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Kenichi Nakashima
*Osaka Institute of Technology*

Surendra M. Gupta
*Northeastern University*

Laboratory for Responsible Manufacturing

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## Contact Information

Dr. Surendra M. Gupta, P.E.
Professor of Mechanical and Industrial Engineering and
Director of Laboratory for Responsible Manufacturing
334 SN, Department of MIE
Northeastern University
360 Huntington Avenue
Boston, MA 02115, U.S.A.

(617)-373-4846   *Phone*
(617)-373-2921   *Fax*
gupta@neu.edu   *e-mail address*

http://www.coe.neu.edu/~smgupta/   *Home Page*

# ANALYSIS OF REMANUFACTURING POLICY WITH CONSIDERATION FOR RETURNED PRODUCTS QUALITY

**Kenichi Nakashima**,Osaka Institute of Technology, Osaka, Japan, +81(6)-6954-4788, nakasima@dim.oit.ac.jp
**Surendra M. Gupta**, Northeastern University, Boston, MA 02115, (617)-373-4846, gupta@neu.edu

## ABSTRACT

This paper deals with the product acquisition control problem and considers returned product quality with two types of classes. The system includes the flow of the product returns from customers to the factory as well as the forward flow of the sales. We formulate the acquisition problem together with product quality and stochastic demand using the Markov decision process. A numerical example is given to show the implementation of the methodology.

## INTRODUCTION

From a macro-level perspective, value propositions for an organization or the industry in which the organization operates, including reverse supply chain strategies (reuse, repair, refurbish, remanufacture, retrieve parts or cannibalize components, recycle, scrap, and redesign returned products) and effective operations of reverse supply chains (handle returns, sort returns by value and ease of remanufacture), may augment organizational competitiveness. It is widely believed that the continuous growth in consumer waste in recent years has seriously threatened the environment. According to the US Environmental Protection Agency (EPA), in 1990, the amount of waste generated in the USA reached a whopping 196 million tons, up from 88 million tons in 1960s [13]. Wann [16] reported that an average American consumes 20 tons of materials every year. To ease such burden on the environment, many countries are contemplating regulations that force manufacturers to take back used products from consumers so that the components and materials retrieved from the products may be reused and/or recycled. For example, Germany has passed a regulation that requires companies to remanufacture products until the product is obsolete. Japan has passed similar legislation requiring design and assembly methodologies that facilitate recycling of durable goods [5]. Comparable regulations are also being considered in the United States. The two legislative acts that are expected to pass within the next few years in the U.S. are the Automotive Waste Management Act (which will enforce the complete reclamation of automobiles) and Polymers and Plastic Control Act (which will enforce the complete reclamation of polymers and plastics) [4].

In our research, we take a closed-loop supply chain perspective, rather than just a forward supply chain perspective, of a company's value chain. In such a closed-loop system, the reverse supply chain portion can create synergies with elements of the forward supply chain to form an integrated value chain environment. In this paper, we examine the optimal product ordering policy with consideration for the returned product quality. The system includes the flow of the product returns from customers to the factory as well as the forward flow of sales. We formulate this control problem together with product quality and stochastic demand using the Markov Decision Process [15]. We consider a single remanufacturing production process that produces a single item product. The finished products are stocked in the factory and are used to fulfill customer demand from outside. The product is produced

using a returned product that belongs to either class 1 or class 2 quality. Each class has different acquisition cost, different remanufacturing cost and different delivery lead time. Therefore, the decision maker has to control two kinds of inventories for the retuned products.

The system is composed of the state that denotes the inventory levels of two quality classes of the returned products, the transition probabilities between states under a policy and the costs associated with the transitions. In this model, we control the numbers of each type of returned products: one is of high quality (class 1) while the other is of lower quality (class 2). We also consider the priorities for the use of the two types of products. Using Markov decision model [12], we can obtain the optimal ordering policy that minimizes the expected average cost per period. A numerical example is considered to illustrate the property of the control policy.

