Review and Improvement of Reverse Logistics in an Electronics Company

by

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Abstract

InFocus is a worldwide leader in the digital display market. Despite its success in sales, the company posted a net loss in profit in year 2005. The major reasons are its high operating cost and high inventory level.

After reviewing its reverse logistics system, we found that current policy to process the returned product does not reap the maximum amount of profit from returns. We proposed to add a new channel to process the product returns. An optimum inventory policy was also developed to maximize the profit. An alternative distribution channel of the service parts was suggested which can cut down the inventory level and reduce the operating cost.

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Chapter 1 Introduction

1.1 InFocus Corporation

InFocus Corporation is the worldwide leader in digital projection technology and services. Its products include projectors, thin displays and related accessories and solutions for business, education, government and home users. InFocus has four product platforms, including portable projectors, meeting room projectors, installation and integration projectors for auditoriums, and home entertainment projectors. InFocus' principal competitors include Epson, NEC, Hitachi, Sanyo, BenQ, Dell, Coretronic, Optima, Panasonic, Sony, Hewlett Packard and Toshiba.

According to InsideMedia, InFocus has the number one market share in the mobile presentation market, retail channel, overall US market, worldwide market, and the PC distribution channel. Its worldwide market share in front projection is now 12% [1].

Despite a great success in sales, InFocus is having difficulties with its operations. The biggest problem InFocus is facing is its exceptionally high inventory level. Together with high operational cost from other fields, InFocus posted a net loss of 80 million US dollars in fiscal year 2005.

In view of the huge amount of loss, InFocus has launched a restructuring operation in order to simplify the business and return the company to profitability. InFocus implemented actions to reduce the cost to serve customers, improve the supply chain efficiency to reduce the operating expenses. The goal of this restructuring plan is to improve gross margins to 16% to 18% by the second half of the year 2006. But unfortunately according to the current data, the restructuring plan was not as successful as expected.

1.2 Reverse Logistics at InFocus

1.2.1 Repair Process of In-Warranty Projectors

As part of the restructuring plan, InFocus moved the service center from US to Singapore at the beginning of year 2006. InFocus expressed special interest in its reverse logistics and customer service sector when our team came in. They pointed out that it might be a potential area where the company could cut down its operating cost.

InFocus divides its global operation into three business areas: US, Asia Pacific and Europe. Third party logistics companies are engaged to manage its customer service in different areas: UPS is in charge of US; PCS is in charge of Asia Pacific area; DEX and UPS jointly manage European area. Besides these big service partners, InFocus also have smaller service centers scattered in the countries of Europe and Asia Pacific. When a projector breaks down, the customer contacts InFocus' service center via telephone or e-mail to get a Return Material Authorization (RMA) number. He subsequently sends the projector together with the RMA number to the third party logistics company for repair. The service partner replaces the faulty unit and sends the projector back to the customer. After the repair work is completed, the third party logistics company claims material and labor cost from InFocus with the RMA number.

The transaction is closed after the claim is granted by InFocus.

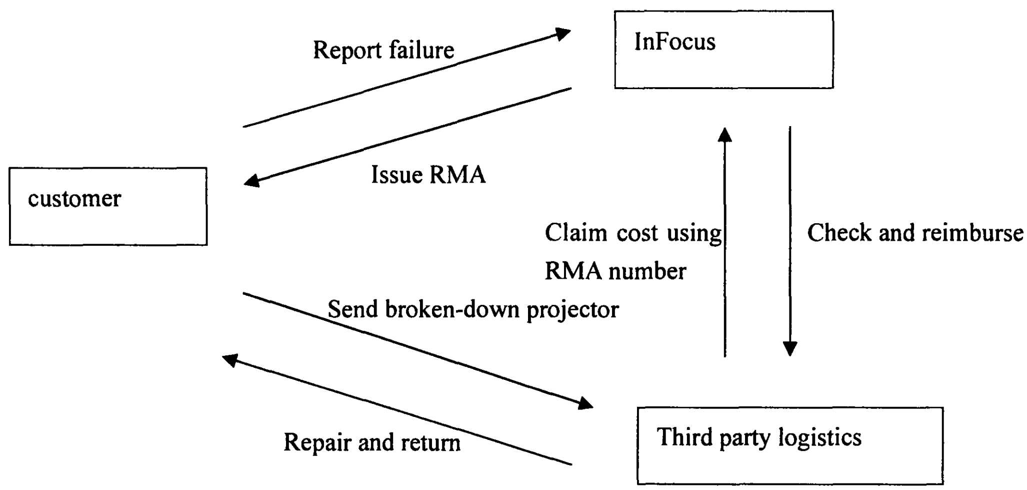


Fig. 1 flow chart of repair process for InFocus

1.2.2 Other Category of Returned Products

Besides broken-down projectors which are still in warranty, there is another category of returned products. InFocus has trade-in programs in US and Europe in order to encourage the sales of new models. Customers can send back their used projectors (regardless of its working condition) to get a new projector at a discounted price. Customers are also allowed to return the product for non-quality-related reasons within 30 days of date of purchase. There are also a small number of projectors which are returned to InFocus after its demonstration period is over. For this category of projectors which are not going back to the customer, InFocus' main policy is to remanufacture the projectors and sell them at a slightly lower price.

After some preliminary analysis, I found that the way in which the company deals with its returned products does not lead to maximum possible profit.

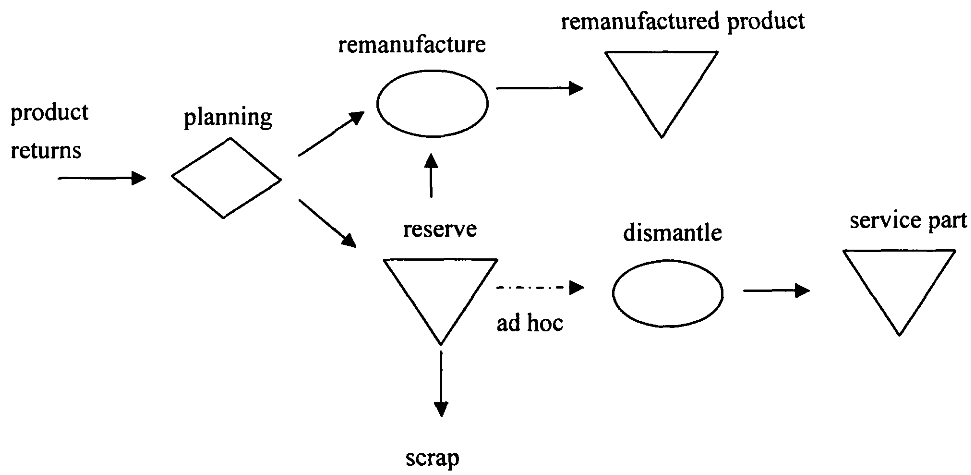


Fig. 2 current flow of returned products in InFocus

Currently remanufacturing is the major channel to process the returned products because the company thinks it is the most profitable way to recover value from returned products. When the projectors are returned to the company, it goes to RMAB (returned material authorization bad) inventory pool. The planning staff reviews this inventory every month and decides the number of projectors to be remanufactured according to the sales forecast from different regions. Remanufacturing was formerly done at the respective third party logistics company. But recently InFocus has switched to the contract manufacturer in China for this operation because of the cheaper labor cost. Dismantling is done on ad hoc basis when there is an urgent need for the part or when the model is too old for resale. Scrapping occurs very rarely, only when the warehouse has far more returned projectors than the company can handle.

The company set a high price for its remanufactured products, only at 15% off its normal price. The brand new projectors come with two years warranty. But the remanufactured ones come with only three months warranty. In addition, the remanufacturing engineer replaces the old lamp only if it has been used for more than 25% of its lifespan. The normal lifespan of a lamp is about 2000 hours; and the lamp is one of the most expensive parts for a projector. It accounts for one quarter of the projector price. Due to the uncompetitive price and sharp contrast between brand new projectors and remanufactured ones, the sales of the remanufactured products of some models are not appealing. Many of them have been accumulating in the warehouse for a long time, which incurred a very high inventory holding cost and tied up a large amount of capital. In addition, since the sales forecast of remanufactured products is lower than the incoming volume of returned products, a lot of bad projectors sit idle in the warehouse for a long time as well. According to the record, the typical shelf life of the returned projectors is around nine months.

Like other consumer electronics products, the value of a projector is very time sensitive because of short life cycle. It depreciates very rapidly with the introduction of new models and innovations. Therefore, InFocus should maximize its profit from returns by fast and smart ways through a variety of channels.

In order to maintain high customer satisfaction, InFocus promises that if the projector cannot be repaired within twelve days, the customer will get a brand new projector from InFocus. Most of the time, failure to meet the twelve day deadline is due to backlog of service parts. Because of this high backlog cost, InFocus and the service centers must maintain high service part inventory level. In addition, the contract manufacturers operate on a make to order policy. This gives rise to a very long lead time. The typical lead time for service parts is around 100 days. Besides that, the lead time is highly variable because of contract manufacturer's capacity constraint, delay from transportation and customs etc. Due to the long and volatile lead time, InFocus has to keep a high service part inventory level. This incurs very high inventory holding cost.

