



A stochastic inventory model with product recovery

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ABSTRACT

The article deals with a stochastic inventory model, considering two types of markets: one for good quality and another for average quality of products. Recovery rates of used products from customers of two different markets are random variables and recovery items are stored in two store warehouses. Warehouse 1 stores the products collected from the customers of market 1 and warehouse 2 keeps the products collected from the customers of market 2. At the end of each generation (cycle period), recovery items of store houses are screened and then they are separated into three types of items. Partly deteriorated items, components of raw material from some of the recoverable products and the disposal items are stored in warehouse 1. Another two types of items, components of raw material from some of the recoverable products and totally disposable items, are stored in warehouse 2. In next generation, components of production lot are combination of recovery and new components. The partly damaged products are re-manufactured along with the defective items during regular production and these are sold in market 2. The philosophy of our model is that, at the beginning of one cycle, production lot-size is combination of new and recovered components and also defective products are re-manufactured with the recovery of partly damaged products from previous generation. The problem is to coordinate optimal production lot size so that the total expected profit in the m th generation of the model is maximized.

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1. Introduction

Nowadays, product recovery is drawing attention due to the increased environmental concerns, government legislations, awareness of natural resource limitation in worldwide and also economical purpose. The objective of product recovery is to recover as much of the economic (and ecological) value as reasonably possible, thereby reducing the ultimate quantities of waste.

A deterministic inventory model dealing with recovery was firstly proposed by Schrady [24]. He analyzed an inventory situation with constant demand and return rates when production and recovery are instantaneous. For this policy, he gave expressions for the optimal control parameter values and discussed their dependence on the return rate. Teunter [26] generalizes the EOQ formulae for $(1, R)$ policies from Schrady [24] by including a disposal option for non-serviceable items, and by using different holding cost rates for produced and recovered serviceable items. Richter [22,23] also includes a disposal option (though a sub-optimal constant disposal rate is required) and studies both $(1, R)$ and $(P, 1)$ policies. However, his model differs from that of Schrady

[24] and Teunter [26] in the existence of a collection point, where used items are collected and from there returned in batches. Richter derives a formula for the total average cost, but simple formulae for the optimal lot sizes are not obtained. Nahmias and Rivera [21] studied an EPQ variant of Schrady's [24] model with a finite recovery rate. The production rate was still infinite. They assumed that the recovery rate is larger than the demand rate, and derive lot-sizing formulae for $(1, R)$ policies. Koh et al. [11] generalized the model of Nahmias and Rivera [21] by assuming a limited repair capacity. Dobos and Richter [5] discussed a model in which the disposal option of the returned items is allowed and all the recycling batches follow the production batches. Teunter [27] derived square-root formulae that determine the optimal production and recovery lot-sizes for two classes of policies: $(1, R)$ and $(P, 1)$. Konstantaras and Papachristos [12] extended the work of Teunter [27] by allowing for complete backordering of demand; however, they also consider only the restricted classes of $(1, R)$ and $(P, 1)$ policies. Konstantaras and Papachristos [14,15] improved Teunter's [27] work by developing an exact solution that leads to the optimal number of manufacturing and remanufacturing lots and their corresponding lot sizes for certain parameter classes. Widyadana and Wee [31] developed an integrated solution procedure for each of the two policies of Teunter [27] using algebraic approaches. Choi et al. [1] presented a joint EOQ and EPQ model for an inventory control problem in a closed loop system, in which the demand can be satisfied by purchasing brand-new

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products and re-manufacturing used products. Tang and Teunter [25] studied the economic lot scheduling problem with returns (ELSPR), which had been motivated by a case study from a company operating a hybrid production line to produce both new car parts and remanufacturing car parts. A number of authors developed inventory models and policies related to the recovery product systems such as Krikke et al. [19], Johnson and Wang [9], Ferguson and Toktay [7], Ma et al. [20], Vadde et al. [29,30], Konstantaras et al. [18], Cárdenas-Barrón [2–4], and Hasanov et al. [8], Konstantaras and Papachristos [13], Konstantaras and Skouri [16], Konstantaras [17]. Most recently, Feng and Viswanathan [6], Teunter [28] proposed two new lot-sizing and scheduling policies, with an innovative inter leaving scheme. In both heuristics, a general (P, R) policy is used. In the first heuristic, the lot sizes for manufacturing and remanufacturing are kept identical across all sub cycles. Their proposed heuristic outperformed the best of the Teunter's [27] policies. Kim and Goyal [10] investigated the optimization problem aimed at integrating both the consumption flow and the recovery flow to guarantee the profitability of closed-loop supply chain. They considered the manufacturer's problem and the corresponding objective was to maximize the profit obtainable from the integrated management of lot-streaming.

