INTRODUCTION

Brent Cartier, Manager for Special Projects in the Materials Department of Hewlett-Packard (HP) Company’s Vancouver Division, clicked off another mile. It had been a long week and it looked like it would be a long weekend as well, based on the preparation that needed to be done for Monday’s meeting with Group Management on worldwide inventory levels for the DeskJet Printer product line. Even when he was busy, he always took the time for the seven-mile bike ride into work—it helped reduce stress in times like this …

The DeskJet printer was introduced in 1988 and had become one of HP’s most successful products (Exhibit 1). Sales had grown steadily, reaching a level of over 600,000 units in 1990 ($400 million). Unfortunately, inventory growth had tracked sales growth closely. Already, HP’s distribution centers had been filled with pallets of the DeskJet printer. Worse yet, the organization in Europe was claiming that inventory levels there needed to be raised even further to maintain satisfactory product availability.

Each quarter, representatives from the production, materials and distribution organizations in Europe, Asia Pacific and North America met to discuss the “I-word,” as they referred to it, but their conflicting goals prevented them from reaching consensus on the issues. Each organization had a different approach to the problem. Production had not wanted to get involved, claiming it was “just a materials issue,” but had taken the time to rant about the continued proliferation of models and options. The distribution organization should have to track and store warehouses of inventory, just because Vancouver Division couldn’t build the right products in the right quantities. The European distribution organization had even gone so far as to suggest that they charge the cost of the extra warehouse space that they were renting back to Vancouver Division directly, instead of allocating it among all the products they shipped. Finally, Brent’s boss, David Arkadia, the Materials Manager at the Vancouver Division, had summarized the
perspective of Group Management at the last meeting when he said, “The word is coming down from corporate: We can’t run our business with this level of unproductive assets. We’re just going to have to meet customer needs with less inventory.”

As Brent saw it, there were two main issues. The first issue was to find the best way to satisfy customer needs in terms of product availability while minimizing inventory. The second and stickier issue involved how to get agreement among the various parties that they had the right level of inventory. They needed to develop a consistent method for setting and implementing inventory goals and get everyone to sign off on it and use it. It was not going to be easy. The situation was especially urgent in Europe. His mind was still filled with the faxed picture that he had received the previous day, showing the dip in product availability levels for some versions of the product at the European Distribution Center (DC), yet he was sure that loads and loads of DeskJets has been shipped to Europe in the past months. His voicemail had been filled with angry messages from the sales offices, and yet the European DC was telling Vancouver that they had run out of space to store Vancouver’s products.

Brent parked his bike and headed for the company showers. His morning shower was another ritual—this was the time he had to review his plans for the day and play out different scenarios. Perhaps a solution would come to him.

**BACKGROUND**

Hewlett-Packard Company was founded in 1939 by William Hewlett and David Packard, with headquarters in Palo Alto, California. It grew steadily over the next fifty years, diversifying from its base in electronic test and measurement equipment into computers and peripherals products, which now dominated its sales. In 1990 HP had over 50 operations worldwide, with revenues of $13.2 billion and net income of $739 million.

Hewlett-Packard was organized partially by product group and partially by function. The Peripherals Group was the second largest of HP’s six product groups, with 1990 revenues of $4.1 billion. The group’s divisions each acted as a Strategic Business Unit for a specific set of products. Products included printers, plotters, magnetic disc and tape drives, terminals and network products.

The Peripherals Group had set technological standards with many of its products, with innovations such as the disposable print head used in its inkjet printers and moving-paper plotters. While these innovations contributed to its success, the Peripherals Group was also recognized for its ability to identify and profitably exploit market opportunities, as in the case of its most successful product, the LaserJet printer.

**The Retail Printer Market**

Worldwide sales of small workgroup/personal printers in 1990 were about 17 million units, amounting to $10 billion. The market tracked personal computer sales closely; the market was
mature in the US and Western Europe but was still developing in Eastern Europe and in the Asia-Pacific region.

Small workgroup/personal printers were sold almost exclusively through resellers. The reseller channels were changing rapidly, particularly in the US. Traditionally, printers had been sold through computer dealers, but as personal computers became commodity products, more and more sales were flowing through superstores and consumer mass merchandisers such as K-Mart and Price Club.