1.3 Objective

Besides remanufacturing, there is another potential channel to process the returned products: dismantle the returned projectors for service parts. We made a comparison of profit from remanufacturing and dismantling process. In the analysis, remanufacture profit is calculated as the average selling price of remanufactured projectors minus the average remanufacturing cost. Dismantle profit is calculated as the price of the most expensive parts (engine and controller board) minus the dismantling and testing cost, and then times the testing yield (In this case yield is assumed to be 0.8, according to the rough estimate of the service engineer).

The result of the analysis shows that dismantling is in fact far more profitable than remanufacturing. If dismantling is integrated systematically into the returned product disposal system, there will be three advantages: (1) The total profit from returned products will be higher since the unit profit from dismantling is generally higher than remanufacturing. (2) The shelf life of returned products could be shortened because of high demand of the service parts. (3) The inventory level of service parts will decrease because the lead time of dismantling and testing is much shorter than those from contract manufacturers. The last two advantages will greatly reduce the inventory holding cost of both returned products and service parts.

The following chart shows the result of the analysis. Greek letters are used here in place of the actual product family names and all the data in this paper are adjusted due to confidentiality of the information.

Product Family	Remanufacture Profit	Dismantle Profit	Remanufacture Demand	Service Parts Demand
α	$292.62	$489.60	4,666	930
β	$575.70	$628.80	878	520
γ	$276.90	$526.99	886	732
δ	$1,371.53	$901.60	300	147
ε	$283.95	$622.91	187	516
ζ	-$51.46	$995.33	29	902

Table 1 profit and demand of selected product families from different channels

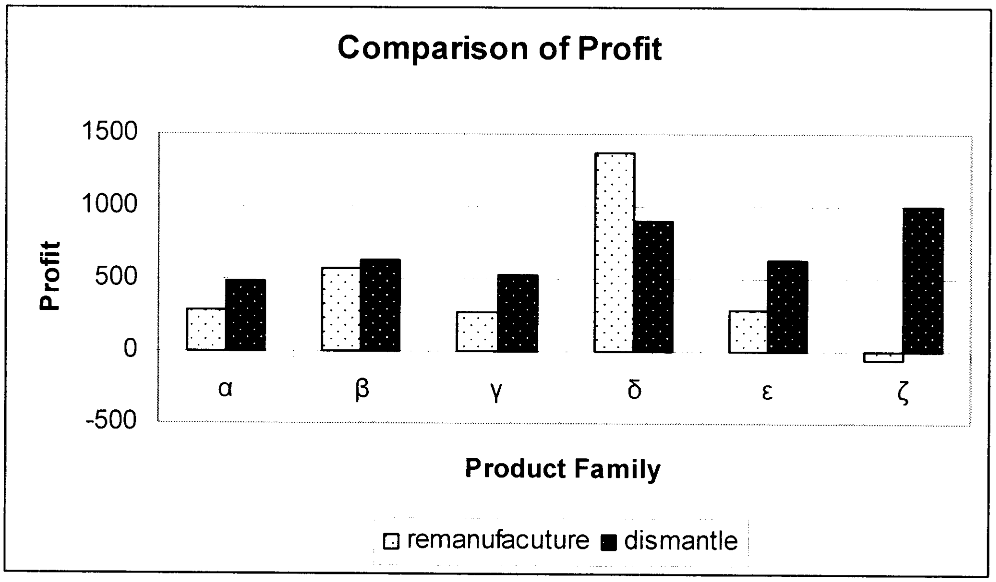


Fig. 3 comparison of profit from different channels

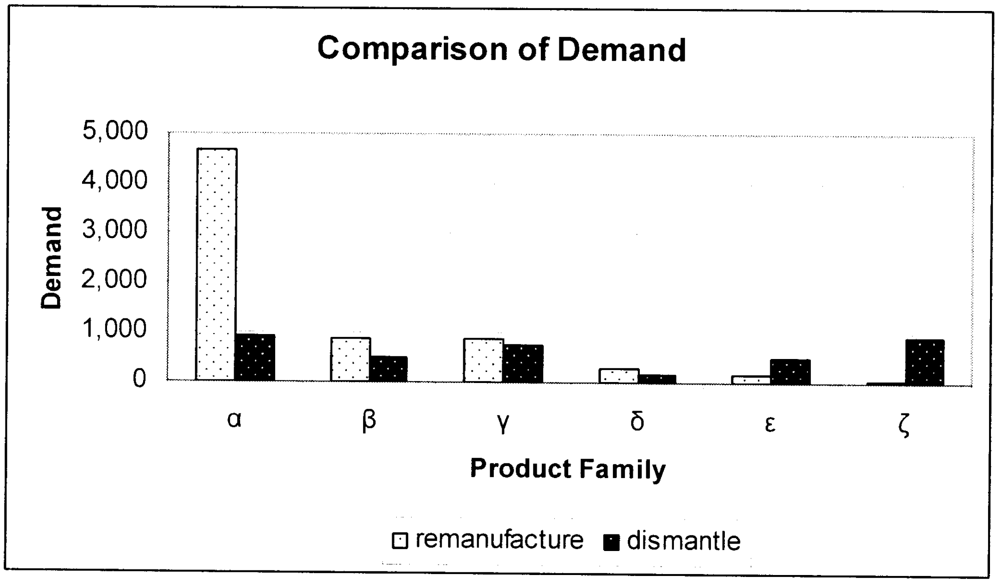


Fig. 4 comparison of demand from different channels

After adding in dismantling as an option, the problem which needs to be solved is how to set the inventory level of the two options scientifically to maximize the expected profit. It is similar to the two echelon divergent supply chain, where a central depot must satisfy the demand at several local stock points. The difference is that the incoming volume in this case is a random number. But we can still use the theories used in 2-echelon divergent supply chain since the outbound scenario is same.

The objective of this project is to develop a decision support system to help InFocus scientifically identify the optimal mix of various disposal channels to maximize its profit from product returns.

1.4 Summary

InFocus is a world leader in the digital display industry. Despite its success in sales, the company is facing difficulties in operations. Two major problems are its high inventory level and high customer service cost. After some preliminary analysis, adding dismantling as an option to process its returned products could partly solve the problem, because

(1) It can increase the overall profit since the profit from dismantling might be higher.

(2) It can shorten the shelf life of the returned products, and save the inventory holding cost for returned products.

(3) It can decrease the safety stock of service parts because the lead time is much shorter.

After adding in one more channel, we need to find a scientific way to allocate the incoming returned products to different channels in order to maximize the expected profit.

Chapter 2 Literature Review

2.1 Reverse Logistics

Traditional supply chain deals mainly with forward logistics, i.e. transporting goods from supplier to manufacturer, wholesaler, retailer and finally the end customer. A lean and efficient supply chain is vital to the company's success. Reverse logistics is defined as "The systems and methods used to move previously-shipped goods from a customer back to a manufacturer or distribution center due to repair, service, credit or order error issues. [2]"

In recently years, companies have been putting increasing emphasis on reverse logistics. The reason is two fold: Firstly, out of environmental concerns, European countries and some US states have passed legislations to request electronics companies to take back their products after they are disposed of by the customers. One example of such laws is directive on Waste of Electrical and Electronic Equipment (WEEE) of the European Union. This will become the future trend of other parts of the world as people become increasingly concerned about environment. Therefore it is obligatory for electronics companies to set up infrastructure to take back and dispose of their used products. Secondly, companies realize that huge profit could be reaped from recovery of returned products. When the competition between companies becomes more intense, reverse logistics emerges as a new field where companies can cut down its operating cost besides the established means like lean manufacturing and forward logistics. The benefit from returned product is especially high for electronics industry because of the short life cycle of the product and low level of mechanical wear and tear from the returns.

Reverse logistics also attracts growing interest from academia. This can be shown by the increasing number of papers published in recent years. The European Union has recognized the impact of reverse logistics and is sponsoring a 5-year research co-operation in this field.

2.2 Case Studies

2.2.1 IBM [3]

IBM is among the pioneers to exploit the profit from reverse logistics. Among its returned products, the most prominent class is the end-of-lease equipment. Leases account for around 35% of IBM's hardware sales. There are also take-back programs in North America, Europe and Asia. IBM has set up a department named Global Asset Recovery Services (GARS) to manage all product returns worldwide.

The recycle options in IBM include refurbishing, recovering components as service parts and recovering on a material level. The following diagram depicts the flow of returned product in IBM.

