

Hewlett-Packard Company Unlocks the Value Potential from Time-Sensitive Returns

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Hewlett-Packard (HP) and other companies producing short life-cycle products with rapid value erosion squander the opportunity to profit from returned time-sensitive products when they treat them as a nuisance. Instead of focusing on cost minimization and technical quality, they should recognize returns as a value stream and maximize the revenue from smart and fast disposition, proper refurbishment, and prompt resale through the appropriate channels. We worked on a project with Hewlett-Packard's remarketing group to unlock the value potential of time-sensitive returns. We analyzed data using simple calculations to reveal the major drivers and magnitude of potential value recovery, and we used simple operations research flow models to evaluate new design and policy options for the reverse supply chain. HP benefited from an integrated end-to-end business approach to product returns.

Key words: industries: computer, electronic; inventory/production: perishable, aging items.

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Early in 2003, we started a project with the Hewlett-Packard Company (HP) in Herrenberg, Germany to redesign its European remarketing processes and improve their performance. HP uses the term *remarketing* for its reverse supply chain operations. These include organizing product returns from the market, determining the best reuse option (product dispositioning), reconditioning, and marketing and selling the reconditioned products. We developed decision models that capture the economics of time-sensitive returns and help HP managers to improve their decisions. We focused on the reverse supply chain for returned notebook and desktop personal computers (PCs) in Europe. The volumes of returned products to HP represent substantial amounts of money.

Time-sensitive products lose their value rapidly. Blackburn (1991) discusses the principles of time-based management. Typical time-sensitive products are consumer electronics, including PCs, printers and

computer peripherals, and mobile phones. All these products have very short life cycles (desktop PCs: three to four months; notebooks: six months; consumer printers: 18 months), and a high risk of obsolescence.

Managers are just now recognizing and understanding the value of time for product returns. They often view product returns as a nuisance whose costs must be minimized (why throw good money into products that consumers have already rejected?). However, our research shows that product returns have recoverable value and are potential sources of revenue; at least if the time between product return and resale is short (Blackburn et al. 2004).

Unfortunately unlike modern, streamlined forward supply chains, reverse supply chains are often fragmented, with numerous managers focused on local efficiencies and economies of scale. Managers lack clear end-to-end visibility. Masses of data may be captured but remain unprocessed, unconnected, and

scattered throughout the organization. Therefore, key information on lead times, product flows, and value erosion is not readily available. Managers are unaware of opportunities for improving and measuring performance in the reverse supply chain and focus on the technical challenges of refurbishment (Guide et al. 2003).

HP estimates the cost of product returns at two percent of total outbound sales dollars for North America. It realizes that product returns represent a potential value stream and that it must approach the problem from a business-economics perspective, instead of making it an exercise in minimizing costs. Reverse supply chains focused on low-cost solutions also tend to be slow (Blackburn et al. 2004). Hence, the product may lose most of its value or become obsolete by the time it is ready for reintroduction to the market.

HP's Reverse Supply Chain for Notebook and PC Returns in Europe

HP's equipment management and remarketing (EMR) division is responsible for handling returned products with significant remaining value. It outsources many of the operations (transportation, receiving, sorting and testing, refurbishment, and distribution) to subcontractors but retains the core management and control functions, such as partner management, product knowledge, and marketing. Its overall goal is to recover as much value as possible from the returned products.

The reverse supply chain is organized around five key activities: product acquisition (obtaining the products from the users), reverse logistics (transporting the products to a facility for inspection, disposition, or remanufacturing), inspection and disposition (determining the condition of the return and selecting the most economically attractive reuse option), refurbishment or remanufacturing (bringing the product to a reusable state), and sales and marketing (selling the refurbished goods at a secondary market) (Guide and Van Wassenhove 2003). HP's EMR division has direct control over the disposition and refurbishment processes, but the other HP groups manage the remaining processes.

EMR operates a centralized reverse supply chain for its notebook and desktop PC returns in Europe (Figure 1). The returns arriving at the remanufacturing center are a mix of commercial returns (because customers change their minds or because the products are defective), channel returns (overstocks or stock adjustments), and demonstration returns. Customers return products to resellers, and periodically the resellers collect and ship them to the returns and remanufacturing site at Isle d'Abeau, near Lyon, France. Channel partners return overstocks in the same fashion. Products used for demonstrations and for testing software applications for potential clients at benchmark centers are transported from the central demo pool in Germany to the facility at Isle d'Abeau.

Workers at the facility inspect the PCs and notebooks upon arrival and decide on their disposition. They may assign returns to direct storage in

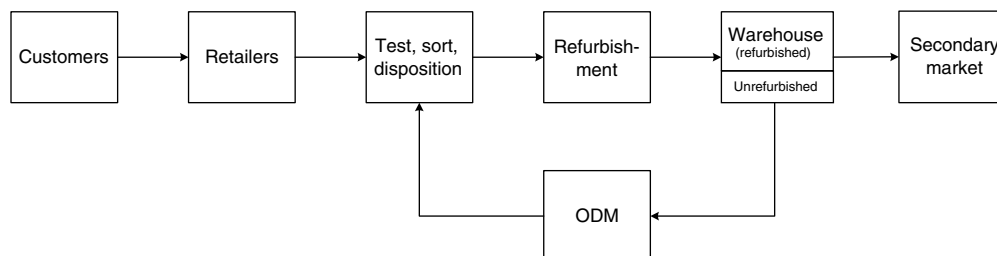


Figure 1: HP Europe operates a centralized reverse supply chain for its notebook and desktop PC returns. After PCs and notebooks arrive at the returns and remanufacturing site, HP inspects and forwards them to one of the following refurbishment options: direct storage in the warehouse, low-touch refurbishment, high-touch refurbishment, or scrap. It stores used notebooks temporarily unrefurbished in the warehouse and sends them to an outsourced design and manufacturing supplier (ODM) for repair.

the warehouse, to low-touch refurbishment, to high-touch (technical) refurbishment, or to scrap. Typically they assign unused products from customer returns and sealed boxes from channel returns to low-touch refurbishment, a set of operations limited to cleaning, relabeling, and ensuring that all the necessary accessories are in the boxes. All used products undergo technical testing and repair if necessary. HP carries out high-touch refurbishment on site only for desktop PCs. It stores unrefurbished notebooks in the warehouse and sends them to an outsourced design and manufacturing supplier (ODM) for repair. After the ODM returns the products, HP sends them through low-touch refurbishment to refurbished products inventory. It sends obsolete and unrepairable returns to the technical value solutions and take back operations (TVS/TBO) division to be sold as is to brokers or scrapped. The final stage in the process is selling the refurbished products, mostly through auctions and catalog sales to specialized partners.

