The Manufacturing Flow Management Process

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Manufacturing flow management is the supply chain management process that includes all activities necessary to move products through the plants and to obtain, implement, and manage manufacturing flexibility in the supply chain. Manufacturing flexibility reflects the ability to make a variety of products in a timely manner at the lowest possible cost. To achieve the desired level of manufacturing flexibility, planning and execution must extend beyond the four walls of the manufacturer. In this paper, we describe the manufacturing flow management process in detail to show how it can be implemented within a company and managed across firms in the supply chain. We examine the activities of each sub-process; evaluate the interfaces with corporate functions, processes, and firms; and provide examples of successful implementation.

Firms that perform the manufacturing activities in a supply chain face several challenges, one of which is to produce products in varieties and quantities that are in synch with the marketplace. However, the production function is known for its traditional ways of performing activities. This appears to be changing given interest in innovative management techniques such as total quality management, just-in-time operations, and continuous improvement. Connecting production management to actual demand represents a sizable opportunity for many companies and supply chains. For example, the potential savings from Efficient Consumer Response, an effort to connect production management with the market in the food industry, have been estimated at $30 billion [1]. Firms that integrate procurement, manufacturing and logistics activities might achieve cost reductions of between three and seven percent of revenues [2], depending the industry.

Determining the right degree of flexibility is important to virtually any company involved in the supply, production, distribution or sales of goods, and is at the center of the manufacturing flow management process.

Increasingly, manufacturers face the challenge of relying on outsourced production activities. Contract manufacturing services provided about 10 percent of all global output in the electronics industry in 1998, totaling approximately $60 billion. It is forecasted that by the year 2008, the figure will reach $1.3 trillion - a 2,167 percent increase [3]. In pharmaceutical chemicals and agrochemicals contract manufacturing represents approximately half of the manufacturing capacity [4]. The medical device industry outsourced roughly $8 billion, or 18 percent of its cost of goods sold, in 2002. The proportion of cost of goods sold outsourced in this industry is expected to increase to 42 percent by 2005 [5].

In large part, outsourced manufacturing is growing as a result of the need for manufacturing flexibility [6]. Manufacturing flexibility enables greater responsiveness to changes in customers' product preferences and quantities demanded [7]. Determining the right degree of flexibility is important to virtually any company involved in the supply, production, distribution or sales of goods, and is at the center of the manufacturing flow management process. While manufacturing activities might be outsourced to suppliers, the commitment to quality and the managerial responsibility has to be retained at the firm.

Manufacturing flow management should be implemented across the members of the supply chain that participate in the flow of products, as well as across those that have an effect on, or are affected by, the degree of manufacturing flexibility achieved by the supply chain as a whole. Through the manufacturing flow management process, management coordinates all activities necessary to move products through the plants, and to obtain, implement, and manage manufacturing flexibility in the supply chain. The process involves much more than the production function within the firm and spans beyond the manufacturer in the supply chain. In fact, it is up to the entire supply chain to make the product flow as smooth as possible, as well as to ensure that the desired flexibility is achieved.

In this paper, a framework for implementing an efficient and effective manufacturing flow management process is presented. We first provide a background on the eight supply chain management processes identified by The Global Supply Chain Forum, which is a consortium of leading practitioners and academics. Because manufacturing flow management is one of the eight supply chain management processes, it requires interfaces with the other seven. We then describe the strategic and operational processes that comprise manufacturing flow management, including the sub-processes and their activities. In addition, we identify the interfaces with the corporate functions, the other supply chain management processes, and other firms. Finally, we present opportunities for future research and conclusions.

Background

Supply chain management has received substantial attention from researchers and practitioners yet, in many companies, management is struggling to implement supply chain management processes. The Global Supply Chain Forum continues to develop the concept of supply chain management and the structure for its implementation. The definition of supply chain management developed and used by The Forum is:

Supply Chain Management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders [8].

The Forum members identified the following eight key business processes that need to be implemented within and across firms in the supply chain (see Figure 1):

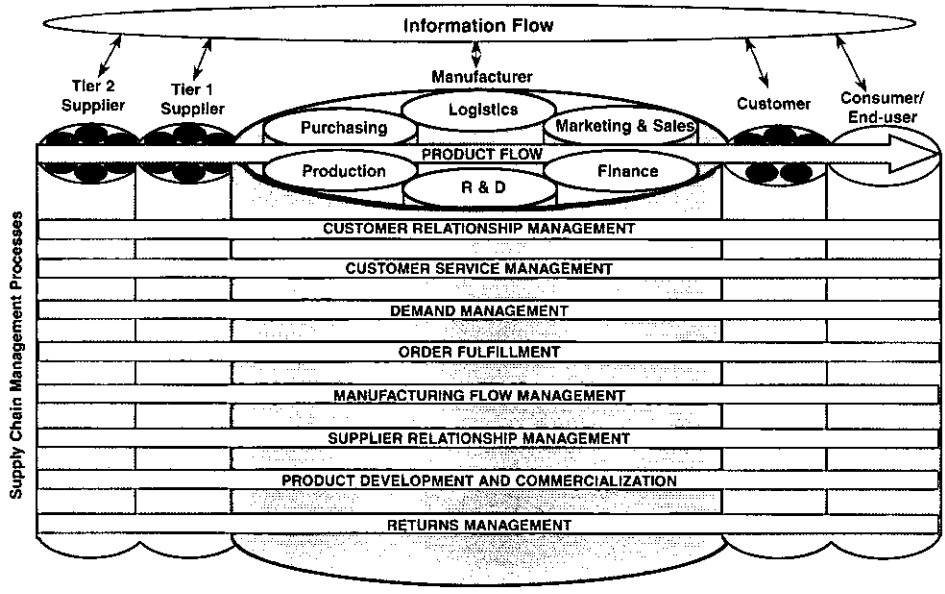
- Customer Relationship Management - provides the structure for how relationships with customers are developed and maintained, including the establishment of Product/Service Agreements (PSAs) between the firm and its customers.
- Customer Service Management - provides the firm's face to the customer, including management of the PSAs, and provides a single source of customer information.
- Demand Management - provides the structure for balancing the customers' requirements with the capabilities of the supply chain.
- Order Fulfillment - includes all activities necessary to define customer requirements, design the logistics network, and fill customer orders.
- Manufacturing Flow Management - includes all activities necessary to move products through the plants and to obtain, implement, and manage manufacturing flexibility in the supply chain.
- Supplier Relationship Management - provides the structure for how relationships with suppliers are developed and maintained, including the establishment of PSAs between the firm and its suppliers.
- Product Development and Commercialization - provides the structure for developing and bringing to market new products jointly with customers and suppliers.
- Returns Management - includes all activities related to returns, reverse logistics, gatekeeping, and avoidance.

Each process cuts across firms in the supply chain and the corporate functions within each firm. It is through the customer relationship management and supplier relationship management processes that most inter-firm activities are coordinated.

Croxton et al. [9] described these eight processes. In this paper, we examine the activities of each sub-process of the manufacturing flow management process; identify the interfaces between functions, processes, and firms; and look at examples of successful implementation. The framework

Through the manufacturing flow management process, management coordinates all activities necessary to move products through the plants, and to obtain, implement, and manage manufacturing flexibility in the supply chain.

