It's Not Just the Big Picture, It's The Whole Picture

LIKE MANY LARGE manufacturing companies operating in the global marketplace, Hewlett-Packard faces growing inventory levels with ever-increasing demands for customer service. TO MEET THE CHALLENGE, HP utilizes a powerful tool Supply Chain Management to model, analyze and revamp essential business processes.

By Corey Billington

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THE GLOBAL MARKETPLACE has swung its doors open wide. Now, manufacturers and suppliers to that tantalizing bazaar are scrambling to find more efficient and economical ways to deliver products, goods and services to their voracious new customer. How to do this is the conundrum of the 1990s?

Like most other suppliers in this lively arena, the Hewlett-Packard Company (HP) is confronting the realities of global competition. Not only is its customer base increasingly far flung, so too are its production and distribution functions. In the classic struggle to respond to these customers' demands for accurate and timely product delivery, our inventories have grown in the last few years. HP has more than three billion dollars invested in worldwide inventories. Not surprisingly, we pay close attention to asset management.

At HP, we see no indication that the underlying forces that necessitate such investments will diminish. Our challenge — solving the riddle of success in the '90s — is to respond to those forces with less total investment.

As often occurs at such critical junctures, new techniques are emerging to address this challenge. Our powerful tool, Supply Chain Management, enables managers and professionals to model, analyze and revamp their essential business processes. We define a supply chain as a network of facilities that procures raw materials, transforms them into intermediate subassemblies and final products, and then delivers the products to customers through a distribution system. HP includes uncertainties associated with procurement, manufacturing and distribution in our supply chain models. Figure 1 shows a typical example of an HP supply chain.

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AT HP WE PRODUCE MAJOR SUBASSEMBLIES such as integrated circuits and printed circuit assemblies in different parts of the world from our products' final assembly. We try to cluster production activities to facilitate interactions with multiple product lines and to take advantage of economies of scale. Also, the need for local manufacturing presence in our key markets applies a counter force. Typically, we localize products for sale globally and distribute them from warehouses near our customers.

The challenge of supply chain management is to balance the requirements of reliable, prompt customer delivery with manufacturing and inventory management costs. To meet this challenge, managers must assess the supply chain in its entirety, not just the sum of its various parts. It's not just a big picture; its the whole picture. In slightly more nuts-and-bolts themes, the essence of supply chain management is to illuminate the relationship between asset costs (inventory and capital equipment) and the time characteristics of customer service (lead-time and variance of customer delivery). Supply chain analysis should enable managers to see clearly which options will afford the greatest improvement toward the ultimate objective of efficient customer satisfaction. At HP, as in most other global manufacturing companies, the keys to effective supply chain management are metrics, models and cooperation.

Metrics and Models

SUPPLY CHAIN MANAGERS require metrics to measure the economic robustness of their product's supply chain configuration. Some choices must be made and the management team must decide if they hope to maximize the profitability of their supply chain or focus attention on minimizing the consequences of unforeseen events. They must understand what their chain's customers require in terms of order speed and reliability.

Analytical models are needed to make sense of the complex supply chain relationships. A manager can make significant contributions to their firm's profitability by developing and interpreting supply chain models. Over the past five years at HP, we have evolved our models from relatively simple simulations into complex nonlinear stochastic mathematical programming models. At a minimum, a firm should understand the basic flows associated with their supply chains. These flows are financial, informational and physical.

From our perspective, the real value of models is that, initially, they objectify the problem. They end the "turf battle" between functional managers. Models and metrics facilitate a collaborative search for an efficient "optimum" solution. Models clarify negotiations and make global collaboration easier between our individual managers responsible for their part of the total supply chain.

HP customers are not only increasingly diverse geographically but more sophisticated and exacting, too. Our channel partners and other resellers now require more rapid and reliable order fulfillment to minimize their costs. They realize now that unreliable deliveries either drive their inventory investments up or their product sales down (sometimes both) due to product delays. Our dealers lose sales, which they don't like. The competitive pressures in our high technology businesses necessitate that we carefully direct our order fulfillment processes and make certain that our asset management is well monitored. Success in the 1990s requires the formation of effective partnerships and cooperation throughout an entire supply chain.