We took a closer look at the returns processes to identify the areas with the greatest value potential and quickly encountered a number of obstacles. These included a fragmented organizational structure, with no end-to-end view; information asymmetries; and poorly aligned incentives. HP had masses of data, but they were not connected nor in the right format for our purposes. We basically needed to understand two things to determine which returns streams had the most profit potential and to establish their time value. First, we needed a profile of the returns with respect to flows, value, and quality and age distributions. Second, we needed to identify the bottlenecks in the process that delayed the moment of value release.

In our study, we eventually concentrated on notebooks and desktop PCs because they constituted about 60 percent of the flows and contributed more than 80 percent of revenue. HP's remaining revenue comes from monitors, handhelds, and workstations. We obtained much of the information only after crunching lengthy data files and linking bits and pieces from different sources until we obtained a workable picture of the reverse supply chain. The data presented in the remainder of the paper is realistic but not real, that is, we have disguised figures to protect company confidentiality.

The Time Sensitivity and Price Elasticity of Product Returns

To protect its brand image, HP requires that all refurbished products be brought to like-new condition. After the ODM refurbishes the notebooks, HP tests them and sells them as quality 1 with warranty. A maximum of 10 percent of the refurbished products fail the tests, and HP sells them as quality 2 without warranty.

To understand the time sensitivity of notebooks and desktop PCs, we used simple linear regression to analyze their sales histories on secondary markets. For example, the average sales prices for quality 1 and quality 2 notebooks decline over time between product launch and the sale of the refurbished product, henceforth called age (Figure 2).

The price difference between the two qualities increases with age and appears quite small early in the life cycle. Early in the products' life cycles, it would seem preferable for HP to sell quality 2 products instead of refurbishing them to quality 1 levels, especially given the high costs of ODM refurbishment and the long delays. However, because doing so might damage HP's brand name, in early 2003, it stopped selling quality 2 products.

HP managers have long believed that they must carefully limit sales quantities for refurbished products to command the best prices. To test this assumption, we regressed the monthly volume sold with

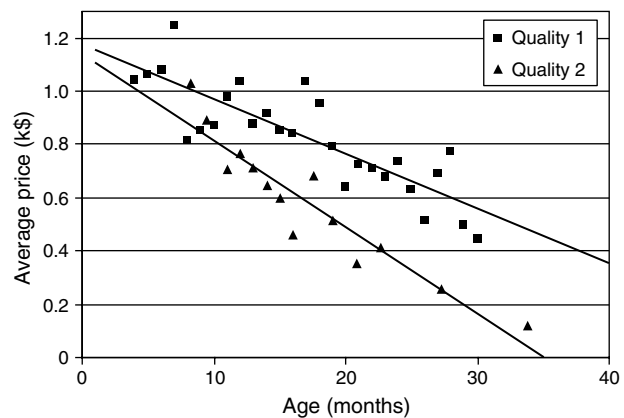


Figure 2: The curves show the rapid erosion in value of notebooks. Quality 1 notebooks lose, on average, \$20 each month, while quality 2 notebooks erode in value faster, averaging \$30 per month.

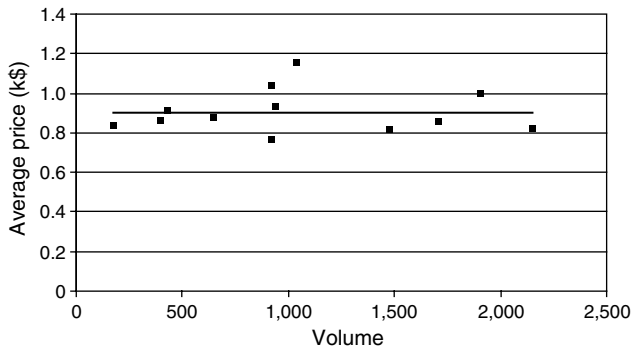


Figure 3: We found little support for the assumption that sales price is negatively affected by sales volume. Regression analysis shows that the variations in sales price can be explained by age differences and that the differences in volume have little effect on price.

the average selling price (Figure 3). For the volumes of quality 1 notebooks sold and other products, we found that there was no support for HP’s beliefs that volumes negatively affect selling prices. For example, the sales price differences around 1,000 sales units per month can be explained by age differences. We found that higher prices correspond to newer products in terms of life cycle. It was clear from the data that age (time since product introduction) is vastly more important than volume, reinforcing time as a major driver. The selling price for a refurbished notebook was about \$900. The range in pricing around the 1,000 sales units per month mark corresponds to

approximately six months difference in product age (Figure 3).

HP was surprised at the strong impact of value erosion on potential revenue and promptly decided to start tracking this indicator for all major product categories. The sales group reluctantly accepted our finding that current volumes apparently did not influence selling price. HP initiated studies to further analyze this effect for other product lines and larger sales volumes. It also decided to start tracking product age systematically.

Identifying Process Flows and Bottlenecks

The front end of the process (product acquisition and returns) is still rather poorly documented (Figure 4). HP remarketing does not have data on how long returned products wait at the resellers. We know that from time to time retailers contact HP to arrange for collection of the product returns. HP enters the returns it accepts in a system and collects them within 15 days on average. Each month, approximately 2,000 notebooks arrive at EMR. (For simplicity, we concentrate on notebooks from here onwards.)