Figure 1
Supply Chain Management:
Integrating and Managing Business Processes Across the Supply Chain



Source: Adapted from Douglas M. Lambert, Martha C. Cooper, and Janus D. Pagh, "Supply Chain Management: Implementation Issues and Research Opportunities," *The International Journal of Logistics Management*, Vol. 9, No. 2 (1998), p. 2.

presented is based on the literature and in-depth interviews with managers in a broad array of industries. In addition, it was further validated in five working sessions with members of The Global Supply Chain Forum over a period of nearly two years [10].

The process presented here is not industry- or context-specific but rather provides guidance to companies that influence, or are influenced by, the process. For example, a grocery retailer that offers private label products should consider formalizing the manufacturing flow management process with its contract manufacturers. In this sense, a retailer may not perform manufacturing itself but relies extensively on the manufacturing capabilities of outside supply chain members to ensure its own success. This example illustrates that the manufacturing flow management process is not the domain of manufacturers alone.

The manufacturing flow management process deals with making the products and establishing the manufacturing flexibility needed to serve the target markets.

Manufacturing Flow Management as a Supply Chain Management Process

The manufacturing flow management process deals with making the products and establishing the manufacturing flexibility needed to serve the target markets. Manufacturing flexibility is defined as "the ability to respond to environmental changes with less time and cost" [11]. The concept and significance of flexibility, broadly defined and as it applies to manufacturing operations, receive treatment in a subsequent section of the paper. Flexibility is important to most operations and particularly so when the manufacturer faces demand variation across a wide assortment of products. Less stable demand environments place a premium on flexible accommodation. The challenge is determining the right degree of flexibility to build into the manufacturing system given that increased flexibility is typically accompanied with increased investment.

Manufacturing flow management, like the other supply chain management processes, relies extensively on external connectivity to accomplish its objectives. While it might initially appear relevant only to the finished goods manufacturer (or assembler), manufacturing flow management is significantly influenced by the up- and downstream members of the manufacturer's

supply chain. Downstream members demonstrate influence through the demand for product assortments that meet expectations in terms of specific attributes, quality, cost, and availability. Meanwhile, upstream members affect the manufacturer's ability to fulfill the customers' expectations. It might be argued that the potential of the manufacturing flow management process is only as good as the capabilities of upstream suppliers. Therefore, it is important to view the manufacturing flow management process as one that extends beyond the four walls of the final assembler.

The manufacturing flow management process has both strategic and operational elements, as shown in Figure 2. The strategic portion of manufacturing flow management provides the structure for managing the process within the firm and across key supply chain members. The operational portion of the process represents the actualization of manufacturing flow management. Developing the strategic process is a necessary first step toward integrating the firm with other members of the supply chain, and it is at the operational level that the day-to-day activities are executed.

Much of the richness associated with the framework is found in the interfaces among processes for it is here that the processes extend beyond the production function to other functions within the firm and other key members of the supply chain. These interfaces might take the form of necessary data transfer, or the sharing of information and ideas with another process team which during regular planned meetings, or ad hoc meetings.

A process team comprised of managers from several corporate functions, including production, purchasing, logistics, marketing, and finance, leads both the strategic and operational processes. The team also might have representation from outside the firm, including key customers, suppliers, and/or third-party service provider. The process team is responsible for developing the procedures at the strategic level and seeing that they are implemented at the operational level. Involvement on the operational level is typically limited to addressing exceptions or problems in execution. While employees outside of the process team might execute parts of the process, the team maintains managerial control.

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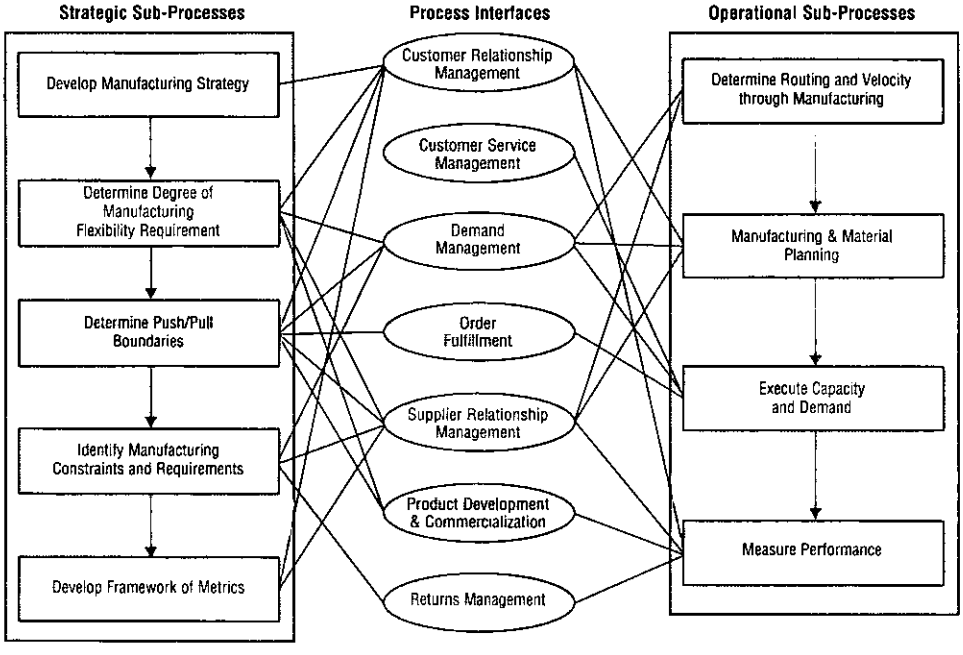
Figure 2
Manufacturing Flow Management



Source: Keely L. Croxton, Sebastián J. García-Dastugue, Douglas M. Lambert, and Dale S. Rogers, "The Supply Chain Management Processes," *The International Journal of Logistics Management*, Vol. 12, No. 2 (2001), p. 22.

The Strategic Manufacturing Flow Management Process

The strategic portion of manufacturing flow management consists of five sub-processes that collectively represent the decision-making infrastructure for the process.

