reduced inventory, improved product quality, reduced space requirements, increased capacity -- if total setup times are reduced, and efficient use of equipment and labor (Goddard 1986, 65).

Less WIP inventory reduces overall investment, speeds up the production cycle time, and makes it easier to monitor the progress of work through the plant. It also makes it possible to move machines closer together, which makes it easier for operators at adjacent machines to communicate with and help one another. The next step is to link machines together through automatic materials handling devices (or even to pass parts manually from worker to worker) and then to increase the number of machines under each worker's supervision. Eventually it may allow the entire automation of closely coupled groups of machines (Hayes and Wheelwright 1984, 358).

JIT has been described as the Japanese-style "hand-to-mouth" material management approach. JIT strives to provide parts in small quantities, ideally one at a time rather than in lots, just in time to go into the parent item. A parts order usually consists of several full standard containers. While this is not one at a time, the quantity involved is generally less than a day's worth and sometimes is only an hour's worth, which approaches the ideal of lotless JIT parts delivery (Schonberger 1983, 36).

In between JIT operations, WIP inventory is kept to a minimum. Material moves along in a steady flow, assisted by material handlers, automated material handling equipment, and the workers. Buffer inventories of partially completed work are not needed at each work station to avoid

delays caused by breakdowns at earlier process stages. Such delays almost never occur. Emphasis is given to preventive maintenance, monitoring of machine performance, and optimized machine speeds (Hayes and Wheelwright 1984, 358).

Finished goods are moved quickly from the floor as well. The inventory that is generated is placed in special boxes at specified places around the plant. These areas are marked, like the aisles, with painted lines (Hayes and Wheelwright 1984, 358).

Most MRP packages allow a large number of lot-sizing rules. These rules either ignore ordering and carrying costs, or include static cost information in computing optimal lot sizes. Carrying costs and setup costs used by MRP are static, fixed-condition values. OPT takes the position that lot sizes should be determined on dynamic information. In the real world, the setup costs on a bottleneck machine could be several thousand dollars (more product could be sold if the machine were running). On a nonbottleneck machine, there are no "real" incremental costs for extra setups (the machine would be down anyway) (Swann 1986, 33). OPT determines lot sizes based upon maximizing plant throughput. There is no way to duplicate this feature with MRP (Swann 1986, 33).

In reality, lot sizes continually vary. Under the assumption of economic lot quantities (ELQ), computer-planned lot sizes are kept larger than is necessary in

order to offset the costs incurred by large setup times. A reduced setup cost is allocated per part. Increased lot sizes will increase the product lead times. This increases carrying and storage costs which will translate into increased overall cost (Plenert and Best 1986, 24).

MRP does not have the ability to split lots or send ahead partial lots (Swann 1986, 30). MRP establishes a lot size for a finished part, then calls for that quantity to be processed at every operation in the routing of the part. For example, the quantity of a component required at final assembly is 175. MRP builds a work order to shear, drill, bend , weld, debur, and paint 175 units. It may make sense to shear 500, drill 350, bend 225, weld, debur and paint 175. OPT logic proposes to establish lot sizes by operation for a given part. This is based on the capacity and priority constraints on the floor at the time the part is to be processed at each operation (Swann 1986, 33).

The same goal could be achieved using MRP software, but this would require the creation of additional part numbers. Lot sizing in MRP is tied to a part number. MRP allows one lot per work order and one part number per work order. Thus, if MRP was used to generate "orders" to shear 500 pieces, then drill only 350 of these pieces, then two separate work orders must be generated, which implies two separate part numbers. Given two numbers, MRP would then allow "optimal" lot sizes to be set for each part. If

10,000 parts were to be routed, each with five-step routings, then 50,000 parts would have to be created -- all with one-step routings. Conventional MRP software could then be used to establish lot sizes for each part/operation (Swann 1986, 34).

This awkward technique could be refined by recognizing the "bottleneck" operations. On the average there are normally five or fewer bottleneck operations in a company. Bills of material in MRP could be constructed to show a logical "break" where the bottleneck operation occurs. The advantage of a tool that allows lot sizing by operation is the ability to split lots and send ahead partial lots. The MRP data base could be structured to accomplish lot sizing by operation. Several drawbacks would result: lot sizes would still be set on static parameters, not computed to optimize the schedule; the data base would be significantly larger (part numbers); work orders would be numerous; and work order management would be more complex (Swann 1986, 34).

The OPT "network" database structure, wherein all routing, bill of material, inventory, cost, and part data are in one file, allows for the "lot size by operation" capability discussed above, and is more efficient from a standpoint of computer processing time (Swann 1986, 34).

JIT and OPT have overcome the lot size problem. In the case of JIT, the strategy is to reduce all setup times

to a minimum so that it will not be a significant factor in determining lot sizes. Then lot sizes can be kept small. In the OPT computer system, variable lot sizes are computed. Additionally, OPT suggests the minimization of setup time in the bottleneck work centers, thereby maximizing the output in these areas, which in turn maximizes the output of the whole facility. OPT believes the reduction of setup time in nonbottleneck work centers only increases the amount of unused capacity (Plenert and Best 1986, 24).

Quality

One of the primary areas of waste in a manufacturing environment comes from poor quality (Goddard 1986, 12). Inspection is an area affected by the reduction of lot sizes. With reduced lot sizes, quality issues take on even greater significance. Because there is less material traveling down the line, quality problems can be highlighted quickly, especially when the responsibility for inspection is turned over to the operator at the source. As lot sizes approach one, quality problems need to be detected before they are passed on to the next work station, or the line could be shut down. By transferring inspection duties to the source, many of the internal inspection and testing steps can be eliminated. As has been said, "Inspectors do nothing to improve quality, they only monitor a process after it's too late" (Goddard 1986, 73).

The JIT system does not tolerate defective parts moving forward between production processes. Attention is devoted to detecting defective quality, improving rework procedures, and identifying the causes for variances. The target objective of zero defects is actively pursued (Rice and Yoshikawa 1982, 7).

In both the Japanese or Israeli systems, quality becomes a part of an operator's function. An operator is not evaluated by the number of parts produced, but rather by how closely total production matches the required production without the generation of any excess inventory or waste. This concept is commonly referred to as "pull" versus "push" (Plenert and Best 1986, 23).