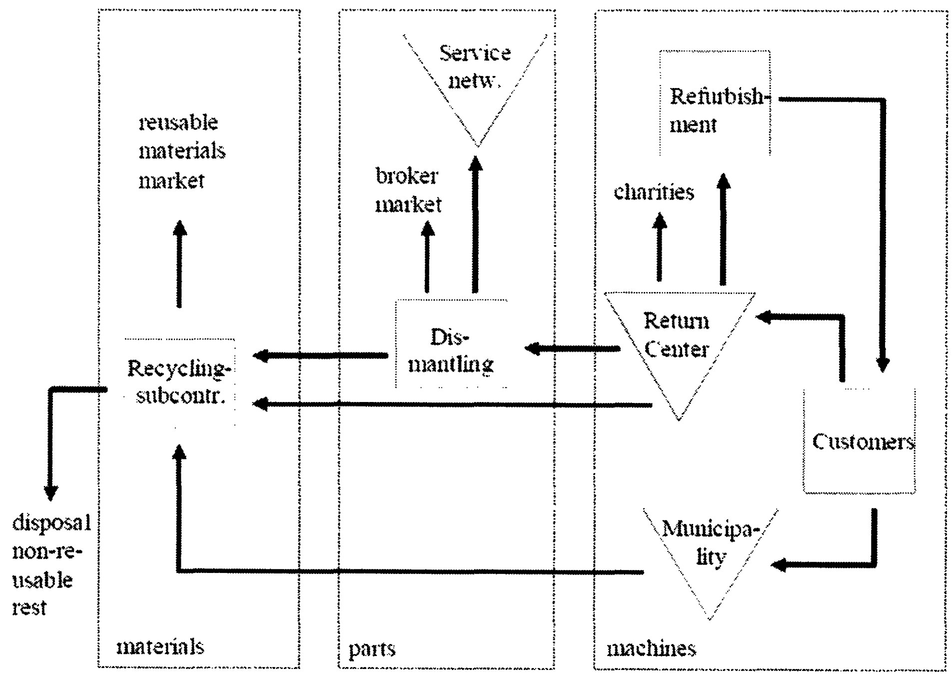


Fig. 5 flow of returned product in IBM [3]

Fleischmann et al. [3] has done a research on the interface between returned products dismantling and service parts inventory. Before the project was done, IBM's dismantling process was an incidental, opportunity drive activity. It was not integrated into the company's planning system. Because of lack of proper planning, a lot of unnecessary parts were dismantled while on the other hand many dismantling opportunities were lost. Fleischmann's work developed a proposal for a systematic integration of dismantling as a regular source into spare parts planning.

The project was on design of dismantling channel, a choice between "push" and "pull" system. In a push system the returned products are dismantled and tested as soon as they become available. While in a pull system they are only dismantled when needed. The first option avoids stocking defective parts, and reduces the lead time, which in turn reduces safety stock. The second option postpones the value adding testing stage, and avoids the risk of testing parts that are no longer needed.

After doing a simulation study, Fleischmann reached a conclusion that push system has a higher profit than pull system.

2.2.2 HP [4]

In HP, the department which handles returned products is called equipment management and remarketing (EMR) Division. The operations include organizing product returns from the market, determining the best reuse option, reconditioning, and marketing and selling the reconditioned products.

EMR has outsourced 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.

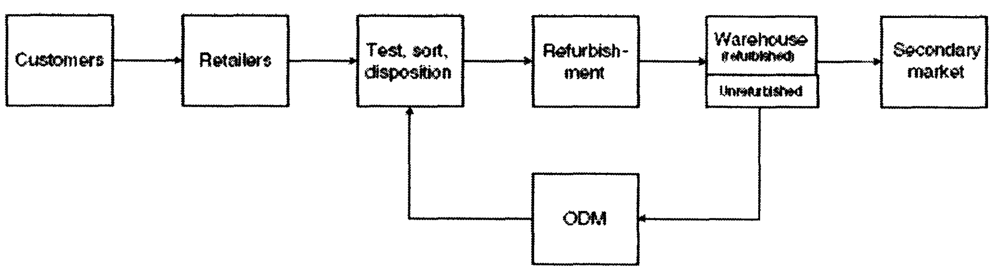


Fig. 6 flow of returned products in HP [4]

Early in 2003, Guild et al. started a project with HP to redesign its European reverse logistics and improve the performance. The author encountered same kind of problems as our team faced in InFocus: a fragmented organizational structure with no end-to-end view; information symmetries etc. HP had masses of data, but they were neither connected nor in the right format for the purposes.

After analyzing the data, the group found that the company did not fully realize the time sensitiveness of their returns. After Outsource Design and Manufacturing supplier (ODM) refurbishes the product, HP tests them and sells them as quality one products with warranty. Around 10% of the refurbished products fail the test; and HP sells them as quality 2 products without warranty.

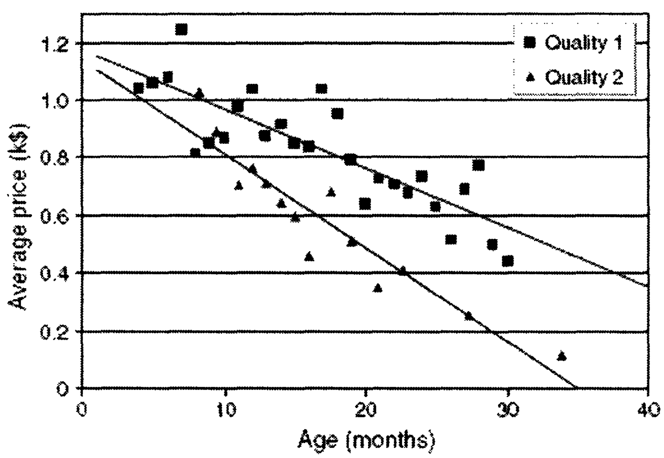


Fig. 7 depreciation of refurbished product with age [4]

The group used simple linear regression to find out how rapidly the value of refurbished product erodes with age (age means the time since the introduction of the model in this case). The management was surprised by the finding and the group went on to find the bottlenecks in the reverse logistics system. The product acquisition and ODM were identified as two major bottlenecks in the system. The group used linear programming to investigate the performance of the system under different scenarios and made a few restructuring suggestions, e.g. refurbishing returns in house. The suggestions are expected to save millions of dollars for HP.

2.3 Remanufacturing

There have been a number of literatures which address the problem of remanufacturing. Vincent P Simpson (1978) [5] proved that the optimum solution structure for an n-period repairable inventory problem is completely defined by three period dependent values: the repair-up-to level, purchase-up-to level and scrap-down-to level. He proposed a convex differentiable cost function of these parameters, and solved it for the optimal inventory position with backward dynamic programming technique in two dimensions with the Kuhn-Tucker saddle point theorems applied in each stage. Van der Laan et al. (1996) [6] studied a single-product, single-echelon production and inventory system with product returns, product remanufacturing and product disposal. In his work the authors considered three different procurement and inventory control strategies and compared the performance of each of the alternative strategies. In another paper of Van der Laan (1999) [7], he made a comparison of push and pull strategies in the remanufacturing system. Minner and Kleber (2001) [8] used Pontryagin's Maximum Principle for finding optimal production and remanufacturing policies for deterministic but dynamic demands and returns when backorders are not allowed. In Kiesmüller et al. (2000) [9] this assumption was relaxed. K. Inderfurth et al. (2001) [10] studied product recovery in stochastic remanufacturing systems with multiple reuse options.

2.4 Summary

As the competition between companies becomes more intense and the environmental regulations become more stringent, reverse logistics has become increasingly important in the company's operation.

In electronics industry, as the value of returns is very sensitive, it is important for the companies to keep the shelf life of returned products short in order to reap the maximum profit. Besides remanufacturing, dismantling the returned products for service parts is also a profitable way to recover value from returns.

Chapter 3 Problem Formulation

3.1 Purpose of Analysis

The current policy which deals with returned products does not generate maximum amount of profit. In this chapter, we use a mathematical model to describe the return process. The solution of this model will be able to tell InFocus the optimum fill-up-to level of each option that will maximize the expected profit from returns.

3.2 Assumptions for Analysis

InFocus reviews its returned product inventory every month. Therefore our analysis is based on a periodic review policy with a review period of one month. In the analysis, we make the following assumptions:

1. The incoming returned products follow Poisson distribution with mean λ_{rt}, the demand of remanufactured products and service parts follows Poisson distribution with mean λ_{rm} and λ_{dm} respectively.
2. The lead times of remanufacturing and dismantling are assumed to be 0. This is because: (1) although the total volume is large, remanufacturing and dismantling are done in several different factory repair centers around the world. Therefore the workload of each factory repair center is not so heavy. (2) Remanufacturing or dismantling one projector does not take long, so we assume the lead time is negligible compare to the review period of one month. Therefore any units which

are allocated to the remanufactured inventory or service part inventory are immediately available for the current month.

3. If there is a backlog for the remanufactured product, the sale is lost. Therefore the backlog cost for remanufactured products is the profit made from selling one unit, i.e. average selling price of the product minus the average remanufacturing cost. If there is a backlog for the service part, the company has to procure a new part. Therefore the backlog cost of dismantled part is the potential saving when the service part comes from the dismantling channel, i.e. the price of service part minus the dismantling and testing cost.
4. All the costs, i.e. inventory holding cost, remanufacturing cost, dismantling and testing cost, backlog cost are time independent. They remain constant throughout the period of analysis.
5. The process flow is depicted in Fig. 8. There are three inventory stocking points: returned products, remanufactured products and service parts. At the beginning of each month, the planning staff will get information on the number of returns from the previous month, the inventory level of remanufactured products and dismantled service parts. He will then decide the respective volume of remanufacturing, dismantling and scrapping. After the decision is made, the stochastic return and demand will be taken into account. At the end of each month, inventory holding cost will be charged to the remaining remanufactured projectors or dismantled service parts. The objective of the planning staff is to minimize the sum of costs (inventory holding cost, remanufacturing cost, dismantling and

testing cost and backlog cost). This is equivalent to maximize the profit from returned products.