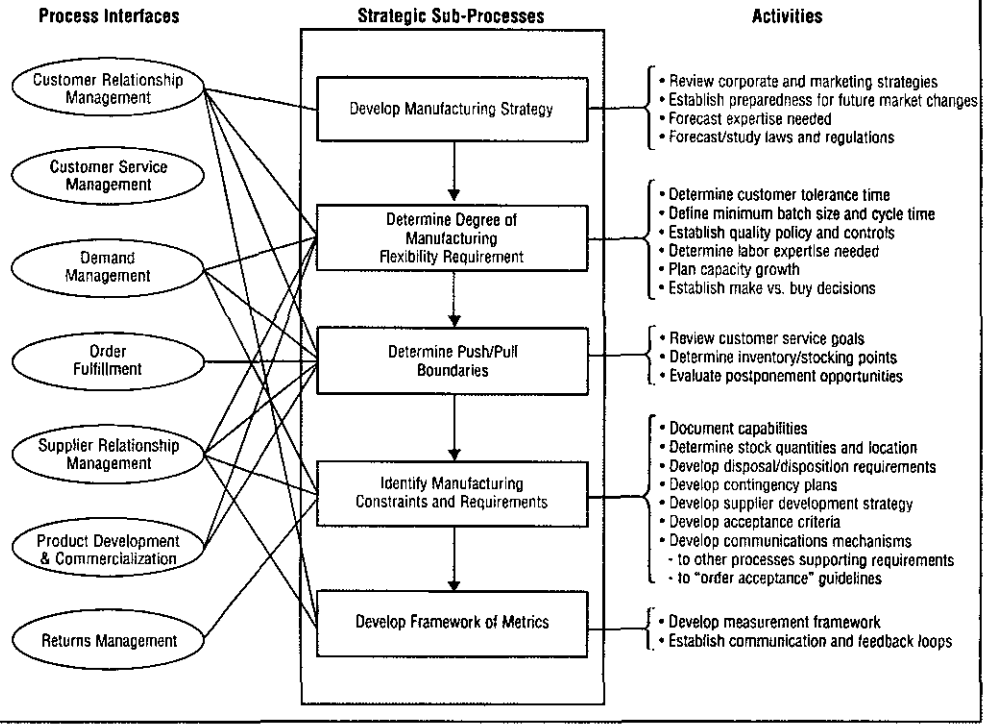
The strategic portion of manufacturing flow management consists of five sub-processes that collectively represent the decision-making infrastructure for the process. This infrastructure embodies the development of the manufacturing plan, the means of execution, limits to execution, and the appropriate measures of performance. We address each of the five sub-processes in order as depicted in Figure 3. This figure includes the activities within each of the sub-processes as well as the important interfaces between manufacturing flow management and the other supply chain management processes.

Develop Manufacturing Strategy

It is in this first strategic sub-process that the manufacturing flow management team develops the manufacturing strategy. The manufacturing strategy dictates the priorities of the production function and the roles of its suppliers and supporting service providers [12]. The manufacturing strategy is not determined by the production function in isolation. Typically, the team will review corporate and marketing strategies to determine the manufacturing strategy that best accommodates customer demand. This marks an important shift in mentality from "We sell what we make," to, "We make what we sell." This important distinction leads to an assortment of products that satisfy the needs of distinct market segments. The production capabilities of the firm play an important role in the determination of a firm's competitive basis, whether that basis is cost, quality, service, or time [13]. When competitive advantage is to be gained by adopting a unique manufacturing strategy or by employing a common strategy more effectively, manufacturing strategy should be an input to the overall corporate strategy. The key is to ensure that the strategy results in value to customers and, ultimately, shareholders.

Strategy determination may be driven, in part, by the manufacturing philosophy of the firm. Two manufacturing philosophies that have gained much interest in recent years are lean manufacturing and agility. These two

Figure 3
The Strategic Manufacturing Flow Management Process



philosophies, while distinct, share a common objective: to satisfy customer demand at the least total cost. It is in the means by which this objective is accomplished that the two philosophies differ. Leanness embodies the relentless elimination of "muda" (the Japanese term for "waste") and is modeled primarily after the Toyota Production System developed by Taiichi Ohno. Ohno identified seven critical wastes to eliminate; these include mistakes, overproduction, overprocessing, unnecessary transport, unnecessary movement by employees, waiting, and defective offerings [14]. Meanwhile, agility is oriented toward mass customization or quick, responsive accommodation of varied demand in terms of volume, variety, and mix through flexible operations [15]. Dell Computer is a commonly cited example of agile manufacturing. The company employs a rapid configuration system for its custom-built computer products in support of its consumer-direct marketing strategy.

Lean principles tend to be favored when products are standard (i.e., offer low variety) and demand is somewhat stable over long product life cycles. This allows extensive planning and a focus on efficient, defect-free production [16]. An agile approach is preferred when product variety is great, demand is highly unpredictable, and product life cycles are short. Agile systems rely extensively on flexible market accommodation.

Interestingly, situations arise where a combination of the two philosophies is appropriate. This so-called "leagile" approach is a hybrid that incorporates elements of both philosophies. Appropriate situations for "leagile" manufacturing might include products as they proceed through their life cycle (i.e., agile in infancy, lean in growth and maturity, and agile in decline), diverse products made of standard components or sub-assemblies (i.e., lean production of components with agile assembly of finished goods), or across product lines (i.e., fast-moving products produced in a lean manner and slow-moving products are produced using agility). Therefore, it is not always wise to identify oneself as a "lean" or "agile" manufacturer given that either philosophy (or a combination of the philosophies) might be embraced as the situation evolves [17]. It is important that the manufacturing strategy fits with the corporate strategy and remains consistent with the strategies of key supply chain members.

Looking beyond paradigms of lean and agile manufacturing are five generic manufacturing strategies. These five strategies from most rigid to most flexible are described briefly below.

- Ship to Stock (STS): Products are standardized and pre-positioned in the market; customers' expectations of immediate availability support the maintenance of speculative safety stock at all points of distribution.
- Make to Stock (MTS): Products are standardized but not necessarily allocated to specific locations; demand is anticipated to be stable or readily forecasted at an aggregate level.
- Assemble to Order (ATO): Products can be customized within a range of possibilities, usually based upon a standard platform; final form of the product is postponed until demand is known.
- Make to Order (MTO): Raw materials and components are common but can be configured into a wide variety of products.
- Buy to Order (BTO): Products demanded by customers can be unique right down to the raw material level; product variety is virtually limitless, though lead time is long as materials are procured, processed into finished goods, and delivered [18].

Figure 4 illustrates the relationship among these five generic strategies. Selection of the best strategy depends largely upon the perceived levels of demand variability across the assortment of products offered by the manufacturer and the ability to forecast long, medium-, and near-term demand accurately. If demand is certain and stable, there is very little need to employ flexibility in a wait-and-see approach. Rather, the manufacturer can buy materials in large batches and enjoy long production runs, recognizing that inventories will be depleted at a known rate. However, given the shrinking product life cycles experienced by many products, greater flexibility is necessary to accommodate uncertainty in demand. Determining the appropriate degree of manufacturing flexibility will be described further in the next sub-process.