Data for the middle part of the reverse supply chain, the actual operations, were more organized and readily available (Figure 4). HP reaches a disposition decision within one to three days of products’ arrival at EMR. Roughly 50 percent of the returned note-

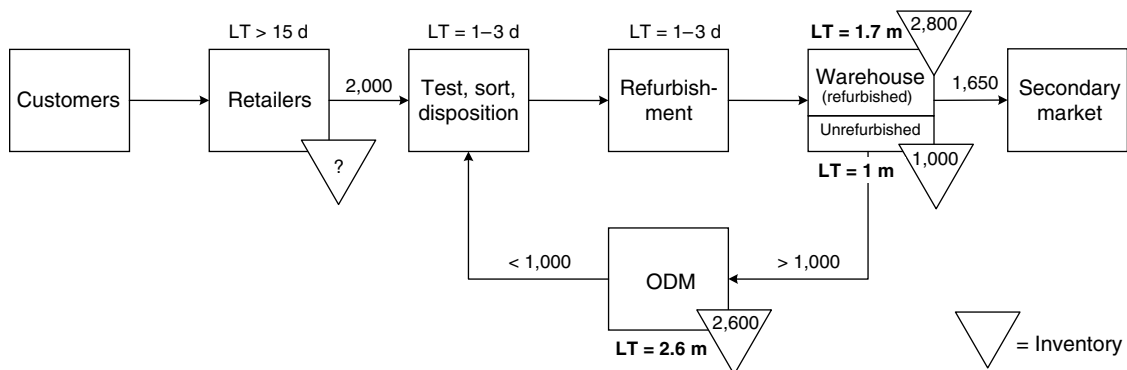


Figure 4: By superposing the average flows (numbers on the arrows), lead times (LTs), and inventories (numbers in triangles) for notebooks on the high-level process map of HP’s reverse supply chain for July through December 2002, we discovered two major bottlenecks: the refurbishment by the outsourced design and manufacturing supplier and the warehouse (the lead times are in bold).

books are unused products, many still in sealed boxes. EMR sends them through low-touch refurbishment on site and on to the warehouse. It stores the remaining 50 percent temporarily at the warehouse before sending them to the ODM for high-touch refurbishment. EMR checks products returned by the ODM again for quality in the low-touch refurbishment area before sending them to the warehouse.

Because of the fragmented nature of the reverse supply chain, we had difficulty getting hard data on the back-end processes (sales and marketing). This situation is typical for many firms selling refurbished products. Marketing and the sales staff do not market refurbished products aggressively because they believe that these sales will cannibalize new-product sales. Our experiences in Europe do not support this widely held belief. We also found that HP had not aligned incentives properly; the compensation for selling refurbished products is much lower than the compensation for selling new products.

We focused mainly on the middle part of the processes because EMR had direct responsibility for these operations. Process improvements in the other areas are possible, but managers believed that HP had to show the value potential of the remarketing organization to convince the other groups to provide coordinated support.

The first major bottleneck our analysis revealed was the ODM notebook refurbishment. The ODM has a maximum capacity of 1,000 notebooks per month.

HP did not keep track of ODM lead times. Using data from two different sources, we plotted cumulative shipments to and from the ODM over 10 months and applied Little’s law (Buzacott and Shanthikumar 1993, Chapter 3). The resulting graph showed that the ODM held large inventories (Figure 5). The ODM’s main interest is not to refurbish products but to design, make, and ship products. The ODM deals with returns reluctantly; this reluctance and the lack of capacity and priority lead to long lead times. The lengthy delays, with lead times averaging 2.6 months, clearly eroded the products’ value. HP was startled by these findings, which were quickly confirmed at the ODM. These delays are another consequence of a fragmented process focused almost exclusively on technical requirements. Lack of attention to flows translates into a lack of data, which frequently leads to unnoticed system bottlenecks.

The second major flow bottleneck we discovered was at the warehouse. At the time of the study, HP had 2,800 refurbished notebooks in the warehouse, and average monthly sales were 1,650 units. Hence, products remained in the warehouse for approximately 1.7 months. In addition, with 2,000 notebooks entering and only 1,650 leaving monthly, inventory was increasing. HP feared that selling prices would suffer if it offered too many units in any month, a misconception that we dispelled. This inaccurate reading of the market caused a self-inflicted bottleneck. HP needed to manage its reverse supply chain from end to end.

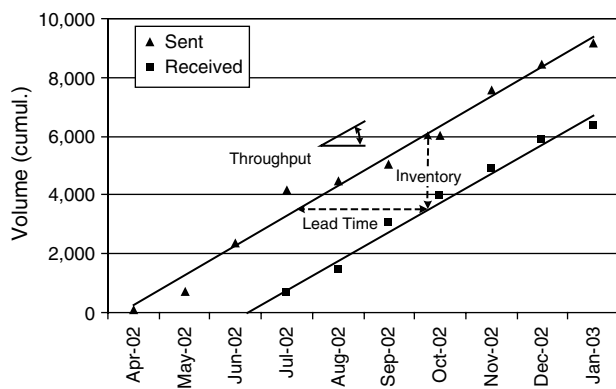


Figure 5: By plotting cumulative shipments to and from the ODM over a 10-month period and applying Little’s law, we saw the long delay (averaging 2.6 months) at the ODM clearly.