Push vs. Pull

U.S. MRP systems are considered push systems. This means that a list of required materials is generated in order to produce a specific number of output units. This in turn generates purchase orders and production orders. There are often large scrap factors inserted that will generate an excess of needed materials "pushed" out at the purchasing end (Plenert and Best 1986, 23). Material is moved as soon as it is ready for the next operation. The feeding operation then works on the next scheduled job. To illustrate this, the market demand for X and Y is translated into a production schedule for Y and production

schedule for X. Both Y and X are lot-sized to economize on ordering and setup costs. Residual inventories of X and Y WIP or final products are usually generated and then depleted during the interim period before the next production cycle. (Rice an Yoshikawa 1982, 5).

Typically, in a push system the feedback loop is much longer than with demand pull. The process might continue building and piling up inventory at a bottlenecked work center. With a demand pull system, which allows a company to maintain visual capacity controls, the flow is immediately stopped until the problem work center is cleared (Goddard 1986, 114).

The JIT system contrasts with the MRP "push-through" approaches in that it strives to eliminate buffer stocks. In JIT, the market demand for Y becomes a production schedule for Y, but the component parts are "pulled through" on a lot-for-lot basis (Rice and Yoshikawa 1982, 5).

In OPT, production is not scheduled with either a "push" or "pull" technique, but on a "bottleneck" basis. The bottleneck areas in a facility are analyzed and then emphasized. Production is planned so that the bottleneck work centers will be utilized to the maximum and all other departments will feed the bottleneck departments so they are working at full production at all times (Meleton 1986, 23). OPT allows buffer stock only at the bottleneck

resources. This will enable product to flow smoothly if a problem appears. Nonbottleneck resources do not require buffer stock since they do not directly impact the flow of production.

Scheduling

Conventional MRP allows only sequential date setting and capacity requirements calculations (Swann 1986, 30). In other words, it assumes that operation number two cannot be started on a lot of material until operation number one is complete. If run times are long and there are a high number of consecutive operations, then the difference between actual and predicted elapsed processing time could be significant. If extensive overlapping is done on the floor, but is not predicted in the scheduling algorithm, then actual elapsed times will be shorter than predicted. If run times are eight hours or longer for a lot, then each overlap could collapse lead times as much as one shift over consecutive processing (Swann 1986, 35).

JIT will not work at all if the Master Production Schedule (MPS) is not constructed to generate continuous, repetitive use of components. Short lead times and small lot sizes are mandatory. A company achieves better results with MRP when the MPS is stable, setup times are reduced, lot sizes are smaller, and lead times are shorter; but these characteristics are not mandatory for the system to

work (Garwood 1983).

In JIT, materials are not fed into the production cycle until the finished product is actually required. Product requirements, not forecasts, trigger production. This is easier to do in Japan because of much shorter lead times. Because the U.S. builds to projected forecasts, large inventories accumulate to satisfy anticipated requirements (Meleton 1986, 23).

Most Japanese industries which apply the JIT system are setup on a general one-year rough-cut master schedule, a one-to-two-month horizon for the detailed production schedule, a ten-day production schedule, and a daily schedule. The ten-day schedule is about 99% reliable or fixed. Each daily schedule is prepared on the previous day. The production manager is in charge of executing the daily production schedule while holding lot sizes as close as possible to one and holding levels of all raw materials and WIP as close as possible to zero (Rice and Yoshikawa 1982, 6).

OPT attempts to do exactly what any intelligent scheduler does. It attempts to avoid scheduled idle time on bottleneck (greater than 100% load) work centers; assign production away from overloaded machines into machines with available capacity; alter lot sizes; combine setups; and send ahead partial lots. It also establishes priorities at operations, thus making "real" queue times for some parts

less than average (expedited parts), or more than average (less time-critical parts) (Swann 1986, 30).

In OPT, production is scheduled on a "bottleneck" basis. The bottleneck areas in a facility are analyzed and then emphasized. Production is planned so that the bottleneck work centers will be utilized to the maximum. All other departments (which are not bottlenecks) will be planned to keep the bottleneck departments working at full production (Meleton 1986, 23).

If there are no bottlenecks, OPT operates very much like classic MRP, but it will also reduce lot sizes to the point where some resources almost become bottlenecks. The result is less WIP, reduced lead time, and a move toward zero inventory. Much of this is accomplished by overlapping schedules using unequal lot sizes for transferring and processing (Vollmann 1986, 42).

A fundamental philosophy in OPT is that an hour lost in a bottleneck resource is lost to the entire factory, while an hour gained in a nonbottleneck resource has no real benefit. This is why capacity utilization of bottleneck resources is of utmost importance. It is achieved through the use of WIP buffers at bottlenecks. Running large lot sizes at bottlenecks reduce the relative time spent in setup, while smaller lots are run through nonbottlenecks at no incremental cost. There are two implications of these procedures: lead times should be shorter so

that smaller lots will move faster through nonbottleneck work centers, and procedures have to be developed to split/join lots as they go through processing (Vollmann 1986, 42).

There are areas in which OPT could use MRP ideas and software subroutines to its advantage. A case in point is master production scheduling. OPT takes forecast and customer order data as inputs to the OPT Product Network, which is equivalent to using only demand management. MRP also uses the production plan as input and then does what-if analysis using rough-cut techniques. Doing this before the MPS is fed back to OPT produces fewer changes in the MPS down the line, as well as forcing managers to face some key judgments that should not be handled by computer subroutine default (Vollmann 1986, 45).

OPT does have an important contribution to make to the field of manufacturing planning and control. Viewed as a shop floor control technique, it outputs a "smart" detailed shop schedule that concentrates on the most important resources in the factory. By finite loading these bottleneck resources only, the computational cost is significantly reduced. Perhaps even more important, by concentrating on the bottlenecks, OPT schedules are less disrupted by the "cascading disturbances caused by the ever present Murphy" (Vollmann 1986, 45).

OPT also makes an important contribution as a master production scheduling procedure. Feedback from the finite loading of the bottleneck resources to the MPS results in an updated MPS that is doable. OPT resolves at least partially, the conflicting priorities produced by finite loading procedures and MRP. By forward finite loading only those work centers or resources that are bottlenecks, inconsistent due date priority problems will be greatly reduced (Vollmann 1986, 46).

OPT offers an advantage in the case of a job shop with many work stations. OPT can reportedly produce a detailed schedule that takes into account capacities and competition for resources that are too difficult for humans to perform. In addition, fine tuning of costs versus delivery time provides even greater flexibility for OPT's performance (Meleton 1986, 18).

Departmental delays compound themselves as lots move through the production sequence; the result is production "waves," which result in "wandering" bottlenecks. These production waves in an MRP system are balanced through the use of safety stock (Plenert and Best 1986, 24).

