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HIGH-MIX, LOW-VOLUME MANUFACTURING PARADIGMS

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ABSTRACT

Systems and reductionist approaches to improving supply chain performance are equally important when considering the multifunctional activities associated with supply chains for high-mix manufacturing environments. Indeed, sound tactical thinking is required to affect improvements that will confer competitive advantage in cost, quality, delivery, responsiveness, technology, and service.

Time is money and is the "universal currency" for attaining competitive advantage. It is important to understand that a high-mix, low-volume manufacturer has less supply chain issues to deal with as compared to repetitive high-volume manufacturing environments (e.g., no distribution or retail outlets). This results in a situation where the manufacturing operations link is amplified in importance within the locus of achievement of value propositions (e.g., cost, quality, delivery, responsiveness, technology, and service).

The organization of decentralized and cooperative high-mix manufacturing systems is referred to as a "holonic" manufacturing system. Each holon's (e.g., machines, parts, products, etc.) activities are determined through cooperation with other holons and not a centralized mechanism (e.g., master planned acknowledge dates). By addressing these interactions with tactically sound approaches, a high-mix manufacturer will be able to respond to dynamic changes cost effectively. Such a manufacturing system will enjoy a high level of agility. Flexibility is a key competitive differentiator in such an environment. It is essential to understand the strategic implications of tactical manufacturing operations decisions. Manufacturing paradigms are mental models used to rationalize manufacturing operations strategy and tactics. The articulation of the future based on present-day mental models often takes the form of a "vision." This vision is used to guide manufacturing organizations to a future desired state of performance. There are numerous manufacturing paradigms from which an operations manager may choose and each choice will not produce equally significant results.

This paper will uncover the problems associated with the many high-mix manufacturing paradigms in use today and their resultant effect on flexibility.

JUST-IN-TIME PARADIGM

Although Just-In-Time (JIT) strategies have achieved phenomenal improvements in repetitive manufacturing environments, they are wholly inappropriate for guiding managers toward competitive advantage in high-mix, low-volume manufacturing environments. This is particularly true in the context of sequencing and scheduling decisions. Unequal work-content times for the mix of products produced result in a situation where it is impossible to balance capacity - a fundamental requirement for successful JIT execution. In order to balance capacity, many JIT implementations require a flexible work force that responds to variability as a matter-of-course in a vain attempt to balance capacity. In such an environment, a high-mix, low-volume manufacturer will find themselves focused more on the flow of people rather than the flow of products. Indeed, the JIT literature explicitly states that a flexible work force is not used as a matter-of-course to respond to variability inherent to unbalanced production lines.

Although a cost reduction strategy focused on the elimination of waste is universally applicable, JIT implementation, particularly from a mixed-model scheduling standpoint, is wholly inappropriate for high-mix manufacturing environments. JIT mixed model schedules are based on aggregate demand and sequences are derived from the percentage demand for each product type. For high-mix manufacturing environments, processing time, capacity constraint considerations, and sequencing decisions are of paramount importance due to the problem of unbalanced capacity. It is impossible to balance capacity in a high-mix manufacturing environment when particular products within the mix of products to be produced have dissimilar processing times at operations process steps. It is a rather trivial process to prove this mathematically through the use of balance delay equations. The implementation of JIT mixed model scheduling techniques in a high-mix, low-volume manufacturing environment can be analogized to the following situation: When the only tool (or philosophy) that you have is a hammer, all problems begin to look like nails.

GROUP TECHNOLOGY PARADIGM

From a scheduling standpoint, lot-sizing, setup time, and work content constraint time considerations are the driving forces behind the development of a feasible (i.e., doable) production schedule. Of paramount importance is setup time. In fact, the reduction of sequence-independent setup time is the only way that a high-mix manufacturer can attain a competitive advantage in responsiveness. This is where group technology fails. Group technology is based on the notion that a particular ordering of products to be produced can significantly affect (i.e., reduce) setup time requirements between adjacent sequenced products. Group technology will therefore dictate the order in which products will have to be produced. Sequencing decisions must be based on process constraint time and available capacity considerations and not localized setup time avoidance criteria.

Local machine setup time avoidance criteria will reduce setup time at the expense of the customer. Additionally, order demand volatility will create unnecessary variability in production operations. For high-mix, low-volume manufacturing environments, demand patterns for particular products may result in a situation where a particular product may exhibit zero demand over a particular time horizon. This can corrupt the entire group technology paradigm. The ability to produce products, irrespective of order, is a fundamental requirement for attaining competitive advantage through flexibility for any high-mix, manufacturer. The goal is to increase the entropy (i.e., defocus) of manufacturing operations. The notion of disorder (from cosmology theory) for any manufacturing environment results in what is referred to as an "entropic" manufacturing environment. Such a manufacturing environment will enjoy a high degree of flexibility. From basic economic theory, it is known that the profitability of a flexible manufacturing firm will be relatively uniform over a particular range of product mix and volumes.

