Getting Ahead of Your Competition Through Design for Mass Customization

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Today's customer demands quick delivery of a highly customized product. The recent movement to mass customization has resulted in increased customer expectations for service and product variety. To support the growth of product variety and its fast delivery, many firms find conventional manufacturing and distribution processes costly and inefficient.

Visionary companies like HP, IBM, and Motorola have experimented with designing their products and restructuring their supply chains to achieve efficient, responsive mass customization.

Although businesses often talk about restructuring their workforce and the overall corporate organization for *mass customization* — producing customized products to meet highly diverse needs of customers in a short leadtime, their actual manufacturing processes are often largely unchanged, except for increased pressure to keep costs down and still provide good customer service.

Brute force mass customization causes great difficulties for the company, but some managers see it as necessary to maintain market share.

The good news is that mass customization need not be painful. Companies such as Hewlett-Packard (HP) and others are using a powerful design concept, known as design for supply chain management, to dramatically improve their supply chain performance. This concept calls for redesigning their product and process designs to counteract the complexity and uncertainty factors that paralyzed their supply chains. This article illustrates the basic principles of design for supply chain management and demonstrates how to apply them to gain a competitive advantage.

The Opportunity

In many industries, the ability to deliver a highly customized product quickly and efficiently to a customer has become *the* characteristic that separates the successful competitors from the also-rans. The growing global market, rapidly changing technologies, and the needs of diverse customers all drive companies to proliferate product options. Faced with increased product variety as well as increasing pressure for fast response to customers, the challenge of effective delivery has become an issue of corporate survival.

Order-to-shipment response time and mass customization are two of the most important areas where companies can develop a competitive edge in the 1990s. Yet the proliferating product options demanded by an ever more diverse marketplace complicate the aim of quick, responsive delivery. Most enterprises already strive for fast delivery performance, yet few attain it, even without the pressure of mass customization. How can firms possibly achieve timely delivery of increasingly complex products? While an agile work force and organizational structure are necessary for mass customization, attempting it without significantly redesigning the products and restructuring their manufacturing and distribution processes can be a recipe for fiscal disaster.

For example, matching the uncertainties of demand in a market with many product options can cause companies major losses. The personal computer industry provides several examples of this. Because forecasters at IBM thought that the 1993 Christmas retail demand for its PCs would outstrip its supply, management decided to build inventory of its ValuPoint and PS/1 line for the Christmas season. The forecasters, however, were wrong. Customers didn't want the models that IBM had in stock. Consequently, as late as August 1994, industry sources said that IBM was still pulling back $600 million of the excess Christmas inventory from its distribution channels.

At about the same time, Compaq Co. began building its inventories of 486-based machines in anticipation of the 1994 Christmas rush. Compaq built up $2.2 billion, or four months' supply, of its personal computers in anticipation of heavy holiday buying. Significant holiday buying did occur, but buyers bought more expensive Pentium machines from Packard Bell rather than 486-based machines from Compaq's enormous stockpile.

Not to be outdone the next year, Packard Bell assumed that customers would purchase 75Mhz Pentium-based machines for the 1995 holiday season. Instead, customers chose to buy faster machines, leaving Packard Bell with significant stocks of 75Mhz machines. *IBM, Compaq, and Packard Bell found out the hard way that they could not guarantee sales through inventory stocks.* Instead, they must offer the product that the customer wants when he or she wants it. This is the essence of mass customization.

Competing successfully in the current market demands that companies provide each customer with his or her desired product options within an increasingly short time window. Companies have developed many techniques to meet the growing challenge of delivering customized products quickly at low cost. Electronic data interchange and computer-aided ordering can cut the time needed to transmit and process customer orders. Investment in flexible manufacturing systems not only allows for faster cycle times but also improves responsiveness to the variable product mix found in a given factory. Finally, the latest developments in electronic commerce help strengthen communication links and can enhance decision-making capabilities for firms operating in the supply chain.

While these techniques are certainly noteworthy steps in the right direction, isolated implementation of logistics improvements, better information flow, shorter cycle times, and flexible factories will not allow a corporation to compete effectively in the future. Competitive advantage lies primarily in the integration of product design and the supply chain. Visionary companies like HP, IBM, and Motorola have experimented with designing their products and restructuring their supply chains to achieve efficient, responsive mass customization. The idea is to design products and realign the manufacturing and distribution activities so that each customization step leading to product variety occurs at the most efficient point in the supply chain, giving the lowest total supply chain cost.

KEY

Design for Mass Customization: The Enablers

The idea behind product design and supply chain restructuring for mass customization is *postponement*. At various points in the supply chain, there are choices about which particular features or functions will be added to the product; the sum of these customizations differentiates the final product option from all others. The placement of these steps offers tremendous opportunities for process improvement. Design for mass customization allows a firm to postpone differentiation to a later point, enabling quick integration of modules to meet a customer's order with minimum cost and inventory or other asset usage. By applying the following principles to their products and manufacturing and distribution networks, companies can improve their delivery competitiveness and save millions of dollars.