## LITERATURE REVIEW

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

Brennan et al. [1], Gungor and Gupta [5], Ilgin and Gupta [6] and Moyer and Gupta [9] reviewed the literature in the area of environmentally conscious manufacturing and product recovery. Minner [8] 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 requirements planning (MRP). In this paper, we confine ourselves to SIC.

Cohen et al. [2] developed the product recovery model in which the collected products are directly used. Inderfurth [7] discussed effect of non-zero leadtimes on product recovery. Muckstadt and Isaac [10] 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 [14] 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.[11] considered a product recovery system with a single class product life cycle. In earlier research, existing models of reverse supply chains in the literature assume a constant quality of returned product. Moreover, product returns were assumed to have constant lead-times and constant cost for remanufacturing, which are not meaningful in industry settings. Addressing stochastic variability of quality of product returns can allow companies to realize additional profitability.

## MODEL DESCRIPTION

We formulate a product aquisition system with stochastic variability using a discrete time Markov decision model. We 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. The product is produced using a returned product that belongs to either class 1 or class 2 quality. Each class has different acquisition cost, different remanufacturing cost and different delivery lead time. Therefore, the decision maker has to control two kinds of inventories for the retuned products.

Figure 1 shows the product aquisition 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. The number of products

produced using normal manufacturing in period $t$ is denoted by $P(t)$. All production begins at the start of a period and all products are completed by the end of the period. Product demand is independent and identically distributed (i.i.d) with mean $D$. The process produces the products using the recovered products that are supplied by two different suppliers with each own acquision cost. It is assumed that the leadtime of the part delivery is one. We use the following notations.

$I_n(t)$ :inventory of class $n$ ($n$=1,2) at the beginning of period $t$

$O_n(t)$ :ordering quantity of class $n$ at the beginning of period $t$

$k_n$ :action as ordering part of class n $(k_n = O_n(t))$

$D(t)$ :demand in period $t$

$a_n$ :acquisition cost per unit part for supplier $n$

$h_n$ :holding cost per unit part supplied by supplier $n$

$c_n$ :remanufacturing cost using part class $n$

$P_n(t)$ :production quantity using pert class $n$ in period $t$

$C_b$ :backlog cost

$L_1$ and $L_2$ : the respective lead times for two classes of used products

$p$ : the selling price of final products recovered (same for either quality class),

The state of the system is denoted by

$$s(t) = (I_1(t), I_2(t))$$

And, each inventory has maximum number $I_{1max}$ and $I_{2max}$. For the number of remanufacturing product: $P_n(t)$, the two resulting remanufacturing policies are provide as follows.

Class 1 Priority Policy:
$$P_1(t) = \min\{D(t), I_1(t)\}, \ P_2(t) = \max\{0, D(t) - I_1(t)\}$$

Class 2 Priority Policy:
$$P_2(t) = \min\{D(t), I_2(t)\}, \ P_1(t) = \max\{0, D(t) - I_2(t)\}$$

If Class 1 parts used prior to class 2
$$P_1(t) = \min\{D(t), [I_1(t)]^+\}, \ P_2(t) = \max\{0, D(t) - [I_1(t)]^+, I_2(t)\},$$
where $[x]^+ = \max(0,x)$

If Class 2 parts used prior to class 1
$$P_1(t) = \max\{0, D(t) - [I_2(t)]^+, I_1(t)\}, \ P_2(t) = \min\{D(t), [I_2(t)]^+\}$$

In regards to the action space, the numbers of orders for supplies are:
$$I_1(t+1) = I_1(t) + O_1(t-1) - P_1(t), \ I_2(t+1) = I_2(t) + O_2(t-1) - P_2(t)$$

Action spaces are shown by
$$K_1(s(t)) = \{0, \cdots, I_{max1} - I_1 - O_1(t-1)\} \text{ and } K_2(s(t)) = \{0, \cdots, I_{max2} - I_2 - O_2(t-1)\}.$$

Each action means that
$$k_1 = O_1(t), k_2 = O_2(t).$$

Transition Probability is

$$P_{s(n),s(n+1)}(k_1,k_2) =$$

$$\begin{cases} \Pr\{D(t)=d\}, & s(t+1) = \{I_1(t)+k_1-P_1(t), I_2(t)+k_2-P_2(t)\} \\ \text{Otherwise} & ,0. \end{cases}$$