In JIT, the entire production sequence is forced to stay in synchronization. A delay at one station delays work at all stations proportionately. Kanban cards and a series of red or yellow lights are used to manage the "heartbeat" of production. The production sequence is

always synchronized and production waves are not allowed to occur (Plenert and Best 1986, 24).

In OPT, production waves are prevented by tighter scheduling by use of safety capacity. Nonbottleneck work centers all have some amount of excess capacity that is used to handle overloads of production. The emphasis is not on "keeping the worker busy," but rather on keeping production flowing smoothly (Plenert and Best 1986, 25).

OPT supplies a more complete schedule than JIT; however, the speed at which JIT supplies a schedule is hard to beat. The speed at which MRP schedules are developed is such that OPT's time performance looks impressive in comparison (Plenert and Best 1986, 25).

OPT offers many scheduling advantages: they are not as time consuming to setup, they do not require as much data, less data accuracy is required, and less computer processing capability is required. In addition, less manpower is required to analyze the schedule, quick schedules allow for the quick modification of the schedules and therefore more flexibility in the schedules, changes can occur in hours rather than days, and quick schedule development allows for simulation to be used in the scheduling process (Plenert and Best 1986, 26).

Bottlenecks

Bottlenecks are created every time required capacity exceeds actual capacity in a work center. With the informal system, bottlenecks are discovered after WIP piles up on the shop floor. When the supervisor says "Just release the work, get it out on the shop floor and we'll get it out," that is a dead giveaway that the informal system has taken over. This is an "after the fact solution." Work gets behind schedule before the bottleneck is discovered and can be reduced (Garwood 1985).

The concept of OPT is that bottlenecks determine the throughput of the plant, thus, only bottleneck-related dates are critical (Plenert and Best 1986, 31). Resources are separated into bottleneck and nonbottleneck resources. Bottleneck resources are scheduled for maximum utilization and nonbottlenecks are scheduled to feed the bottlenecks (Meleton 1986, 14).

Bills of material, routings, and capacities for nonbottleneck processes do not have to be precise, since they do not affect throughput. In other methods, engineers define every part in every bill of materials, when in fact some parts just are not important (i.e., low cost items that can best be handled by two-bin or other line stock techniques) (Plenert and Best 1986, 31).

OPT is described as a form of computerized JIT. Like JIT, OPT concentrates on bottlenecks to improve production,

run small lots, and allow more setups. Unlike JIT, OPT allows planning in advance for bottlenecks rather than forcing the shutdown of operations as they occur. Therefore, the chief advantage of OPT, is its ability to model the company's current or future production requirements, predict bottlenecks, and allow corrections before the problems actually occur. The JIT system must continually monitor its production lines and operators to locate the wandering bottlenecks. OPT releases the workers from this type of pressure and the requirement to locate and solve the problem during production (Meleton 1986, 19).

Inventory

"Microeconomic theory in the U.S. has commonly proposed that the general objective of any company is to maximize profits by maximizing revenues while minimizing costs." A company that is involved in repetitive manufacturing would prefer to "attain steady production rates of each product on separate production lines, with all production of component parts and all deliveries of purchased parts items feeding smoothly and continuously into the assembly lines over perfectly balanced and efficient feeder lines" (Rice and Yoshikawa 1982, 8). In practice, however, capacities are limited and must be used for different products, and procurement is generally discontinuous. Thus, productive stages and capacities must be separated and uti-

lized in flexible fashion (Rice and Yoshikawa 1982, 8).

Both the JIT and MRP systems recognize that the EPQ formula might be useful for certain independent demand inventories, but it is usually a poor description of the production process. Two critical problems in production processes are that demand is generally very lumpy, and time phasing must be controlled. The JIT system focuses on the lumpiness of demand and the establishment of work priorities. It does this by continuous, close monitoring and control of work flow rates; constant intervention by workers and managers, and the use of the kanban tickets to authorize and track activity. The EPQ formula tries to show the trade-off for minimizing holding costs against setup costs for building the buffer inventory between operations. The JIT system tries to eliminate the need for any buffer inventory and to improve priority control but at the potential cost of excessive setup charges (Rice and Yoshikawa 1982, 8). JIT might be looked upon in part as a kind of an MRP system in which the time increments are very short --possibly only minutes or at most an hour or two in length The MRP master schedule is exploded into requirements and requirements that are generated are time phased to appear just-in-time (Rice and Yoshikawa 1982, 9). The JIT system therefore assumes, and enforces, that setup costs should be negligible. JIT minimizes holding costs by minimizing stock levels (Rice and Yoshikawa 1982, 8).

Shifting the load off the stockroom is exactly what JIT point-of-use storage is all about. As the name implies, this places inventory at the actual point of use. Point of use storage means a company can avoid double handling material and reduce the potential for damage (Goddard 1986, 73).

To make this technique work, it is important that the quantity at the point-of-use is small; otherwise a company is doing nothing more than relocating the stockroom. Without rapid turnover, the associated problems of accurate, stationary inventory will most likely crop up (Goddard 1986, 73).

The EPQ formula tries to estimate, on an average basis how large inventories should be between successive work centers to compensate for unbalanced lines. JIT tries to balance lines perfectly to eliminate this need. JIT benefits from each worker being able to do different tasks as needed. U.S. firms have trouble balancing lines because workers tend to be specialized. MRP accepts unbalanced lines and tries to quickly react to changes in work queues on a net requirements basis (Rice and Yoshikawa 1982, 9).

MRP usually explodes requirements according to whatever lead times are fed into the calculations. When it appears that production will fall past-due, the first option is often to compress lead times by expediting and lapping operations, before resorting to restating the mas-

ter schedule. JIT tries instead to normally compress lead times, using operations-lapping and line rebalancing as standard procedures (Rice and Yoshikawa 1982, 10).

One study revealed some interesting Japanese attitudes toward computerized control. One interview was with a Japanese manufacturer of computers that was using JIT for production control. Being computer-oriented, they expressed some interest in moving toward more information display on CRT's and more computerized data management. A second firm interviewed was an automobile manufacturer. They try to use CRT's as much as possible in the centralized control centers but have no interest in ever using CRT's on the shop floor. Their reasoning is that they believe that the visual control and human concern coming from the JIT system are absolutely necessary for production management. A third manufacturer was found to have unsuccessfully tried to install an MRP system and was now considering getting rid it. A fourth firm uses MRP for long range control and JIT for daily control (Rice and Yoshikawa 1982, 10).