HP Supply Chain Example

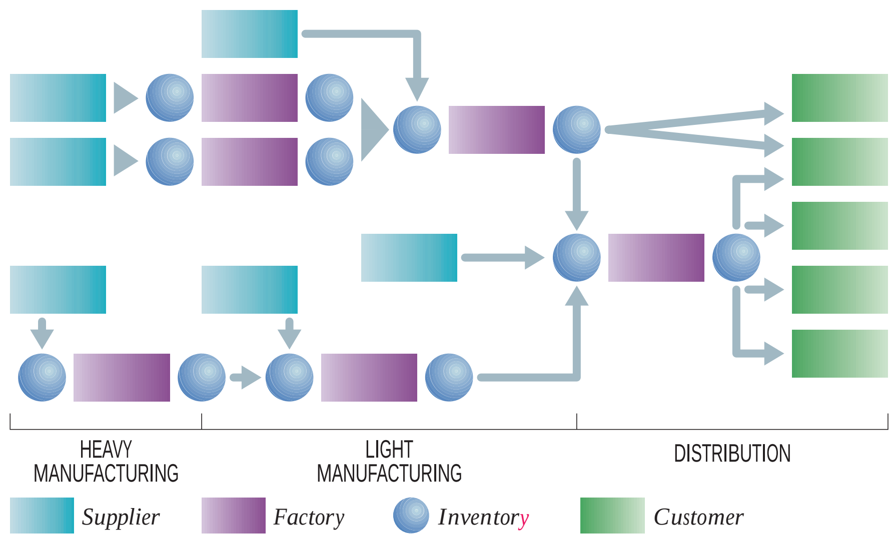

FIGURE 1

Another complication in our industry results from shorter and shorter product life cycles. Products are obsolete almost before they are introduced. Short life cycles — six to 12 months for some products — require that inventory and production planners set stocking levels and capacity plans with little or no historical data about a product. These decisions expose the company to potentially huge end-of-life inventory write-offs.

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Furthermore, market pressures require HP to procure and manufacture each product globally. For example, one of our products has major subassemblies manufactured in Asia and the United States; we assemble it to order near our European customers.

We are committed to strategic supply chain analysis and management at HP. We must be. Our customers require rapid and reliable order fulfillment. Shortened product life cycles and the increasing globalization of our markets forced us to strengthen our resolve.

The Optimum Investment

BECAUSE OF THE MOUNTING PRESSURES on industry, the supply chain manager has an opportunity to exert a profound and positive influence on company profitability. One of the largest contributions is to ensure that appropriate metrics are adopted. Good metrics ensure that decisions made locally to improve local performance actually improve the overall performance of the supply chain from the customer's perspective.

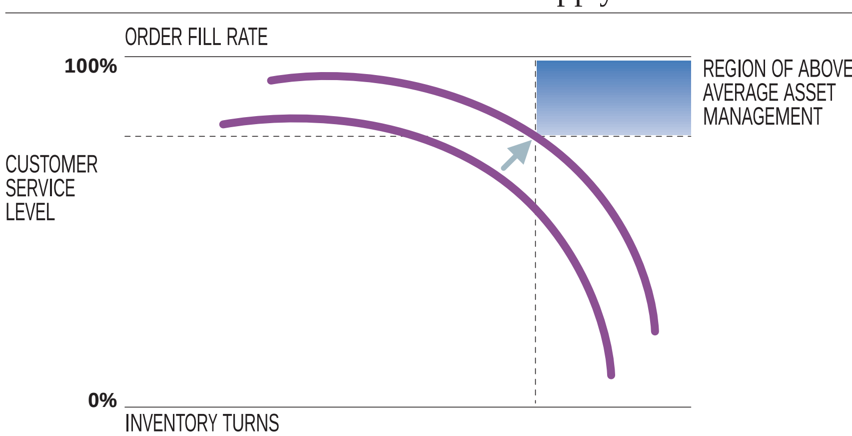
At HP, we see too often situations where local managers invest to improve their part of the supply chain, but the resulting change brings little or no value to the end customer. Worse still, we have seen situations where investments resulted in lower overall supply chain performance. For example, a manager at a chip fabrication facility increased capacity (at considerable expense) to improve responsiveness, yet analysis showed that her chips caused late shipments of the printed circuit assemblies. So, even though the chip manager's reliability increased and she improved her local metrics, delivery performance to the supply chain's customers did not improve. Ironically, the cost of the total supply chain actually increased with no increase in customer service. This situation has now been successfully addressed.