Though the concept of postponement is simple, successful implementation requires the integration of product design, supply chain structure, and assembly process. There are three enablers and their corresponding design principles that together form the basic building blocks for an effective mass customization program. All three enablers are integral to the restructuring of the supply chain for effective mass customization; they should therefore not be viewed as independent and disjointed principles.

1. *Product modularity*: a feature of the overall design of a final product that enables the product to be built by easily integrating independent modules.

Before and After Standardized Components

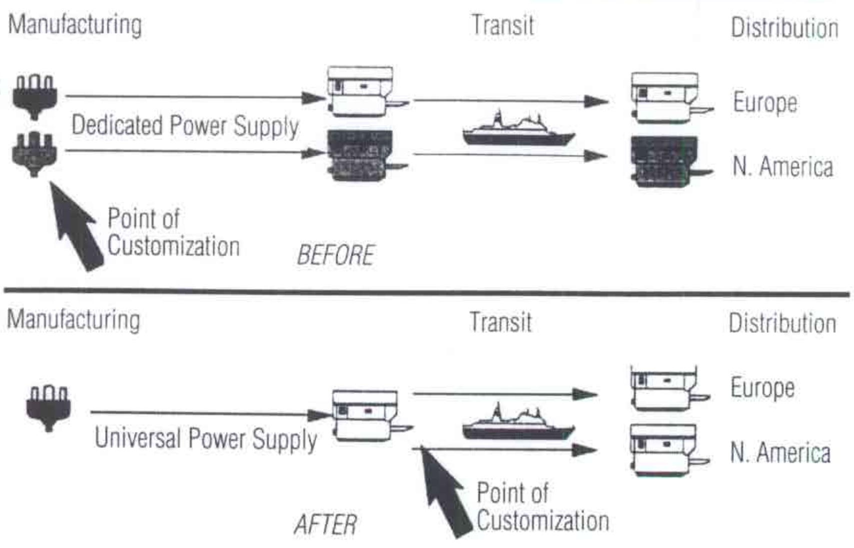

Figure 1. *Product is not differentiated until it is loaded at the port.*

2. *Process modularity*: a feature of the design of manufacturing or integration processes that allows processes to be relocated or rearranged easily to support different distribution network designs.
3. *Agile supply chain network design*: the design of the supply chain physical network (location, number and structure of manufacturing and distribution facilities, inventory positioning) to facilitate cost-effective movement of base units, and fast, responsive, flexible movement of finished, customized goods to the customer.

Enabler 1 — Product Modularity

Product modularity provides a supply chain with the essential flexibility to customize a product quickly and inexpensively. Product modularity requires that firms design products that can be assembled and tested easily. Such modularity provides several benefits.

early
common
stdzd
independent

First, modularity separates the composition of the end products into parts and/or subassemblies that are common, and those that are not. This separation allows for the use of common parts and subassemblies in earlier stages of the production process, allowing these earlier stages to be standardized for all product options. Second, modularity allows the production of the modules to be carried out independently. In fact, the production of the modules can be done in parallel, significantly shortening the time required for production. Third, modularity makes it easier to diagnose production problems and isolate potential quality problems.

Product modularity requires the use of two design principles that support mass customization: standardization of components and postponement of the subassemblies that differentiate the product. A dedicated power supply (one which cannot automatically convert voltage) is an example of a component that is not modular. In the global electronics market, building a dedicated power supply into the product in the first stages of production forces the manufacturer to commit to the product's final destination country early in the process. If the production process is long or if the factory to end-customer delivery time is significant, the power supply complicates mass customization.

Each of the principles of product modularity suggests a solution to this problem. A firm could standardize components, designing or purchasing a single power supply that would work for all its customers. Alternatively, the firm could postpone the subassembly, delaying the assembly of the power supply into the unit until a point in the process closer to the customer. Either method offers significant advantages in flexibility and potentially lower costs.

HP has successfully implemented the standardization strategy for a computer peripheral product that sells in Europe and North America. The core engine that constitutes the bulk of the finished product is made in Japan and is shipped by sea to the two markets. Before designing for mass customization, the product had a dedicated power supply of 110V and 220V which immediately differentiated the product by end customer market as soon as production began in Japan. Under the improved design, a universal power supply that works in all countries is built into the product. The product is not differentiated until it is loaded at the port to be shipped to its actual destination. A side benefit of the universal power supply in this case is that HP can easily ship products from one continent to another when significant imbalance of demand and supply exists between geographic regions.

At the time when production of the core engine begins in Japan, the engine manufacturers only need to know the aggregate worldwide demand. Such standardization strategies can yield great cost savings. Figure 1 illustrates this concept.

Value of Common Components = Cost of Demand Uncertainty

Standardization of components to support mass customization requires careful analysis, as the standardized components may increase the material cost of the product.