Capacity

The OPT approach is to finite schedule the bottleneck operations and not try to rebalance nonbottleneck operations. One area in which OPT is superior to MRP is in the area of capacity planning. OPT limits the load in bottle-

neck areas to 100% as a constraint of the planning process. Thus repeated iterations are not needed to "schedule away" overloads. The planner's job using OPT is not to juggle the MPS, lot sizes, or capacities. The job is to communicate and explain why due dates will be missed. What OPT can also do is tell you much sooner, and without the repeated iterations of MRP, when you have met an immovable object and must change delivery dates (Swann 1986, 36).

MRP can also produce prioritized schedules, tied together from the MPS down to each department via bills of materials and routings. Such "integrated" schedules are an improvement over independently-developed order point or "short list" schedules. If a company has capacity constraints, complex routings, significant setups, and if in general MRP, despite accurate data, just will not produce good schedules, then OPT is a more appropriate scheduling tool than MRP (Swann 1986, 36).

Flexibility

JIT is by far the most flexible because of its minimal lot sizes and low inventory levels. However, OPT, since it also tends to schedule lower levels of inventory, and since it allows for flexible lot sizes, allows for more flexibility in production than MRP (Plenert and Best 1986, 25).

OPT does not require a total reorganization of the factory as JIT does, but OPT still offers many of the same

benefits. In installing an OPT system, the entire factory is not necessarily affected, since OPT can be phased into the factory. OPT also allows for parallel operation with the MRP system so the proper operation of the OPT system can be assured (Plenert and Best 1986, 25).

Data Accuracy

In MRP, data accuracy is critical throughout the entire system. In OPT, data accuracy is only critical in the bottleneck areas. Both MRP and OPT require sophisticated computer systems to generate production schedules, but OPT is typically faster (Plenert and Best 1986, 25).

OPT needs less accuracy for nonbottleneck parts and work centers, but greater accuracy for bottleneck parts. Since both programs require detailed knowledge of product structures, processes, data bases, and accurate transaction processing as well as managerial commitment, there is no basis for believing OPT is easier to understand or implement (Vollmann 1986, 43).

OPT is an example of separating "the vital few from the trivial many," and thereafter providing a mechanism to utilize this knowledge for better manufacturing planning and control. (Vollmann 1986, 43).

In JIT, the need for data accuracy becomes almost zero. Computer systems are not needed in JIT. Production flow is managed so tightly by sight that a computer would

not produce information quickly enough (Plenert and Best 1986, 24). The Japanese language alone, with over 2000 characters, prevents any realistic way of implementing a computer system.

Cost

The benefits of a completely simulated production plan are best realized with OPT. MRP is too complex, and JIT is not complete enough for simulation planning (Plenert and Best 1986, 25).

MRP, because of its high data accuracy requirements, is the most costly. JIT, because of its negligible data requirements, is the least expensive. OPT, once again, falls in between (Plenert and Best 1986, 25).

Because of the improved ability for production planning and the ease in changeover, OPT is the best production and inventory control technique when a changeover from MRP is desired (Plenert and Best 1986, 26).

Production

MRP and JIT techniques have some similarities. The factory must be consistently on schedule. Machine breakdowns, delays, etc., must be at a minimum. Both techniques require excellent quality, for example, very little scrap or rework (Goddard 1983).

MRP requires a computer and is best when in an environment of job-lot manufacturing with large product variety

-- a highly competitive environment. It improves customer service, and cuts excess inventories. MRP works even with diverse product lines and deep bills of material (Schonberger 1983, 39).

JIT requires only peripheral computer use. It is best when used in an environment of repetitive manufacturing with moderate product variety. JIT drastically cuts inventories and simplifies planning and control (Schonberger 1983, 39).

Although both techniques have similar prerequisites to be effective, they have a few significant differences. MRP can be applied in any manufacturing company -- job shop, process industry, repetitive manufacturing or one-of-a-kind engineered to order products. JIT cannot (Goddard 1983).

JIT itself -- without the computer and MRP processes -- is capable of reducing inventories even more than MRP or OPT. JIT reacts to shop floor conditions instead of planning in advance. In the JIT system a manually prepared card circulates with each standard parts container to identify the part and its source and destination. The using work center sends empty containers, with kanban identifiers, back to supply points when more parts are needed. The number of standard containers of a given part number is set equal to the demand during leadtime, plus a small buffer to account for output variability. The Japanese use JIT as a productivity improvement device: When a supervisor removes

a container and its kanban, the reduced inventory buffer runs a risk of running short parts -- unless the worker providing the parts can avoid work delays. The incentive to avoid work stoppages smooths output, cuts buffer stock, and improves productivity (Schonberger 1983, 37).

MRP production scheduling systems sequence tasks as if the plant has infinite resources available. Schedules are adjusted by adding a clean-up step, capacity requirements planning (CRP). This two-step procedure cannot be as efficient as developing the optimal schedule in one step. Both JIT and OPT schedule production assuming a limited capacity. In JIT, the Kanban card is used to control capacity. In OPT, the bottleneck is used. Additionally, OPT, by allowing for more variable constraints than MRP, merges the MRP and CRP functions into one production planning tool (Lundrigan 1986, 24).

OPT production benefits include: bottlenecks in the production process are specifically defined; improvements are easily made on the bottlenecks because of their clear definition; simulation can be used to test variations in plant output and how this will effect the plant load; capacity changes can be simulated; actual manufacturing resources are taken into account; and maximization of output and simultaneous minimization of WIP inventory occurs as a basis for optimization (Plenert and Best 1986, 26).

Available Computer Packages

JIT is not offered as a computer package since it is not a software program. Research found only one source of OPT -- Creative Output, Inc. of Milford, Connecticut. No pricing information could be obtained.

A wide range of companies offer MRP packages. Examples include Anacomp; RSD, Inc.; and MADIC. The Anacomp package costs $40,000, allows a maximum of 100,000 part numbers, and an infinite number of BOM levels. The RSD, Inc. package sells for $10,000, allows infinite part numbers, and a maximum of ninety-nine BOM levels. MADIC's package is priced at $105,000, allows infinite part numbers, and seventeen BOM levels. The different MRP packages vary in capacity, interfaces, and modules. Implementation support by the various companies also differs.

SUMMARY

The history of the systems gives insight as to how and why each was developed. MRP was developed in the U.S., JIT in Japan, and OPT in Israel. The working environments in the U.S., Japan, and Israel are extremely different. For example, in the U.S. there is no land space restriction and factories tend to be very spread out. Land space is a problem in both Israel and Japan where it becomes a major production constraint.

In the U.S. the major market for manufactured products is within the country. In Japan and Israel, the major markets for their products are outside of the country. Repairs or replacements to defective products are highlighted by the fact that they are thousands of miles away from their originating facility. In the U.S., repairs are not that expensive and it is sometimes desirable to make a lower quality product in order to generate a replacement market.