Predictably, we have found that we deliver higher value to our customers when we invest to increase the capacity of our bottleneck processes. Without proper supply chain metrics and analysis, managers in different parts of the world find it difficult to know and to agree on the bottleneck process in their supply chain. Proper metrics are as important to the performance of a supply chain as they are to the performance of a factory or of a company.

Figure 2 shows two common supply chain metrics, order fill rate and inventory turns, plotted together. In tandem, these metrics yield an efficient frontier upon which a product line supply chain operates. In supply chain models, the efficient frontier is defined by the uncertainties (supplier delivery, manufacturing transformation and demand forecasting), product complexities, and operating policies that the supply chain must manage. By increasing inventory levels and reducing inventory turns, a supply chain manager can increase customer service. Drop inventories and service drops too.

FIGURE 2

Supply Chain Investments



The supply chain manager's first goal is to find the low cost (or high profit) point on the efficient frontier to operate. This involves a tradeoff between inventories and service levels. Good supply chain managers ensure that their investments increase the performance of the supply chain on both measures. They try to move the efficient frontier with their investments.

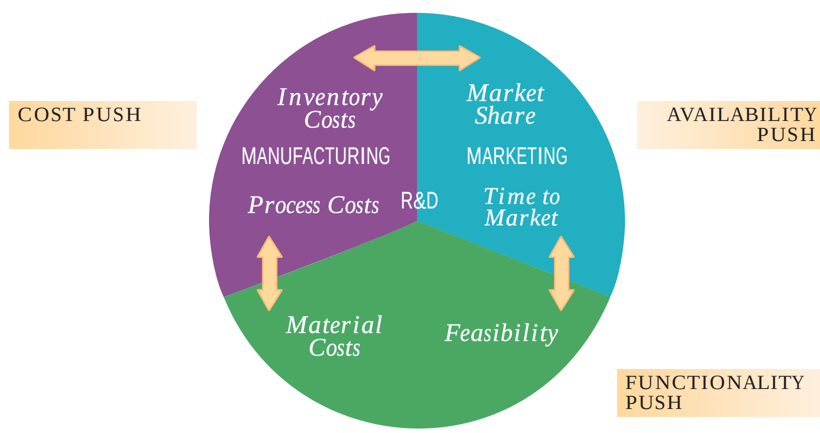
An investment should produce higher customer service per dollar of inventory or capacity. In other words, the supply chain system should become more efficient as a result of investments to reduce the impact of uncertainty. As shown on Figure 2, supply chain investments should improve the exchange relationship between order fulfillment and inventory investment.

FACILITATE NEGOTIATIONS

ANOTHER ROLE OF SUPPLY CHAIN MANAGEMENT is to facilitate negotiation between different functional areas. Figure 3 represents typical supply chain negotiations that occur between different functional areas at HP. Manufacturing is responsible for managing inventory and processing costs. Marketing is charged with maximizing market share and revenues. Finally, R&D is responsible for a product's material cost and the feasibility of a product's design. Any group's individual agenda could easily thwart a collaborative search for effective solutions.