In our model, we consider a stochastic inventory model with products recovery involving two types of selling markets (M_1 denoting market 1 for perfect quality products and M_2 denoting market 2 for average quality product). The problem is to coordinate optimal production lot size inventory so that the total expected profit in the m th generation of the model is maximized. Here, we study the model for the products where the used products can be recollected from the environment and that recollected products have a market value such that these can be used as raw-material of the products or these can be used after re-manufactured. There are several products such as electronics goods, clothes, and furniture.

The main novelty of our paper is outlined below:

- In the model, we consider two types of markets (market 1 (M_1) for good quality branded items and market 2 (M_2) for average quality items (not branded)).
- The demand rates of markets are random.
- The recovery rate of products from customers of M_1 and M_2 are random variables.
- Product collection processes from the customers of two types of markets are different. From the customers of M_1 , three types of products (partly damaged products, components of raw material from some of the recoverable products and totally disposable items) are collected and from the customers of market 2 (i.e. for average quality items collected people), two quality products (components of raw material from some of the recoverable products and totally disposable items) are collected.
- Also, we develop the model up to n th generation.

2. Fundamental assumptions and notations

2.1. Assumptions

The following assumptions are made to develop the model:

- The model under consideration comprises of two markets, demand of M_1 is for good quality products and demand of M_2 is for average quality products and both demands are random variable.
- Production rate and re manufacturing rate are constant.
- The recovery rate of product from customers of M_1 and M_2 are random variables and are stored in respective two store houses.

- Proportion of defective items during production is constant.
- At the end of each cycle, the recoverable products of store houses are inspected and are separated into three types of products (partly damaged products, components of raw material from some of the recoverable products and totally disposable items) for store house 1 and two types of products (components of raw material from some of the recoverable products and totally disposable items) for store house 2.
- In initial generation, raw material of production are all new and only defective items during production are re-manufactured.
- For the production in the present generation (except initial generation), some new raw materials and a percentage of components of raw materials from both the store houses already recovered from the customers in the previous generation from the source of raw materials in the present generation. The defective items found during regular production in the present generation and partly damaged items which have already been recovered in the previous generation are remanufactured in the present generation.
- Maximum recovered items are a proportion of total selling items.

2.2. Notations

The following notations are used throughout the paper:

Q	production lot size
P	production rate per unit time
P_1	remanufacturing rate per unit time
Q'	recovery components of raw materials lot
Q_1	serviceable items lot for M_1
Q_2	serviceable items lot for M_2
X	demand for the products in M_1 (a random variable)
$f(\cdot)$	probability density function of X
$F(\cdot)$	cumulative density function of X
Y	demand for the products in M_2 (a random variable)
$g(\cdot)$	probability density function of Y
$G(\cdot)$	cumulative density function of Y
λP	production rate of perfect items
$(1 - \lambda)P$	production rate for defective items, where $0 < \lambda < 1$
R	product recovery rate of used products from market 1 (a random variable)
$\xi(\cdot)$	probability density function of R
R_1	product recovery rate of used products from M_2 (a random variable)
$\zeta(\cdot)$	probability density function of R_1
α	fraction of product recover from recovered items of M_1
β	fraction of components from recovered items of M_1 , where $\alpha + \beta \leq 1$
μ	fraction of components from recovered items of M_2 , where $\mu \leq 1$
C_n	new component cost per unit item
C_r	purchasing cost per unit of recovered item from M_1
C'_r	purchasing cost per unit of recovered item from M_2
C_p	production cost per unit item
C'_p	remanufacturing cost per unit item
C_s	inspection cost per unit of recovered item of M_1
C'_s	inspection cost per unit of recovered item of M_2

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