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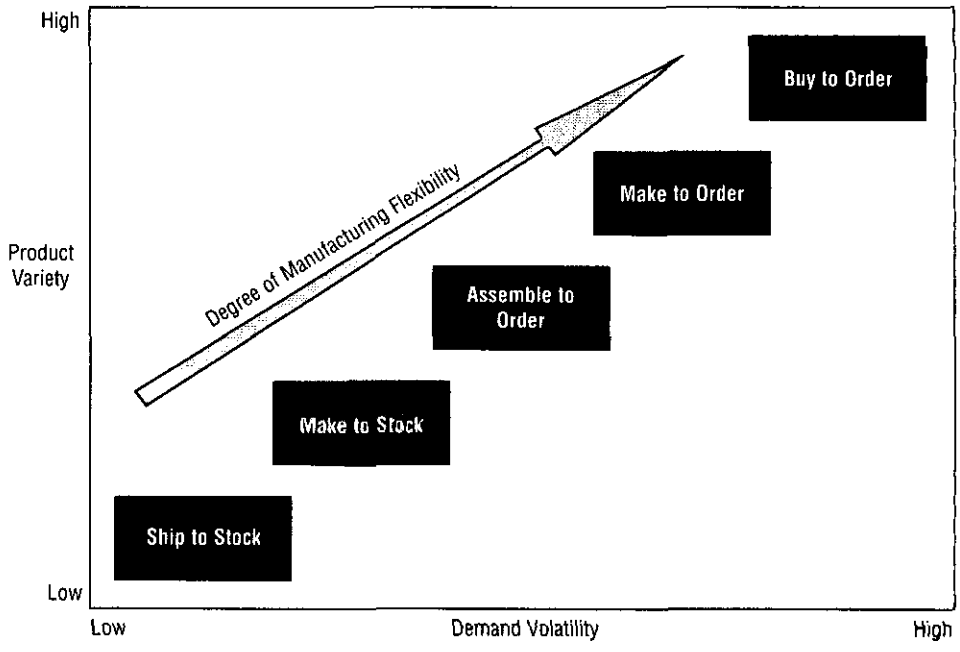
Figure 4
Five Generic Manufacturing Strategies



Source: Adapted from J. Ben Naylor, Mohamed M. Naim, and Danny Berry, "Leagility: Integrating the Lean and Agile Manufacturing Paradigms in the Total Supply Chain," *The International Journal of Production Economics*, Vol. 62, (1999), pp. 107-118.

In addition to monitoring current market conditions is the need to develop preparedness for dramatic changes that might affect the future state of the market. These changes might include the advent of radically new products that make current offerings obsolete, or the development of new materials or technologies that revolutionize a manufacturing process. One such example is found in the common usage of carrageenan, a seaweed extract used by toothpaste manufacturers to thicken and stabilize the toothpaste formula. It is believed that a substitute for carrageenan is in the offing. The substitute will cost half of what carrageenan costs per unit of finished product. Carrageenan suppliers face the challenge of reacting to the impending threat in order to retain their customers. Should the threat become imminent, the suppliers will have to invest heavily in either a new process or product to remain viable.

Thus, for the evaluation of future scenarios, the team needs to predict the technological changes expected for the medium- and long-term future. Changes in technology might be accompanied with new expertise needed. These changes, depending on their impact, might not only be regarded as a strategic manufacturing decision, but also as a shift in business strategy. Forces that affect the manufacturing strategy might stem from competitive forces, but also from environmental policies and other regulations. For instance, government support for the advancement of hydrogen fuel cell technology can invigorate an industry. However, regulations can extinguish an industry just as easily - as has been seen in the past with asbestos-based products, lead-based paints, and R-12 refrigerant, among others.

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In developing the manufacturing strategy, the manufacturing flow management team works in close collaboration with the customer relationship management team to ensure that production capabilities match market demands. In fact, it is the responsibility of the customer relationship manager team to communicate market conditions and opportunities that establish the competitive priorities for the marketing, purchasing, and logistics functions as well as manufacturing.

Determine Degree of Manufacturing Flexibility Requirement

The second strategic sub-process builds upon the first by determining the degree of manufacturing flexibility required to accommodate demand. Manufacturing flexibility ensures the company's ability to manage resources and uncertainty to meet various customer requests. Flexibility can have different meanings in different contexts. Table 1 summarizes types of flexibility and provides the definition for each. The most frequently cited views of flexibility are those that refer to the production function, such as mix, volume, and expansion flexibility. However, supply chain management processes apply beyond the firm, including important points of contact between members. Within this cross-functional context, other organizational aspects need to be considered and will influence the firm's degree of flexibility. Therefore, we have included in Table 1 a broader view of flexibility that transcends the production function.

There are several factors that drive the need for manufacturing flexibility. As previously noted, demand characteristics factor prominently in the determination of manufacturing flexibility. Demand volume, variation, and predictability of the variation are at the top of the list of considerations. Also important to consider is the customer's tolerance for waiting and reaction to an out-of-stock situation by either switching to a substitute product, back-ordering, delaying the purchase, or getting the item from an alternative supplier/store [19]. Characteristics associated with the product itself include the variety (i.e., the level of standardization or differentiation), stage and expected duration of the product life cycle, complexity of the product, and profit margin of the product. Finally, the lead times that can be achieved in

Manufacturing flexibility ensures the company's ability to manage resources and uncertainty to meet various customer requests.

Table 1
Types of Flexibility

Type of Flexibility	Definition
Organizational Flexibility	
Manufacturing or Operations	The ability of the organization to manage production resources and uncertainty to meet various customer requirements
Market	The ability to mass-customize and build close relationships with customers, including designing new products and modifying existing ones
Supply	The ability to reconfigure the supply chain (geographically) as sources of supply and customers change
Information Systems	The ability to align information systems with changing customer demands
Production Flexibility	
Mix	The ability to change over to a different product quickly and economically without changes in capacity
Volume	The ability to operate at various batch sizes and/or at different production volumes economically and effectively
Expansion	Modular building and expanding capacity
Material Handling	The ability to effectively transport different work pieces between various processing centers over multiple paths
Process (routing)	The ability to process a given set of part types using multiple routes effectively
Machine	The ability of a machine to perform different operations economically and efficiently
Work-center (labor)	The ability of the workforce to perform a broad range of tasks economically and effectively

Source: adapted from Duclos, Leslie K., Robert J. Vokurka and Rhonda R. Lummus, "A Conceptual Model of Supply Chain Flexibility," *Industrial Management & Data Systems*, Vol. 103, No. 6 (2003), pp. 446-456; and Zhang, Qingyu, Mark A. Vonderembse and Jeen-Su Lim, "Manufacturing Flexibility: Defining and Analyzing Relationships among Competence, Capability, and Customer Satisfaction," *Journal of Operations Management*, Vol. 21, No. 2 (2003), pp. 173-191.

different levels of the supply chain will influence the degree of manufacturing flexibility that will be required to satisfy demand. For example, a flexible manufacturing system might be called upon to offset deficiencies in suppliers' lead times or outbound delivery times.

Generally, more flexibility is preferred over less. However, there is a cost associated with developing manufacturing flexibility. Therefore, the targeted type and degree of flexibility should fit the overall business strategy [20]. Since key customers will be identified in the customer relationship management process, management may pursue the implementation of higher degrees of flexibility and/or specific types of flexibility for key customers. Additionally, managers must be confident that the firm will be rewarded by its customers for providing heightened degrees of manufacturing flexibility. The ability of the demand management process to recognize demand volatility and, in fact, to manage it effectively, might reduce the need for manufacturing flexibility.

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Once the desired degree of manufacturing flexibility has been determined, attention turns to how best to achieve it. Batch sizes and cycle times, which can vary by product, market, or life-cycle stage, must be defined. The customer relationship management team provides critical input toward these determinations. Avery Dennison's Graphics division has established distinct approaches to accommodate fast-moving and slow-moving products. Fast-moving products are produced in large batches in a lean manner - knowing that demand will exist for them. Slower-moving products are produced on an as-needed or MTO basis. Prior to implementing this mixed-mode strategy, Avery struggled to achieve next-day service (from order receipt to shipping). Today, the business achieves same-day service across the product line at a very high level. This improved accommodation of demand has helped a market contender become the market leader [21].

