

Hewlett-Packard Gains Control of Inventory and Service through Design for Localization

HAU L. LEE

*Department of Industrial Engineering and
Engineering Management
Stanford University
Stanford, California 94305*

COREY BILLINGTON

*Strategic Planning and Modeling
Hewlett-Packard Company
3000 Hanover Street
Palo Alto, California 94304*

BRENT CARTER

*Vancouver, Washington Division
Hewlett-Packard Company
18110 SE 34th Street
Camas, Washington 98607*

At Hewlett-Packard (HP) Company, design for manufacturability has recently been adopted as a principle for product design and development. Frequently overlooked is the relationship between design and the eventual customization, distribution, and delivery of the product to multiple markets. Different markets may have different requirements for the product due to differences in taste, language, geographical environment, or government regulations. We use design for localization or design for customization for design processes that take into account the operational and delivery service considerations for the multiple market segments. We developed an inventory model that the HP's Deskjet-Plus Printer Division used to evaluate alternative product and process designs for localization. Significant benefits can be obtained by properly exploring the opportunities in this design for localization concept.

In recent years, interest has increased in bridging the gap between product design and manufacturing. Product design evaluations should include consideration of the impact of the designs on manufacturability, cost, and quality. Consequently,

such concepts as "design for manufacturability," "design for assembly," "design for testability," "design for producibility," and "design for quality" have received widespread attention and support [Whitney 1988, Dean and Susman 1989,

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and Taguchi and Clausing 1990]. One critical element in product design has been overlooked: the relationship between design and the eventual customization, distribution, and delivery of the product to multiple market segments. These segments may have different requirements of the product due to differences in taste, language, environment, or government regulations. The design of the product and of the manufacturing process can affect the company's operational costs and its delivery service to its customers. We use the terms *design for localization* or *design for customization* to represent design processes that take into account the operational and delivery service considerations for multiple market segments.

Usually, in manufacturing products suitable for different market segments, manufacturers produce basic products that contain most of the features and components of the finished products and assemble the final products with some additional components that differentiate the products for different market segments. For example, a computer manufacturer might consider different countries as the market segments. The computer products would differ in the power supply module to accommodate local voltage, frequency, and plug conventions. Keyboards and manuals would be produced to suit the local language. Telecommunication products may also be differentiated by the communication protocols supported. In some cases, the need for localized versions of a product results from government-imposed local content requirements.

Depending on the design of the product and the production process, the localiza-

tion or customization might be performed differently: for some product designs, the main factory assembles differentiating modules. For some, distributors assemble the differentiating modules just before shipping them to customers; and for some, the customer performs the final customization.

Where customization is performed can greatly affect the company's inventory and service trade-off. Delaying customization increases the company's flexibility to respond to changes in the mix of demands from different market segments. The company can improve its responsiveness to orders or reduce its investment in inventory.

Hence, the designs of the product and of the production process can affect the degree of localization, the site at which localization can be done, and the cost of localization. To design for localization, design engineers should consider the cost and service implications in designing product for market segments.

We developed an inventory model to address the consequences in inventory costs and delivery service that result from different design alternatives. The model has been used to support the manufacture of Deskjet-Plus printers at the Vancouver, Washington Division of Hewlett-Packard Company (HP).

The Deskjet-Plus Supply Chain

The Deskjet-Plus is one of several printers manufactured by the Vancouver Division of HP. The manufacturing process has two stages: (1) printed circuit board assembly and test (PCAT); and (2) final assembly and test (FAT). In PCAT, electronic components such as ASICs (application-specific integrated circuits), ROM (read only mem-

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ory), and raw printed circuit boards used to make logic boards and print head driver boards for the printers are assembled and tested. In FAT, such subassemblies as motors, cables, key pads, plastic chassis and "skins," gears, and the printed circuit boards from PCAT are assembled to produce working printers, which are then tested. The sources for the components are other HP divisions and external suppliers worldwide.