THEORY OF CONSTRAINTS PARADIGM

Theory of constraints is highly effective under the condition of singular constraints and/or bottlenecks. A bottleneck is defined as a process step(s) that has insufficient capacity to respond to the demands of the marketplace. This will limit throughput (i.e., the rate at which a manufacturer generates revenue through sales). Deterministic models are used to ascertain the profit making potential of the organization for the mix of products ordered. The particular products resulting in the highest profitability will be produced to the bottleneck's available capacity level. The products remaining will not be produced. The ability to flex capacity is a function of overtime, outsourcing, cosourcing, purchasing additional technologies, setup time reduction, lot-sizing, and sequencing rules. If a manufacturer offers and advertises the ability to deliver a particular portfolio of products, and fails to live up to this commitment on a consistent basis, they may put their very existence in jeopardy as a direct result of rampant customer dissatisfaction. Also of importance is the realization that lower margin products may leverage higher margin products, now or in the future. This consideration is seldom, if ever, considered in the profit-per-constraint minute calculation that is used for ascertaining which particular products will be produced at the bottleneck operation.

Multiple moving constraints are inherent to high-mix manufacturing environments. Fundamental to multiple constraints in a serial flow high-mix manufacturing environment is the fact that the total processing time (i.e., makespan) is not simply the sum of all work content times for dissimilar products produced at a particular constraint operation. This has been demonstrated to be true given the advent of the Multiple Constraint Synchronization (MCS™) algorithm. Indeed, sequencing decisions alone are a significant determinant of variability in a high-mix manufacturing environment. This will have a direct impact on available capacity. Feast and famine production flows are inherent to high-mix manufacturers that do not understand, and fail to respond to, the relationship between sequencing considerations and manufacturing process variability.

Arguing that multiple constraints in a high-mix manufacturing environment can be effectively remedied by subdividing the production line into separate production lines such that the newly created production lines have only one constraint is a business decision destined to fail. In addition to requiring more factory space, the newly created (singular constraint) production lines will fall victim to incoming order volatility. A decrease in orders for particular products may result in a situation where excess available capacity exists at one particular production line and an increase in orders for particular products may create an overload condition on another production line. A high-mix manufacturer's competitive position will be damaged by not being able to produce particular products causing an overload at one production line at the production line experiencing a capacity deficit.

High-mix manufacturing operations business decisions must be made in the context of the resultant effect they have on flexibility. Flexibility increases or decreases disproportionately. For example: The total number of possible sequences for n products on m production lines is $(n!)^m$. A decrease in the mix of products (n-x) that can be produced on a particular production line (m-y) will decrease mix flexibility disproportionately $[(n-x)!^{m-y}]$. Increased mix flexibility results in a consequent reduction in production line volume fluctuations that in turn increases volume flexibility. Volume fluctuations can be measured by using simple variance measures.

ERP/MRPII (ENTERPRISE/MANUFACTURING RESOURCE PLANNING) PARADIGM

Enterprise Resource Planning (ERP) and Manufacturing Resource Planning (MRPII) are for the most part, the same thing. One argument analogizes the situation where a point in time occurred when the world stopped calling the automobile a horseless carriage and started calling it a car. The ERP acronym is often used to denote the concept of the holistic supply chain. When considering the supply chain for high-mix manufacturing environments, the supply chain is radically different than that encountered by repetitive high-volume manufacturers. Products are most often designed at, manufactured at, and shipped from a single entity. Complexity in supply chain linkages are most often within the locus of raw material suppliers and the purchasing function. For high-mix, low-volume manufacturing environments, distribution centers and retail outlets are virtually non-existent due to the low volumes of products produced. The supply chain problem, per se, is thus simplified as contrasted with repetitive high-volume manufacturing environments.

There are problems inherent to ERP/MRPII manufacturing planning and control systems. The use of backward scheduling techniques from customer order promise dates results in a situation where randomization occurs in start times. The requirement to iteratively reconcile capacity load profile imbalances at constraint operations during capacity requirements planning often prove to be difficult. Another shortcoming of ERP/MRPII is the requirement for establishing lead times that are constant when in fact they are dynamic variables. Fixed lead times create shop floor scheduling and priority problems. What is needed is a capacity planning process that will detect overloads and underloads during the ERP/MRPII process and automatically reschedule the ERP/MRPII system in an integrated way to effectively use available factory capacity.