The TaylorMade-Adidas Golf Company employs a similar mixed-mode approach to create a made-to-order, custom golf club deliverable in 24 hours. While make-to-stock clubs still represent the primary share of the company's business, demonstrating that custom clubs can be produced quickly and at a reasonable cost has reinforced the company's reputation as a best-in-class manufacturer [22]. Further reinforcement was found in 2002 when the United States Golf Association (USGA) revised its standards for clubs' coefficient of restitution (or "springiness"). The USGA extended the acceptable limit only to revert to its original level less than three months later, thereby making the company's top-selling product a non-compliant club in USGA-sanctioned events. By working closely with the product development and commercialization team, the manufacturing flow management team employed an unprecedented degree of manufacturing flexibility that allowed TaylorMade to market a redesigned, compliant club within twelve days of the USGA's reversed decision [23].

Beyond consideration of the manufacturer's current capabilities, there must be consideration of the manufacturing strategy's complete time horizon to determine whether current capacity is sufficient to support sales objectives. Incorporating information developed by the customer relationship management team and the marketing function regarding market growth, penetration of new markets, and sustained growth, the manufacturing flow management team will develop capacity and ability to respond to anticipated growth.

A final, critical consideration in this sub-process is whether the manufacturer can and should perform the value-added processing in-house. As indicated in the Introduction, companies often will hire an external, contract manufacturer to fulfill specific manufacturing needs or to supplement supply during rapid growth or seasonal demand. In still other instances, however, the company may choose to outsource its traditional manufacturing responsibilities entirely. More firms today are choosing to build brands rather than physical products, outsourcing the full scope of manufacturing responsibilities to one or more contract manufacturers who can provide desired products at a lower cost. Companies such as The Limited, Nike, Lucent Technologies, Sara Lee, Ericsson, and Alcatel rely extensively on outsourced manufacturing to focus on new product development, marketing, and distribution [24].

Determining when and what to outsource is a challenge. Masterfoods USA outsources production when the company either lacks a production capability or simply prefers not to own the technology. Masterfoods also employs contract manufacturers for temporary capacity during peak sales seasons. The 3M Company employs a similar logic but refuses to outsource manufacturing activities for which it believes it enjoys a competitive advantage. Even when companies choose to "buy" rather than "make" key components or finished goods, it is important that they maintain the strategic planning responsibilities [25]. Given the importance of this decision, contributing analysis and insights will be gathered not only from production management but also from purchasing, logistics, finance, and senior executives in the company.

Should the company opt to outsource production, significant responsibilities would shift from manufacturing flow management to the supplier relationship management process. Manufacturing expertise must remain in the company, however, to ensure that the supplier operates in a manner consistent with the company's competitive priorities but also within legal and social boundaries. For this reason, the manufacturing flow management process team remains an important voice, protecting the company's interests when outside sources provide critical manufacturing services.

The process team will interact frequently with the supplier relationship management process team even when no manufacturing activities are outsourced. The manufacturing flexibility of a firm will be influenced by the flexibility of key suppliers. Therefore, the supplier relationship management process team will provide assessment of suppliers' flexibility. They will also use this interaction with the manufacturing flow management process team to identify opportunities for improvement among the suppliers.

Determine Push/Pull Boundaries

The degree of manufacturing flexibility of each member of the supply chain influences the placement of push/pull boundaries. Push/pull boundaries refer to the positioning of decoupling points in the supply chain — up to which supply is pushed forward as make-to-stock but beyond which demand drives make-to-order execution [26]. The key to determining a push/pull boundary is recognizing the stage of value-added processing in which differentiation from a standard configuration takes place. In a buy-to-order arrangement, manufacturing flexibility is at a premium and the primary decoupling point is upstream from the manufacturer given that raw materials are unique to the individual finished good. At the other extreme, ship-to-stock strategies generate a standardized product, allowing the decoupling point inventories to reside in the manufacturer's distribution channel [27].

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In ship-to-stock and make-to-stock arrangements, the customer can usually enjoy immediate satisfaction of an in-stock product (even though the product may not exactly match the customer's specific needs). If longer lead times can be negotiated with customers through the product-service agreement developed by the customer relationship management team, greater opportunities for postponement become possible. Postponement reduces speculation and risks associated with finished goods inventories [28]. Should short or immediate lead times be set forth in the PSA, the manufacturer will have little choice but to pursue a speculative arrangement, position goods in the marketplace in advance of demand, and hope that the goods sufficiently meet customers' expectations in terms of appearance, performance, and quantity.

Supply chains that lack the ability to respond quickly to changes in customer tastes and the pace of demand usually incur the real costs of oversupply and the opportunity costs of undersupply common with the bullwhip effect [29]. The primary responsibility of ensuring that the manufacturer remains in concert or just ahead of customer demand rests with the customer relationship management team in collaboration with the demand management process team. The product development and commercialization process is also involved to the extent that different product designs can be developed to accommodate manufacturing better and perhaps make postponement opportunities viable. Meanwhile, the supplier relationship management team is responsible for ensuring

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that suppliers fully understand their roles and responsibilities in support of the manufacturing flow management process.

Once the primary decoupling point is determined, the order fulfillment process must act in support of the push-pull decision to ensure that customers' expectations are fulfilled with minimal delay. In fact, the postponement of manufacturing activities might shift processing responsibilities typically performed by production to the logistics function of the business. Responsibilities would be limited ordinarily to light processing, such as packaging, labeling, and assembling display units. For instance, Hewlett-Packard (HP) has long performed the bundling of power supplies and users' manuals with print-imaging equipment in the distribution operation to support international sales. This effort is critical given that users in different nations will have different needs. Delaying the bundling of these items until demand is recognized by region prevents HP from speculating the nations from which demand originates. General Mills employs a similar strategy by bundling children's coloring books and similar promotional items with breakfast cereals at the company's distribution centers throughout the U.S. By performing these activities closer (in terms of time and proximity) to the retail customer, General Mills experiences less uncertainty in short-term demand and minimizes its risks of inventory obsolescence [30].

Identify Manufacturing Constraints and Requirements

After the push-pull boundaries are determined, the strategic process team addresses the roles and responsibilities of the supply chain members to identify manufacturing constraints and requirements for desired performance. Recognizing bottlenecks in the manufacturing process is critical in achieving this objective. Among the more common constraints are labor and equipment resources. Ensuring that existing resources meet current and future demand ranks among the greatest difficulties for manufacturers.

Products that experience significant demand seasonality are particularly susceptible to periods of substantial under- and over-capacity. Manufacturers often hire temporary workers to offset the problem of insufficient labor on a short-term basis. With regard to equipment and facility resources, manufacturers will outsource excess production, build in advance, or use overtime capacity to ensure ready inventory availability when demand peaks. The ability to forecast these changes in demand patterns accurately is essential to providing adequate supply at the lowest possible cost. Therefore, the demand management process team not only must be aware of potential bottlenecks or problems in manufacturing flow but also must communicate demand forecasts well in advance, with continuous updates that provide greater accuracy in the near-term.