FIGURE 3

Functional Negotiations



The negotiations between manufacturing and marketing often revolve around stocking levels. Higher stocking levels reduce shortages, increase market share by shortening product lead-times and minimize sales lost due to product shortages. Thus, the marketing function normally advocates higher stocking levels. Unfortunately, higher stocking levels increase asset costs and lead to higher end-of-life inventory charges. At HP we use supply chain analysis to facilitate negotiation between marketing and manufacturing. Supply chain models allow us to estimate the additional inventories required to satisfy higher service levels.

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Fundamental Relationships

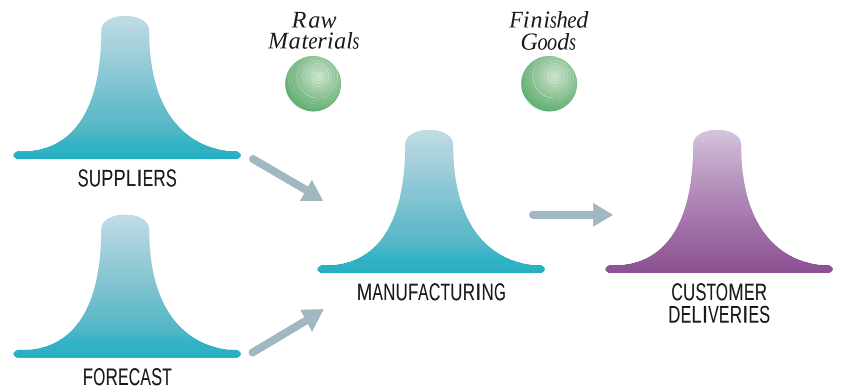

FIGURE 4

SUPPLY CHAIN

These costs can be traded off against the benefits of more reliable customer service. Negotiations become more objective, less political, and use available data more effectively.

Normally, negotiations between R&D and manufacturing revolve around direct material costs (a benchmark for R&D) and the costs of the assembly process (manufacturing's measure). Dialogue between manufacturing and R&D can lead to design decisions that not only reduce processing costs, but improve the overall effectiveness of the supply chain. For example, different designs and their associated material costs allow for different degrees of product postponement.

In its simplest form, postponement means to stock a product in a generic, uncompleted form until a customer order is received and then to convert the generic product into a final product while the customer waits. Postponement often improves the relationship between inventory levels and customer service. For example, a product with many options may have the options designed into software and added at the distribution center in the customer's geographic region or added by the customer after they purchase the product. This generally reduces the stocking levels needed for high customer service.

Historically, R&D would balk at such a move, which might increase material costs or lengthen product development time. The design team looks poor when measured by traditional, functional metrics. Supply chain analysis allows us to determine if the reduction in supply chain inventory costs exceeds the added material cost.

We have learned that traditional functional metrics applied without considering the total supply chain consequences often results in lower profitability, higher cost and lower customer service. Overall, proper supply chain metrics and analysis can bring functional areas together in a proactive rather than reactive way. They help to ensure that all investments in uncertainty reduction improve the financial effectiveness of the product line.

● MANAGED UNCERTAINTY

AFTER SUPPLY CHAIN METRICS have been instituted and data become available, a manager can contribute by developing, using and interpreting models. Representing systems like the one shown in Figure 1 with models that adequately account for supply chain uncertainties has been a focus of attention at HP for more than seven years.

During the 1980s, our supply chain managers focused attention on the performance of factory nodes. Requirements for increasing quality and shortening lead time using techniques like TQC, six sigma and JIT became fashionable and resulted in significant improvements. Recently, these techniques have given way to supply chain management that considers more than the isolated factories. Adopting a customer perspective, it focuses equal attention on the performance of the factory nodes, the links between factories, and the performance of the entire system. Supply chain models attempt to measure the entire value proposition of the organization and the effect of uncertainties on performance.

Figure 4 depicts the fundamental relationships that exist among the three major types of uncertainty that we model in a supply chain node. A one node example should illuminate the fundamental relationships that are used to create our more complex supply chain models. We measure long-term uncertainty associated with each supplier, with the manufacturing transformation process, and with the demand forecasting process. We fit distributions to each uncertainty.