To localize the Deskjet-Plus for different countries, HP packages the appropriate

One critical element in product design has been overlooked.

power supply module (with the correct voltage and plugs) and the appropriate manual with the printer. In the past, the factory performed this step. Hence, the factory produced finished printers destined for all other countries. It then sorted them into three groups for the distribution centers (DCs) in North America, Europe, and Asia and the Pacific. We refer to this process as *factory-localization*.

The Vancouver plant ships to the three distribution centers by sea. We use the term *supply chain* to describe the network of manufacturing and distribution sites [Cohen and Lee 1988].

The printer industry is highly competitive. HP's computer dealers like to carry as little inventory as possible, but must supply products to end-users quickly. Consequently, HP is under increasing pressure as a manufacturer to provide high levels of availability at the DCs for the dealers. In response, HP management has decided to

operate the DCs in a make-to-stock mode to provide very high levels of availability to the dealers. Hence, the DCs operate as inventory stocking points with large safety stocks to meet a target off-the-shelf fill rate, where the replenishment of products comes from manufacturing.

Manufacturing, on the other hand, operates in a pull mode. It sets production plans to replenish the DCs just in time to maintain the target safety stocks. To ensure material availability, HP also sets up safety stocks for incoming materials at the factory.

Three major sources of uncertainty can affect the supply chain: (1) delivery of incoming materials (late shipments, wrong parts, and so forth); (2) internal process (process yields and machine downtimes); and (3) demand. The first two can cause delays in replenishing stocks at the DCs. Demand uncertainties can lead to inventory buildup or to backorders at the DCs. Under "factory-localization," HP ships the different versions of the Deskjet-Plus to the two non-US DCs by sea, with a transit time of about a month. Because of this long lead time, the DC has limited ability to respond to fluctuations in the demand for the different versions of the product. To ensure prompt service for the customers, the European and Far East DCs have to maintain high levels of safety stocks. For the North American DC, the situation is simpler, most of the demand is for the US version, and there is little localization product mix fluctuation.

Limiting the inventories in the Deskjet-Plus supply chain and at the same time providing the high level of service needed has been quite a challenge to the Vancou

ver Division's management. The manufacturing group in Vancouver has worked hard on supplier management to reduce the uncertainty caused by delivery variability, to improve process yields, and to reduce machine downtimes at the plant. The progress made has been admirable. However, improving the forecast accuracy of product-mix demands remains a formidable task. This is why it considered product/process designs as a way to improve the effectiveness of inventory in the supply chain. Design changes can ameliorate the impact of poor forecasts.

The linkage between manufacturing and distribution is one opportunity. If the shipment lead times between manufacturing and distribution were drastically reduced, for example, by shipping by air, then the manufacturing plant's ability to respond to product-mix fluctuations at the DCs would be greatly enhanced. However, air shipment is very costly, and HP found it to be an ineffective alternative.

Localization at the DCs provides a more attractive alternative. The factory would manufacture and ship a generic Deskjet-Plus printer without the power supply module and manual. The DCs would then localize the generic product to the different specific options as needed. From standard inventory theory, such a change would have the benefit of the risk pooling effect, and consequently, HP would need less safety stock in finished goods. We will term such a strategy "DC-localization." However, because Vancouver is not far from the US DC, and because the whole US demands essentially one option of the product, it is more efficient for Vancouver to localize the US option at the factory.