Manufacturing constraints and requirements will lead to the development of the inventory policy for each facility in the supply chain network structure. The inventory policy will include how much inventory is to be held in the form of raw materials, subcomponents, work-in-process, and finished goods, and how often inventory will be replenished. Finally, the inventory policy will determine the appropriate actions in the event of a stockout, which will be coordinated with demand management and, eventually, incorporated with contingency plans. Contingency plan development is imperative in minimizing disruption when problem situations cannot be anticipated or avoided [31].

Manufacturing flow management is enhanced as upstream supply chain members understand their roles and engage in synchronized flow to support the manufacturer's value-added processing. The process team is responsible for developing communication mechanisms that make synchronization possible across companies. In addition, the team develops criteria for acceptable quality throughout the manufacturing processes. The supplier relationship management process facilitates this interaction with the supply base. The supplier relationship management team is charged not only with coordinating responsibilities with suppliers, but also jointly developing and implementing process improvement initiatives. Opportunities for process improvement often can be more easily identified by upstream supply chain

members than by the manufacturer. Cargill, Inc., for instance, works closely with its food processing customers to develop not only better products but also better processes for improved product flow.

The manufacturing flow management process team will also participate in the development of the disposition requirements and returns management strategy. The disposition guidelines are developed in the returns management process [32]. However, the manufacturing flow management team will possess know-how regarding the methods for disassembling and disposing of the manufactured products. Disposition options include sending the product to landfill but the more preferable option is recapturing value. Therefore, the manufacturing flow management team participates in the feasibility analysis of the disposition options, including the determination of materials that can be reused or recycled, as well as the development of refurbishing and remanufacturing capacity.

Develop Framework of Metrics

In the final strategic sub-process, the process team develops the framework of metrics to be used to measure and improve the performance of the process. A uniform approach should be used throughout the firm to develop these metrics [33]. The team should start by understanding how the manufacturing flow management process can directly affect the firm's financial performance, as measured by economic value added (EVA) [34]. The true test of the process' effectiveness is found in the value it creates. Figure 5 provides a framework that shows how manufacturing flow management can impact sales, cost of goods sold, total expenses, inventory investment, other current assets, and fixed assets.

Though the financial implications of production operations typically focus on cost reduction, the manufacturing flow management process should be credited with revenue enhancement associated with successful execution as well. For example, better manufacturing flow management can result in higher sales and healthier margins through consistent availability of products that meet customers' specific needs. Manufacturing flexibility that accommodates changes in product attributes and volume allows the company to meet demand better than rivals and to do so with lower inventory investment. Together, these factors strengthen customer loyalty and support repeat business. Loyal customers are also more likely to direct a greater proportion of their business to the proven manufacturer, improving the company's "share of customer."

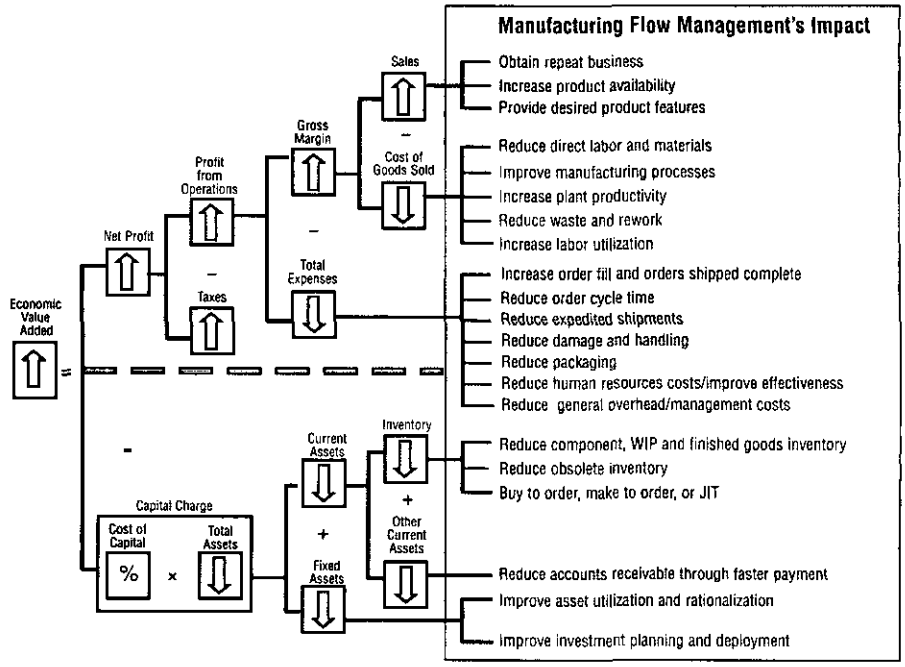
Cost of goods sold can be reduced as a result of reduced labor and material expenses. Improving manufacturing processes, increases plant productivity. Reducing waste and rework, and increasing labor utilization are other potential sources of savings. Non-manufacturing expenses also can be reduced through improved manufacturing flow management. A responsive manufacturing process leads to better order fill rates and orders shipped complete. Not only will order fill increase but it will be achieved faster and with fewer expedited shipments. A process focused on quality in execution will reduce damage and handling expense and perhaps investment in packaging. In addition, a well designed and implemented manufacturing flow management process can reduce human resource costs and improve the effectiveness of employees.

Better manufacturing flow management increases inventory turns and reduces inventory in its various states of completion (component, work in process, and finished goods). Manufacturing flexibility accommodates demand with less inventory obsolescence. More responsive supply and improved order fill should lead to fewer disputes with customers, and reductions in accounts receivable. Finally, better manufacturing flow management can lead to lower fixed assets through improved asset utilization and facility rationalization, as well as better investment planning and deployment. It is only through demonstrating the manufacturing flow management process' contribution to the greater success of the firm and supply chain that further investments in the process will be justified and rewards for good performance will be determined.

Upon recognizing the impact of manufacturing flow management on the firm's financial performance, as measured by EVA, the team must develop metrics that guide behavior in production operations and yield desired performance. The metrics

Though the financial implications of production operations typically focus on cost reduction, the manufacturing flow management process should be credited with revenue enhancement associated with successful execution as well.