Two Node Supply Chain

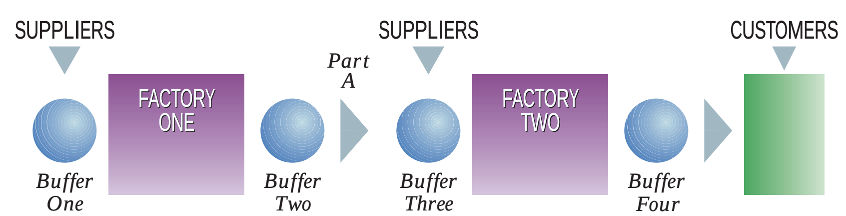

FIGURE 5

To characterize our supply chain uncertainties, we adopt some conventions. We combine transportation uncertainties with the uncertainties of the upstream operation. For incoming parts to a factory, quality problems and return delays are included with parts' transportation delays and traditional supplier uncertainties (shipping late). A delivery is not considered complete until quality material is available for use by the assembly line. We include material receiving variabilities — part of the overall factory process — with the manufacturing uncertainties. We characterize forecast uncertainties from marketing forecasts and actual sales data using the expected manufacturing lead time as the offset period for the marketing forecast.

For a single node factory, orders are late because of material shortages (parts or finished goods)or insufficient capacity. Our economic analyses trade off raw material investment, finished

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goods investment, and capacity availability against a desired level of customer service.

EXAMPLES

COMPLEX SUPPLY CHAIN DYNAMICS exist with just two factories connected. Consider Figure 5, where Factory 1 supplies Factory 2 with Part A. The final product of Factory 1 is a raw material for Factory 2. Consider a situation where all uncertainty is buffered using finished goods stocks at Factory 2 (Buffer 4) — Buffers 1,2 and 3 have no safety stocks. Also assume that Factory 1 is Factory 2's most unreliable supplier.

Adding raw material stocks of Part A at Factory 2 (Buffer 3) and reducing finished goods stocks in Buffer 4 may reduce costs without reducing expected order delivery to the customer. An even better solution, depending on customer lead times and capacity availability at Factory 1, may be to add raw material buffers at Factory 1. Such buffers would make Factory 1 more reliable, reducing the need for Part A and finished good inventory. Remember that stock values increase as you proceed down the chain. Buffer 1 inventories provide more uncertainty protection per dollar of inventory than Buffers 4 provided that part A is Factory 2's constrained part.

Inventory investments at Buffer 1 have decreasing marginal value. The supply chain benefit quickly decreases when Factory 1 becomes more reliable than other suppliers to Factory 2. Re-deployment of inventory from Buffer 4 to Buffer 1 within this simple supply chain may decrease total supply chain inventory costs without reducing expected customer service. Even for this simple example, determining the most cost effective place to buffer uncertainty is complex and could benefit from modeling analysis.

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In general, supply chain managers must determine the most effective material stocking levels for all buffers, the capacity levels for each factory, and the most appropriate customer service levels. Flaws in these decisions or their execution can lead the supply chain to operate below its efficient frontier (Figure 2).

All uncertainties combine within a supply chain, but their

SUCCESSFUL APPLICATION:

Relocating the "Localization" Of HP's DeskjetPlus Printer

HEWLETT-PACKARD'S Vancouver (Washington state, USA) Division manufactures the DeskjetPlus printer and distributes it to customers through four world-wide distribution centers. These centers are located in North America, Europe, Latin America and Asia. Because this product is sold into virtually every country on every continent, the printers must be configured with power supplies compatible with local voltage and plug conventions. They must also be accompanied by manuals printed in the language of the end user. Initially, all of this "localization" activity was done at the printer factory. However, the printer industry is highly competitive and it is advantageous for a dealer (and HP) to carry as little inventory as possible. On the other hand, dealers must be able to meet immediate customer demand. HP has endured tremendous pressure to provide its dealers with high levels of product availability while maintaining minimal inventories.