The U.S. offers a wide range of product variability. Japan, on the other hand, restricts the product output to only a few selections. Product modifications are extremely difficult in the Japanese environment, and it is also more difficult to give efficient turnaround response time on

customized products when they have to be shipped overseas. The Israeli system claims to be a compromise of these two methodologies, allowing more product variability than the Japanese system.

Because of these differences, their exists a difference in production methods. U.S. factories are typically very large and spread out, which allows a large build-up of the inventory necessary to handle the product variability requirements.

MRP production scheduling systems sequence tasks as if the plant has infinite resources available. Schedules are adjusted by adding a clean-up step, capacity requirements planning (CRP). This two-step procedure cannot be as efficient as developing the optimal schedule in one step. Both JIT and OPT schedule production assuming a limited capacity. In JIT, the Kanban card is used to control capacity. In OPT, the bottleneck is used. Additionally, OPT, by allowing for more variable constraints than MRP, merges the MRP and CRP functions into one production planning tool.

The U.S. industry puts workers under a time restraint to build product, with a speed rather than a quality orientation. For JIT and OPT, workers are cross-trained. Cross-training allows for effective problem solving. A flexible worker can participate when problems arise at any point on the line, rather than just their operation.

The JIT system is based on the assumption that set-up costs and order costs are negligible. Much effort is needed to force the real shop environment into being consistent with this assumption. The workers are responsible for pursuing this target. Setup time plays an important role in the OPT approach. It is a major factor in deciding lot sizes and in running larger lots through bottleneck work centers. The OPT philosophy dictates that set-up times must be reduced and saved at all costs but only for bottleneck operations; thereby maximizing the output in these areas, which in turn maximizes the output of the whole facility.

The JIT objective is to hold all lot sizes at zero. The strategy is to reduce all setup times to a minimum so that they will not be a significant factor in determining lot sizes. OPT determines lot sizes based upon maximizing plant throughput. Variable lot sizes are computed. It does so dynamically, considering conditions as they actually exist. MRP systems assume that a part is passed through all stages of production in a fixed-size lot. In reality, lot sizes continually vary. MRP keeps lot sizes larger than is necessary in order to offset the costs incurred by large setup times. MRP does not have the ability to split lots or send ahead partial lots.

As order quantities are reduced, quality issues take an even greater significance. By transferring inspection

duties to the source, many of the internal inspection and testing steps can be eliminated. The JIT target objective of zero defects is actively pursued. In both the Japanese and Israeli systems, quality becomes a part of an operator's function.

U.S. MRP systems are considered push systems. There are large scrap factors inserted into production that generate an excess of need materials "pushed" out at the purchasing end. The JIT system strives to eliminate buffer stocks. Component parts are "pulled through" on a lot-for-lot basis. OPT production is not scheduled with either a "push" or "pull" technique, but on a "bottleneck" basis. OPT allows buffer stock at bottleneck resources only, as these are the only points that directly impact the production flow.

Conventional MRP assumes that operation number two cannot be started on a lot of material until operation number one is complete. JIT mandates short lead times and small lot sizes. Production requirements, not forecasts, trigger production. The JIT production manager is charged with executing the daily production schedule while holding lot sizes as close as possible to one unit of production and holding levels of all raw materials and WIP as close as possible to zero. In OPT, production is planned so that the bottleneck work centers will be utilized to the maximum and all other departments which are not bottlenecks will be

planned to keep the bottleneck departments working at full production at all times. A fundamental philosophy of OPT is that an hour lost in a bottleneck resource is lost to the entire factory, while an hour gained in a nonbottleneck resource has no real benefit.

Departmental delays compound themselves as lots move through the production sequence; the result is production "waves," which result in "wandering" bottlenecks. These production waves in an MRP system are balanced through the use of safety stock. In JIT, the entire production sequence is forced to stay in synchronization. A delay in one station delays work at all stations proportionately. In OPT, production waves are prevented by tighter scheduling and through the use of safety capacity.

OPT considers production bottlenecks as the basis for scheduling and capacity planning, and requires resources to be separated into bottleneck and nonbottleneck resources. Like JIT, OPT concentrates its attention on bottlenecks to improve production, run small lots, and allows more setups. Unlike JIT, OPT allows planning in advance for bottlenecks rather than forcing the shutdown of operations as they occur. The chief advantage of OPT, therefore, is its ability to model the company's current and future production requirements, predict bottlenecks, and allow corrections before the problems actually occur.

JIT shifts inventory from the stockroom to the place of actual use. It tries to balance lines perfectly to eliminate the need for large component inventories between successive work centers. U.S. firms have trouble balancing lines because workers tend to be specialized.

The OPT approach is to finite schedule the bottleneck operations and not try to rebalance nonbottleneck operations. OPT limits the load in bottleneck areas to 100% as a constraint of the planning process. Thus, repeated iterations are not needed to "schedule away" overloads. MRP assumes infinite capacity.

JIT is by far the most flexible because of its minimal lot sizes and low inventory levels. However, OPT, since it also tends to schedule lower levels of inventory and since it allows for flexible lot sizes, allows for more flexibility in production than MRP.

In MRP, data accuracy is critical through the entire system. In OPT, the strain is lessened somewhat in that data accuracy is only critical in the bottleneck areas. In JIT, the need for data accuracy becomes almost zero.

MRP, because of its high data accuracy requirements, is the most costly. JIT, because of its negligible data requirements, is the least costly OPT falls in between.

MRP does well in what it was designed to do -- plan materials. MRP can also provide shop schedules that are superior to manually developed independent schedules. Both

MRP and OPT requires a solid foundation. A company may, in fact, find it needs both tools: MRP for net requirements and OPT for realistic shop schedules. Using OPT as a schedule tool in, for instance, a job shop, does not preclude the need for accurate bills of material and disciplined inventory planning and control. MRP is the appropriate tool to provide bill of material and inventory management features. OPT is not "easy MRP", and is no more likely than MRP to produce good outputs from bad inputs.

OPT claims to take the best of MRP -- a computerized data base system -- and the best of JIT --improvements in flow and the elimination of waste -- and combines them.

MRP and OPT work best in a job-lot manufacturing environment with a large product variety. They can both work with diverse product lines and deep bills of materials. JIT, on the other hand, works best under repetitive manufacturing environments with moderate to low product variety.