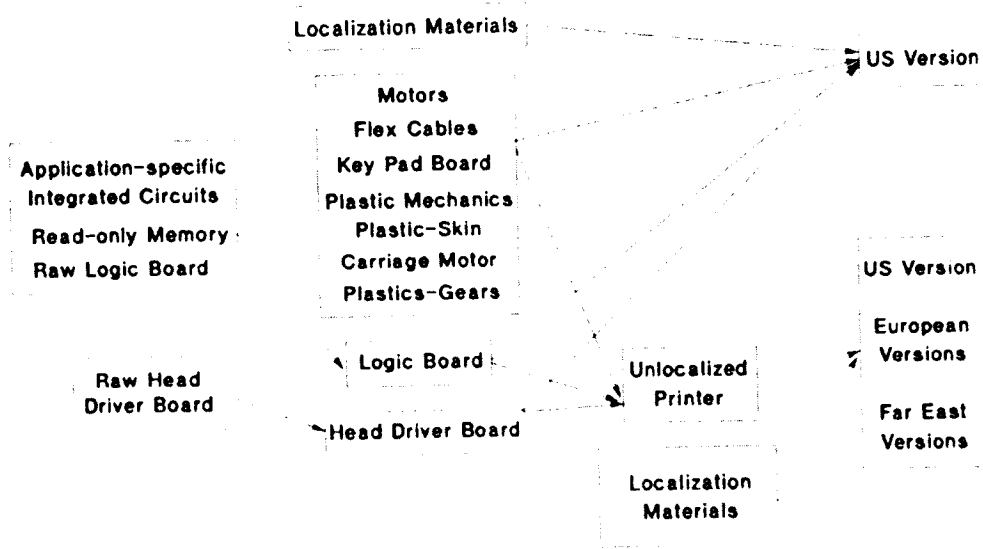
Hence, the more realistic alternative HP considered is for Vancouver to manufacture two types of deskjet printers: (1) a fully localized US option; and (2) a generic product without the power supply module and manual, to be shipped to Europe and the Far East for localization there (Figure 1).

To implement DC-localization, HP had to make some design changes to the product. It had to redesign the product so that the power supply module would be the last component added on and so that the

DC-localization would lead to a reduction of 18 percent in total inventory investment.

DC could add it on easily. To minimize the time that it takes to localize the product, HP wanted this assembly to be a simple operation, for example, a simple plug-in. Moreover, even if the addition of the power supply module and the manuals to the product is a simple kitting process, HP had to make some investment to equip the international DCs with such a capability.

In terms of inventory control, as long as all complete printers were assembled at the factory, it kept all safety stocks of the power supply modules and manuals; when the DCs localize finished products, they also keep safety stocks. The Vancouver factory keeps safety stocks of the US power supply modules and manuals to produce fully localized US printers, whereas the remote DCs keep stocks of the international power supply modules and manuals. Semi-finished goods, that is, unlocalized versions of the product, are



- ▶ Stage 1: printed circuit board assembly and test, performed at factory
- ▶ Stage 2: final assembly and test, performed at factory
- ▶ Localization: performed either at factory or at distribution

Figure 1: The two-stage manufacturing process, the bill of materials, and the two localization strategies for the Deskjet-Plus. The arrows represent the two stages in manufacturing, as well as the localization step. The boxes represent inputs and outputs.

stocked at the European and the Far East DCs. When they receive actual orders, the DCs quickly localize the generic version into the specific products required.

Since the DC-localization alternative involves some product redesign and investment at the DCs, HP needed to evaluate the cost-effectiveness of such an alternative by quantifying the inventory benefits. Such an analysis was a critical input to management's decision.

An Inventory Model for the Deskjet-Plus Supply Chain

Although the planners use many local rules and adjustments in managing the in-

ventory levels at each of the DCs, the basic principles they use follow: at each DC, management sets a target inventory level for each product so as to achieve the desired fill rate. The target inventory level for a particular 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, such a target inventory level is usually expressed in terms of weeks of supply. The planners review the actual inventory position (inventory level plus inventory in the pipeline) each week. This weekly review period corresponds to

the frequency with which products are shipped from the factory to the DCs in Europe and Asia. Studies on transportation economics have shown that this frequency allows Vancouver to maximize its use of containers for shipment. The quantity needed to bring the inventory position back to the target level constitutes the production requirement (to satisfy that DC) at the factory. 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 (queuing) effects, process downtimes, and other unexpected disruptions (power outages, special celebrations at the plant, and so forth).