Before and After Module Postponement

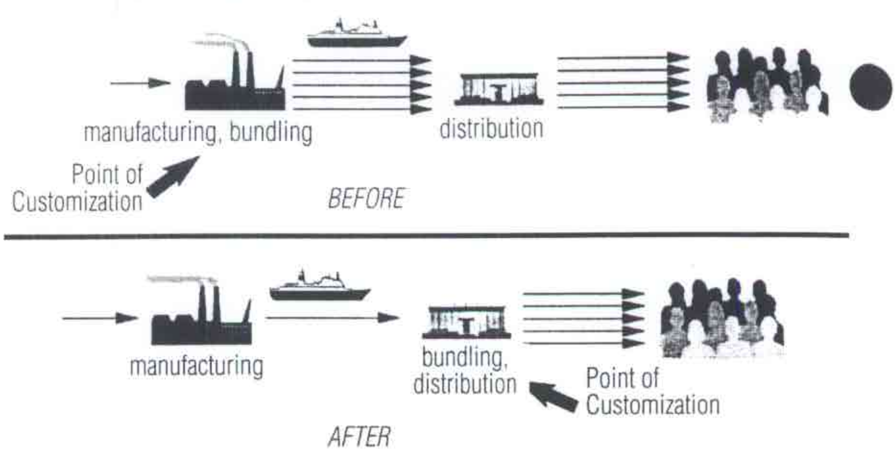

Figure 2.

HP learned that the value of common components depends on the uncertainty in product demand across its geographically-spread markets, the leadtime to replenish its parts stocks from far-flung suppliers, the length of the product life cycles, and the cost of shipping finished products between countries. The greater the uncertainty, the longer the leadtime, and the lower the logistics cost, the greater will be the value of standardization.

In particular, since HP found that forecasting the mix of options customers want is most difficult at the beginning and the end of a product's life cycle, shorter product life cycles increase uncertainty. Therefore, the cost benefit of standardization increases in a highly customized short-life environment. An accurate assessment of the value of standardizing components, therefore, needs a thorough analysis of all these factors, so that any extra costs due to the standardized components can be properly weighed against the benefits to the supply chain from standardization.

[illegible]
RATE uses

When key components are not designed for mass customization, cost-effective mass customization may not be economically viable, as the following example illustrates. A manufacturer of chemical analysis equipment wanted to reduce the leadtime to ship a customer order from six weeks to two days. The complex and difficult assembly and testing of this product took about three weeks. The company decided to pursue postponement as a means to reduce leadtimes with the lowest possible inventory investment. Managers planned to hold inventory of almost-finished goods and perform the final assembly (customization) steps when specific customer orders reached the factory. Unfortunately, the product design required the manufacturing process to build the complex instrument around a power supply *and* power cord dedicated to a particular country. This design would have required the manufacturer to hold safety stocks of 13 different country configurations at $50,000 per product stocked. Because of this design, the company decided that it could not afford to offer shorter leadtimes.

HP and other companies, however, have solved this design problem (known as design for localization) to meet the diverse country options in Europe and South America. Instead of HP localizing its DeskJet printers (such as adding power supply and cord, manuals, and possibly software) at the factory before shipping them to Europe, the European distribution center procures the local power supply and localization materials and performs the localization steps. Such a postponement strategy has saved this HP division millions of dollars. Similarly, Philips Corporation has modularized the design of its electronic devices so that the "bundling" of the accessories for the devices can occur at the distribution centers instead of at the factory, a response identical to the HP DeskJet case. These practices are illustrated in the Figure 2.

In another instance at HP, designers initially balked at adding $2.50 to the material cost of a product to create a generic ink-jet printer that both Mac and DOS users could use. (The other option was continuing to produce two separate printers.) The HP division conducted an analysis that included material cost, duties, logistics, manufacturing cost, and costs associated with inventory. This comprehensive supply chain analysis demonstrated that spending the additional $2.50 could deliver several times that in supply chain cost savings, in addition to helping downstream supply chain partners (computer resellers and retailers) hold only one stock of DeskJets instead of two. In fact, a major retailer elected to sell the HP DeskJet 850 partially because of the advantages of being able to service both Mac and DOS customers with the same stock of DeskJets: lower inventory costs, less shelf space, and lower associated overhead.

WALMART

+ BULK PACK

Enabler 2 — Process Modularity

Process modularity does for operational processes what product modularity does for products. Here we aim to de-couple a production process so that it breaks down into sub-processes. Without de-coupling, the complete process must be done without interruption, often leading to long cycle times and to inflexibility in meeting demands for multiple end products. De-coupling the pro-

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With and Without Postponed Process