Figure 5
How Manufacturing Flow Management Affects Economic Value Added (EVA®)



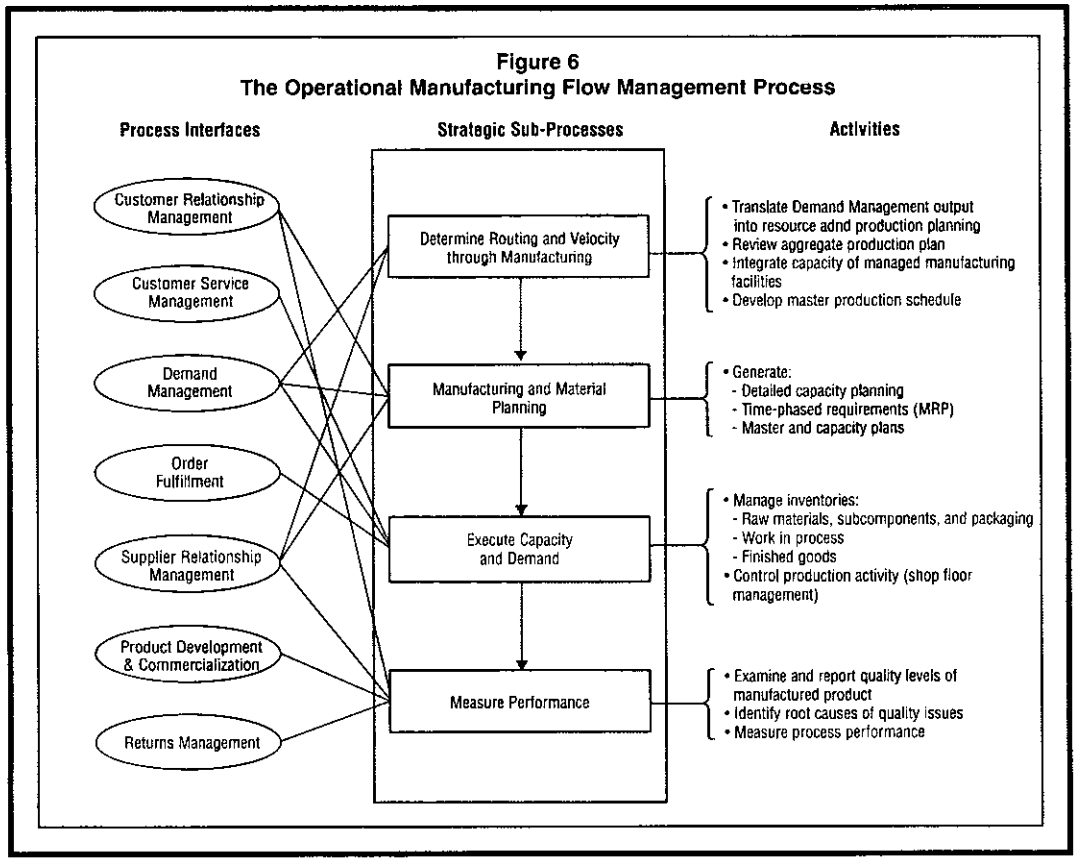
Source: Adapted from Douglas M. Lambert and Terrance L. Pohlen, "Supply Chain Metrics," *The International Journal of Logistics Management*, Vol. 12, No. 1 (2001), p. 10.

assess efficiency and effectiveness in terms of important performance criteria such as product quality, productivity, cycle time, inventory levels, cost, and safety. The importance of these measures should correlate closely with the prioritization of competitive bases, as determined by the manufacturing strategy and must be tied back to financial measures. The manufacturing flow management team coordinates the metrics with the aid of the customer relationship management team to ensure appropriateness and importance to customers. To the extent possible, the manufacturer should gather both formal and informal input from customers (next-tier customers and end users should they not be the same). Metrics for upstream performance might also be devised for the supplier relationship management team to assess the contribution of suppliers to process performance. In the same way metrics are coordinated with customer relationship management so that the customers reward the firm, metrics are also communicated to supplier relationship management to reward suppliers' efforts to firm success. The manufacturing flow management process will generate input to guide the supplier relationship management team in seeking process improvements from the supply base.

Finally, the framework for metrics should provide the basis for aligning the efforts of the corporate functions. Traditionally, interface between functions focused on efficiency (e.g., production) and functions that are focused on the customers (e.g., marketing) has been a source of conflict. This type of conflict may be resolved through better communication, teamwork, better understanding of the other one's responsibilities, and clarification of goals [35]. The appropriate framework for metrics should facilitate internal integration; it should enable viewing the firm's activities holistically across the corporate functions.

The Operational Manufacturing Flow Management Process

The operational portion of manufacturing flow management is the realization of the process developed at the strategic level. Despite the apparent



similarities between the operational sub-processes and the production function internal to most manufacturers, key differences exist. These differences include the guidance provided by the infrastructure developed at the strategic level and the interfaces that link the operational sub-processes in a structured way to the other seven supply chain management processes. There are four sub-processes that represent the operational flow. Each is depicted in Figure 6 and described successively.

Determine Routing and Velocity through Manufacturing

The first operational sub-process establishes the execution of the plan set forth in the strategic portion of the process. Determining the routing and velocity of materials and goods through manufacturing is the first step. The demand management process provides critical input to this sub-process, primarily though sharing the aggregate production plan. This plan is based on historical demand, marketing and sales strategies, and general market intelligence.

Upon reviewing the aggregate production plan, production management assesses the volume capacity across the manufacturing network and allocates volume to each plant. To the extent that production is outsourced to third parties, the supplier relationship management team will be instrumental in communicating with these external service providers. Each plant then develops its own master production schedule (MPS) that dictates which products to produce, when, and in what quantities. The master production schedule reflects the manufacturing priorities set forth at the strategic level, recognizing the products and customers that are most important to the manufacturer's profitability. In addition, it reflects the manufacturing strategy among the range of possibilities (buy to order, make to order, assemble to order, make to stock, and ship to stock). Factors such as capacity limitations, manufacturing constraints, production setup time and costs, and inventory carrying costs are considered when developing the MPS [36]. There is communication with the supplier relationship management team to ensure that the supply base is committed to the accommodation of

To the extent that production is outsourced to third parties, the supplier relationship management team will be instrumental in communicating with these external service providers.

the manufacturing priorities.

As manufacturing firms gain greater flexibility in their operations, less reliance will be placed on advanced planning. Rather, agility will be emphasized where rapid accommodation of varied customer demands proves both efficient and valued in the marketplace. While flexibility is regarded among the most promising opportunities in manufacturing, most operations remain driven by sales forecasts that subsequently determine routing and velocity.

Manufacturing and Material Planning

Once the MPS is determined, orientation shifts to the detailed planning of capacity and inbound materials necessary to "feed" the production schedule sufficiently. The material requirements plan (MRP) identifies the quantities and timing of all subassemblies, components, and raw materials needed to support production of the "parent" items [37]. The MRP, therefore, serves as the prime operational interface between manufacturing flow management and supplier relationship management. Along with the MPS, product-specific bills of materials and on-hand inventories drive the MRP explosion that yields the desired quantities of input materials required at any given time to support product flow. The MRP includes not only material inputs for the product but also packaging material.

Synchronizing available capacity and demand represents the on-going effort to provide sufficient, timely supply with minimal inventories, asset and labor productivity consistent with established standards, and high quality throughout the process.

Next, production management develops the capacity resource plan, which represents a time-phased plan of the capacity needed from each resource. Should a capacity or materials shortage be identified, the team will interact, on the one hand, with the demand management team to find possible solutions to the bottleneck from the demand side. On the other hand, the process team will interact with the supplier relationship management process team to work with materials suppliers or with third-party providers, if manufacturing activities are outsourced.