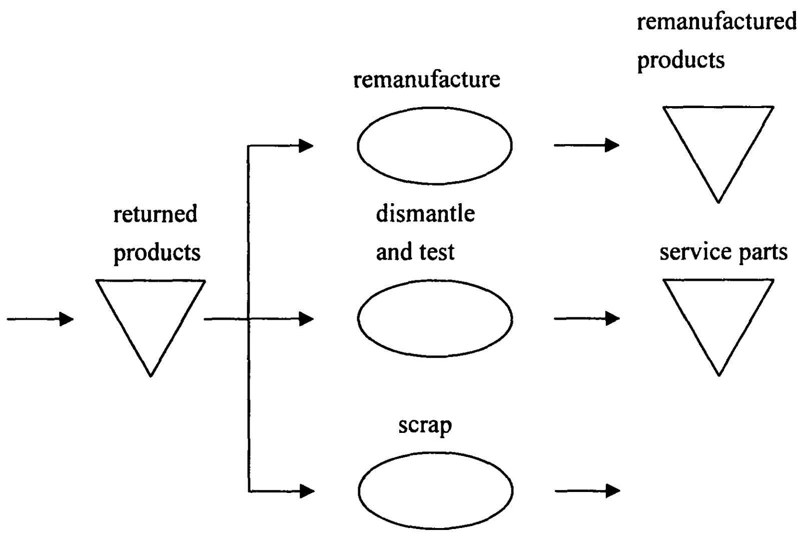


Fig. 8 process flow of the model

3.3 Stochastic Programming

The following is a list of parameters which are used in the analysis:

p_{rm}: average selling price of remanufactured projector

p_{dm}: price of service part

c_{rm} : remanufacturing cost

c_{dm} : dismantling and testing cost

h_{rt}: holding cost of returned product

h_{rm} : holding cost of remanufactured projector

h_{dm}: holding cost of dismantled service part

b_{rm}: backlog cost of remanufactured projector

b_{dm}: backlog cost of dismantled service part

λ_{rt}:mean of returned product per month

λ_{rm}:mean of remanufactured projector demand per month

λ_{dm}:mean of dismantled service part demand per month

R_t: returned product quantity in period t

$D_{rm,t}$: demand for remanufactured quantity in period t

$D_{dm,t}$: demand for dismantled service part in period t

$i_{rt,t}$: initial inventory level of returned product in period t

$i_{rm,t}$: initial inventory level of remanufactured projector in period t

$i_{dm,t}$: initial inventory level of dismantled part inventory in period t

$x_{rm,t}$: remanufactured quantity in period t

$x_{dm,t}$: dismantled quantity in period t

$x_{s,t}$: scrapped quantity in period t

y:yield of dismantling and testing

C_{rm}:expected inventory holding cost and backlog cost of remanufactured product

C_{dm}:expected invenotry holding cost and backlog cost of dismanlted service part

C_{rt}:expected inventory holding cost of returned product

$\phi_R(R)$:probability distribution function of return

$\phi_{D_{rm}}(D_{rm})$:probability distribution function of demand of remanufactured product

$\phi_{D_{dm}}(D_{dm})$:probability distribution function of demand of dismantled service part

We can formulate a dynamic stochastic programming model. The objective is to minimize the sum of remanufacturing cost, dismantling and testing cost, inventory holding cost and backlog cost. A mathematical description of the objective is

$$Min\ \ E\left\{\sum_{t=1}^{T}\begin{bmatrix} c_{rm}x_{rm,t}+c_{dm}x_{dm,t}+h_{rt}(i_{rt,t}-x_{rm,t}-x_{dm,t}-x_{s,t}+R_t) \\ +h_{rm}\max(i_{rm,t}+x_{rm,t}-D_{rm,t},0)+h_{dm}\max(i_{dm,t}+x_{dm,t}-D_{dm,t},0) \\ +b_{rm}\max(D_{rm,t}-x_{rm,t}-i_{rm,t},0)+b_{dm}(D_{dm,t}-x_{dm,t}y-i_{dm,t},0) \end{bmatrix}\right\}$$

The initial inventory level of the current month should be equal to the initial inventory level of the previous month plus the incoming volume of the previous month, and then minus the demand of the previous month. Therefore the dynamic restrictions on inventories are:

$$i_{rt,t+1}=i_{rt,t}+R_t-x_{s,r}-x_{rm,t}-x_{dm,t}$$
$$i_{rm,t+1}=i_{rm,t}+x_{rm,t}-D_{rm,t}$$
$$i_{dm,t+1}=i_{dm,t}+x_{dm,t}y-D_{dm,t}$$

The total volume of scrap, remanufacture and dismantle should not exceed the sum of the initial return inventory and the return of the current month. A static restriction on the returned product is:

$x_{s,t} + x_{rm,t} + x_{dm,t} \le R_t + i_{rt}$

Non-negativity restrictions are

$x_{s,t} \ge 0$

$x_{rm,t} \ge 0$

$x_{dm,t} \ge 0$

The end of the planning period corresponds to end of service life (EOSL) in InFocus. All the warranty should expire and no more product of this model should be sold beyond this point of time. Therefore all the left over stocks at the end of the planning period should be scrapped.

$x_{s,T+1} = i_{rt,T+1} + i_{rm,T+1} + i_{dm,T+1}$

We can see that it is a Markovian process, and the optimum decision is dependent on the state of inventory at the beginning of each week (i_{rt}, i_{rm}, i_{dm}).

The expected inventory holding cost of returned products is

$$C_{rt} = h_{rt} \int_0^\infty (i_{rt} - x_{rm} - x_{dm} - x_s + R)\phi(R)dR$$

The expected inventory holding cost and backlog cost of remanufactured product and dismantled parts can be written as

$$C_{rm}(n) = h_{rm} \int_0^n (n - D_{rm})\phi(D_{rm})dD_{rm} + b_{rm} \int_n^\infty (D_{rm} - n)\phi(D_{rm})dD_{rm}$$

$$C_{dm}(n) = h_{dm} \int_0^n (n - D_{dm})\phi(D_{dm})dD_{dm} + b_{dm} \int_n^\infty (D_{dm} - n)\phi(D_{dm})dD_{dm}$$

According to Bellman's optimality principle, the formulation can be written as

$$f_t(i_{rt}, i_{rm}, i_{dm}) = \min \left\{ \begin{array}{l} c_{rm}x_{rm} + c_{dm}x_{dm} + C_{rt} + C_{rm}(i_{rm} + x_{rm}) + C_{dm}(i_{dm} + x_{dm}) + \\ \int_0^\infty \int_0^\infty \int_0^\infty f_{t+1}(i_{rt} - x_s - x_{rm} - x_{dm} + R, i_{rm} - D_{rm} + x_{rm}, i_{dm} - D_{dm} + x_{dm}) \\ \phi_R(R)\phi_{D_{rm}}(D_{rm})\phi_{D_{dm}}(D_{dm})dRdD_{dm}dD_{rm} \end{array} \right\}$$

with $f_{T+1}(i_{rt}, i_{rm}, i_{dm}) = 0$.

The principle of optimality is often written in a recursive form,

$$f_t(k_t) = \min\{v(k_{t,}c_t) + E[f_{t+1}(k_{t+1})]\}$$

where k_t is the state variable, which is the initial inventory level in this case; c_t is the control variable, which is the volume of scrapping, remanufacturing and dismantling. $v(k_{t,}c_t)$ is the cost function, which is equal to $c_{rm}x_{rm} + c_{dm}x_{dm} + C_{rt} + C_{rm}(i_{rm} + x_{rm}) + C_{dm}(i_{dm} + x_{dm})$ in the case of InFocus. $E[f_{t+1}(k_{t+1})]$ is the expected value of f for the subsequent periods, which is equal to

$$\int_0^{\infty}\int_0^{\infty}\int_0^{\infty} f_{t+1}(i_{rt} - x_s - x_{rm} - x_{dm} + R, i_{rm} - D_{rm} + x_{rm}, i_{dm} - D_{dm} + x_{dm})\phi(R)\phi(D_{rm})\phi(D_{dm})dRdD_{dm}dD_{rm}$$

The usual way to solve this problem is by induction. First we find the solution for a single period problem, and then we test whether this solution is ideal for a multi period scenario.