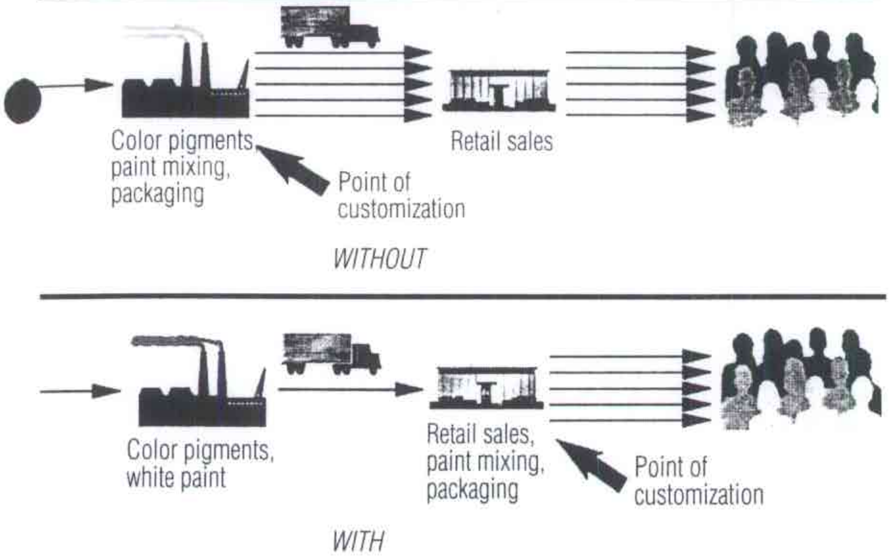

Figure 3.

sum

together:
mfg control
flex "
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duction process promotes flexibility and thus supports mass customization. Process modularity has three key principles: process postponement, process resequencing, and process standardization.

Color-matching paints at your neighborhood hardware store is a good example of process postponement. Imagine if individual stores had to stockpile different paints to match every customer color demand. Fortunately, low-cost chromatography has made it possible to modularize the mass customization of paint. Generic paint (tint base) is made at the factory, as are the multiple color pigments. Hardware and paint stores stock the generic paint and the color pigments, and combine them to match a customer's color sample on demand. This innovation provides the customer with a virtually unlimited number of consistent color choices, while significantly reducing the inventory of paint that a store needs to stock. This is *postponement*; the process that differentiates the product into paints of many colors was postponed from the factory to the retail stores. In this case, the key to postponement was de-coupling the total paint production process into two sub-processes, paint pigment production and paint mixing. Figure 3 illustrates this concept.

Process modularity also offers advantages in retail apparel. Apart from specialized stores, most department outlets sell finished clothing with little or no provision for final customization to fit the customers' body dimensions and tastes. Most cloth is dyed, cut, and sewed to pre-determined dimensions, making low-cost mass customization difficult if not impossible (tailored clothing is usually quite expensive).

...process resequencing... enables low cost postponement of product variety

An emerging technology in the fashion industry effectively splits the production process of finished clothing into two modular sub-processes: body measurement, and cut and sew. The "Body Scanner," currently under development, uses computer and optical technology to accurately measure a person in a store, much as a tailor does today. The computer sends the measurements to the clothing vendor, who cuts and sews the garment within 48 hours. This technology slices inventory by combining the advantages of centralized, automated apparel factories and the flexibility of an on-site tailor. The result is a completely customized garment for about the same cost as an off-the-shelf item. While the retail outlet has to invest in the purchase and maintenance of the Body Scanner, the purchase can significantly improve sales per square foot, as the outlet only needs to hold samples instead of stock in all sizes and colors.

This type of customization can also reduce a retailer's losses to end-of-season discounts, which are common because of the difficulties of matching demand with supply. A typical clothing retailer realizes full price for only 50 to 60 percent of his or her clothing inventory. With the process postponement achieved with the Body Scanner, the retailer could realize full price on virtually all of his or her inventory. The clothing manufacturer also benefits from greatly reduced inventory risk, as manufacturers hold more stable raw stocks of fabric in the factory rather than highly-volatile finished goods in the retail store.

The second principle of process modularity, process resequencing, enables low-cost postponement of product variety. Once the total operational process is de-coupled into modular sub-processes, as in the example above, we can consider resequencing these sub-processes. This was what Benetton did starting in the 1970s in its sweater manufacturing operations. Instead of first dyeing the yarn into multiple colors and then knitting the yarn into finished garments, Benetton resequenced the dyeing and knitting sub-processes. Dyeing the yarns first immediately defines the final color of the product, while knitting first does not. Hence, the yarns were first knitted into finished garments in their natural (white) colors. The resequencing of the two steps effectively postponed the point of product differentiation into colored sweaters. Benetton dyed the natural colored sweaters (differentiated the product) upon receipt of either an order or at least a better idea of consumer color tastes for that season. This switch saved them millions of dollars in inventory obso-