In an effort to meet this challenge, the Vancouver management pushed hard on traditional solutions. They improved productivity by reducing delivery variability and machine downtimes. They considered alternative shipping modes such as air versus sea, but air freight proved too costly. The real solution to supplying dealers around the world with exactly the right product proved to be by relocating the "localization" step in the product assembly process from the factory to the various distribution centers. We ultimately concluded that because the Vancouver factory was not that far from the North American distribution center that the factory would retain the localization of the U.S. printers; the Asian, Latin American and European models would be localized at the distribution center (DC) in those regions.

The data to create the supply chain model and subsequently support this decision was elicited from a variety of sources. Planners supplied weekly inventory positions from each of the DCs. The target inventory level for a product is a function of the length and variability of the lead time to replenish the stock from the factory and, the level and variability of demand for the product. At HP, that figure is generally expressed in weeks of supply. Transportation time to each of the DCs was noted along with plant capacity. Since the factory holds no finished goods inventory, the lead time for the factory to replenish the DC's stockpile is the sum of the transportation time from the factory to the DC, the manufacturing flow time at the factory, and any possible delay due to material shortages, congestion effects, downtimes and other unexpected disruptions such as power outages. The production time log from the factory documented actual downtimes which directly correlated to the replenishment of inventory at the DCs.

VALIDATION

THE MODEL WAS VALIDATED by looking at one of the Vancouver products. Several months were selected to carefully track inventory levels, material shortage, process downtime profiles and service levels. Using the target levels set by management for those months, we used the inventory model to predict fill rates at the DCs. We then compared the model's predictions to fill rates observed in the field and the actual fill rates were very close to our predictions.

Once we validated the model, we used it to evaluate the two localization alternatives. Under different target customer service

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impact is mitigated by inventory buffers. Ultimately, they create an expected uncertainty associated with customer deliveries. Customer delivery uncertainty is managed tactically by expediting orders through the supply chain. An example is the rescheduling of tasks when a supplier is late.

At HP, we normally do not consider expediting in our strategic supply chain models. Instead, our strategic models attempt to measure the long-term behavior of our supply chains. We use tactical models to make the most of our replanning resources. In our strategic context, lowering uncertainties or increasing buffer stocks result in higher customer delivery probabilities. Regardless of the modeling approach taken, a strategic supply chain model must allow managers to determine the efficient frontier of their supply chain and the relative effect of any uncertainty reduction on customer delivery.

Supplier uncertainty can be filtered by raw materials or finished goods buffers. There are any number of ways to reduce supplier uncertainties. For example, shift to faster transportation modes. Use air rather than sea. Purchasing from local suppliers can also help, as can buying from suppliers that produce higher quality parts. Late deliveries from suppliers create a "wave of lateness" that propagates downstream from suppliers towards the customers. The supply chain managers must determine how much supplier uncertainty to allow to appear as missed customer deliveries and how much money to invest in "stopping the wave."

LATE DELIVERIES FROM SUPPLIERS create a "wave of lateness" that propagates downstream from suppliers towards the customers.

THE SUPPLY CHAIN MANAGERS must determine how much supplier uncertainty to allow to appear as missed customer deliveries and how much money to invest in "stopping the wave."

Manufacturing is responsible for missing a customer order when they haven't planned to have sufficient capacity in place. A manufacturing uncertainty, like unexpected downtime, affects customer delivery probabilities. Increased levels of finished goods buffers or increased manufacturing capacity reduce the impact of these manufacturing uncertainties. Managers can reduce manufacturing uncertainties by reducing unexpected machine downtime of

levels ranging from 80 to 99.9 percent, the model computed the respective target inventory levels for the finished goods at the DCs plus the material costs at the factory and the DCs under the two localization alternatives.

