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PERFORMANCE EVALUATION OF A PRODUCT RECOVERY SYSTEM

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ABSTRACT

We present a Markov model to evaluate a product recovery system with stochastic variability stemming from customer demand, recovery rate and disposal rate. The model is composed of the states that denote the number of products in inventory, the transition probabilities between states and the costs associated with the transitions. Using this model, we can calculate the total expected cost per period. An example is considered to illustrate the implementation of the methodology.

INTRODUCTION

The escalating growth in consumer waste in recent years has started to threaten the environment. Product recovery is mainly driven by the escalating deterioration of the environment and aims to minimize the amount of waste sent to landfills by recovering materials and parts from old or outdated products by means of recycling and remanufacturing. Product recovery includes collection, disassembly, cleaning, sorting, repairing and reconditioning broken components, reassembling and testing [1], [5]. Here we focus on product recovery in a remanufacturing system under stochastic variability.

In this paper, we present an analytical approach to evaluate a product recovery system with stochastic variability stemming from customer demand, recovery rate and disposal rate. The system is formulated using a discrete time Markov chain. It is composed of the states that denote the number of products in inventory, the transition probabilities between states and the costs associated with the transitions. In this approach, we consider two types of inventories: one is the actual product inventory in a factory whereas the other is the virtual inventory that is still in use by the customers. We also consider disposal and return. Using the Markov analysis, we calculate the total expected cost per period. An example is considered to illustrate the implementation of the methodology.

LITERATURE REVIEW

We present a brief review of the literature in the areas of product recovery modeling of remanufacturing systems with stochastic variability.

Gungor and Gupta [4] and Moyer and Gupta [8] reviewed the literature in the area of environmentally

conscious manufacturing and product recovery. Minner [7] pointed out that there are the two well-known streams in product recovery research area. One is stochastic inventory control (SIC) and the other is material requirement planning (MRP). In this paper, we restrict ourselves to SIC.

Cohen et al. [2] developed the product recovery model in which the collected products are directly used. Inderfurth [6] discussed effect of non-zero leadtimes on product recovery. Muckstadt and Isaac [9] dealt with a model for a remanufacturing system with non-zero leadtimes and a control policy with the traditional (Q, r) rule. Van der Laan and Salomon [11] suggested push and pull strategies for the remanufacturing system. Guide and Gupta [3] presented a queueing model to study a remanufacturing system. Nakashima *et al.*[10] considered a product recovery system with a single class product life cycle.

FORMULATION

We formulate a product recovery system with stochastic variability using a discrete time Markov model. Consider a single process that produces a single item product. The finished products are stocked in the factory and are used to fulfill customer demand. Traditional inventory models focus only on the inventory in the factory. In a remanufacturing system, however, we need to account for the outdated products that are collected from the customers as well. That is, a remanufacturing producer has to consider the products in use as the part of the future inventory. Consequently, we treat the products currently in use by the customers as virtual inventory. It is therefore important to manage the virtual inventory until it is collected and used in remanufacturing in addition to controlling the inventory on hand.

Figure 1 shows the product recovery system in a remanufacturing environment. Remanufacturing preserves the product's identity and performs the required disassembly and refurbishing operations to bring the product to a desired level of quality at some remanufacturing cost. On the other hand, normal manufacturing produces the products by using new resources. The number of products produced using normal manufacturing in period t is denoted by $P(t)$. Products are produced via normal manufacturing and/or via remanufacturing using the parts taken back from the customers. All production begins at the start of a period and all products are completed by the end of the period.

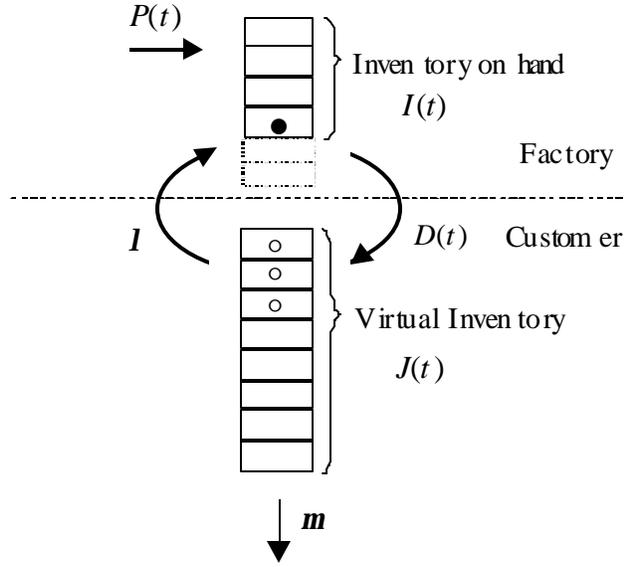


Figure 1: A Product Recovery System

All the products bought by customers are new. We assume that the number of finished products and that bought by customers are $I(t)$ and $J(t)$, respectively. If a backlog occurs, $I(t)$ takes on a negative value. Demands in successive periods, $D(t)$, are independent random variables with known identical distributions and densities. Products are recovered at the rate of I and disposed of at the rate of m . It is assumed that $I + m \leq 1$.