When T = 1, the objective function is

$$f_t(i_{rt,}i_{rm,}i_{dm}) = \min\{c_{rm}x_{rm} + c_{dm}x_{dm} + C_{rt} + C_{rm}(i_{rm} + x_{rm}) + C_{dm}(i_{dm} + x_{dm})\}$$

The optimal fill-up-to level N_{rm}, N_{dm} should be chosen such that remanufacturing cost (or dismantling and testing cost) should be equal to the marginal decrease in the cost of inventory holding and backlog. i.e.

$$c_{rm} = -C'_{rm}(N_{rm})$$

$$c_{dm} = -C'_{dm}(N_{dm})$$

When there are not enough returns, the optimal allocation of scarce returns should be determined such that the marginal cost decrease from increasing one unit of each option should be equal, i.e.

$$c_{rm} + C'_{rm}(\bar{N}_{rm}) = c_{rm} + C'_{rm}(\bar{N}_{rm}) \qquad (1)$$

And

$$\bar{N}_{rm} - i_{rm} + \bar{N}_{dm} - i_{dm} = i_{rt}$$

Therefore the policy should be

$$i_{rt} \geq N_{rm} - i_{rm} + N_{dm} - i_{dm} \Rightarrow x_{rm} = N_{rm} - i_{rm}, x_{dm} = N_{dm} - i_{dm}, s = i_{rt} - x_{rm} - x_{dm}$$
$$i_{rt} < N_{rm} - i_{rm} + N_{dm} - i_{dm} \Rightarrow x_{rm} = \bar{N}_{rm} - i_{rm}, x_{dm} = \bar{N}_{dm} - i_{dm}$$

When the return volume is enough to fill the gap between the ideal fill-up-to level and the current inventory level, each option is filled to its respective ideal level, and the excessive returns should be scrapped. When there is a deficit of the returns, we follow the rule described in equation (1) to allocate the return to different options.

We can see that the solution from stochastic programming is very complicated because the decision depends on every state in a complex way. When it comes to multi-period case, the amount of computation would be too large for it to be feasible in practice. So we would not continue with this method in this paper and find a heuristic approximation instead.

3.4 Heuristic Approximation

Annual holding cost of remanufactured products and dismantled service parts is calculated as 30% of the price (10% annual interest cost, 15% depreciation cost and 5% handling cost); holding cost of the returned product is calculated as 10% of the price since remanufacturing, dismantling and testing are value-adding processes. Backlog cost for both options are the average selling price minus the average process cost. While remanufacturing cost differs by different product families, the dismantling and testing cost is uniform at $40 dollars per unit.

As mentioned before, the expected inventory holding cost and backlog cost of remanufactured product are

$$C_{rm}(n) = h_{rm} \int_0^n (n - D_{rm})\phi(D_{rm})dD_{rm} + b_{rm} \int_n^\infty (D_{rm} - n)\phi(D_{rm})dD_{rm}$$

$$C_{dm}(n) = h_{dm} \int_0^n (n - D_{dm})\phi(D_{dm})dD_{dm} + b_{dm} \int_n^\infty (D_{dm} - n)\phi(D_{dm})dD_{dm}$$

It can be proven that the above functions are convex [11], thus the optimal policy should be fill-up-to-N policy. There are two possible scenarios in practice: (1) the number of returns is enough to fill the two options to their respective optimum inventory level. (2) Volume of returns is not enough to fill the gap between the optimum and current inventory level. In the second scenario we need to find a way of allocating the scarce returns so that the expected profit will be maximized.

3.4.1 There are more than enough returns

When we decide the optimum inventory level for each option, it's a trade-off between inventory holding cost when there is an excess and backlog cost when there is a shortage. Therefore we can determine the optimal fill-up-to level for remanufactured product (N_{rm}) and dismantled service part (N_{dm}) using the Newsvendor model.

The overage cost is the inventory holding cost of one month, and underage cost is the loss of profit from selling one remanufactured product or the price difference that has to be paid to buy a new service part.

$$P(N_{rm} \leq D_{rm}) = \frac{b_{rm}}{b_{rm} + h_{rm}} \qquad (2)$$

$$P(N_{dm} \leq D_{dm}) = \frac{b_{dm}}{b_{dm} + h_{dm}} \qquad (3)$$

Determination of the optimum level of returned products which are kept as reserve is a bit tricky. The cost of one unit in the reserve is the inventory holding cost, the profit of this unit is realized when there is a deficit in the returns (the unit is taken out from the reserve for remanufacturing or dismantling) and the remanufactured or dismantled unit is sold or used in the following month. The optimum level is when the marginal cost is equal to the marginal profit.

Let $Y_t = R_t - (N_{rm} - i_{rm,t} + (N_{dm} - i_{dm,t})/y)$, the optimum inventory level for reserve should be

$$h_{rt} = P(Y_t < 0)\left\{P(D_{rm,t} > \tilde{N}_{rm,t})(P_{rm} - c_{rm}) + P(D_{dm,t} > \tilde{N}_{dm,t})(P_{dm} - c_{dm})\right\}$$

where $\tilde{N}_{rm}$ and $\tilde{N}_{dm}$ are inventory levels that the two options would have been filled up to without the reserve unit. Since Y_t, $\tilde{N}_{rm}$ and $\tilde{N}_{dm}$ are random numbers of unknown distributions, it is impossible to find the solution analytically. Therefore we will use simulation to find the optimum reserve level.

When the reserve size increases, the inventory holding cost is expected to increase whereas the backlog cost is expected to decrease. The total cost should be at minimum with an optimum reserve size. The profit would be at maximum at this level.

In the simulation of Chapter 4, we will vary the size of the reserve, and find out the corresponding profit. A graph of profit against reserve size will then be plotted; the reserve size with the highest profit will be set as the optimum.

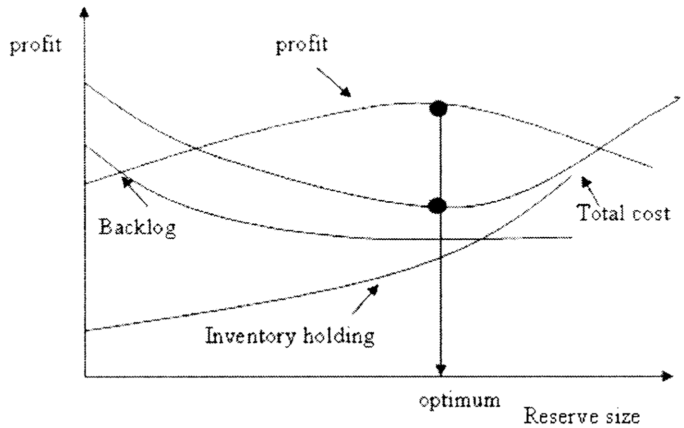


Fig. 9 method of finding the optimum reserve size

3.4.2 There are not enough returns to satisfy N_{rm} and N_{dm}.

Under this scenario,

$$R \le N_{rm} - i_{rm} + \frac{N_{dm} - i_{dm}}{y}.$$

Let Z_{rm} and Z_{dm} be the marginal profit of remanufacturing and dismantling, $\overline{N}_{rm}$ and $\overline{N}_{dm}$ be the fill-up-to level when the volume of return is smaller than the gap between the optimal level and the actual inventory level at the beginning of each month.

$$\begin{aligned} Z_{rm}(\overline{N}_{rm}) &= P_{rm}P(D_{rm} \ge \overline{N}_{rm}) - h_{rm}P(D_{rm} < \overline{N}_{rm}) - c_{rm} \\ &= P_{rm}(1 - P(D_{rm} < \overline{N}_{rm})) - h_{rm}P(D_{rm} < \overline{N}_{rm}) - c_{rm} \\ &= P_{rm} - c_{rm} - (P_{rm} + h_{rm})F(\overline{N}_{rm} - 1) \end{aligned}$$

where $F(x) = P(D \le x)$

Similarly, $Z_{dm}(\overline{N}_{dm}) = \left\{P_{dm} - c_{dm} - (P_{dm} + h_{dm})F(\overline{N}_{dm} - 1)\right\} y$

The levels $\overline{N}_{rm}$ and $\overline{N}_{dm}$ are determined such that the marginal profit for increasing one unit from each option is equal, i.e. $Z_{rm}'(\overline{N}_{rm}) = Z_{dm}'(\overline{N}_{dm})$

Because of the discrete nature of $\overline{N}_{rm}$ and $\overline{N}_{dm}$, the left hand side of the equation will not be exactly equal to the right hand side, but we can find the combination of

$\bar{N}_{rm}$ and $\bar{N}_{dm}$ which has the least difference between them.

The two levels can be found using a very simple algorithm described in Fig. 10.