The retail printer market was composed of three technology segments: impact/dot matrix (40%), inkjet (20%) and laser (40%). Dot matrix was the oldest technology, and was viewed as noisy and of lower print quality compared to the other two types. The dot matrix printer market share was expected to fall to 10% during the next few years as the technology was replaced by either inkjet or laser printers in all applications except multi-part forms and wide carriage printing. Prior to 1989, most customers were not aware of inkjet technology. However, customers were discovering that inkjet print quality was almost as good as laser print quality at a much more affordable price. Sales had increased dramatically. In the monochrome market, it remained to be seen which technology would eventually dominate at the low end. Much would depend on the pace at which technology developed in both areas, and the relative costs.

HP and Canon separately pioneered inkjet technology at their respective corporate laboratories during the early 1980s. The key technological breakthroughs had been ink formulation and the disposable print head. HP had introduced its first disposable head model, the ThinkJet printer, in the late 1980s, while Canon had just introduced one in 1990.

HP led the inkjet market in the US, while Canon led the market in Japan. European competitors included Epson, Manisman-Tally, Siemens’ and Olivetti, though only Olivetti had introduced a printer with a disposable print head by 1991. Some dot matrix printer companies were also starting to offer inkjet printer products.

Inkjet printers were rapidly becoming commodity products. The end customer, choosing between two inkjet printers of equal speed and print quality, increasingly used general business criteria such as cost, reliability, quality and availability to decide. Product loyalty continued to decrease.

The Vancouver Division and its Quest for Zero Inventory

In 1990, Vancouver Division’s mission statement read: “Our Mission is to Become the Recognized World Leader in Low Cost Premium Quality Printers for Printed Communications by Business Personal Computer Users in Offices and Homes.”

The Vancouver Division, located in Vancouver, Washington, was established in 1979. HP saw an opportunity to provide personal printers for the relatively new, fast-growing personal computer market. HP consolidated personal printer activities from four divisions (Fort Collins, Colorado; Boise, Idaho; Sunnyvale, California; Corvallis, Oregon) to the Vancouver site. The
new division became part of HP’s Peripherals Group and was chartered with the design and manufacturing of inkjet printers.

As Bob Foucoult, the production manager and one of Vancouver’s first employees recalled, “Management was pulled from all over HP and plopped down in Vancouver. There was no cohesive staff and no cohesive set of business practices—perhaps that’s why we were so open to new ideas.”

The manufacturing organization realized early on that a fast, high-volume process would be required for success in the printer market. With the current (1979) 8–12 week cycle time and 3.5 months of inventory, the Vancouver Division would be doomed to fail. They looked within HP for knowledge of high-volume processes, but found none. HP, being an instrument company, only had experience building low volume, highly customized products using batch processes.

One day in mid-1981 two Vancouver managers happened to take seats on a plane next to two professors—Richard Schoenberger (Nebraska University) and Robert Hall (Indiana University). Schoenberger had just written a rough draft for a paper called “Driving the Productivity Machine” about a manufacturing process being used in Japan: Kanban. Vancouver’s management recognized the promise of this “new” manufacturing concept and Robert Hall recognized an opportunity to have his ideas tested in the US. They decided to work together.

Within a year Vancouver had converted the factory to stockless production and had reduced inventory from 3.5 months to 0.9 months, with a drastic reduction in cycle time. Vancouver became a showcase factory for the Kanban process; between 1982 and 1985 over 2,000 executives from within and outside HP toured the process. Vancouver impressed visitors by having them sign a raw printed circuit board as they arrived, then presenting them with a finished printer, made with that PC board using the standard process, an hour and a half later.

There was one key element missing, however. As Bob Foucoult puts it, “We were all dressed up but had no one to take us to the dance.” Vancouver had not yet introduced a successful, high-volume product that would take full advantage of the advanced production line. Vancouver had introduced products based on HP’s latest inkjet technology, but, as with any new technology, they had to gain experience to work the bugs out. The early models had poor resolution and required special paper for printing, resulting in limited success in the market place.

In 1988, things started to change. Vancouver introduced the DeskJet printer, a new model with near letter-quality resolution using standard paper. The introduction was a wild success. Since the manufacturing process had been in place and had been thoroughly exercised, all that was needed was to “flip the switch.” HP’s knowledge and implementation of the InkJet technology, combined with its streamlined manufacturing process, gave HP the edge needed to become the market leader in the inkjet printer market.