Quantifying Value Potential

We used simple analysis to help HP understand the potential value it was losing in the notebook reverse supply chain: Let us assume that refurbished notebooks have an average selling price of \$1,000 per unit and a steady state flow rate of 2,000 units per month. We established previously that value erosion is \$20 per unit per month (Figure 2). The 1,000 notebooks undergoing high-touch refurbishment spend, on average, one month in the warehouse awaiting shipment to the ODM, 2.6 months at the ODM for refurbishment, and 1.4 months in refurbished goods inventory (lead time in stock = $2,800/2,000 = 1.4$ months). The other 1,000 units destined for low-touch

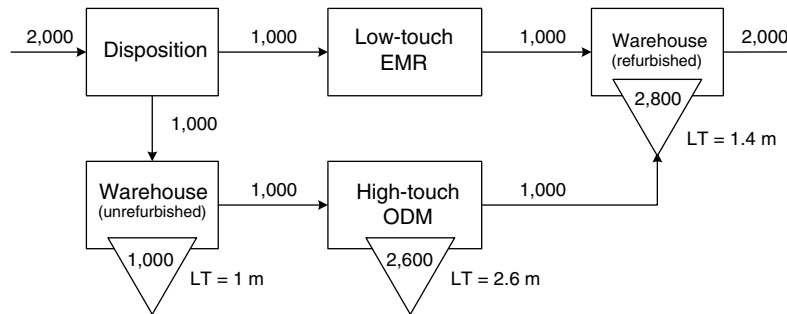


Figure 6: In creating this simplified flow diagram for notebooks, we assumed steady-state flow rates of 2,000 units per month across the returns and remanufacturing site and 1,000 units per month at the outsourced design and manufacturing partner.

refurbishment spend on average only 1.4 months in the system (assuming for clarity that refurbishment lead time is negligible) (Figure 6). The total value erosion per month is therefore $(1,000 \text{ units} * 1.4 \text{ months} + 1,000 \text{ units} * 5 \text{ months}) * \$20 \text{ per unit per month} = \$128,000$, that is, \$64 per unit on average. The 6,400 units of work in progress in the system also represent \$6.4 million in immobilized capital and a substantial financing cost, even at the current cost of capital (in 2004).

We applied these and other back-of-the-envelope calculations to a wide range of product returns and presented the results to HP management. The managers were stunned at the amount of value erosion because of delays in the reverse supply chain and by the amount of immobilized capital. For the notebook example (Figure 4), they had no difficulty identifying immediate actions to improve performance, the most obvious being to reduce lead time in high-touch refurbishment and to remove the sales constraints.

We also investigated the influence on price of several other factors, including localization (language) options, lot sizes, and sales channels (for example, auctions). However, they were all second-order effects, and we concentrated on quality and age as the most critical issues to address.

HP, convinced of the value potential, also asked us to perform a much deeper analysis, including end-to-end process mapping, OR modeling, and development of a performance scorecard for the reverse supply chain.

Optimizing Value Recovery

We developed linear-programming models based on network-flow principles to explore alternative scenarios, with the objective of maximizing HP's profits. We developed multiperiod models because HP is concerned with dynamic situations in which the supply of returns and market conditions change over time. Because the value of time is a key parameter in our models, we partitioned the notebooks by age classes using monthly time periods. The models require the user to specify the supply of unrefurbished products by age class as well as the (maximum) demand for refurbished products for each month. The maximum demand can be infinite, and that was our assumption in the experiments and the formulation. We did some limited tests with finite demand for HP's use internally to address its concern that prices would drop if it released too many refurbished products to the market at one time. Specifically, in the formulation, we have supply nodes corresponding to products less than one month old, between one and two months old, and so on (Figure 7).

The model constraints are those of the well-known network flow problem, that is, flow conservation at the nodes, lower and upper bounds on arc flows, and perhaps additional constraints, such as limited refurbishment capacity in each month (Bazaraa et al. 1990). One can easily construct subnetworks for different refurbishment options (scrap, low-touch or high-touch refurbishment, or any other option, such as sell directly to brokers as is).

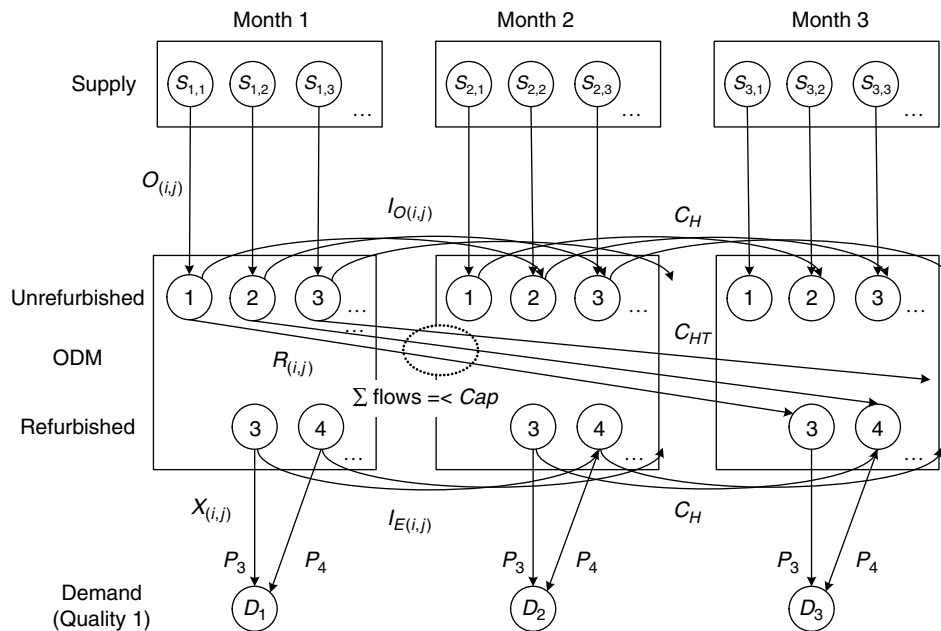


Figure 7: We modeled each refurbishment alternative as a subnetwork. The network displayed here represents high-touch refurbishment by the ODM, assuming the ODM lead time is two months. $S_{1,1}$ denotes the number of returned notebooks under one month old in month one that require high-touch refurbishment. These notebooks can remain in unrefurbished inventory at cost C_H per unit and per month, or be sent to the ODM for refurbishment at cost C_{HT} per unit. They will then become available for sale on the secondary market in month three, where they can fetch a price of P_3 per unit, corresponding to notebooks between two and three months of age.