Before and After Process Resequencing

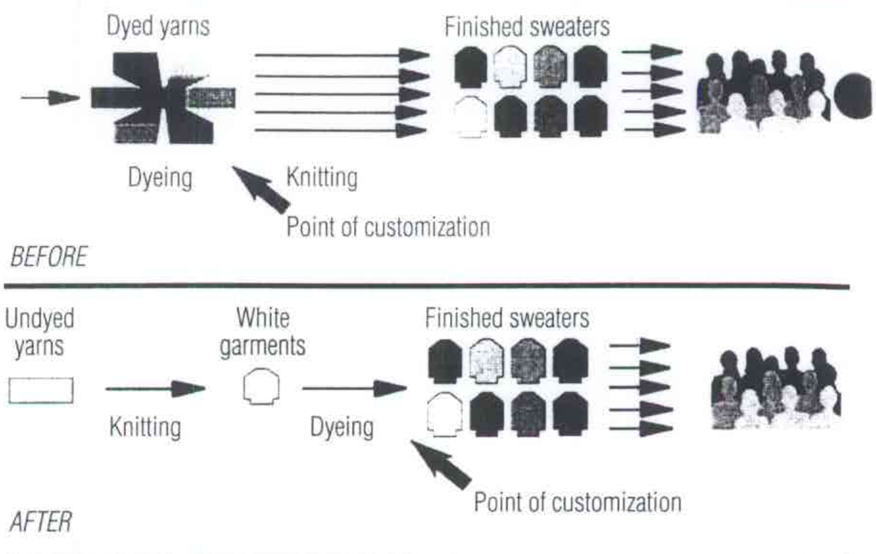

Figure 4.

lescence charges. Figure 4 illustrates postponement through resequencing.

The third principle of process modularity is process standardization. Like product designs, the design of the manufacturing process can have a large impact on when a product gets differentiated into different varieties. Standardizing pieces of the production process so that they do not differentiate the product helps improve the flexibility of the supply chain.

For example, a major manufacturer of disk drives used process standardization to improve its flexibility and responsiveness to changing customer demand. The company supplied AT&T, NeXT, and HP with disk drives. It had trouble matching supply with demand, as its customers often revised their orders at the last minute. A complex, time-consuming stage of disk drive manufacturing is the testing and burn-in of the disk drive. To test and burn-in a drive, the company inserted a printed circuit board prior to the test process. Since each customer normally required a distinct circuit board, the insertion of the printed circuit board immediately defined the drive's final customer destination. The firm discovered that the test process could be de-coupled into two subprocesses, the first one consisting of standard tests that are common to all end products, and the second consisting of customized tests and burn-in that are specific to each individual end product.

The company found a way to perform almost all of the test process without inserting the final customer board. The manufacturer ran all of its disks through the standardized test process using a specifically-designed board, then stocked the generic units until an order arrived. Upon receipt of an order, the firm added the circuit board the customer required and shipped the product. Through the standardization of the testing process and the division of tasks between the standard sub-process and the customized sub-process, they successfully postponed the point of product differentiation. This process greatly enhanced the manufacturer's flexibility at a much lower inventory cost than was possible under the non-standardized process. Figure 5 shows how postponement works in the disk drive example.

Enabler 3 — Agile Supply Chain Network Design

Supply chain network design is an important part of a company's manufacturing strategy. Determining the number and location of factories and distribution centers involves complex decisions. It requires balancing factors such as response time to a customer order, local presence rules in certain countries, duties, transportation time and costs, local labor and occupancy costs, and the replication of fixed assets. Distribution design is the subject of much debate among logistics experts. One camp contends that companies should focus on lowering costs, using centralized distribution networks (one depot or warehouse serving multiple customer regions); another faction asserts that companies should emphasize service, by means of decentralized networks. Depending on the situation, either side can be right. Effective distribution network design can allow a company both to optimize costs and to provide fast, effective service, which, taken in combination, will

> *...the design of the manufacturing process can have a large impact on when a product gets differentiated into different varieties.*

Before and After Process Standardization

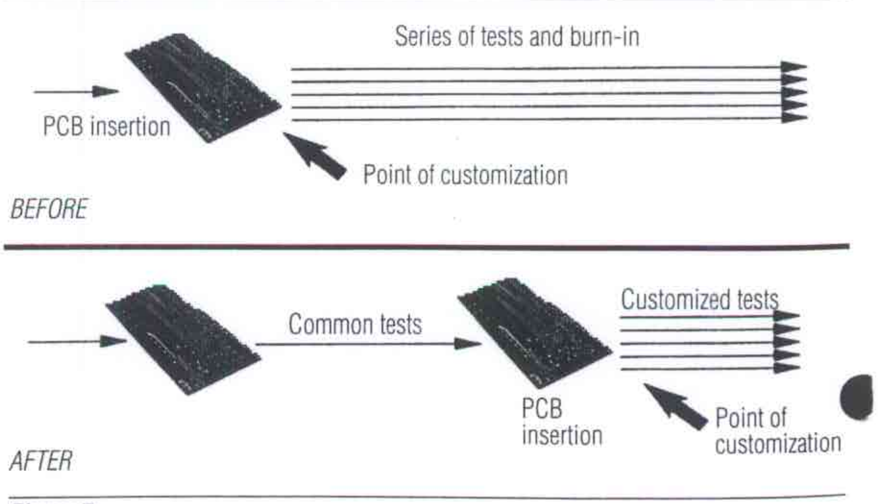

Figure 5.

... lower direct unit costs need to yield to the larger benefits of a simplified process or a more finely tuned supply chain.

floor space to other uses, and displaying related products and accessories to mutual advantage. The mass customization afforded by postponement can increase profitability significantly.