The DeskJet Supply Chain
The network of suppliers, manufacturing sites, distribution centers (DCs), dealers and customers for the DeskJet product comprised the DeskJet supply chain (Exhibit 2). Manufacturing was done by HP in Vancouver. There were two key stages in the manufacturing process: (1) printed circuit assembly and test (PCAT) and (2) final assembly and test (FAT). PCAT involved the assembly and testing of electronic components like ASIC’s (application specific integrated circuits), ROM (read-only-memory), and raw printed circuit boards to make logic boards and print head driver boards for the printers. FAT involved the assembly of other subassemblies like motors, cables, key pads, plastic chassis and “skins,” gears and the printed circuit assemblies from PCAT to produce a working printer, as well as the final testing of the printer. The components needed for PCAT and FAT were sourced from other HP divisions as well as from external suppliers worldwide.

Selling the DeskJet in Europe required customizing the printer to meet the language and power supply requirements of the local countries, a process known as “localization.” Specifically, the localization of the DeskJet for different countries involved assembling the appropriate power supply module, which reflected the correct voltage requirements (110 or 220) and power cord terminator (plug), and packaging it with the working printer and a manual written in the appropriate language. The design of the product was such that the assembly of the power supply module had to be done as part of the final assembly and test process, and therefore the localization of the printer was performed at the factory. Hence, the finished products of the factory consisted of printers destined for all of the different countries. These products were then sorted into three groups destined for the three distribution centers: North America, Europe and Asia-Pacific. Exhibit 3 details the Bill of Materials.

Outgoing products were shipped to the three distribution centers by ocean. In Vancouver, inventories of the components and raw materials were maintained to meet production requirements, but otherwise, no significant buffer inventories between the PCAT and FAT stages were kept. Management had continued to prefer to maintain no finished goods inventory at the factory, a tradition that was started in 1985 as described in the previous section. From the DCs, the products were then shipped to distributors, resellers, and retailers. In Europe, the products might first be shipped to HP’s individual country offices, managed by the individual country managers.

The total factory cycle time through the PCAT and FAT stages was about a week. The transportation time from Vancouver to the US DC, located in San Jose, California, was about a day, whereas it took 4-5 weeks to ship the printers to Europe and Asia. The long shipment time to the DCs in Europe and Asia was due to ocean transit and the time to clear customs and duties at port of entry.

The printer industry was highly competitive. Customers of HP’s computer products (resellers) wanted to carry as little inventory as possible, yet maintaining a high level of availability to end-users (consumers) was critical to them. Consequently there had been increasing pressure for HP as a manufacturer to provide high levels of availability at the DCs for the resellers. In response, management had decided to operate the DCs in a make-to-stock mode in order to provide very high levels of availability to the dealers. Target inventory levels, equal to the forecasted sales plus some safety stock level, were set at the three DCs.
As mentioned earlier, Vancouver prided itself as an almost “stockless” factory. Hence, in contrast to distribution, manufacturing of the DeskJet printer operated in a pull mode. Production plans were set to replenish the DCs “just-in-time” to maintain the target inventory levels. To ensure material availability, safety stocks were also set up for incoming materials at the factory.

There were three major sources of uncertainty that could affect the supply chain: (1) delivery of incoming materials (late shipments, wrong parts, etc.); (2) internal process (process yields and machine downtimes); and (3) demand. The first two sources of uncertainties resulted in delays in the manufacturing lead time to replenish the stocks at the DCs. Demand uncertainties could lead to inventory buildup or backorders at the DCs. For the European and Asian DCs, since finished printers were shipped from Vancouver by ocean, the consequence of the long lead-time was that the DC’s ability to respond to fluctuations in the demand for the different versions of the product was limited. In order to assure high availability to customers, the European and Asian DC’s had to maintain high levels of safety stocks. For the North American DC the situation was simpler; since an overwhelming majority of the demands was for the US version there was little localization-mix fluctuation.

The Distribution Process

At HP, while a typical DC shipped hundreds of different peripheral and computer products, a small number of products accounted for a large share of the volume. The DeskJet printer was one of these high volume products.