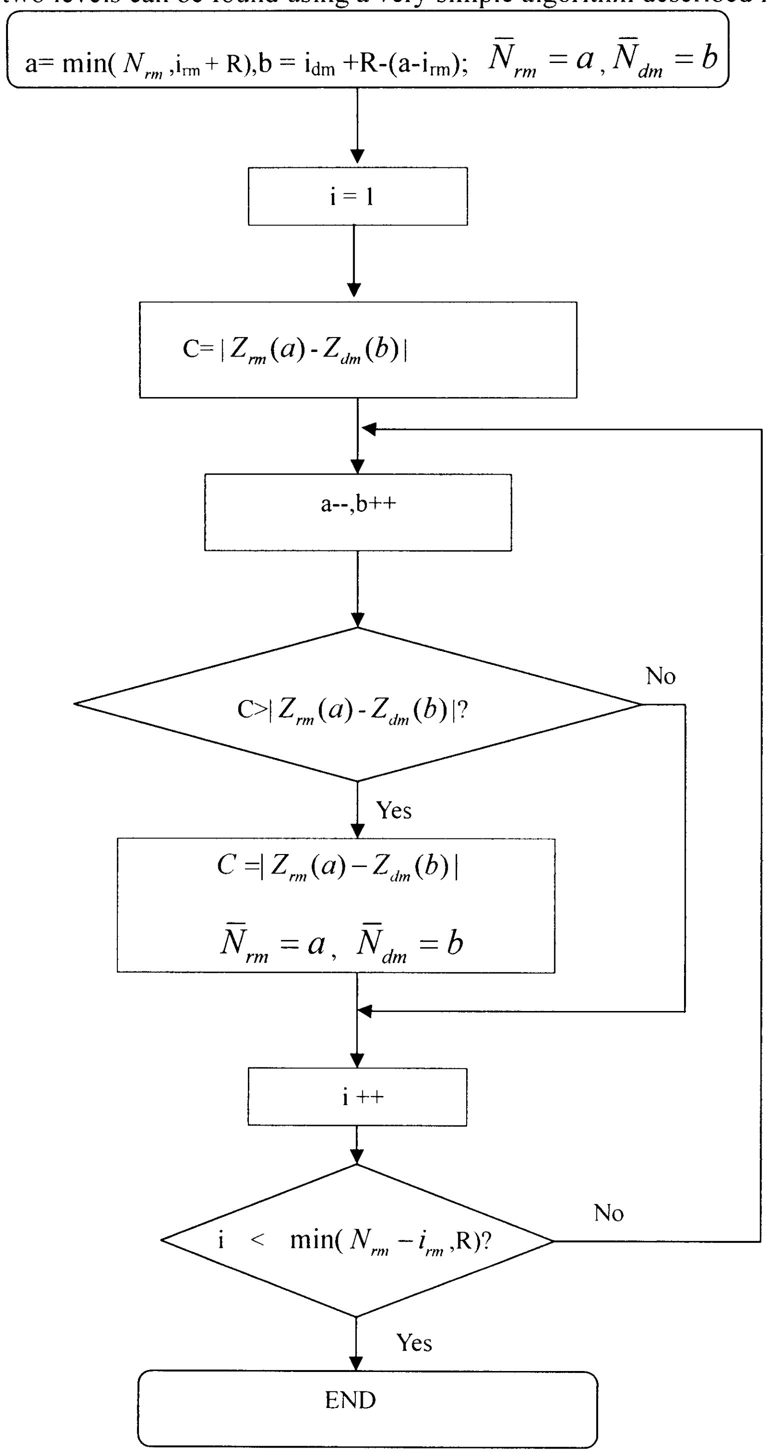


Fig. 10 algorithm to find the optimum fill-up-to level when there is a deficit

3.5 Ideal fill-up-to levels of selected product families

The following table shows the parameters of the selected product families:

Product Family	λ_{rl}	λ_{rm}	λ_{dm}	h_{rm}	h_{dm}	p_{rm}	p_{dm}	c_{rm}	c_{dm}
α	259	389	78	14	16	548	652	255	40
β	82	73	43	20	21	808	826	233	40
γ	86	74	61	16	17	651	698	374	40
δ	110	25	12	48	29	1902	1167	530	40
ε	196	16	43	15	20	589	818	305	40
ζ	43	2	75	13	32	500	1284	551	40

Table 2 parameter used during the simulation

From equation (2) and (3), we can the following fill-up-to level:

Product family	$\mathbf{N_{rm}}$	$\mathbf{N_{dm}}$
α	423	96
β	89	56
γ	88	77
δ	35	19
ε	23	56
ζ	0	92

Table 3 optimum fill-up-to level of the two options

We can see that the returns of product families α, β and γ are not enough to satisfy the demand of remanufactured products and service parts, therefore most of the time we need to allocate the scarce return resource. In contrast, the returns of product families δ and ε are far more than the demand, so we need to scrap the excess promptly to save the inventory holding cost. The remanufacture profit from product family ζ is negative, so all the returns should go to the dismantling channel.

3.6 Summary

The decision support system can be summarized as follows:

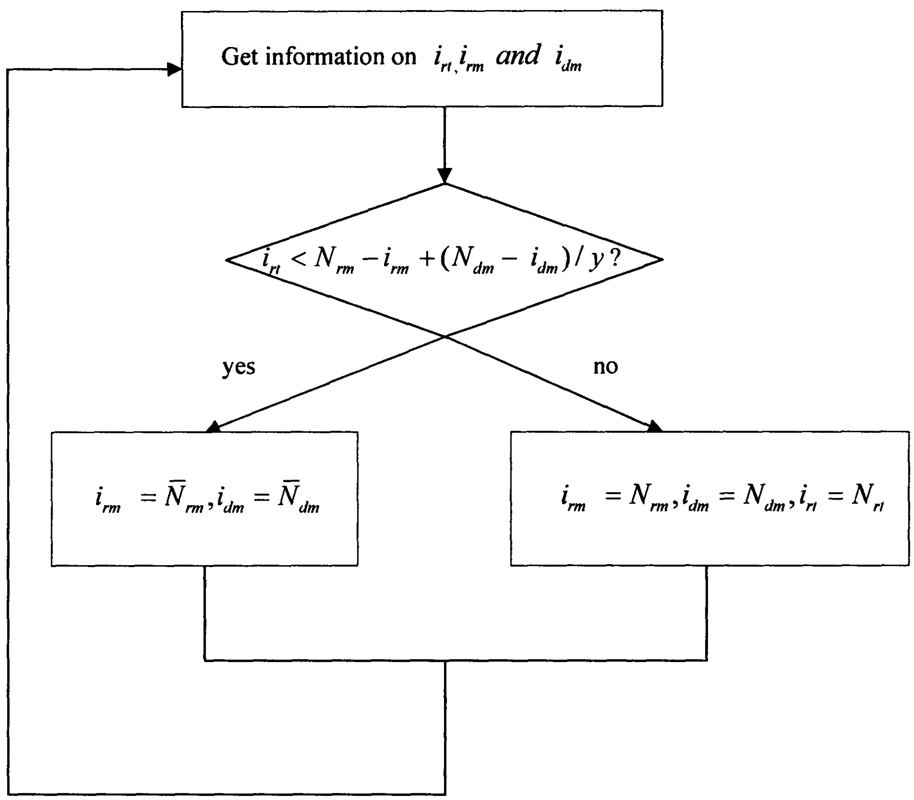


Fig. 11 decision support system

i is the initial inventory level, N is the ideal inventory level and $\bar{N}$ is the optimum allocated inventory level when the return is not enough to fill the gap between the ideal level and the initial inventory level.

A stochastic dynamic programming method is presented. However, its prohibitive amount of calculation makes it unrealistic for real life. A heuristic approximation using news vendor theorem and simulation is then presented. An ideal fill-up-to level is found using newsvendor theorem. When return volume is higher than the gap between the ideal inventory level and current inventory level, the two options and the reserve are filled up to the optimum level, and the rest is scrapped. When the return volume is not enough to fill the gap, the two options are filled such that the marginal profits from the fill-up-to-level of the two options are approximately the same.

The simulation result will be presented in the next chapter.