We applied these types of formulations to explore alternative refurbishment scenarios and improve disposition decisions. We will describe just two simple examples: In the first, we analyzed a disposition strategy in which HP performs low-touch refurbishment for notebooks in house. In the second, we analyzed the frequently occurring peak in returns caused by some special event. Given that the ODM has limited capacity for refurbishment, which could lead to big queues and great erosion in value, we explored the disposition option of selling returned notebooks as is to brokers for a fixed price.

Inspection-Disposition Alternative Policies

HP’s traditional disposition strategy for notebooks was simple: used notebooks are sent to the ODM followed by low-touch refurbishment at EMR, *unused* products undergo only low-touch refurbishment at EMR. Considering the long ODM lead times and substantial refurbishment costs, we investigated the impact of reducing product flow to the ODM by processing some used notebooks differently (Figure 8).

Because the outcome of the new testing procedure was unknown at the time of the study, we introduced a parameter α ($0 \leq \alpha \leq 1$) denoting the fraction of products that would pass the test successfully. A low value of α indicates that the incoming notebooks are generally of poor quality (and require extensive refurbishment), while a high value of α indicates that incoming notebooks are all of high quality. Testing costs \$35 per unit; which is higher than the low-touch refurbishment cost of \$15 but much lower than the cost for repair at the ODM of \$200. In addition, the lead time for testing would be at most a few days, and notebooks passing the test would avoid the erosion in value caused by the long ODM lead times.

We constructed a linear-programming model for the policy test network and investigated a range of values for the returned notebook quality (α). These experiments revealed interesting insights (Figure 9). (In the appendix, we give a formulation of the model and a detailed description of input data.)

We found that HP could achieve significant savings. For instance, for $\alpha = 0.5$ and an ODM lead time

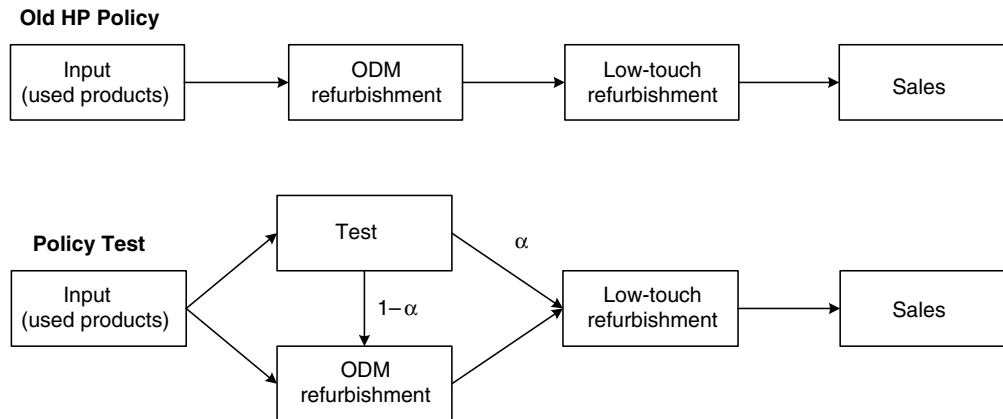


Figure 8: With its new policy, HP has two options: continuing to send the notebooks directly to the ODM or first testing them. It assumes that notebooks that pass the test successfully have no defects and low-touch refurbishes them in-house. By using this process, HP produces notebooks of the same quality as the ODM refurbished products. HP sends notebooks failing the test to the ODM for repair.

of three months, the potential additional profit compared to the old policy is \$95,000 per month. During our analysis, HP managers had done some real-life testing, which allowed them to estimate the actual value of α as around 0.5 to 0.7.

The shape and position of the curves are affected by the model’s parameters and input data. Besides the

quality of the input stream, the age of the products may influence the optimal disposition strategy, as may the market price as a function of the age, constraints on the market, lead times, and the costs and capacities of the refurbishment options. In any case, the model results for different scenarios convinced HP that the potential profits justified its implementing the new testing policy.

Supply Surge Alternative Policies

With a slightly modified model, we explored the impact of a peak supply in a given month caused by special events (Figure 10), something HP experienced quite regularly. We assumed that the regular supply (1,000 used notebooks per month, $\alpha = 0.5$) was distorted in one month by a peak load of 2,000 or 5,000 used notebooks. Given that the ODM could refurbish only 1,000 notebooks a month, and following its traditional policy, HP would have to refurbish some of the notebooks elsewhere to avoid blowing up the system. We modified the model to incorporate the option of sending untested products, as well as those failing the test in the case of the testing procedure, to brokers instead of the ODM, who salvage them for \$150 and \$50 per unit, respectively and irrespective of age. In the past, HP had sold notebooks as is to brokers in such situations and wanted the model to provide it with insight into when and how to use this option judiciously.

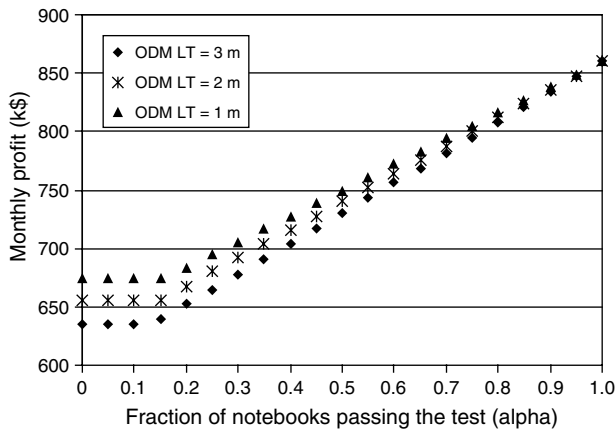


Figure 9: For one of our experiments, we display the monthly profit as a function of α and for different ODM lead times. When $\alpha = 0$, it makes no sense to send notebooks to the test because they are all defective. In this scenario, HP’s old policy (send all the used notebooks to the ODM) is optimal. The old HP policy remains optimal only for low values of α (the horizontal part of the curves). As incoming quality improves, it becomes optimal to introduce the new testing procedure.