With ample plant capacity, the factory can assume that manufacturing lead time is unaffected by the replenishment quantities and their variabilities. If this were not the case, then the factory should explicitly model manufacturing lead time as a function of the replenishment quantity. An example is a linear function with the coefficient given by the manufacturing cycle time. In that case, the manufacturing lead time would be a random variable whose mean and variance are functions of the mean and variance of the replenishment quantity.

To estimate the delays due to these various causes, we used empirical data based on the production time-log in Vancouver. The time log documents the frequency and duration of process disruptions. We used these data to estimate the mean and variance of the delays at the factory, and con-

sequently, of the replenishment lead time from the factory to the DCs.

Hence, we can model the inventory system at each DC as a standard periodic review, order-up-to system [Nahmias 1989] where the period is a week. We have also assumed that the demand per week for a product is stationary and normally distributed. The stationarity assumption is rea-

Delays due to material shortages and process downtimes are usually short.

sonable for a mature product such as the Deskjet printer. The uncertainties such an inventory system faces include demand and replenishment lead time. Such a simple inventory model is easy to use, but we should recognize its limitations. For example, the basic model assumes that demands in different time periods are independent and that successive replenishment lead times are also statistically independent. We also make the assumption that the demands for the different product versions of the printer are statistically independent. By treating each DC as a single inventory system, we also ignore the multi-echelon nature of the network, and consequently we do not consider such issues as lateral resupply among the DCs, allocation of stock by the factory to the DCs in times of limited supply, and correlation of demands across the DCs. Nevertheless, we found the resulting model to be adequate for the following reasons. First, delays due to material shortages and process downtimes are usually short (relative to the period of a week), and they tend to occur indepen-

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dently. Second, since the DCs are located on three different continents, lateral shipments are possible but uneconomical and inefficient, so that they are seldom used. Hence, the demands across the DCs are quite independent of one another. Third, initial validation of the model (described later) indicated that the model is of sufficient accuracy for policy evaluation.

In the appendix, we outline the basic inventory model we used. For the factory-localization alternative, each of the product versions at a DC has its own replenishment lead time, and independent target inventory levels can be set. The replenishment lead times at the DCs differ by the transit time from the factory to the DCs. For the DC localization alternative, each DC stocks the generic product, whose mean and variance of demand equals the sums of the means and variances of the amount of different product versions stocked at the DC.

We validated the inventory model by considering one of the Vancouver products. We selected two months (November 1989 and April 1990) for tracking inventory levels, material shortage, process downtime profiles, and service levels. Using the target inventory levels set by man-

agement for those two months, we used the inventory model to predict fill rates at the DCs. We compared these fill rates to those observed in the field. For the two months chosen, the actual fill rates and the predicted fill rates were very close (Table 1). We made similar observations at the individual DC level.

We then used the model to evaluate the two localization alternatives. Under different target fill rates that range from 80 to 99.9 percent, the model computed the respective target inventory levels for the finished goods (one localized and one unlocalized) at the DCs, plus the material costs at the factory and the DCs, under the two localization alternatives.

Analysis of Localization Alternatives

Table 2 shows the average inventory levels (in weeks of supply) of finished goods (localized or unlocalized Deskjet-Plus printers) and localization materials at the DCs and the factory under the two localization alternatives with a fill rate target of 98 percent. For the DC localization alternative, localization materials are stocked at the Far East DC and at the European DC.

For this alternative, localization materials are also stocked at the factory for localiz-

	Downtime Frequency in Vancouver	Finished Goods Inventory	Predicted Fill Rate	Actual Fill Rate
Nov 89	High	DC1: 8.4 wks DC2: 2.8 wks DC3: 5.1 wks	88%	86%
Apr 90	Low	DC1: 9 wks DC2: 2.6 wks DC3: 5.8 wks	99%	99.9%

Table 1: The model was validated by comparing predicted fill rates with actual fill rates in two months.