Finished goods inventory levels (FGI) for a given service target are our measure of performance. We measure FGI as the average inventory level at the DCs. Under the DC-localization alternative, printer FGI levels are much lower, while localization inventory materials are higher at the Far East, Latin American and European DCs. The reduction of the total dollar value of printer inventory from factory-localization to the DC localization is 21 percent. The corresponding increase in localization materials worldwide is 24 percent. But printers are much more valuable than localization materials. The overall dollar impact is that DC localization would lead to a reduction of 18 percent in total inventory investment in the supply chain with no change in service to the customers. We expected to save millions and our expectations were met.

We considered many issues in our localization analysis. As the Asia Pacific and European markets grow, the dollar value of the inventory savings for DC localization will increase and because a localized printer contains localization materials, it has a higher value than an unlocalized product. Consequently, the capital tied up in transit is reduced with DC localization. Also, shipping unlocalized printers to the Far East and Europe afforded HP another cost savings opportunity. Unlocalized printers can be shipped in bulk because the localization materials are stored and added at the DCs. This, greatly reduced our transportation costs.

The highly competitive printer industry has pushed Hewlett-Packard to maximize the efficiency of its worldwide distribution network.

Other factors add further to the appeal of DC localization. Increasing the "local content" or "manufacturing" presence makes a product more marketable. We also developed a local supply base for the localization materials, creating a collaborative presence and an economic benefit to local economies.

Product design determines, in part, the viability of the DC localization process. Up front engineering resources must design the product to localize late in its assembly cycle. Shifting some of these traditional "manufacturing" functions to the DCs also requires the retrofitting of equipment and capabilities at the DCs. A further consideration involves the willingness and ability of the personnel at the DCs to perform these new functions. Some training and re-orientation is required. Thus, supply chain decisions must address issues outside of inventory management and requires the worldwide managers to work together to effectively manage their supply chain.

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bottleneck machines, by increasing capacity levels, by reducing setup times between products, and by increasing the quality of products. The challenge for the manufacturing supply chain manager is to determine which opportunities create the best financial return. Models help do this.

(Above and below) Hewlett - Packard's production and distribution functions are as far flung as its customer base, creating a complex supply chain problem for the company.

Finally, forecast (demand) uncertainty propagates up the chain from our distribution centers through the factories to our suppliers. The magnitude of forecast uncertainty at each point in a supply chain is affected by downstream inventory buffers. In the one node example, finished goods buffers protect both the factory and the suppliers from forecast uncertainty. Raw material buffers only protect suppliers. Forecast uncertainty can be reduced by improving data sources and forecasting techniques, by reducing the lead-time of the factory, and by designing products that allow for postponement.

Supply chain models must allow their managers to determine the efficiency and effectiveness of their supply chain. The efficiency of the supply chain can be estimated by the position of a supply chain's actual inventory turns and order fill rates relative to the levels predicted by a validated supply chain model. Supply chain effectiveness is determined by how successful the supply chain managers can be relative to competitors and if they are operating their chain at the maximum profit point on the efficient frontier. We have seen instances where supply chain managers faced a situation where their supply chain would not be competitive even if it operated on the most profitable efficient frontier point. In these situations especially, the managers need to make significant strategic changes to improve their supply chain.

CONCLUSION

THE EXTRAORDINARY SHIFTS in the perception and solution of supply chain issues require close and confident cooperation among all of the participating players. As noted earlier, both marketing and R&D have important roles to play. Product design determines the manner in which the product is assembled and shipped. The collaboration with marketing sets the product features to be preserved or enhanced while applying supply chain cost-cutting techniques.

The importance of organizational readiness and robust internal communications and cooperation cannot be overstated. For example, the ability and willingness of our distribution centers to pick up new and different responsibilities were pivotal to the success of the relocation of the Deskjet localization function (see accompanying story). This example demonstrates the importance of supply chain models for facilitating the negotiations necessary to ensure that maximum advantage is gained from our supply chain investments. Our keys to effective supply chain management are metrics, models and cooperation.

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