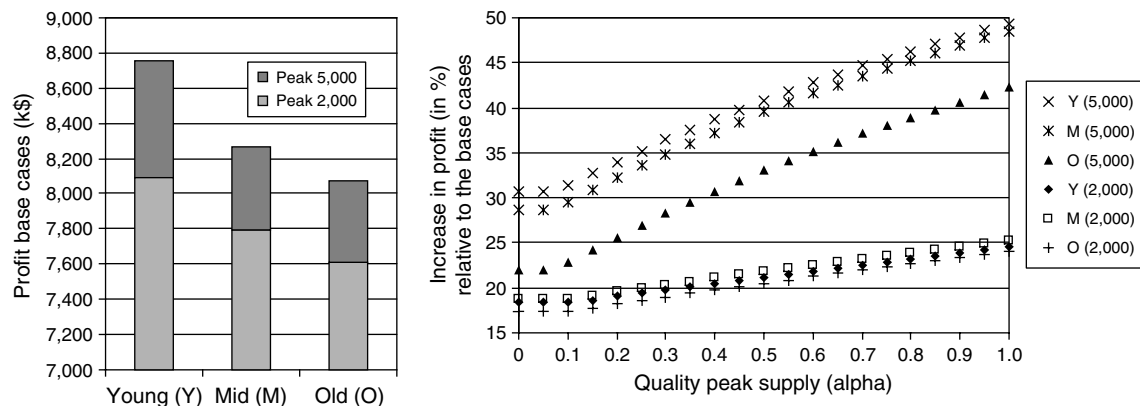


Figure 10: The curves show the percentage increase in yearly profit when HP uses the option of testing returned PCs and sending them to brokers, relative to six different cases of peak supplies and as a function of the quality of those peak supplies (α_{peak}). The six cases correspond to a small or a large peak supply of 2,000 or 5,000 units, respectively, and to three different ages of notebooks in the peak supply (young, middle-aged, or old, corresponding to 3.5, 11.5, and 19.5 months on average). We kept the quality of the regular supply (1,000 units per month) constant at $\alpha = 0.5$.

We examined six base cases corresponding to the maximal profits under HP’s old strategy of allocating unrefurbished products to the ODM or to brokers based on age only, with no regard for quality (no testing option). For a constant peak size, the profit drops as peak supplies age. The marginal profit also diminishes for older products: increasing the peak from 2,000 to 5,000 units results in additional profits of \$665,000, \$479,000, and \$460,000 for young, middle-aged and old products, respectively. Clearly, the old system had limited ability to deal with peak supplies. HP could improve the system by incorporating the test policy (Figure 10). Indeed, by using information on the quality of returns, HP can redirect products that would flow to the ODM in the old system to on-site low-touch refurbishment, freeing up capacity at the ODM for notebooks that really require high-touch refurbishment. Not surprisingly the relative improvement with respect to the base cases increases when the peak supply consists of better quality products. As the peak supply increases, however, the impact on profit increases and the effect of product age becomes more pronounced, that is, younger products result in greater improvement. Typically, the optimal disposition strategy varies for low α_{peak} values (poor-quality products), while for larger values of α_{peak} , the optimal strategy is to send all returned products to testing. The region where the optimal policy changes depends

on such factors as quality of regular supply, height of the peak, cost for testing and processing, capacity constraints, and value erosion. We can explore changes in these parameters easily using the model. Managers can then choose a robust returns-disposition strategy or gain insight about the conditions under which they should modify decisions concerning disposition, refurbishment, and market allocation.

Management Recommendations and Benefits

Our analysis led to a number of useful insights for managers at HP. First, managers came to recognize the value of time and its impact on profitability. Second, they became aware of what they already knew. HP collected and tracked data that enabled us to model the process and evaluate a number of scenarios, but the relevant data were difficult to extract from existing databases. HP managers now know what data they should track explicitly and how to interpret the information. Finally, the models indicate that HP can achieve high savings in the short term. The models also help managers to decide which products to refurbish locally and which to send to the ODM. HP is currently implementing our recommendations.

It also became very clear that the ODM acted as a bottleneck in the system. The ODM is operating

at peak capacity, and any increase in return volumes would increase lead times and inventories. HP managers estimate that 50 to 70 percent of the used notebooks can be redirected from repair at the ODM to in-house low-touch refurbishment, saving \$95,000 to \$147,000 per month on the monthly flow of 1,000 notebooks. HP can achieve these savings only if the products are not delayed elsewhere in the reverse chain and if market conditions remain more or less the same. HP has renegotiated its contract with the ODM since our analysis.

A Roadmap for Reverse Supply Chain Redesign

We believe that our methodology is widely applicable. Other companies whose products have short life cycles are struggling with the same problems as HP. They lose a lot of money if they treat time-sensitive returns as a nuisance. ODMs focus on new products and simply do not give repairs high priority. When such firms as HP outsource refurbishment operations with new manufacturing, they must explicitly address product returns and refurbishment in their contracts. Because time is a major driver of value recovery, they should examine the entire reverse supply chain in terms of flows and bottlenecks.

From our project with HP, managers of other companies can learn how to successfully manage time-sensitive returns:

(1) Treat returns as a value stream, not a waste stream.

(2) Consider the entire reverse supply chain. Any subprocess can become a system bottleneck. Strive for a lean and seamless reverse supply chain.

(3) Identify and develop the right performance metrics and track them systematically using a simple visual scorecard. Retrieve data from multiple sources if necessary, and transform the data into useful information for making informed decisions. Use facts to dispel strong existing, and perhaps erroneous, beliefs.

(4) Construct simple models based on the right information, paying particular attention to the economic impact of time. Use sophisticated models only after you understand the key process drivers and obtain accurate information.