		Factory Localization (Weeks of Supply)	DC-Localization (Weeks of Supply)
Far East Distribution Center	Printers	13.4	9.8
	Localization Materials	0	11.0
European Distribution Center	Printers	5.2	3.5
	Localization Materials	0	5.2
US Distribution Center	Printers	3.2	3.2
	Localization Materials	0	0
Vancouver Factory	US Localization Materials	2.8	2.8
	Other Localization Materials	3.9	0
Worldwide Total (Weighted Average)	Printers	4.4	3.5
	Localization Materials	3.3	4.0

Table 2: Inventory levels at all sites of the supply chain to achieve a service target of 98 percent were compared under the two localization strategies. In factory localization, Vancouver localizes printers for all distribution centers which stock localized printers. For DC localization, the distribution centers stock unlocalized printers, which are then localized at the distribution centers on demand.

ing the product for the US market. Given the close proximity of the factory to the US DC, the inventory levels of the current partial DC localization alternative would not be too different from a full-scale DC localization alternative where the US DC localizes the US printers.

We consider the finished goods inventory (FGI) levels for a given service target to be a measure of performance. FGI is the average inventory levels at the DCs. Under the DC-localization alternative, FGI levels are much lower, while localization materials inventory levels are higher at the Far East and European DCs (Table 2). Under such an alternative, there is less total printer inventory, although there are higher stocks of localization materials at the DCs. Since the values of printers and localization materials differ, we evaluated

the alternatives in terms of dollar investment.

The reduction in the total dollar value of FGI investment from factory-localization to DC localization is 21 percent, whereas the corresponding increase in localization materials worldwide is 24 percent. 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 the DCs' service to the customers. The dollar value of that 18 percent is in millions. Figure 2 shows the FGI levels under the two alternatives at various levels of fill rate target.

We considered a range of material shortage and downtime profiles, and sensitivity analysis showed similar results.

Our analysis indicates that the inventory savings to be gained from changing from

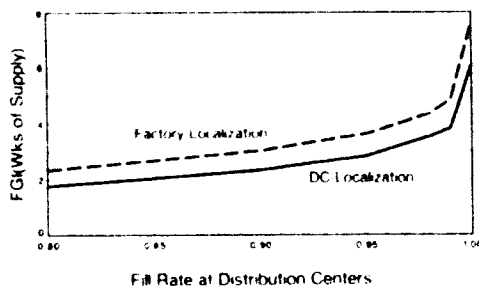


Figure 2: DC-localization achieves lower inventory levels for different service targets than factory-localization.

factory-localization to DC-localization is substantial. By continuing the current investment in inventory, HP could greatly improve customer service (off-the-shelf fill rate) by changing from factory-localization to DC-localization. Our analysis quantifies the inventory or service benefits to support management in its evaluation of the design and process changes needed to introduce DC-localization.

Additional Considerations

Many other factors should be considered in a comprehensive evaluation of the localization alternatives. We based our analysis on the demands for the printers at the different DCs. As the Asian-Pacific and European markets for printers grow, the dollar value of the inventory savings for DC-localization will increase. Because a localized printer contains localization materials, it has a higher value than an unlocalized printer. Hence, the capital tied up in inventory in transit is also lower when localization is performed at the end of the chain. Although the magnitude of such a difference is much smaller than the difference in inventories held at the DCs and the factory, this factor should be included in a thorough evaluation.

Of further interest is how to value the savings associated with reducing inventory. This requires a careful analysis of the real holding and opportunity costs incurred by committing capital to inventory. The quantification of the difference in inventory investment from the model enables management to perform sensitivity analysis based on alternative rates of holding and opportunity costs of inventory.