Chapter 4 Simulation Result and Discussion

4.1 Flow Chart of Simulation

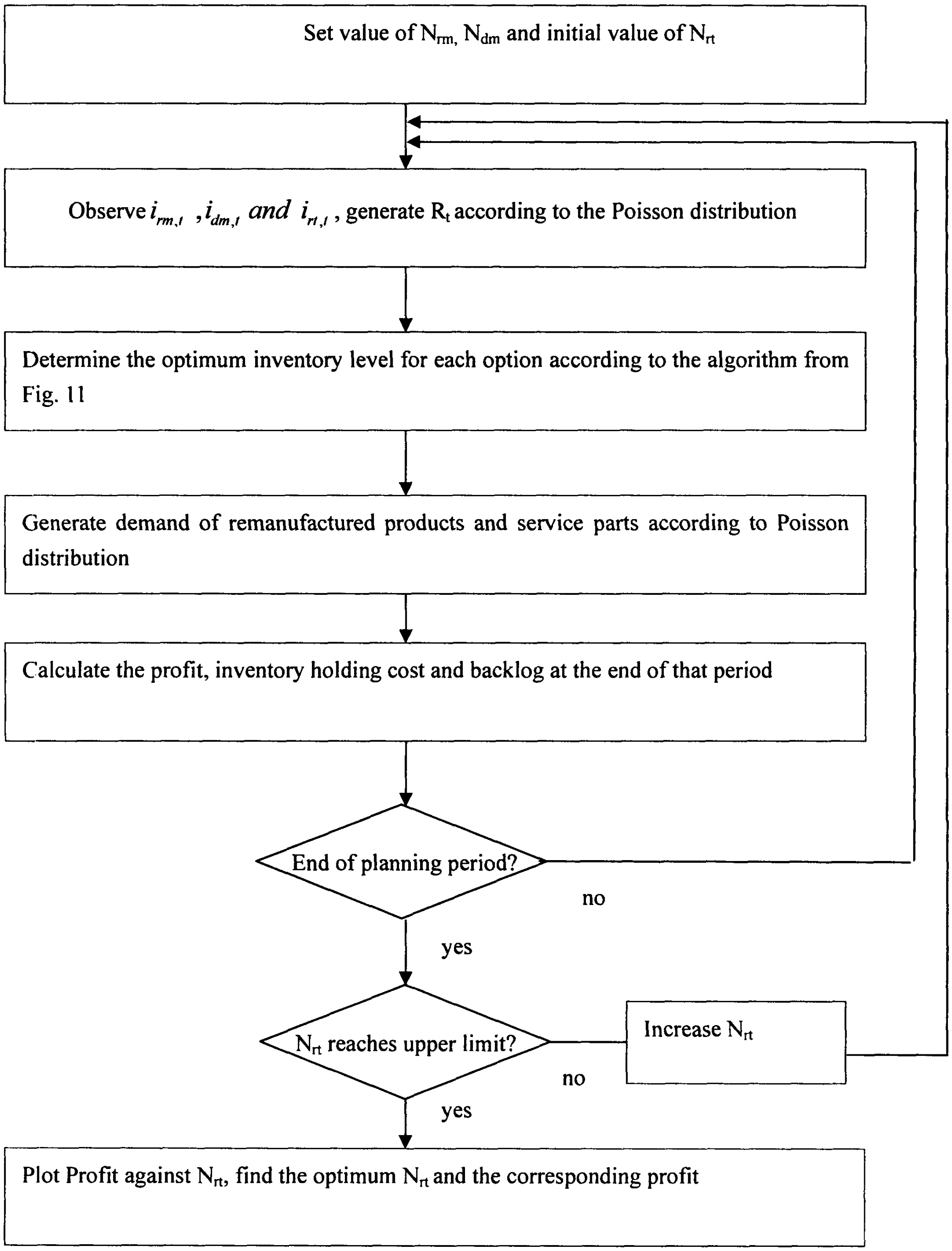
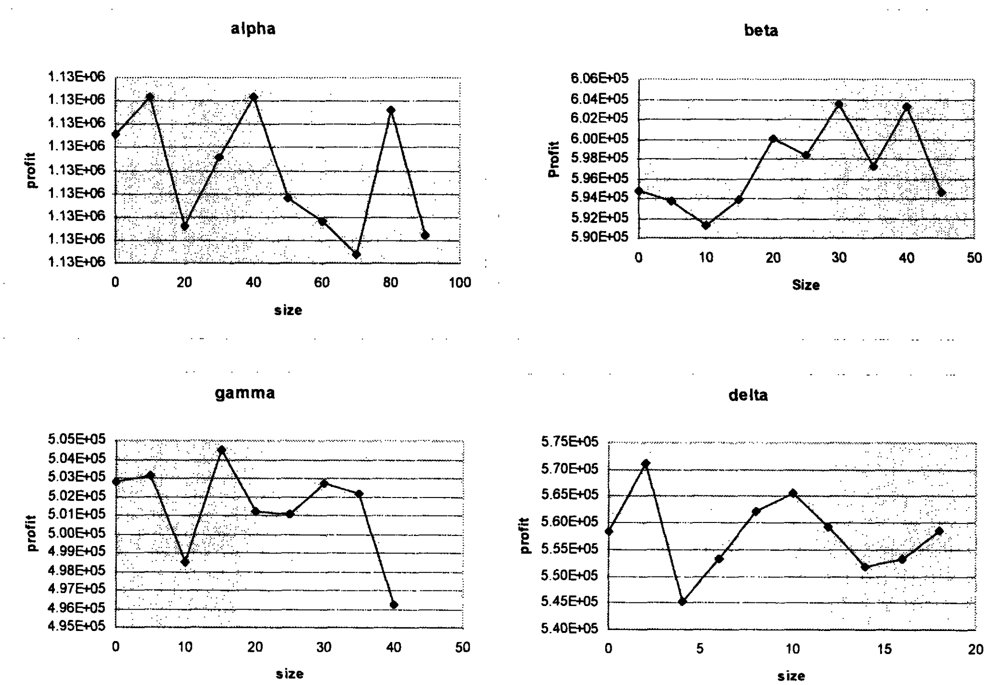


Fig. 12 flow chart of simulation

The simulation is done by a Matlab Program. Fig.12 depicts the flow of simulation. N_{rm} and N_{dm} are the optimal fill-up-to levels of each option, $i_{rm,t}$,$i_{dm,t}$ *and* $i_{rt,t}$ are the initial inventory levels of remanufactured products, dismantled service parts and return. R_t is the random return each month. N_{rt} is the size of the return reserve. At the beginning of each month, the inventory is filled up to the optimal level calculated from methods of Chapter 3; then random return, random demand from remanufacturing products and service parts are taken into account. At the end of each month, the profit is calculated. Each simulation is run 20 times and an average is found to serve as the expected profit. Finally, the profit is plotted against reserve size to find the optimum size of return reserve.

4.2 Optimal Reserve size N_{rt}



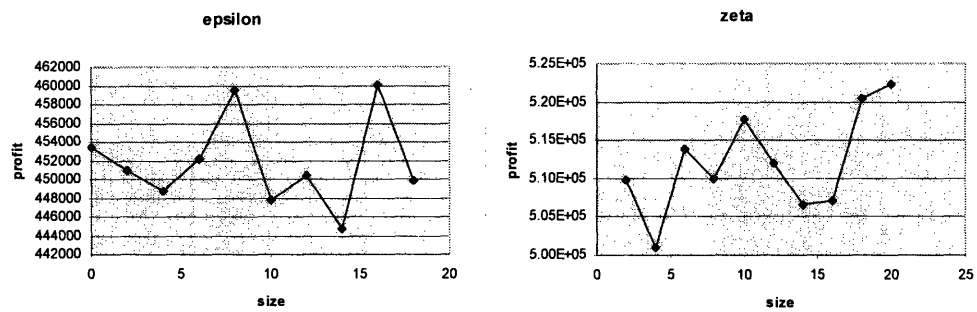
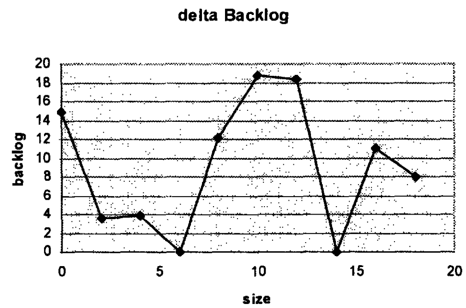


Fig. 13 diagrams of expected profit against reserve size

As can be observed from the above graphs, the profit of all the product families fluctuates in a small range without an obvious trend. The fluctuation can be explained by the random nature of the returns and demand generated. It shows that N_{rt} has no significant impact on the profit of selected product families. This phenomenon can be explained as follows:

(1) When λ_{rt} is significantly smaller than $\lambda_{rm}+\lambda_{dm}$, e.g. α, β and γ, there is hardly any scrap. Therefore the size of N_{rt} is irrelevant.

(2) When λ_{rt} is significantly larger than $\lambda_{rm}+\lambda_{dm}$, e.g. δ and ε, the incoming monthly returns should be more than enough to satisfy the demand of that month, the probability of the units in the reserve being used in the following months is extremely small. The backlog of these two product families occurs because the demand of certain month is higher than the optimum service level. This could not be helped by putting returned units in reserve since they cannot fill the gaps of the current month. Therefore backlog of these two product families does not decrease when the reserve size increases.



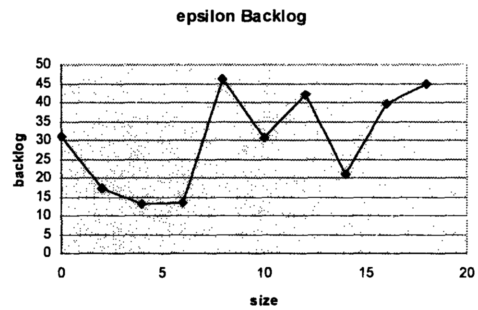


Fig. 14 effect of reserve size on backlog of two product families which have excess

From the simulation result, N_{rt} has no effect on the profit of the chosen product families. Therefore we recommend InFocus to scrap the excess returns immediately for product families δ and ε to save the warehouse space and planning trouble.

4.3 Comparison of expected profit from the proposed policy and current policy

The table and graph below show a comparison of the expected profit from our proposed policy and current policy. Under the current policy, returned projectors are remanufactured most of the time. When the number of returns exceeds the demand of remanufactured projectors, the returns will be stored in the warehouse until the return inventory grows so high that the company thinks they are far more than necessary. Our policy proposed dismantling as another channel to process the returns. A systematic inventory policy was also developed to minimize the inventory holding cost and backlog cost.