The state of the system is denoted by

$$s(t) = (I(t), J(t)). \quad (1)$$

The transition of the each inventory is given by

$$I(t+1) = I(t) + P(t) + IJ(t) - D(t) \quad (2)$$

$$\text{and } J(t+1) = J(t) - IJ(t) - mJ(t) + D(t). \quad (3)$$

It is assumed that $P(t) = \max\{0, I_{max} - I(t) - IJ(t)\}$.

The transition probability is defined as

$$P_{s(t)s(t+1)} = \begin{cases} \Pr\{D(t) = d\} & \text{if } S(t+1) = (I(t) + P(t) + IJ(t) - d, \\ & J(t) - IJ(t) - mJ(t) + d), \\ 0 & \text{otherwise.} \end{cases} \quad (4)$$

Total cost per period, $Q(t)$ is given by

$$Q(t) = cP(t) + qIJ(t) + h[I(t)]^+ + b[-I(t)]^+ + dmJ(t) \quad (5)$$

where the parameters are as follows:

c : the normal manufacturing cost of a new product

q : the remanufacturing cost of a product

h : the holding cost per unit

b : the backlog cost per unit

d : the out-of-date cost per unit

We can calculate the stationary distribution of the system by solving a set of linear equations of the steady state distribution. We can then obtain the total expected cost per period using equation (5).

NUMERICAL RESULTS

In this section, we investigate the properties of the product recovery system using an example. It is supposed that $\Pr\{D(t)=2\} = \Pr\{D(t)=3\} = 0.5$ and $I_{max}=10$. The cost parameters are set as follows:

$$c=1, \quad h=1, \quad b=10, \quad \text{and} \quad d=10.$$

Figure 2 shows the behaviour of the expected cost per period with $I=0.2$ and $m=0.5$ when remanufacturing cost, q is varied. The expected cost of the system increases linearly under constant remanufacturing and disposal rate.

Next, we investigate the effect of the out-of-date cost and the remanufacturing cost. Table 1 shows the numerical results with $I=0.2$ and $m=0.5$.

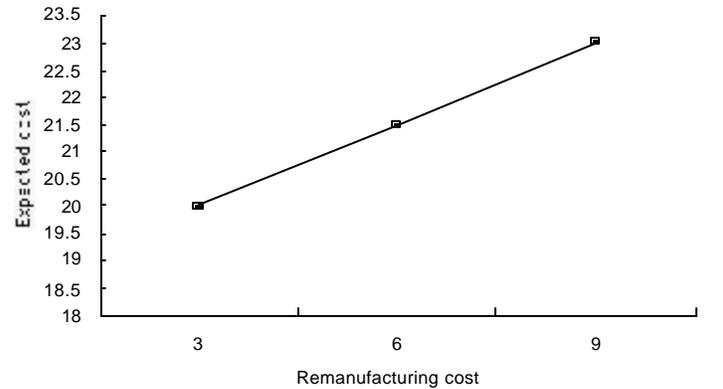


Figure 2: Optimal recovery rate

Table 1: The expected costs with varying cost parameters

		Remanufacturing cost		
		3	6	9
Out-of-date cost	10	19.99	21.5	23
	20	32.5	34	35.5
	30	44.5	46.5	47.8

Table 2 shows the result of performing analysis of variance on the data in Table 1. We can determine the effect the cost

parameters on the expected cost under the fixed remanufacturing and discard rates.

Table 2: Analysis of variance

Factor	S	f	V	F ₀
out-of-date cost	920.3573556	2	460.1786778	22254.74**
remanufacturing cost	14.47402222	2	7.237011111	349.99**
Error	0.082711111	4	0.020677778	
Sum	934.9140889	8		

$$F(0.05,2,4)=6.944$$

We find that the out-of-date cost is a more important parameter of the product recovery system under constant remanufacturing and discarded rate.

PROPERTY OF A SPECIAL CASE

We can determine the performance property of a special case in the product recovery system. Let $sa(t) = I(t) + J(t)$. By using this and equations (2) and (3), we have the following:

$$\begin{aligned} sa(t+1) &= I(t+1) + J(t+1) = I(t) + J(t) + P(t) - \mathbf{m}J(t) \\ &= sa(t) + P(t) - \mathbf{m}J(t) \end{aligned} \quad (6)$$

We can rewrite $P(t) - \mathbf{m}J(t)$ as $\max\{-\mathbf{m}J(t), I_{\max} - I(t) - (1 + \mathbf{m})J(t)\}$. If $1 + \mathbf{m} = 1$, we obtain the following:

$$\begin{aligned} sa(t+1) &= sa(t) + \max\{-\mathbf{m}J(t), I_{\max} - sa(t)\} \\ &= \max\{sa(t) - \mathbf{m}J(t), I_{\max}\} \end{aligned} \quad (7)$$

CONCLUSIONS

We proposed the new analytical approach for evaluating the product recovery system with stochastic variability. The system formulated using a discrete time Markov chain model. We calculated the total expected cost per period. Numerical results showed the properties of the system. Finally, we derived the property of a special case of the product recovery system.

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