The expected reward is given by

$$r_{s(t)}(k) = pD(t) - \sum_{n=1}^{2}(k_n a_n + c_n P_n(t) + h_n I_n(t))$$

It is formulated as an average Markov decision process of time to maximum average profit, g:

$$g + v_i = \max_{k_1 \in K_1(i), k_2 \in K_2(i)} \left\{ r_i(k_1,k_2) + \sum_{j \in S} p_{ij}(k_1,k_2)v_i \right\}$$

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 the above equation.
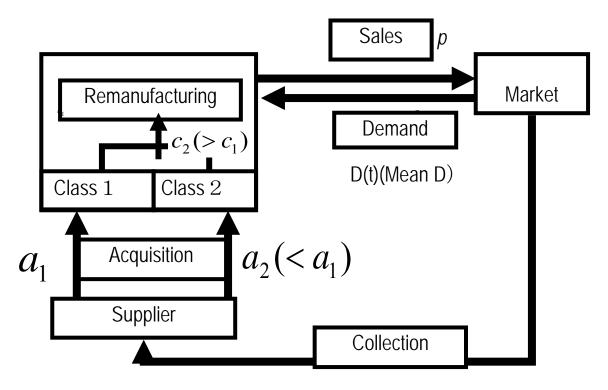


**Fig.1: Remanufacturing Model**

## NUMERICAL RESULTS

In this section, we obtain the optimal ordering policy for a product acquisition system under stochastic demand.

The distribution of the demand is given by

$$\Pr\{D_n = D - \frac{1}{2}Q + j\} = \binom{Q}{j}\left(\frac{1}{2}\right)^Q, (0 \le j \le Q)$$

where $D=3$ and $Q$ is an even number and the variance($\sigma^2$) is $Q/4$. We can obtain the expected average reward per period under the steady state of the system.

$I_{1max} = 5$; $I_{1min} = 0$; $I_{2max} = 5$; $I_{2min} = 0$; average $D = 2.0$, and decentralization = 1.0.

The cost parameters are: $(c_1, c_2) = (2, 4)$; $(a_1, a_2) = (2, 1)$; $(h_1, h_2) = (1, 1)$. Also, $k_2$ is assumed as fixed ordering system and considered as $I_{max}$, average profit computes to be 17.097. The optimal purchase policy for $(c_1 = 2, c_2 = 4)$ is provided in Table 1.

### Table 1: Optimal Control Policy

| Average demand 2 | decentralization 1.0 | $g = 17.097$ | |
|---|---|---|---|
| $(I_1, I_2)$ | $k_1$ | $(I_1, I_2)$ | $k_1$ |
| (0,0) | 5 | (3,0) | 2 |
| (0,1) | 5 | (3,1) | 2 |
| (0,2) | 4 | (3,2) | 2 |
| (0,3) | 1 | (3,3) | 2 |
| (0,4) | 1 | (3,4) | 0 |
| (0,5) | 1 | (3,5) | 2 |
| (1,0) | 4 | (4,0) | 0 |
| (1,1) | 4 | (4,1) | 0 |
| (1,2) | 1 | (4,2) | 0 |
| (1,3) | 1 | (4,3) | 0 |
| (1,4) | 1 | (4,4) | 0 |
| (1,5) | 1 | (4,5) | 0 |
| (2,0) | 3 | (5,0) | 0 |
| (2,1) | 0 | (5,1) | 0 |
| (2,2) | 3 | (5,2) | 0 |
| (2,3) | 3 | (5,3) | 0 |
| (2,4) | 3 | (5,4) | 0 |
| (2,5) | 3 | (5,5) | 0 |

## CONCLUSION

We formulated the acquisition problem together with two types of product qualities and stochastic demand using the Markov Decision Process in a remanufacturing system. Numerical results illustrated

the optimal ordering policy that maximized the expected average profit per period for the product acquisition system with different kinds of quality classes.

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