The conclusion of this study is that both JIT and OPT are more productive than MRP, and the OPT system is more complete than the JIT system. The OPT system develops a detailed operating philosophy, not just an operating procedure, and it includes many of the features of the JIT system and additional benefits as well.

SUMMARY CHART

	MRP	JIT	OPT
CROSS TRAINING	not addressed	necessary	necessary
SET UPS	not addressed	reduce to negligible	reduce only in bottlenecks
LOT SIZES/WIP	fixed, large lots	lot size=1	variable
QUALITY	not addressed	important	important
PUSH VS PULL	push	pull	neither
SCHEDULING	not flexible	based on demand	bottlenecks dictate
BOTTLENECKS	safety stock	N/A	safety capacity
INVENTORY	not addressed	point-of-use	not addressed
CAPACITY	infinite	N/A	finite
FLEXIBILITY	least	most	middle
DATA ACCURACY	critical	not needed	critical only in bottlenecks
COST	most	least	middle

CONCLUSIONS

MRP does well in what it was designed to do -- plan materials. MRP can also provide shop schedules that are superior to manually developed independent schedules. Both MRP and OPT requires a solid foundation (Swann 1986, 37). A company may, in fact, find it needs both tools: MRP for net requirements and OPT for realistic shop schedules. Using OPT as a schedule tool in, for instance, a job shop, does not preclude the need for accurate bills of material and disciplined inventory planning and control. MRP is the appropriate tool to provide bill of material and inventory management features (Swann 1986, 36). OPT is not "easy MRP", and is no more likely than MRP to produce good outputs from bad inputs (Swann 1986, 37).

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FUTURE RESEARCH

Suggestions for additional research include: the detailed implementation process involved for each technique and the detailed discussion of potential problems that will need to be overcome; the investigation of how vendor location, service and quality is handled by each technique; the study of companies that have attempted the implementation of OPT and the successful and unsuccessful results; a detailed study of implementing new production techniques in a union environment.

IMPLEMENTING NEW PRODUCTION PHILOSOPHIES

Many managers believe a good portion of their responsibility is to identify and solve problems. What a company finds, however, is that wrong problems are often attacked, implementation of solutions is time consuming and poorly executed, and often fails. One reason for this is that managers often do not ask nor listen to those closest to production -- the people on the shop floor (Hendrick 1988, 30).

Managers perceive their responsibility is to solve problems and that this is not direct labor's job. There is often an attitude that direct labor does not have the ability nor the self-motivation to identify and solve problems, and to manage their implementation. Another fear might be the surfacing of embarrassing problems and solutions which the manager thinks he should have seen, and did not (Hendrick 1988, 30).

Cross-training is another area that often is found difficult to implement. When realistic cross-training proposals are developed, both job description and compensation structures become a barrier to implementation. People at the lowest levels of the organization are usually paid for the job, not just their specialized ability, and not for

their value as a more horizontally and vertically flexible team member. Unionized companies face these barriers more than non-union companies; however, non-union companies can be just as unresponsive to the reduction of these barriers (Hendrick 1988, 30).

The development of profit sharing or bonus plans for operators are often at odds with the basic manufacturing philosophies that are being implemented. The quantitative goals of output are the easiest to measure, but do not facilitate the philosophy of smooth flow and quality. Management must develop job classifications, descriptions and compensation plans which support these philosophies (Hendrick 1988, 30).

Another hard to overcome philosophy is the idle labor policy. If a problem occurs in a work center, the work center and upstream work centers should stop production until the problem is solved. Managers do not like to see idle labor. This results in the tendency to "work around" the problem to keep labor fully utilized. The problem with this is that it creates more WIP. The same result happens when a work center continues production after its quota has been met (Hendrick 1988, 30).

These two problems can be reduced by cross-training so that otherwise idle workers can assist a bottleneck area, and by redefining the concept of productive work to include problem solving (Hendrick 1988, 30).

The threat of layoffs works against the successful implementation of improved manufacturing philosophies. Direct labor has a tendency to slow down if they do not see a huge backlog of work behind them. What needs to be emphasized is that the high cost, poor quality, poor customer service, and obsolete designs that occur from this train of thought result in an inability for the company to respond to competition -- and this is what leads to layoffs (Hendrick 1988, 31).

Management must evaluate their contribution to overall cycle times through their imposition of paperwork reports and controls on direct labor. Their own lot processing of paper and untimely responses to decisions also slow down the movement of hardware (Hendrick 1988, 32).

Finally, management must realize that direct labor costs are almost always the smallest portion (usually 10-20%) of total costs when compared to material and overhead costs. The real leverage of cost reduction can be achieved by reducing material and overhead costs, not in concentrating on direct labor costs. Direct labor should, in fact, be involved in the process of reducing the material and overhead costs (Hendrick 1988, 32).

CASE STUDY

Scenerio

Drayton Industries is producing a highly technical navigational and targeting system for the U.S. military. Though presently producing one-third of a unit per month, a production ramp up over a two year period will top out at twenty-one units per month. The contract is considered low volume.

An MRP system is used to develop the build schedule. Due to part shortages, production realizes a large number of delays. Because of this, wandering bottlenecks occur on the manufacturing floor. Lots currently consist of one unit each.

WIP is stored at different places depending on its stage of completion. Lots return to the stockroom upon completion. Because of the low volume, normal capacity constraints do not exist at this point in time.

The production operators are members of a union, and are fairly specialized in their tasks. Their performance strictly reflects the quantity of units completed. No connection is made between performance and quality.

Analysis

Until the part shortage situation is under control, Drayton Industries will not be able to successfully implement any production philosophy. It is assumed that part shortages will not be a factor.

Drayton should look to implementing a combination of the three philosophies discussed in the report. The first item to be discussed is operator training. In order to maximize the utilization of manpower, cross-training must be incorporated. Although union environments normally do not prefer this structure, it can be done. In order to accomplish this, the union must be brought into the process in the beginning so that their issues and questions can be addressed from the start.

Goddard cites several examples of where this has been accomplished. Xerox went to great expense to demonstrate to the union leaders the nature of the company's competition. They convinced the union that Xerox's market position was being threatened and gained the union's support for the program. Cummins UK included unions in their process development, and devised incentive bonus programs based on worker flexibility. They called these "skill modules." Though there was initial reluctance to the cross-training, they communicated the need and the improvements, and they realized few transition problems (Goddard 1986, 52).

Because of the importance of meeting schedule when involved in a government contract, it is not advisable to attempt to obtain raw materials "just-in-time" from the supplier. This does not eliminate, however, the ability to create such an environment on the production floor.