Utilizing repetitive manufacturing based ERP/MRPII software solutions supplied by vendors that do not explicitly consider the adverse affects that group technology, improper sequencing, and improper lot-sizing have on the achievement of customer order service objectives will damage the competitiveness for any high-mix manufacturer. Acknowledge dates must be derived through techniques that forward schedule production operations such that promised delivery dates are derived. This will prevent the problem of random start times and the resultant decrease in available

capacity that will occur. The adverse affect of random start times can be analogized to why traffic jams occur on two-or-more lane highways.
To achieve maximum benefit from ERP/MRPII, management and users must be thoroughly educated in its capabilities and shortcomings. Educated users that are led by highly competent managers can create substantial operating improvements that offer a competitive advantage over less educated competitors. In fact, education may be the only real lasting source of competitive advantage in today's competitive marketplace.

FINITE CAPACITY PLANNING PARADIGM

Finite capacity planning is the preferred technique for properly scheduling high-mix manufacturing environments. Production operations are forward scheduled based on mathematical models that explicitly rationalize available constraint capacity with processing time considerations. This approach offers valuable insights that often conflict with commonly accepted paradigms such as:

- The schedule should be communicated to all manufacturing operations and suppliers
- Competitive advantage is directly related to the flow of materials and information
- Utilization and activation of a resource are not synonymous
- The process batch many times should not equal the transfer batch
- The process batch should be variable, not fixed
- Lead times are the result of a schedule and can not be predetermined
- Balance flow, not capacity
- Time saved at a non-constraint is a mirage
- Time lost at a capacity constraint is lost forever.

Finite capacity schedules are short term schedules with time horizons of one day or less. Fundamental to proper finite capacity planning technique is Shortest Processing Time (SPT). SPT is a necessary requirement given the assumption that delivery performance is based on the proportion of jobs that are delivered on-time. SPT is optimal for mean flow time, mean inventory level, and is distinctly superior for reducing the percentage of late jobs. The principle of SPT can be analogized to the passing lane of a highway and the express checkout counters found in grocery stores. In the case of a highway, the objective is to prevent a Corvette from having to follow a Model-T. In the case of the express checkout counter, we do not want a person with one item to have to wait for a person with a half-hour checkout time. These real-world cases are referred to as Truncated Shortest Processing Time (TSPT) and are based on controlling of the routing of cars or groceries to be processed. Fortunately, a manufacturer has absolute control of the order and timing in which orders are to be released to the factory floor. By successively scheduling jobs in order of non-decreasing processing time (i. e., SPT) a significant improvement can be made over a less adept competitor. Amazingly enough, SPT is relatively robust to the measurement of processing time. This facilitates easy on-floor implementation. The work force is simply asked to pick the job that represents the shortest processing time.

The Multiple Constraint Synchronization (MCS™) algorithm can be used to develop a short term schedule (i.e., sequence) that will minimize variability and makespan. The algorithm explicitly evaluates processing time, setup time, and lot sizing criteria to effectively utilize capacity constraint capacity.

It is disconcerting that manufacturing planning and control software vendors claim the solutions that they offer are "optimal." High-mix manufacturing problems are, in fact, intractable (a.k.a., non-deterministic polynomial complete). Intractability stems from the inability to solve the parallel machine problem in polynomial time (i.e., the computation time is inordinately long). This is true in spite of the speed of present day computers. The simplest parallel machine problem is just as difficult as the most difficult parallel machine problems one can encounter (a.k.a., nondeterministic polynomial hard). For instance, say that we have four identical machines in parallel and we want to determine the optimal sequence (i.e., balance the workload of ten different jobs with arbitrarily different processing times as equally as possible across all four machines). There are 10^4 different possible sequences and each one will have to be explicitly evaluated in order to determine the optimal sequence. Heuristics have been developed to alleviate the problem of intractability for virtually all real-world high-mix manufacturing problems. The only problem is that the solution is not "optimal."

The time that inventory spends in the production system as value-adding is so small that it is astonishing that management focuses as much attention as it does on machine technology and manufacturing planning and control information systems. A focus on technology will only serve to improve the value-adding capability of the manufacturing organization. Without a concerted effort focused on the reduction of the non-value-adding component of manufacturing lead time, the purchase and installation of a new manufacturing planning and control information system will only serve the purpose of enabling managers to make poor decisions more rapidly. The new information system will thus create more problems than it will solve. This is a ready-fire-aim approach often employed by failed management to improve manufacturing operations performance.

