Available online at www.sciencedirect.com
SCIENCE DIRECT®
Computers & Industrial Engineering 46 (2004) 431–441
computers & industrial engineering
www.elsevier.com/locate/dsw

# Lot-sizing for inventory systems with product recovery

Ruud Teunter*

*Faculty of Economics, Econometric Institute, Erasmus University Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands*

**Abstract**

We study inventory systems with product recovery. Recovered items are as-good-as-new and satisfy the same demands as new items. The demand rate and return fraction are deterministic. The relevant costs are those for ordering recovery lots, for ordering production lots, for holding recoverable items in stock, and for holding new/recovered items in stock. We derive simple formulae that determine the optimal lot sizes for the production/procurement of new items and for the recovery of returned items. These formulae are valid for finite and infinite production rates as well as finite and infinite recovery rates, and therefore more general than those in the literature. Moreover, the method of derivation is easy and insightful.


*Keywords:* Product returns; Recovery; Lot sizing; EOQ/EPQ

## 1. Introduction

Product recovery (repair, refurbishing, remanufacturing) is receiving increasing attention. In the past, engagement in recovery activities was often driven by legislation or by associated environmentally friendly image. But nowadays, the main reason for companies to become involved with product recovery is economical. Being active in product recovery reduces the need for virgin materials and thus leads to reduced costs.

Our attention is focused on Original Equipment Manufacturers that are involved with product recovery. These differ from specialized recovery companies in that they also produce/procure new items. Moreover, we assume that recovered items are as-good-as-new and sold on the same market as new items. See Fig. 1.

We address the problem of determining optimal lot sizes for production/procurement and recovery. This problem was first studied by Schrady (1967). He analyzes the problem in the traditional Economic Order Quantity (EOQ) setting: deterministic and continuous demand and return, infinite production

* Tel.: +31-10-4081523; fax: +31-10-4089162.
*E-mail address:* teunter@few.eur.nl (R. Teunter).

0360-8352/$ - see front matter 
doi:10.1016/j.cie.2004.01.006

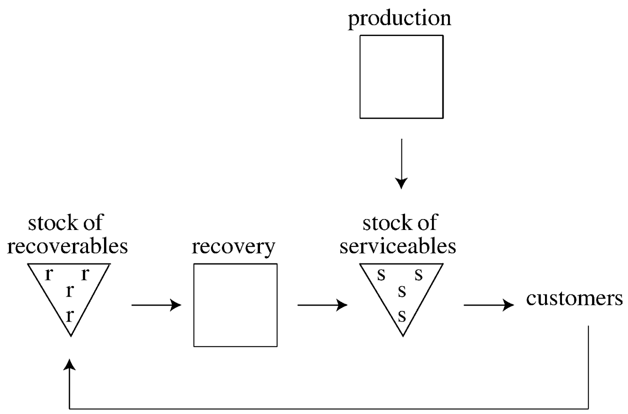


Fig. 1. Inventory system with product recovery.

and recovery rates. The objective is to minimize the total cost per time unit for placing orders and for holding inventory (different holding cost rates for recoverable items and serviceable items). He considers policies that alternate one production lot with a fixed number $R$ of recovery lots ($(1, R)$ policies for short), and derives a pair of simple EOQ formulae.

Mabini, Pintelon, and Gelders (1992) discuss an extension of Schrady's model to a multi-item case.

Teunter (2001) generalizes the EOQ formulae for $(1, R)$ policies from Schrady (1967) by including a disposal option for non-serviceable items, and by using different holding cost rates for produced and recovered serviceable items. Furthermore, he also derives EOQ formulae for policies that alternate a fixed number $P$ of production lots and one recovery lot ($(P, 1)$ policies for short).

Richter (1996a,b) 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 (1967) and Teunter (2001) 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 (1979) study an EPQ variant of Schrady's model with a finite recovery rate. The production rate is still infinite. They assume that the recovery rate is larger than the demand rate, and derive lot-sizing formulae for $(1, R)$ policies.

Koh, Hwang, Sohn, and Ko (2002) also assume that the production rate is infinite and that the recovery rate is finite. Their study is more general that that of Nahmias and Rivera (1979), since they allow the recovery rate to be both smaller and larger than the demand rate, and they consider both $(P, 1)$ and $(1, R)$ policies. For all four combinations, they derive a closed-form expression for the average total cost which can be used to determine the optimal lot sizes numerically. We remark that the $(1, R)$ policies proposed by Koh et al. (2002) differ from those proposed by Nahmias and Rivera (1979) (which are generalizations of Schrady's policies) in the timing of the recovery lots. As is explained in Appendix A, the $(1, R)$ policies in Nahmias and Rivera (1979) are better if the holding cost rate for serviceable items is larger than that for recoverable items, which is usually the case since recovery adds value to an item.

To summarize the above mentioned findings, lot-sizing formulae have been derived for both $(P, 1)$ and $(1, R)$ policies, for infinite and finite recovery rates, but only for infinite production rates. In this