(5) Use the models to analyze the economic impact of alternative designs and operational policies.

(6) Align the organizational structure and the incentives and reward systems to unleash the potential economic profit from the reverse supply chain.

These six steps echo the well-known basic principles of sound managerial decision making: metrics, models, and organizational readiness. HP pioneered global supply chain design in the early 1990s using these principles. It collected the necessary data, evaluated the alternatives based on fact-driven modeling, and ensured that the organization was ready for change.

The development of reverse supply chains parallels the development of global supply chains; however, in many companies, reverse supply chain management is at the stage that global supply chain management was 15 years ago, below top management's notice, fragmented, poorly resourced, and lacking adequate systems. However, in mature markets with declining profit margins, lack of attention to the reverse supply chain may severely undermine profitability.

Time has a central role in reverse supply chain design and management. Product life cycles are decreasing, customers demand liberal product-return policies, and profit margins are shrinking. These business realities increase the importance of reverse supply chains. Our project shows how simple operations research models help managers to reap the profits hidden in their returned products.

Appendix

The objective in the linear-programming models is to maximize value recovery (profit) from returned, used notebooks. The formulation below is the version we used in the experiments with the peak supply. Notebooks can be sent directly to brokers or to the ODM for high-touch refurbishment or they can be tested first. HP's EMR low touch refurbishes products without defects. It sends defective products to the ODM or to the brokers. ODM refurbished products undergo an additional low-touch check at EMR. Our formulation is cyclic over a T period horizon but can easily be modified. The age classes and the processing lead times are derived from the planning base period (e.g., one month). In the example, we assume lead times of three months for refurbishment by the ODM and

fast lead times (zero) for the other stages. We specify a maximum age a_{\max} after which we no longer track aging (products older than a_{\max} months have lost most of their value). The notation and formulation are as follows:

Indices

$i = 0, \dots, T - 1$ specifies the period in the planning horizon.

$j = 1, \dots, a_{\max}$ specifies the age class of the product.

Parameters

$S_{(i,j)}$ = supply of unrefurbished notebooks of age class j in period i .

$\alpha_{(i)}$ = quality parameter: the fraction of the notebook supply in period i that would pass the test successfully.

Cap = maximum number of notebooks the ODM refurbishes during each period.

C_T = cost for testing.

C_H = inventory holding cost.

C_{LT} = cost for low-touch refurbishment at EMR.

C_{HT} = cost for high-touch refurbishment by the ODM + cost for low-touch refurbishment at EMR.

$P_{(j)}$ = revenue from a refurbished notebook of age class j on the secondary market.

P_B = revenue from sending a notebook (without testing) to the brokers (price independent of age).

P_{dB} = revenue from sending a defective notebook (after testing) to the brokers (price independent of age).

Variables

$T_{(i,j)}$ = number of notebooks of age class j tested in period i .

$O_{(i,j)}$ = number of notebooks of age class j sent to the ODM (without testing) in period i .

$O_{d(i,j)}$ = number of (defective) notebooks of age class j sent to the ODM (after testing) in period i .

$B_{(i,j)}$ = number of notebooks of age class j sent to the brokers (without testing) in period i .

$B_{d(i,j)}$ = number of (defective) notebooks of age class j sent to the brokers (after testing) in period i .

$I_{O(i,j)}$ = unrefurbished notebook inventory of age class j at the ODM at the end of period i .

$I_{E(i,j)}$ = refurbished notebook inventory of age class j at EMR at the end of period i .

$R_{(i,j)}$ = number of notebooks of age class j on which refurbishment at the ODM started in period i . (After high-touch refurbishment, the products are sent to EMR, undergo a low-touch check, and are ready for resale in period $i+3$.)

$X_{(i,j)}$ = number of notebooks of age class j sold in the secondary market in period i .

Model Formulation

Maximize

$$\sum_{i,j} (P_{(j)}X_{(i,j)} + P_B B_{(i,j)} + P_{dB} B_{d(i,j)}) - (C_T + \alpha_{(i)} C_{LT}) T_{(i,j)} - C_{HT} R_{(i,j)} - C_H (I_{O(i,j)} + I_{E(i,j)}) \quad (1)$$

subject to

$$T_{(i,j)} + O_{(i,j)} + B_{(i,j)} - S_{(i,j)} \leq 0 \quad \forall i; \forall j, \quad (2)$$

$$(1 - \alpha_{(i)}) T_{(i,j)} - O_{d(i,j)} - B_{d(i,j)} = 0 \quad \forall i; \forall j, \quad (3)$$

$$O_{(i,j)} + O_{d(i,j)} - R_{(i,j)} - I_{O(i,j)} = 0 \quad \forall i; j = 1, \quad (4)$$

$$\begin{aligned} & I_{O((T+i-1) \bmod T, j-1)} + O_{(i,j)} + O_{d(i,j)} \\ & - R_{(i,j)} - I_{O(i,j)} = 0 \quad \forall i; 1 < j < a_{\max}, \\ & I_{O((T+i-1) \bmod T, j-1)} + I_{O((T+i-1) \bmod T, j)} + O_{(i,j)} \\ & + O_{d(i,j)} - R_{(i,j)} - I_{O(i,j)} = 0 \quad \forall i; j = a_{\max}, \\ & \alpha_{(i)} T_{(i,j)} - X_{(i,j)} - I_{E(i,j)} = 0 \quad \forall i; j = 1, \quad (5) \\ & \alpha_{(i)} T_{(i,j)} + I_{E((T+i-1) \bmod T, j-1)} - X_{(i,j)} - I_{E(i,j)} = 0 \\ & \quad \forall i; j = 2, 3, \end{aligned}$$