FORECASTING PARADIGM

Although a build-to-order environment is the most cost-effective positioning choice for a high-mix manufacturer, forecasting is a necessary requirement for reducing aggregate lead times by stocking raw materials in anticipation of future demand. The use of statistically-based forecasting techniques in a high-mix, low-volume manufacturing environment is not a core competency. Statistically-based forecasting methods make the following three assumptions:

. Demand is continuous
. Demand is smooth
. Forecast error is normal and Gaussian distributed (i.e., bell curve).

It is ludicrous to accept these assumptions for a high-mix, low-volume manufacturing environment, yet many high-mix manufacturers employ statistically-based forecasting methods to anticipate future demand. The use of simulation-based methods that use recent demand history (e.g., 18 months) significantly outperform statistical techniques and should be adopted.

INNOVATION PARADIGM

Innovation is most often associated with the design related activities of a product that requires some degree of intricacy to manufacture. The lines between competitors based on technology considerations are becoming more and more "blurred" as time moves forward. Differentiation is now based on quality, cost, delivery, responsiveness, and service as related to manufacturing operations.
It is disappointing that many manufacturers fail to obtain the return-on-investment that can be realized by investing in the education of their most important asset - the work force. In order to attain competitive advantage, the education of the work force in the fundamentals of manufacturing planning and execution is becoming a competitive imperative. A highly educated work force equipped with the tools, techniques, and methods required to facilitate the innovative thinking required to compete and win in today's competitive marketplace can differentiate a manufacturer from it's competitors. The work force represents the greatest source of flexibility. The greatest contribution of the work force results from their problem solving capabilities. A highly trained and flexible work force will enhance overall manufacturing capabilities.

OUTSOURCING PARADIGM

Manufacturers are abandoning vertical integration in favor of outsourcing. Most often this is a direct result of manufacturers failing to recognize the strategic importance of time as a competitive weapon for attaining competitive advantage. The notion of time as related to the flow of information and inventory is referred to as "Theory-T." Those manufacturers that have attained competitive advantage based on time are winning and those that have failed to respond to this competitive reality are ceasing to exist. This is unfortunate. Abandoning manufacturing core competencies (or their development) in favor of outsourcing to virtual suppliers will not allow a company to differentiate itself in the marketplace.

The result can only create a competitive environment characterized as a polyopoly. Monopoly, duopoly, oligopoly, or even competitive advantage itself are at risk for a company pursuing such a strategy. Brute force marketing and innovations in technology will become the central foci for attaining competitive advantage in this marketplace.

In general, outsourcing decisions should not include the complete transfer of a product. This will reduce the ability of a manufacturer to recover overhead costs. The capability to produce products should be maintained in-house and at the virtual supplier - cosourcing. The virtual supplier will only produce particular products when an excess capacity condition occurs. If a complete carte blanche transfer of a product is made to a virtual supplier, there is a risk of losing in-house expertise. Cosourcing enhances flexibility while outsourcing does not.

CHANGE PARADIGMS

The framework for organizational change is generally categorized as follows:

. Continuous Improvement
. Restructuring
. Reengineering
. Reinventing

Continuous improvement involves incremental improvements based on the principles of total quality control(TQC). Restructuring is a short term strategy employed by failed management to buy time for improving performance by reducing the asset base of the company. This is no guarantee that improved levels of performance will occur in the future. Restructuring is commonly employed by corporate turn around artists. Reengineering affects change by extending known competencies, and is therefore a defensive strategy.

Reinventing is a competitive imperative for those organizations that want to lead rather than follow in today's competitive marketplace. Upper management must fund and support activities designed to facilitate the learning necessary to reinvent their manufacturing organizations. Reinvention requires individuals who work well under pressure and are characterized as loving to win and hating to lose. Benchmarking is the first step toward reinvention. The purpose of benchmarking is to avoid reinventing solutions already discovered and tested. Leaders battle for the future while others are catching up. Contenders in the fight for the future must break away from the paradigms of the present. Leaders lead learning and make it safe rather than dangerous.

CONCLUSION

The adoption of flexible manufacturing systems requires cross-functional coordination between all functions of a high-mix manufacturing organization. This will have a significant effect on how a company is managed. Attaining competitive advantage will only occur through the implementation of manufacturing paradigms that place an emphasis on flexibility. In a flexible manufacturing environment, economies of scale and increasing product mix are mutually reinforcing. Most importantly, performance improvements resulting from increased mix, volume, and work force flexibility can create effective barriers against the competition.