Making a postponement decision involves the requirement to evaluate not only every aspect of the manufacturing process but the entire system. The traditional approach is doing everything possible to reduce the direct cost per unit. However, this new response to highly complex and competitive global markets implies that lower direct unit costs need to yield to the larger benefits of a simplified process or a more finely tuned supply chain.

An illustration of this maneuver is a circuit breaker manufactured by General Electric. After seeing that the entire product line would have to be revamped to increase divisional profits, the product team redesigned the product so it could be assembled at customer locations. The number of parts was reduced from 600,000 to just 300 in a standardized unit — clearly a step in the right direction — but to make the whole scheme work, these units now required more copper (as raw material) than the previous version. Nevertheless, even though direct material cost per unit increased, the postponement of the final assembly process saved money overall and greatly increased customer order fulfillment.

Costs

Design for postponement may entail costs that are not immediately obvious. When product assembly — some or all — is accomplished at a distribution center (as with the Deskjet-Plus) or at customer locations, there are costs associated with getting parts and materials to these sites. Should procurement also be done at these locations, there is potential for lost leverage because purchasing will be done in smaller lots or from more suppliers than when a single shipment was delivered to the factory.

Mass customization does not have to lead to financial ruin.

Postponement may involve capital costs as well. We have already seen that the paint manufacturer may incur the cost of blending machines to customize the product in every store — an enormous financial outlay as well as a managerial challenge. In a high technology environment, a postponement decision might necessitate the purchase or retooling of specialized equipment. The driver in each situation is the imperative to get the right product into the hands of the customer at the right moment for the lowest *total* cost. The approach is far more likely to work if the product remains generic through most (or all) of the production cycle — with mass customization taking place as close as possible (in time and space) to the point of delivery.

Conclusion

As industries recognize that the bulk of the costs of products and services can only be reduced by changing the design of those products and services, modifying the design of the entire supply chain holds great promise for reducing costs and improving delivery speed. The movement toward mass customization is inevitable, given current competitive forces and technological advancements, but trying to implement mass customization by brute force is not the solution. Joint design of products, processes, and the distribution networks offers companies the greatest leverage to achieve cost-effective mass customization.

The quality movement has taught the business community several important lessons. First, since design for quality has become the mainstream approach for quality improvement, using design as the foundation for mass customization represents a natural extension of this success. However, we have also learned that such an approach intensifies the need for multi-functional teams to work together and communicate with one another effectively.

Many of the success stories that we described resulted from the collaborative efforts of manufacturing, engineering, distribution, and marketing organizations. We cannot stress enough the importance of departments working together. In addition, in some of the examples that we described, the design principles were implemented with the involvement of other companies in the distribution channel. These collaborative efforts among multiple companies in a supply chain are also a necessary ingredient for successful design of supply chain projects.

Mass customization does not have to lead to financial ruin. By avoiding the errors associated with "brute-force" mass customization and by carefully applying the set of new design principles that we have outlined, companies can realize its true competitive advantage. The results, in the form of improved profit margins and more satisfied customers, will speak for themselves.

translate directly into competitive advantage.

Consider, for example, the case of computer network server sales in Brazil. In 1994, IBM, Compaq, and HP were all vying for a share of Brazil's rapidly expanding server market. IBM decided to build the product locally. This enabled IBM to gain a huge cost advantage because of Brazil's high duties and complex local content laws, so the company could effectively price HP and Compaq out of the market. IBM was therefore able to seize a significant chunk of market share from HP. IBM priced their product just below HP on all major deals; they could also deliver a fully customized system in a few days, far faster than the service HP could provide from its California facility. IBM had leveraged its manufacturing and distribution organization to achieve a competitive advantage.

IBM forced HP to rethink its Brazilian server manufacturing strategy. HP sales and marketing functions quickly realized that IBM had a significant advantage in delivery speed and cost, a lethal combination. The HP business responsible for this product line pulled together a team representing Brazilian sales and marketing, world-wide manufacturing, and logistics and customs experts for Brazil. The team analyzed potential lost revenue from doing nothing and potential revenue gains from a Brazilian server assembly site. The team then compared this revenue differential to the additional costs of operating in Brazil and the logistics and customs implications of the alternatives. The results, expressed in net profit, convinced even the most skeptical U.S. managers that opening an assembly facility in Brazil was the right decision.

... having a distribution center that can do customization in a market region can also increase sales...

The same pattern appears in many of the emerging markets that hold rich promise for the future. For example, India, China, and Brazil, which together represent about half of the world's population, have complex local content rules which require companies to set up some type of manufacturing activity locally. Without portable, globally-standardized manufacturing and distribution processes, companies cannot effectively enter these new markets.

With postponement ... a company can concentrate core manufacturing at a few factory sites.

The emerging market example illustrates the importance of distribution network design. After adopting the techniques of product and process modularity, companies then should restructure their distribution networks to get maximum benefit from postponement. Process and product modularity, after all, will allow companies to postpone the final customization steps until the product has left the factory; this change creates a new opportunity to redefine the distribution network.