Drayton can use its existing MRP system to set a monthly build schedule. This schedule should then be broken down into a weekly, and then finally, a daily build schedule. The weekly schedule should be used to enable a smooth transition flow into the daily schedule. No more should be built than is required by the schedule.

Quality should be greatly emphasized. With decreased lot sizes, quality issues can be spotted and dealt with quickly. Operators should be held responsible for the hardware they build. They should be evaluated on how closely total production matches the required production without the generation of excess inventory or waste, rather than on how many parts were has produced. Any necessary rework should be performed by the operator responsible for creating it. Performance reporting should reflect the above. (For example, the operator earns zero standards for rework done on "his" hardware. This is then included in the overall performance rating.) As quality improves, inspection steps should be evaluated for possible elimination.

Initial analyses by industrial and manufacturing engineering to improve production, run small lots, and allow more setups should place emphasis on the bottleneck operations. All subsequent activities must place a bottleneck resource as the first priority, whether they be scheduling or line stoppers. This is where the greatest benefits and most detrimental impacts can be realized by manufacturing. An hour lost in a bottleneck resource is lost to the entire factory. Bottlenecks are the only locations where buffer stock should be permitted while manufacturing processes are being refined.

Tooling should be evaluated for redesign to reduce setup times. As setups approach zero, lot sizes can approach one. This is because lot sizes are determined by spreading the machine setup into the production time for each piece. Great flexibility can be realized when setups are an insignificant factor in the determination of lot sizes. Unless setups are reduced, daily, and possibly weekly, schedules may not be feasible.

The importance of reducing lot sizes has many benefits. These include the ability to spot quality problems quickly, and to incorporate design changes into the normal manufacturing process. Both of these help to eliminate rework which not only causes manufacturing to operate inefficiently, but contributes to the degradation of the product. By minimizing lot sizes, WIP is reduced also.

Excessive WIP is nothing more than the relocation of the stockroom onto the manufacturing floor. Where inventory is necessary, a point-of-use storage technique should be utilized. This will avoid the double handling of material, which not only increases efficiency, but also reduces the possibility of damage. Floor stock should also be implemented. Low cost items such as screws and nuts should be stocked at the workstation. A kanban or "two bag" concept can be used -- when a material handler observes the operator has opened one of two bags of screws stocked at the workstation, a kanban card is delivered to the stockroom to signal the need for another bag of screws to be assembled. Each bag contains approximately a month's supply of screws. The stockroom attendant thus has a fairly large time frame in which to fill the request, and can do so in between priority jobs.

The above suggestions can only be implemented with the cooperation of all levels within Drayton Industries. Support must "trickle down" from upper management. Although this research paper concluded the OPT manufacturing technique appeared theoretically better than either JIT or MRP, each technique possesses qualities that might prove applicable to individual situations. It is not practical to totally abolish the existing system. The above concepts utilize Drayton's present resources, and are a combination of the three philosophies tailored to the described case.

APPENDIX A

JIT

JIT

Philosophy/Definition

The real substance of JIT is that it is the outgrowth of a cultural system of attitudes that are very different from those of most American firms. Japanese production occurs as a team effort, with bottom-up consensus and motivation (Rice and Yoshikawa 1982, 10).

JIT identifies a philosophy and set of goals for a manufacturing business. In the broadest sense, the goal is the elimination of waste. JIT is not backed up by any set of techniques. It's a philosophy that focuses attention on the elimination of waste by manufacturing just enough of the right items just in time (Garwood 1984).

JIT is a philosophy that encourages solving problems, not covering them up with band-aids such as excess inventory, safety stock or padded lead times. Among the items that must be eliminated to achieve the JIT goals are excessive lot sizes, quality rejects, machine breakdowns and excessive transit time in the manufacturing process. JIT encourages teamwork in achieving these goals (Garwood 1984).

Toyota's definition of a JIT system is to produce "only necessary items in a necessary quantity at a necessary time" (Goddard 1986, 11).

The production process side of JIT has five fundamental areas. The first area is that of "multifunctional" operators and the concept of operator involvement on the shop floor. The second is workplace organization, or the way the company organizes and performs good housekeeping on the factory floor. Next comes the concept of preventive maintenance. Fourth is the idea of standard containers. These not only speed up to the process of being able to count parts and improve the reliability of the part count, but eliminate cardboard and a great deal of dirt and waste that clogs many factories today because of the many different kinds of cardboard or paper containers that are used to transport parts. The idea of standard containers such as tote boxes also encourages the concept of more standardized automated material handling equipment. Tote boxes can be bar coded so each can be identified as it moves throughout the factory system. The last part of the production process is the concept of minimum setup time. It is no longer assumed that machine setups or changeovers have to take hours or days. The goal is to reduce the setup time on any piece of production machinery to minutes. This is the step that allows the reduction of lot sizes (Gunn 1987, 58).

A key principle of JIT manufacturing is to make just enough -- no less and no more. This means that if the production rate is 100 per day, that is all that should be produced each day. But what happens if everything goes right or the people find a more effective way to meet the daily quota or capacity requirement and finish early? How can the remaining time be used productively? Traditionally, the answer was to keep going and make as many as you possibly could or make a few more now, just in case everything does not go right tomorrow. Of course, this alternative built inventory, but that was not the shop floor's responsibility. Efficiency, utilization, and cost were their concerns. More direct labor absorbed more overhead. Maximizing the output was incorrectly interpreted as maximizing efficiency and utilization while minimizing product costs (Garwood 1986).

But there are other, possibly better, alternatives to use the remaining time more productively. Workers could be transferred to another area that is having problems and need more output. The time could be used to cross-train, making people more flexible and easier to move the next time there is a capacity imbalance. Operators could do some preventive maintenance on their equipment. Unfortunately, these alternatives silence the noise in the shop and send a false signal that the factory isn't productive. The traditional measurement systems, particularly the

financial measurements, would send out an immediate alarm of lower efficiency, lower utilization and unfavorable labor variances -- all implying higher product costs (Garwood 1986).

The meaning of "kanban" in manufacturing means "a marker to control the sequencing of job activities through sequential processes". A typical kanban is a card which contains the following information: stock location, part number and description, kanban number, part quantity/kanban, code number of what kanban is attached to, and work station location (Rice and Yoshikawa 1982, 2).

The ultimate JIT inventory system is a production line. Parts are passed from worker to worker, as in a bucket brigade, without pause to collect carrying charges, A production line is attained through production engineering rather than through inventory system development. Actually, the line is so engineered as to eliminate the need for an inventory system. The production line is by no means a Japanese device. Rather, the Japanese commitment to pursue JIT makes production lines generally more likely in sub-assembly and fabricating areas, not just in final assembly (Schonberger 1983, 37).