Product Family	Current Policy	Proposed Policy
α	$912,270	$1,127,950
β	$490,900	$597,086
γ	$236,600	$501,367
δ	$295,960	$557,908
ε	$49,909	$451,784
ζ	-$3,723	$513,523
Total Difference		**$1,767,702**

Table 4 comparison of profit from current policy and proposed policy

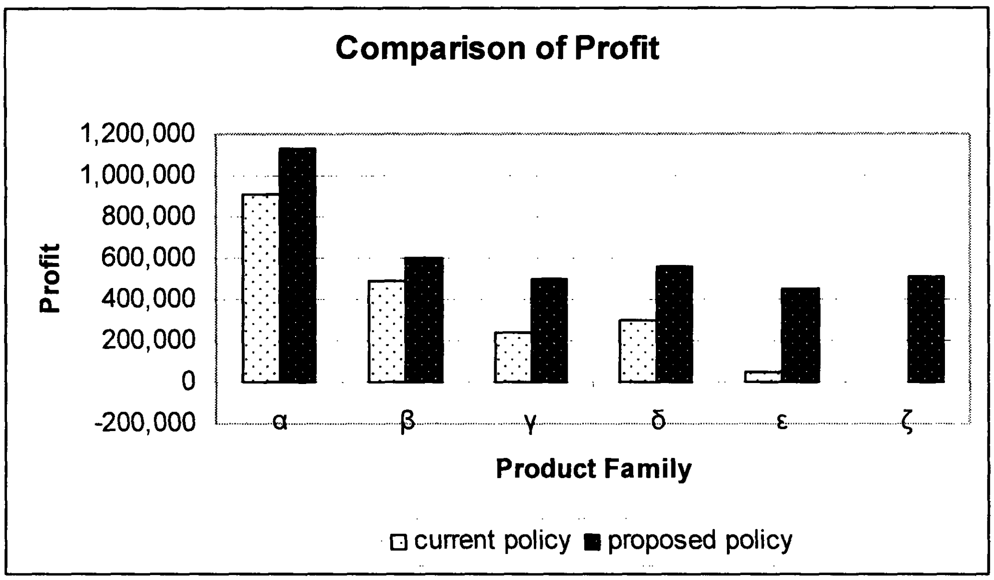


Fig. 15 comparison of profit from current policy and proposed policy

From the diagram above, we can see that the expected profit from the proposed policy is significantly higher than the current policy. For ζ, the profit from remanufacturing is negative. Meanwhile there is a high demand for its costly service part. By abandoning the remanufacturing channel and dismantling all the returned projectors, the profitability is greatly improved. Another great jump occurs in ε family. This is due to the savings of inventory holding cost by scrapping the excess promptly and also the addition of a more profitable channel. The improvements of other product families are mainly because of the higher profit brought by dismantling.

4.4 Summary

From the simulation result, we can see that putting excess return units into the reserve does not have an impact on the backlog of the chosen product families. We recommend InFocus to scrap the excess immediately from product family δ and ε to save the inventory holding cost.

The profit from returned products is also greatly improved because of adding in a more profitable channel and scrapping the excess returns promptly.

Chapter 5 Other Suggestions

5.1 Distribution System for Service Part

5.1.1 current distribution system

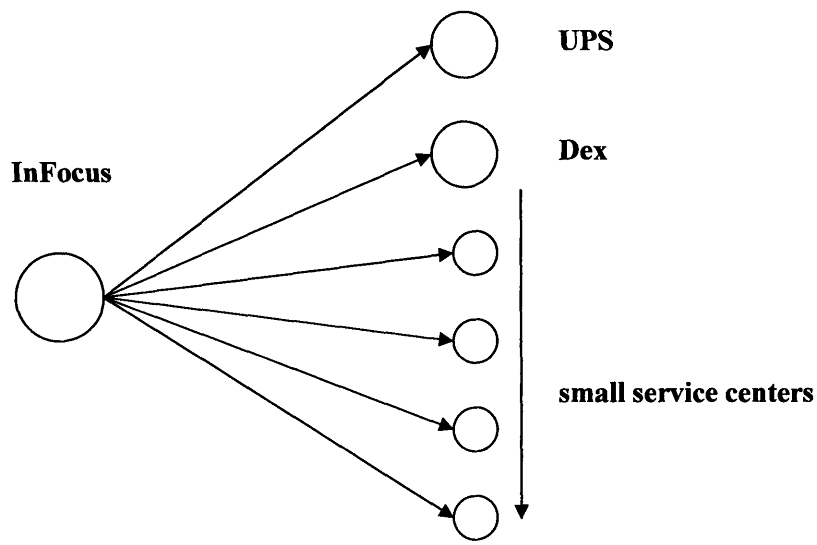


Fig. 16 current distribution system of InFocus

InFocus employs a buy-and-sell model for its service part. The service partners pay the full price of the service part when they purchase it. They are not able to return the service part if it becomes excess or obsolete. InFocus compensates its service partners for risk of excess and obsolete part by paying them an extra 5% of the price for each part that has been used in warranty repair. We can see that although this policy makes some financial compensation to the service partners, it does not encourage them to hold inventories.

As mentioned before, InFocus suffers a great loss when there is a backlog of service parts, because InFocus has to give the customer a new piece if it is not able to repair the projector within twelve days. Therefore InFocus should develop a policy which can minimize the probability of service part backlogs.

5.1.2 Proposed distribution channel

InFocus should set up a centralized information system which stores the real time inventory level at all the service centers. According to the observed demand and sales data of that region, InFocus advises the service center its fill-up-to level. If the service part is not used after certain amount of time, InFocus takes it back. If there is a shortage in one of the service centers, transshipment from the nearest possible spot is possible since the inventory level of all the service centers is visible to everyone else in the system. The proposed system is depicted in Fig. 17.

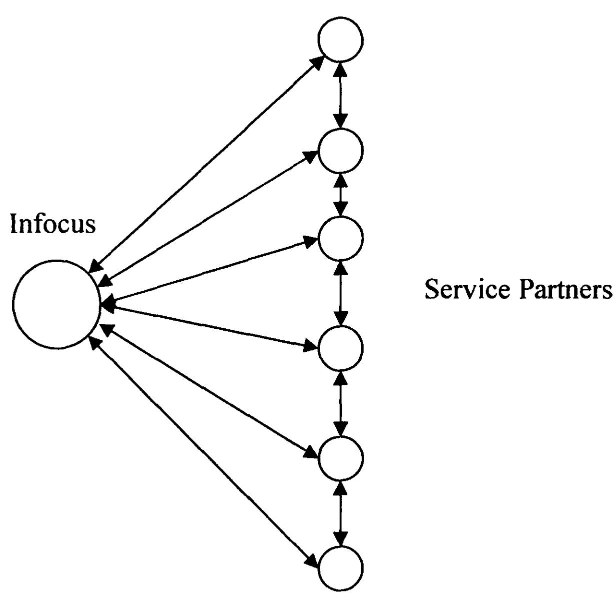


Fig. 17 proposed distribution channel

There are four advantages with this system:

(1) InFocus can react to the demand of the customers directly instead of the orders from the service center. After removing the layer of service center, the bull

whip effect is avoided. A linear regression analysis of my teammate[12] shows that the demand of service part is strongly correlated to the sales of projectors. Therefore InFocus should have a better idea of the parts demand than the service partners because they put their order only according to experience. Therefore the proposed method should increase the accuracy of the demand forecast.

(2) Because of the take back policy, the service centers are willing to hold inventories, thus reduce the risk of stock out.

(3) The amount of safety stock can be reduced because transshipment is possible. Therefore the inventory holding cost will be reduced.

(4) InFocus can save the 5% “excess and obsolete” charge paid to the service partners.

5.2 Summary

With the proposed distribution strategy, the risk of the service part backlog as well as the safety stock level will be reduced.

Chapter 6 Conclusion and Future Study

6.1 Conclusion

From the data available from InFocus, we realize that the current way used by InFocus cannot achieve the maximum possible profit from returned products. We recommend InFocus integrate another channel: dismantling returned products to service parts into the planning system. This system can:

(1) maximize the profit from returned products

(2) decrease the safety stock of service part inventory and subsequently reduce the inventory holding cost.

The simulation result shows that for product families whose average return is greater than average demand of remanufactured product and service part, holding excess returns of each month as reserve does not have significant impact on the backlog of the following month. Therefore we recommend InFocus to scrap whatever is left to save the warehouse space and planning trouble.

6.2 Future Study

There might be other possible ways to process the returned product. For example, InFocus could sell the projectors as is for a very low price. The model developed in this paper can be extended to processing returns with N options. When the number of options is more than two, the allocation rule which is developed in section 3.3.2 requires too many computations. A simplified allocation rule is needed. One candidate is linear allocation rule.

When the number of returns is not enough, the deficit is distributed to the individual options according to a fixed proportion q_i.

$$\overline{N}_i = N_i - q_i \times (\sum_1^n N_i - \sum_1^n i_i - R)$$

A proper algorithm needs to be developed in order to maximize the expected profit from this allocation rule.

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