The Operations Manager of each regional DC reported into a Worldwide Distribution Manager, who reported directly to HP’s Vice President of Marketing, and dotted line to the Peripherals Group Manager (peripherals made up the bulk of shipments through distribution centers). Each Operations Manager had a staff of six functional managers, representing Finance, MIS, Quality, Marketing, Physical Distribution and Distribution Services. The first three functions were similar to their respective functions in a manufacturing organization. Marketing was responsible for interactions with customers. Physical Distribution was responsible for the “physical process,” i.e., from receiving through shipping. Distribution Services was responsible for planning and procurement.

The major performance measures for a typical DC included Line Item Fill Rate (LIFR) and Order Fill Rate (OFR). LIFR was calculated as the total number of customer order line items filled divided by the total number of customer line items attempted. (Each time HP tried to pull material for a line item, it was counted as an attempt.) OFR was a similar measure, but was based on orders completed, where an order contains multiple line items. Secondary performance measures included inventory levels and distribution cost per gross shipment dollar. The two major costs were outbound freight and salaries. Freight was charged back to the product lines based on the actual number of pounds of product shipped. In addition, the DC estimated the “percentage of effort” required to support a particular product line and charged that percentage of non-freight costs back to that product line. The system was somewhat informal, and major
negotiations took place between the DCs and the major product lines during the budget-setting process to determine the percentage allocation that was appropriate for each product line.

The DCs had traditionally envisioned their process as a simple, straight-line, standardized process. There were four process steps:

1) Receive (complete) products from various suppliers and stock them
2) Pick the various products needed to fill a customer order
3) Shrink-wrap the complete order and label it
4) Ship the order via the appropriate carrier.

The DeskJet printer fit well into the standard process. In contrast, other products, such as personal computers and monitors, required special processing, called “integration,” which included addition of the appropriate keyboard and manual for the destination country. Although this extra processing didn’t require much extra labor, it was difficult to accommodate in the standard process and disrupted the material flow. Furthermore, the DCs’ materials management systems supported distribution (pass-through processing of “end-items” in the form of individual models and options) and did not support manufacturing (assembly of components into a final product). There were no MRP (Material Resource Planning) nor BOM (Bill of Materials) explosion systems, and the DCs did not have adequate people trained in component procurement.

There was considerable frustration within the distribution organization regarding the support of assembly processes. In general, top management stressed the DC’s role as a warehouse, and the need to continue to “do what they were best at — distribution.” Tom Beal, the US DC Materials Manager expressed the general concern when he said, “We have to decide what our core competency is and what value we add. We need to decide whether we are in the business of warehousing or integration, then adopt strategies to support our business. If we want to take on manufacturing processes (here) we have to put processes in place to support them.”

The Inventory and Service Crisis

To limit the amount of inventory throughout the DeskJet supply chain and at the same time provide the high level of service needed had been quite a challenge to Vancouver’s management. The manufacturing group in Vancouver had worked hard on supplier management to reduce the uncertainties caused by delivery variabilities of incoming materials, on improving process yields and on reducing downtimes at the plant. The progress made had been admirable. However improvement of forecast accuracy remained a formidable task.

The magnitude of demand imbalances was especially alarming in Europe. It was becoming quite common to have product shortages for model demands from some countries, while inventory of some other models kept piling up. In the past, the target inventory levels at the DCs were based on safety stocks that were a result of some judgmental rule of thumb. It seemed like the increasing difficulty of getting the right balance of inventory for the various production options meant that the safety stock rules would have to be revisited.
David Arkadia had solicited the help of a young inventory expert from Corporate HP, Dr. Billy Corrington to help him put in place a scientifically based safety stock system which would be responsive to demand uncertainties and replenishment lead times. Billy had formed a team consisting of Laura Rock, an industrial engineer, Jim Bailey, the planning supervisor and Jose Fernandez, the purchasing supervisor from Vancouver to rehaul the safety stock management system. They were to recommend a method for calculating appropriate safety stock levels for the various models and options at the three DCs. Gathering appropriate data turned out to be a task that the team spent a lot of time at. They now felt that they had a good sample of demand data and were developing the safety stock methodology (Exhibit 1). Brent was hoping that this new methodology would solve the inventory and service problem. It would be nice if he could tell his management that all this inventory and service mess was due to their lack of a sound safety stock methodology, and Billy’s expertise would then be their savior.