In the past, if a company's distribution network performed only the tasks of warehousing and distribution, a company with many product options benefited very little from having many distribution centers all over the world. The inventory investments required to support multiple product options were enormous. However, with process or product modularity making the final customization steps separate and easy, distribution centers need only stock products in generic form instead of finished end-products. Consequently, it can be cost-effective to have more distribution centers, each of which stocks generic products and performs the final customization steps or, in some cases of highly modular products and production processes, builds a product to order. Moreover, the fact that distribution centers now perform light manufacturing steps (the integration and final testing) creates the potential marketing value of a local manufacturing presence. Cohen and Lee suggest, in their work with Apple Computer, that the value of local presence can be considerable.

As our computer example for the Brazilian market shows, having a distribution center that can do customization in a market region can also increase sales, since this set-up can significantly improve response times to customers. In many industries, consumers will not wait six weeks for a product; they want it now. Because of factory construction and maintenance costs, locating factories in many market regions does not solve this problem. With postponement, however, a company can concentrate core manufacturing at a few factory sites. This solution offers the advantages not only of economies of scale and control, but also, through increasing the number of distribution centers with customization and final testing capabilities, of high responsiveness and local presence.

Let's return to the personal computer industry for a final example of the power of the integration of product, process, and distribution network design to achieve cost-effective mass customization. Today's desktop PC is a highly customized product — some manufacturers offer thousands of different configuration permutations to their customers. The PC consists of industry-standard, pre-tested components. It is among the most modular product designs in today's electronics industries. The production process for a PC is extremely modular; a manufacturer has many different choices of how and where to build the PC. Given this product and process flexibility, PC manufacturers have enormous leverage in the design of their distribution networks to pass that flexibility on to customers as responsiveness to orders at a low cost to the PC manufacturer.

Under the assembly and distribution models common to the PC industry in 1994, most PC manufacturers built product to stock, as in the IBM and Compaq examples we described earlier. Problems associated with stocking the right mix of products to match customer demand plagued the system; inventory write-offs and end-of-life sales occurred frequently. Processor chip prices drop every three months, and memory prices can halve in a year.

In early 1994, HP conducted a supply chain analysis of its PC manufacturing and distribution strategies. HP analysts discovered that as a result of the modular structure of the product and production process, they could postpone all steps of the final assembly of a PC (integrating the PC board, processor, chassis, power supply, storage devices, and software) to their distribution network. The products could be built upon the arrival of orders in locations close to customers, thereby saving on transportation and duty costs and greatly increasing return on assets when compared with stocking finished goods or partially completed units. As a result of this analysis, HP implemented build-to-order at all of its distribution centers in early 1995, leaving its competitors rushing to catch up.

A Compaq executive lamented in the trade press that HP was "light years ahead of the competition" in its ability to deliver quickly at a low cost because of build-to-order. While this is a slight exaggeration, HP did gain a significant lead on most of its competitors. While IBM and Compaq struggled to unload mountains of inventory, HP enjoyed better service to its customers at a lower cost. HP effectively leveraged product, process, and distribution network design to deliver a highly customized product faster and, we assume, cheaper than similar competitors. PC manufacturers are all catching up with HP these days. IBM is aggressively postponing their product configuration steps at resellers while Dell leapfrogs competitors by selling direct to customers and customizing products on order.

Figure 6 summarizes the enablers and their corresponding design principles.

Design for Mass Customization Framework

Enablers	Design Principles
Product Modularity	• Commonality • Postponement of modules (product configuration)
Process Modularity	• Resequencing of processes • Postponement of processes • Process standardization
Agile Network Design	• Postponement of modules and processes • De-coupling points by inventory stocking

Figure 6.

Cost Trade-Offs

In every instance of postponement, the manufacturer has to make classic decisions driven by the demand for diversity. Consider the household paint example again. Recognizing the boundless appetite for color in home decor, a paint manufacturer could attempt to satisfy consumers by making vast quantities of popular shades and smaller batches of more obscure hues. Shipping all that paint to retail outlets constitutes one expense, and the floor space required to store and display the available colors would add another layer of expense to the product. In addition, devoting that much floor space to paint displays would limit the area available for other revenue-generating items — brushes, rollers, wallpaper, varnish, stains, and specialty items.

In the postponement scenario, one or more generic versions of the product are manufactured and shipped. The retailer stores a generous amount of this base paint, along with pigments for creating an almost infinite spectrum of colors . In the decision to postpone the coloring step, the cost of equipment required to add pigment and mix paint must be included in the analysis. For manufacturers with hundreds or thousands of outlets, mixing equipment represents a considerable investment, and the maintenance of this equipment at so many locations would be another concern. The cost of training personnel for custom blending of paint would be an added expense that might reflect quality issues with inexperienced or inattentive employees.