APPENDIX B

OPT

OPT

Philosophy/Definition

Like JIT, OPT attacks waste in the factory, but more efficiently. OPT can focus on the critical resource. By directing management to focus its energies on bottlenecks, it succeeds in maximizing throughput. OPT's unique scheduling system makes it a simulation tool that permits the user the ability to measure the effects of planned improvements before money is spent on them. Eight rules of OPT encourage industry to look at manufacturing differently (Lundrigan 1986, 3).

1. "Balance the Flow, Not Capacity"

   In the past, manufacturing has tried to balance capacity and then tried to maintain flow. Maintaining flow in a balanced (?) plant typically takes the form of keeping the workers and machines working at full capacity. The result is a "make work for work's sake" syndrome, characterized by inventory stacks that can not be converted to marketable goods. By contrast, the Japanese rule is, "If you don't need it, don't make it" (Lundrigan 1986, 3).

2. "Constraints Determine Nonbottleneck Utilization"

   Bottlenecks pace production for the entire system. The level of utilization of noncritical resource must be determined by the needs of the critical one. The only place to keep machines working at 100% capacity is at the bottleneck, since the bottleneck governs output and brings in profits (Lundrigan 1986, 3).

3. "Activation is Not Always Equal to Utilization"

   To activate a resource when the resulting output cannot get through a bottleneck is making waste in the form of excessive inventory (Lundrigan 1986, 3).

4. "An Hour Lost at a Bottleneck is an Hour Lost for the Entire System"

   If we have a true bottleneck that is being utilized to its full potential, an hour lost at that bottleneck can never be made up. Output of the entire factory is lost (Lundrigan 1986, 3).

5. "An hour saved at a Nonbottleneck is a Mirage"

   By definition, a nonbottleneck resource is made up of three time elements: run time, setup time, and idle time. A new fixture that saves setup time and converts it to process time at a noncritical resource will cost the company money because it can only produce parts that a bottleneck can not process. A new fixture that converts setup time to an hour of idle time will not increase the throughput of the system

either. Money has been lost through engineering, buying, installing, and running the new machine (Lundrigan 1986, 3).

6. "Bottlenecks Govern Throughput and Inventory"

   There is usually a large queue of inventory just in front of a bottleneck, while subsequent operations are running with little or nothing in queue. Parts can not be used any faster than the bottleneck will allow, so why make them before they are needed? (Lundrigan 1986, 4).

7. "Process Batches Should Be Variable, Not Fixed"

   In traditional MRP systems the lot size is determined by a fixed lot-sizing rule. There is no relationship between the lot size and what is required to balance the flow of the manufacturing cycle. The Japanese pull only what is required by use of Kanbans. They avoid taxing the system with strictly defined lots, and instead let production flow determine the size of the lot (Lundrigan 1986, 4).

8. "Set the Schedule of Examining All the Constraints Simultaneously"

   MRP predetermines lot sizes. The system has fixed lead times, and the schedule is set according to lead times. Only by running the schedule can capacity constraints be seen. OPT suggests all the constraints of a network be considered simultaneously - management

policies, routings, setups, quantities, times to run, tooling, maintenance, schedule delays, scrap, changes in personnel, changes in customer demands, and etc. (Lundrigan 1986, 4).

The primary stated OPT objective is increasing profits through maximizing throughput. Flow, not capacity utilization, is important. Since throughput is limited by bottleneck resources, all efforts are devoted to maximizing capacity utilization in these work centers (Vollmann 1986, 43).

Capacity can never be totally balanced. Manpower is utilized most effectively by cross training, so that total manpower becomes the bottleneck resource. To the extent that unique skills become the bottleneck, one can not achieve good overall capacity utilization without building up unneeded inventories. This concept is consistent with the "Japanese" idea that workers who are not at bottleneck operations should not be paced by a 100% work load, but should rather utilize extra time in other activities such as quality improvement and skill enhancement (Vollmann 1986, 43).

Utilization of a bottleneck is critical while poor utilization on nonbottleneck resources costs nothing. The traditional cost accounting view requires that all operators should be working at all times, but if these people are working on nonbottleneck resources the net result could

be to increase WIP and cause confusion in scheduling other work centers. OPT maintains that it is all right not to work if no work is needed; in fact, problems could be caused by doing otherwise (Vollmann 1986, 44).

The scheduling module is similar to MRP in that it is a backward scheduling, infinite capacity system. It has been called smart MRP, since it has the ability to split and overlap orders. The module is run to create a schedule as to identify the critical resources in the system (Lundrigan 1986, 7).

Running the scheduling module allows the generation of utilization reports that identify the overloaded resources. Before the most heavily utilized resources are categorically defined as critical resources, all data for these resources must be verified to insure accuracy. After this has been done, the resources are declared bottlenecks (Lundrigan 1986, 7).

Recognizing that any schedule calling for resource utilization greater than 100% is impractical, OPT separates the heavily utilized resources in the original network from those resources with excess capacity. OPT produces a schedule that recognizes the split. OPT forward schedules that part of the network that involves the most heavily utilized resources so that their load never exceeds 100%. Meanwhile, the scheduling module schedules those resources demonstrated to have excess capacity so that their output

"serves" the bottlenecks in a manner that bottlenecks can handle (Lundrigan 1986, 8).

OPT is particularly valuable as a plant start-up tool. Using the same data that manufacturing engineers now use to estimate facility requirements, OPT can forecast how many of each resource -- including personnel --will be required in a plant not yet built. Since the simulation takes all constraints of the plant under consideration at the same time, the results will be more accurate than anything engineering has yet been able to produce (Lundrigan 1986, 11).

Some of the disadvantages of OPT are that the costing and accounting systems are disrupted preventing efficiencies from being calculated, job cost control data has been restricted in some areas, and performance evaluations no longer exist (Lundrigan 1986, 11).

Disadvantages of OPT are primarily due to its data maintenance requirements. The tight network organization of each product would be very difficult and time consuming to keep current. Another cost of computerization is the new computer expertise skills required by OPT's implementation. Added costs such as training and constant maintenance of product networks, along with the high level of discipline required on the shop floor are other disadvantages. There is the fear that any delay in updating the system or in following the tight schedule produced will be disastrous. A procedural aspect of OPT that deserves men-

tioning is the forward scheduling emphasis of the OPT module. Costs of early finish times are a danger in this methodology, and due to the strict requirements of following the schedule, a foreman would not be prone to delay processing (Meleton 1986, 18).

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