One issue that continually came up was the choice of inventory carrying cost to be used in safety stock analyses. Estimates within the company ranged from 12% (HP’s cost of debt plus some warehousing expenses) to 60% (based on the ROI expected of new product development projects). Another issue was the choice of target line item fill rate to be used. The company target was 98%, a figure that had been “developed” by marketing.

As faxes and phone calls about the worsening situation at the European DC kept pouring in, Brent also began receiving other suggestions from his colleagues that were more aggressive in nature. Talks about Vancouver’s setting up a sister plant in Europe had surfaced. Would the volume in Europe be large enough to justify such a site? Where should it be located? Brent knew that the European sales and marketing folks would like such an idea. He also liked the idea of having a European plant to take care of the inventory and service problem in Europe. Maybe that would put a halt to his recent loss of sleep.

There was certainly a group that advocated more and more inventory. It was simple logic, according to them. “When it comes down to real dollars, inventory costs do not enter into the P&L statements, but lost sales hurt our revenues. Don’t talk to us about inventory-service tradeoffs. Period.”

Kay Johnson, the Traffic Department supervisor, had long suggested the use of air shipment to transport the printers to Europe. “Shortening the lead time means faster reaction time to unexpected changes in product mix. That should mean lower inventory and higher product availability. I tell you, air freight is expensive, but it is worth it.”

Brent recalled his conversation at lunch with a summer intern from Stanford University. The enthusiastic student was lecturing Brent that he should always try to tackle the “root of the problem.” Going to the root of the problem, according to the intern, is what the professors taught at school, and was also what a number of quality gurus preached. “The root of the problem is that you have a horrible forecasting system. There is no easy way out. You’ve got to invest in getting the system fixed. You must find a way to reduce the magnitude of demand uncertainties.” Brent also remembered how he lost his appetite at that lunch, as he was listening to the student, who was so eager to volunteer his advice.
What Next?

Brent reviewed his schedule for the day. At 11:00 he planned to meet with Billy, Laura, Jim and Jose to review the recommended inventory levels they had calculated using the safety stock model. He was somewhat concerned about what level of change the model would recommend. If it suggested small changes management might not feel the model was useful, but if it suggested large changes they might not accept it either.

After lunch he would meet briefly with the materials manager and the manufacturing manager to review the results and sketch out their recommendations. At 2:00 he would talk with the US DC materials manager by phone. That night he could reach Singapore and Saturday morning he could reach Germany. Hopefully he could get buyoff from everyone.

He wondered, too, if there wasn’t some other approach that he should be considering. He knew that whatever numbers he came up with would be too high.
Exhibit 1
Data Sheet for DeskJet Printers

The HP 2276A, HP 2277A
DeskJet and DeskJet PLUS Printers

Technical Data

Highlights

* Superior alternative to impact dot matrix printing
  - Laser quality output
  - Quiet
  - Attractive desktop design
  - Easy to use

* DeskJet
  - 1988 Dateline printer of the year

* DeskJet PLUS
  - 2 to 5 times faster than original DeskJet
  - Built-in landscape printing
  - Taller font (up to 30 points)
  - More built-in fonts
  - Improved print quality
  - DeskJet hardware and software compatibility
Exhibit 2
The Vancouver Supply Chain

Supplier \(\rightarrow\) IC Mfg
Supplier \(\rightarrow\) PCAT \(\rightarrow\) FAT
Supplier \(\rightarrow\) Print Mech Mfg

US DC \(\rightarrow\) Customer
Europe DC \(\rightarrow\) Customer
Far East DC \(\rightarrow\) Customer

Key:
IC Mfg: Integrated Circuit Manufacturing
PCAT: Printed Circuit Board Assembly and Test
FAT: Final Assembly and Test
Print Mech Mfg: Print Mechanism Manufacturing

Exhibit 3
Bill of Materials for DeskJet Printer

Raw Wafers \(\rightarrow\) ASIC
Raw PCB \(\rightarrow\) PCB
Raw Head Driver Board

Print Mechanism \(\rightarrow\) DeskJet Printer
Cables, Key Pad, Motors, Plastics, …

Power Supply, Power Cords
Finished Product
Manuals, Packaging Materials, Other Localization Materials
### Exhibit 4

Monthly Demand Data by Region and Option Type

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