The most compelling factor in choosing to postpone this differentiating step, however, is that it virtually guarantees high order fulfillment and customer satisfaction. Because the product is maintained in its generic form, a concurrent benefit is greatly reduced inventory. In this application of postponement, the benefits are twofold: the customer is certain of getting exactly the right product, and the merchant can improve the business by balancing the required inventory, allocating

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An illustration of this maneuver is a circuit breaker manufactured by General Electric. After seeing that the entire product line would have to be revamped to increase divisional profits, the product team redesigned the product so it could be assembled at customer locations. The number of parts was reduced from 600,000 to just 300 in a standardized unit — clearly a step in the right direction — but to make the whole scheme work, these units now required more copper (as raw material) than the previous version. Nevertheless, even though direct material cost per unit increased, the postponement of the final assembly process saved money overall and greatly increased customer order fulfillment.

Costs

Design for postponement may entail costs that are not immediately obvious. When product assembly — some or all — is accomplished at a distribution center (as with the Deskjet-Plus) or at customer locations, there are costs associated with getting parts and materials to these sites. Should procurement also be done at these locations, there is potential for lost leverage because purchasing will be done in smaller lots or from more suppliers than when a single shipment was delivered to the factory.

Postponement may involve capital costs as well. We have already seen that the paint manufacturer may incur the cost of blending machines to customize the product in every store — an enormous financial outlay as well as a managerial challenge. In a high technology environment, a postponement decision might necessitate the purchase or retooling of specialized equipment. The driver in each situation is the imperative to get the right product into the hands of the customer at the right moment for the lowest *total* cost. The approach is far more likely to work if the product remains generic through most (or all) of the production cycle — with mass customization taking place as close as possible (in time and space) to the point of delivery.

Conclusion

As industries recognize that the bulk of the costs of products and services can only be reduced by changing the design of those products and services, modifying the design of the entire supply chain holds great promise for reducing costs and improving delivery speed. The movement toward mass customization is inevitable, given current competitive forces and technological advancements, but trying to implement mass customization by brute force is not the solution. Joint design of products, processes, and the distribution networks offers companies the greatest leverage to achieve cost-effective mass customization.

The quality movement has taught the business community several important lessons. First, since design for quality has become the mainstream approach for quality improvement, using design as the foundation for mass customization represents a natural extension of this success. However, we have also learned that such an approach intensifies the need for multi-functional teams to work together and communicate with one another effectively.

Many of the success stories that we described resulted from the collaborative efforts of manufacturing, engineering, distribution, and marketing organizations. We cannot stress enough the importance of departments working together. In addition, in some of the examples that we described, the design principles were implemented with the involvement of other companies in the distribution channel. These collaborative efforts among multiple companies in a supply chain are also a necessary ingredient for successful design of supply chain projects.

Mass customization does not have to lead to financial ruin.

Mass customization does not have to lead to financial ruin. By avoiding the errors associated with "brute-force" mass customization and by carefully applying the set of new design principles that we have outlined, companies can realize its true competitive advantage. The results, in the form of improved profit margins and more satisfied customers, will speak for themselves.

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References

Billington, C. and T. Davis, "Manufacturing Strategy Analysis: Models and Practice," *Omega*, Volume 20, No. 5/6, 1992, pp. 587-595.

Cohen, M.A. and H.L. Lee, "Resource Deployment Analysis of Global Manufacturing and Distribution Networks," *Journal of Manufacturing and Operations Management*, Volume 2, Number 2, 1989, pp. 81-104.

Dapiran, P., "Benetton — Global Logistics in Action," *Asian Pacific International Journal of Business Logistics*, 5, 1992, pp. 7-11.

Lee, H.L., "Design for Supply Chain Management: Concepts and Examples," *Perspectives in Operations Management*, edited by R. Sarin, Kluwer Academic Publishers, Boston, 1993, pp. 43-65.

Lee, H.L. and C. Billington, "Managing Supply Chain Inventory: Pitfalls and Opportunities," *Sloan Management Review*, Volume 3, Number 3, Spring 1992.

Lee, H.L., C. Billington and B. Carter, "Hewlett-Packard Gains Control of Inventory and Service Through Design for Localization," *Interfaces*, Volume 23, Number 4, 1993, pp. 1-11.

Lee, H.L. and C. Billington, 1994. "Designing Products and Processes for Postponement," *Management of Design: Engineering and Management Perspectives*, edited by S. Dasu and C. Eastman, Kluwer Academic Publishers, Boston, pp. 105-122.

Lee, H. L. and E. Feitzinger, "Product Configuration and Postponement for Supply Chain Efficiency," *IERC Conference Proceedings*, Nashville, 1995.

Lee, H.L. and M. Sasser, "Product Universality and Design for Supply Chain Management," *International Journal of Production Planning and Control, Special Issue on Supply Chain Management*, June 3, 1995, pp. 270-277.

Pine, B.J., B. Victor, and A.C. Boynton, "Making Mass Customization Work," *Harvard Business Review*, September-October, 1993, pp. 108-119.

Rifkin, G., "Levi Offers Women Made-To-Order Jeans," *San Jose Mercury News*, Nov. 8, 1994.

Zarley, C., "Manufacturers Race to Install Full Build-To-Order Capabilities," *Computer Reseller News*, March 6, 1995.

Zarley, C., "IBM Allows Channel To Perform Final Assembly On PCs," *Computer Reseller News*, May 29, 1995.

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