$$\begin{aligned} & \alpha_{(i)} T_{(i,j)} + I_{E((T+i-1) \bmod T, j-1)} + R_{((T+i-3) \bmod T, j-3)} \\ & - X_{(i,j)} - I_{E(i,j)} = 0 \quad \forall i; 3 < j < a_{\max}, \\ & \alpha_{(i)} T_{(i,j)} + I_{E((T+i-1) \bmod T, j-1)} + I_{E((T+i-1) \bmod T, j)} \\ & + R_{((T+i-3) \bmod T, j-3)} + R_{((T+i-3) \bmod T, j-2)} \\ & + R_{((T+i-3) \bmod T, j-1)} + R_{((T+i-3) \bmod T, j)} \\ & - X_{(i,j)} - I_{E(i,j)} = 0 \quad \forall i; j = a_{\max}, \end{aligned}$$

$$\sum_j R_{(i,j)} \leq Cap \quad \forall i, \quad (6)$$

$$\begin{aligned} & T_{(i,j)}, O_{(i,j)}, O_{d(i,j)}, B_{(i,j)}, B_{d(i,j)}, I_{O(i,j)}, I_{E(i,j)}, \\ & R_{(i,j)}, X_{(i,j)} \geq 0 \quad \forall i; \forall j. \quad (7) \end{aligned}$$

The different terms in the objective function (1) are the revenue from selling refurbished products on the secondary market and unrefurbished products to the brokers, the cost for testing and the cost for refurbishing the products without defects (fraction $\alpha_{(i)}$), the ODM cost for repairing the notebooks, and the inventory costs for holding unrefurbished products at the ODM and refurbished products at EMR. Constraints (2) are the supply constraints: unrefurbished notebooks are sent to the test, to the ODM, or to the brokers. Constraints (3) express conservation of flow for products that turned out to be defective after testing: products that failed the test can be sent to the ODM or to the brokers. Constraints (4) are the flow-conservation constraints for unrefurbished products at the ODM. For $1 < j < a_{\max}$, the constraint expresses that the ending inventory from the previous period (age class $j - 1$) and the notebooks sent to the ODM (age class j) should in total be equal to the new ending inventory (age class j) plus the notebooks on which refurbishment started (age class j). For $j = 1$ and $j = a_{\max}$, minor modifications are required to formulate begin and end of age tracking appropriately. Constraints (5) express in a similar way flow conservation of refurbished products at EMR. For $3 < j < a_{\max}$, the ending inventory from the previous period (age class $j - 1$), the notebooks that passed the test (age class j), and those on which ODM refurbishment started three periods earlier (age class $j - 3$) should in total be equal to the new ending inventory (age class j) plus the notebooks sold on the secondary market (age class j). As in (4), some adaptations are required when $j = 1..3$ and $j = a_{\max}$. Constraints (6) are the capacity constraints at the ODM, and constraints (7) are the nonnegativity conditions. Other constraints, such as limitations on the market demand, are easily incorporated.

The results in Figure 9 (ODM LT = 3 months) can be obtained by removing the $B_{(i,j)}$ and $B_{d(i,j)}$ variables and using the following data:

Supply $S_{(i,j)}$: 1,000 units per month, subdivided in age classes ($j - 1$ months < age $\leq j$ months): $j = 1$: 0 units; $j = 2..5$: 25 units in each class; $j = 6..15$: 80 units in each class; and $j = 16..19$: 25 units in each class. This age distribution is based on historical data.

Costs: $C_T = \$35$ per unit; $C_H = \$8$ per unit per month; $C_{LT} = \$15$ per unit; and $C_{HT} = \$215$ per unit.

Revenue: Starting at \$1,100 per notebook and eroding by \$20 per month, i.e., $P_{(j)} = \$1,100 - (j - 1) \times \20 .

The ODM capacity is $Cap = 1,000$ units each month. We explored different supply quality levels (α varies from 0 to 1 with increment 0.05), but the quality of the supply $\alpha_{(i)}$ was the same in every month of the planning horizon ($T = 12$ months). The maximum age parameter was set sufficiently large ($a_{\max} = 37$).

In the peak-load experiments, the broker prices P_B and P_{dB} equal \$150 and \$50 per unit for untested notebooks and tested, defective notebooks, respectively. For one month we changed the regular supply (as described above) to a small or a large peak load (2,000 or 5,000 units) of young, middle aged, or old notebooks. The age distribution in the peak supply was as follows:

Young products, large peak: $j = 2..5$: 1,250 notebooks in each class.

Young products, small peak: $j = 2..5$: 500 notebooks in each class.

Middle-aged products, large peak: $j = 10..13$: 1,250 notebooks in each class.

Middle-aged products, small peak: $j = 10..13$: 500 notebooks in each class.

Old products, large peak: $j = 18..21$: 1,250 notebooks in each class.

Old products, small peak: $j = 18..21$: 500 notebooks in each class.

The quality during the months with regular supply was kept constant ($\alpha_{(i)} = 0.5$ for $i \neq \text{peak}$), while the quality of the peak supply α_{peak} varied from 0 to 1 (increment of 0.05).

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Herbert Reiss, Vice President and General Manager, Equipment Management and Remarketing, Hewlett-Packard Co., writes: “Within HP Company I am responsible for a worldwide action business unit, called Equipment Management & Remarketing. I provide leadership to HP Remarketing organizations in different regions, such as Americas, Europe, Asia, China, and Japan.

“This letter is to support the manuscript “Hewlett-Packard Company Unlocks the Value Potential from Time-Sensitive Returns.” The project was carried out in cooperation with the Hewlett-Packard Remarketing group in Germany and accurately reflects the improvements made to the processes.

“The result of this project was really eye opening for my organization and delivered tremendous value towards improving our existing business model. As a first step the organization in Europe applied the recommended changes for our PC business resulting in a substantial improvement both in value recovery and inventory velocity. In a second step we plan to leverage the outcome with the remarketing organization in other regions around the globe which will even enhance the financial benefit for the company.

“I believe the results are applicable to a wide range of product returns for HP and we are exploring how to extend the results from this pilot study to other HP groups for other product lines and other regions.”