Shipping unlocalized printers to the Far East and European DCs under the DC-localization alternative provides HP with a major opportunity to reduce transportation cost, another point to consider. An unlocalized printer is much less bulky than a localized one, because the localization materials and many of the final packaging materials that are needed for the customers do not have to be bundled with the printer. The factory can ship the unlocalized printers in bulk pallets and cut the cost of transportation.

To implement DC-localization, HP needs to change the product design. This requires valuable engineering resources. Moreover, it would have to add final configuration and packaging capability to the Far East and European DCs—at a cost. DC-localization of subsequent Vancouver products and products from other divisions will also provide substantial savings to offset this one-time investment.

Other nonquantifiable factors should be considered as well. For example, increasing "local content" and local "manufacturing" presence can make a product more marketable, a factor that supports localization of the products at the non-US DCs [Cohen and Lee 1989]. There is also a need to develop a local supply base of the localiza-

tion materials for the DCs. The pros and cons of decentralizing or regionalizing supply of materials should be considered [Cohen and Lee 1989]. Finally, since DC-localization requires the DCs to perform some operations that are traditionally viewed as manufacturing activities, they may have cultural and organizational barriers to overcome.

After considering both the quantifiable and the nonquantifiable factors, the Vancouver Division estimated that the combined net savings of adopting the DC-localization alternative for the Deskjet-Plus printers would be well over several million dollars per year. The division is now beginning to design or redesign all current and future products to support the DC-localization strategy.

Conclusion

The Vancouver, Washington Division of Hewlett Packard is redesigning all its current products to support DC-localization. This approach has become an integral part of its product development process.

Most companies have not fully explored the concept of design for localization. It offers tremendous opportunities for increased flexibility, reduced inventory investment, and improved service. Design for localization should be an important strategy consideration for companies that wish to compete successfully in a global market.

Acknowledgment

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APPENDIX

Inventory Control Model for a DC

For a product at a DC, let

S = order-up-to level (target stock level);

L = supplier lead time (in weeks);

D = demand per week; and

X = demand during lead time plus one week.

Let $E(x)$, $s(x)$ and $Var(x)$ denote the mean, standard deviation and variance of a random variable, respectively. We can compute $Var(X)$, and consequently, $s(X)$, as

$$\begin{aligned} Var(X) &= E[Var(X|L)] + Var[E(X|L)] \\ &= E[(L+1)Var(D)] + Var[(L+1)E(D)], \text{ and} \\ &= [E(L)+1]Var(D) + [E(D)]^2 Var(L). \end{aligned}$$

The order up-to level is then given by $S = E(D)[E(L)+1] + ks(X)$, where k is the safety stock factor. To determine the safety stock factor, we use the approximation formula in Nahmias (1988, p. 653) for the estimation of fill rate:

$$\text{Fill rate} = 1 - \left[\exp(-0.92 - 1.19k) \right. \\ \left. - 0.37k^2 \right] s(X) / L(D). \quad (1)$$

For a given fill rate target, the safety stock factor is found by solving equation (1).

The average inventory level is the sum of safety and cycle stock, and is given by $ks(X) + E(D)/2$.

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Harold E. Edmondson, Vice President, Manufacturing, Product Generation Team, Hewlett-Packard Company, 3000 Hanover Street, Palo Alto, California 94304, writes, "The supply chain model developed by the authors was used to quantify the inventory and service trade-offs in the evaluation of alternative localization strategies for the DeskJet-Plus printers in the Vancouver Division of Hewlett-Packard. The results of the model analysis confirmed the effectiveness of the strategy for localizing the printers at remote distribution centers. Such a design strategy has significant benefits in terms of increased flexibility to meet customer demands, as well as savings in both inventory and transportation costs. We are pleased that we have adopted such a strategy.

"I should add that the design for localization concept is now part of our manufacturing and distribution strategy. The supply chain model has continued to be used to evaluate other design changes for new products in Vancouver and in other parts of Hewlett-Packard."

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