The supplier relationship management team not only prepares suppliers for future material needs but keeps manufacturing informed of any potential hazards or disruptions that might be encountered upstream in the supply chain. Management should be aware of material shortages, price changes, possible labor strikes, and capacity problems in processing or transportation that might influence the inbound flow of materials. For instance, many North American manufacturers were affected by the West Coast port closures of October 2002, essentially cutting off supply from Asia for a period of several weeks. During such times, customer relationship management may be involved to the extent that problems arise in fulfilling demand. Should capacity prove insufficient to meet the needs of all customers, the demand management team will designate the order of manufacturing priorities.

Execute Capacity and Demand

Execution follows the completed planning process. This sub-process involves frequent interface with the demand management and order fulfillment process teams to maintain optimal flow of materials, work-in-process, and finished goods. Daily checks may be employed to ensure that schedule attainment is achieved - providing adjustments as necessary. In addition, the supply of packaging materials must be sufficient to ensure that shortages do not disrupt the flow of inbound materials and outbound goods. This is particularly challenging for manufacturers using returnable packaging in a closed-loop system.

Synchronizing available capacity and demand represents the on-going effort to provide sufficient, timely supply with minimal inventories, asset and labor productivity consistent with established standards, and high quality throughout the process. Timely execution relies on well developed plans and an ability to adapt to variation in the process. For this reason, quality programs such as Six Sigma and its associated blackbelt training are popular means to reduce process variance. To the extent that processing time can be lessened and the variance minimized, the manufacturer can better meet customers' changing needs with less disruption and lower costs [38].

Beyond demand management and order fulfillment, the synchronization of capacity and demand calls for interaction with customer service management. This primarily will take the form of executing the order acceptance guidelines established in the

strategic sub-process associated with manufacturing capabilities. Customer service failures will be minimal in number and severity if customer service management personnel are prepared to make reasonable promises that affect manufacturing and its support functions. Problems only worsen when unreasonable promises are extended or when problem resolution requires time and resources already dedicated to existing orders.

Measure Performance

The final operational sub-process involves process assessment and improvement. The manufacturing flow management process, like all of the other supply chain management processes, spans beyond the four walls of the company. The manufacturing flow management team must therefore not only measure performance within the firm's manufacturing plants but must also relate this performance to the broader supply chain.

The manufacturing flow management team regularly tracks performance measures and conveys these metrics to the customer relationship management and supplier relationship management teams. Recognition of problems may only be possible through external measurement of performance. With regard to customer satisfaction, for instance, internal measures alone will not capture the disparity between what a customer expects and what is actually delivered. This information can only be obtained by communicating with the customer. The customer relationship management team is well positioned to gather this information on behalf of manufacturing flow management and order fulfillment. The same might be true of problems on the inbound side of the manufacturing operation. For this reason, regular conversation with suppliers through the supplier relationship management team ensures that inbound materials flow with minimal disruption. The customer relationship management and supplier relationship management teams can then use these metrics to generate cost and profitability reports. These reports are valuable when negotiating services with key material and service providers, and when determining rewards for customers and suppliers who have positively influenced the performance of the manufacturing flow management process [39].

To the extent that problems arise between manufacturing flow management and any other process area, the relevant process teams should be sought for input. For instance, product design flaws or inconsistencies between product design and manufacturing processes would incorporate the expertise of the product development and commercialization team. In addition, the returns management process can provide important indications of design or manufacturing problems based upon the unfortunate situation of customers recognizing flaws before they can be reconciled internally. Once a root cause is determined, the involved process teams resolve the problem and share the resolution with parties internal and external to the company that might be affected. This is particularly important in the case of product recalls for safety reasons.

Research Opportunities

In this paper, we further developed the manufacturing flow management process and provided a more in-depth explanation of the issues and activities involved in each sub-process. While we have clarified the process and started to provide a roadmap for its implementation, there are several research opportunities that remain:

- Determining the appropriate degree of manufacturing flexibility that best meets customer demand at the lowest supply chain cost;
- Developing methods for achieving desired manufacturing flexibility;
- Determining the costs and benefits to the supply chain derived from improved manufacturing flow management;
- Identifying the information technology and types of systems that are needed to support the manufacturing flow management process;
- Developing and empirically testing a framework that links traditional production metrics to the performance measurement of manufacturing flow management which should extend beyond the borders of the firm; and
- Implementing the manufacturing flow management process across firms in a supply chain, documenting implementation issues and how obstacles were overcome.

The manufacturing flow management team regularly tracks performance measures and conveys these metrics to the customer relationship management and supplier relationship management teams.

Conclusions

The manufacturing flow management process is one that centers on the conversion of materials and components into finished goods demanded by the market. The areas of operations management, operations research, and industrial engineering are well versed in recognizing new, better ways to perform the conversion activities within the four walls of the manufacturer. Supply chain management, on the other hand, seeks ways to improve performance by leveraging the capabilities of not only the production function within the firm but also the capabilities of supply chain members. While manufacturing flow management represents only one of the eight key processes of supply chain management identified by The Global Supply Chain Forum, it is a critical driver of success for all entities that make up that supply chain.

To the extent that added value can be demonstrated, interest shifts from whether to implement manufacturing flow management and its complementary supply chain management processes to concern for how quickly the benefits can be rendered.

While the preponderance of responsibility for both strategic and operational processes rests with the manufacturer, customers and suppliers significantly influence, and are influenced by, the manufacturing flow management process. Much of this influence is channeled through the customer relationship management and supplier relationship management teams, respectively. In fact, customer relationship management interfaced with four of the five strategic sub-processes and two of the four operational sub-processes. Supplier relationship management is involved in four of five strategic sub-processes and three of four operational sub-processes. It is not only through internal efforts of the manufacturer but through the efforts of material and service providers that the desired degree of manufacturing flexibility is achieved to accommodate changing market demands.

Capturing demand information and, in fact, better managing demand is critical to the manufacturing flow management process as well. The close relationship between manufacturing flow management and demand management is characterized by the many interfaces between these two processes. The ability of the demand management process to anticipate demand with precision alleviates the need of the manufacturing system to be flexible. However, the trend in most industries is one of frequent and often dramatic change, driving the need for greater flexibility.

While many of the arguments supporting implementation of the manufacturing flow management process make conceptual sense, quantifying the benefits in terms of financial impact remains a significant challenge. To address this challenge, economic value added analysis was introduced as a way to help sell the value of manufacturing flow management as a supply chain management process. Demonstrating the bottom-line significance of strategic and operational change in the supply chain will only grow in importance. Economic value must be abundantly clear both within the firm and with cooperating supply chain members to gain buy-in and long-term commitment toward a common objective. To the extent that added value can be demonstrated, interest shifts from whether to implement manufacturing flow management and its complementary supply chain management processes to concern for how quickly the benefits can be rendered.

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[10] Members of The Global Supply Chain Forum are top executives of leading firms from a wide variety of industries, such as communications and technology, consumer packaged goods, fashion apparel, commodity merchandising, oil and petrochemicals, automotive manufacturing, athletic equipment, household plumbing and accessories, and consumer electronics. Member companies represent all possible locations across a supply chain: original suppliers, manufacturers of industrial products (business-to-business), manufacturers of consumer products, distributors, and retailers. Therefore, the manufacturing flow management process presented here represents combined knowledge and experiences from leading firms in the corresponding industry.

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