Int. J. Production Economics 129 (2011) 195–203

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

# Short life-cycle deteriorating product remanufacturing in a green supply chain inventory control system

Chun-Jen Chung [a], Hui-Ming Wee [b,*]

[a] Department of Information Application, Aletheia University, Pei-Shih Li , Matou , Tainan 72147, Taiwan, ROC
[b] Department of Industrial Engineering, Chung Yuan Christian University, Chungli 32023, Taiwan, ROC

ARTICLE INFO

*Article history:*
Received 6 May 2009
Accepted 8 September 2010
Available online 25 October 2010

*Keywords:*
Integrated production inventory model
Deteriorating items
Short life-cycle green products
Remanufacturing

ABSTRACT

Due to global warming, environmental consciousness and shortening product life-cycles, more attentions have been paid to ecological protection and resource utilization. Green products and production process designs significantly influence the environment and resource re-usage. The relevant EU regulations, such as WEEE and EuP, have reduced negative effects by controlling the disposals and the resource re-usage. In this study, green product designs and remanufacturing efforts are investigated when we develop an integrated production inventory model with short life-cycles. A numerical example is provided to illustrate the theory. We have shown that new technology evolution, remanufacturing ratios and system's holding costs are critical factors affecting decision making in a green supply chain inventory control system.



## 1. Introduction

In the last decade, due to environmental and ecological responsibility, enterprises are trying to reuse, remanufacture and recycle the used products to reduce the negative impact on environment, especially the manufacturers of the electrical consumer products. Therefore, the reverse manufacturing problem, which is strongly related to all stages of a product development, nowadays is a critical problem to all level of the electrical and computer industry. This paper considers and simplifies the reverse manufacturing problem from an electrical industry. Green product design and systems collaboration have become major issues faced by organizations. For greening issues, several countries at all levels are developing waste handling prohibitions, regulations, or incentive programs to encourage alternative disposition of electronic waste, and ensuring that producers or consumers of such products are more responsible for their safe disposal (Boks et al., 1998). Governments have begun implementing regulations that impose various requirements on manufacturers with respect to their end-of-life (EOL) products. Owing to some regulations and international proposals, such as European Union's proposal for a directive on Waste Electrical and Electronic Equipment (WEEE) and directives of energy using Product (EuP), an increasing number of manufacturers engage in modifying product designs and incorporate EOL product reuse concepts into product and component design to reduce recovery and remanufacturing costs (Toffel, 2002). Such regulations seek to reduce both the volume and toxicity of waste by increasing the incentives for manufacturers to fully incorporate EOL concerns into product design (Fishbein, 2000; Toffel, 2002). Hence, green product design has become hot board of supply chain management and received increasing attention recently since proper product design can significantly influence the cost of energy usage, disassembly, component inspection and repair, remanufacturing, recycling and waste disposal.

Consequently, the goal of this paper is to develop a production inventory policy considering green product design with the new technology evolution and remanufacturing. The optimal inventory system is developed to comprehend the importance of related factors in the policy and to find the influence of costs in a green supply chain. A short life-cycle product with a stationary demand is considered.

Prior to delving into this study, a brief description of the major influencing factors must be noted for clarification.

First, life-cycle design seeks to maximize the life-cycle value of a product at the early stages of design, while minimizing cost and environmental impact. Ishii et al. (1994) introduced the concept of the life-cycle value and illustrated a prototype computer tool of Design for Product Retirement (DFPR). Their paper focused on product retirement and advanced planning for material recycling. For the issue of designing for remanufacturing or recycling, Klausne and Wolfgang (1999) outlined a concept to integrate product repair and product take-back. They showed that the replacement of a large share of conventional repairs with remanufacturing and reconditioning would result in a higher

* Corresponding author. Tel.: +886 03 2654409.
*E-mail addresses:* cjchungboy@gmail.com (C.-J. Chung), weehm@cycu.edu.tw (H.-M. Wee).

0925-5273/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpe.2010.09.033

service level in product repair. Moreover, the regulation of Eco-Design Requirement for Energy-using Products (EuP) was announced by EU in 2005. The purpose of these regulations is to reduce the usage of energy and resource by incorporating ecological considerations along with product design from a product life-cycle perspective. The environmental regulations highlighted have significantly influenced the industries at all levels. Some researchers find that product design has critical link with environmental issues and business contracts. For example, Bovea and Vidal (2004) considered an evaluation method to identify the product value with the consideration of environmental factor. They proposed a model that allows user to add value for customer to a product, by means of the integration of the environmental, cost and customer valuation during its design process. Their model combines three methodologies: Life-Cycle Assessment (LCA), Life-Cycle Cost (LCC), and Contingent Valuation (CV) to quantify the customer's value in terms of customer's Willingness-To-Pay (WTP) for a product that incorporates certain environmental improvements. Lin et al. (2010) presented a proposed model which addresses the drivers of innovation in channel integration in supply chain management. Their results indicate that a significant relationship has been established between market orientation and supply chain performance. Their findings also confirmed that value co-creation and the value constellations as the drivers of innovation in channel integration are positively associated with supply chain performance. Hua et al. (2011) investigated the optimal product design strategy of a manufacturer in a two-stage supply chain that consists of an upstream manufacturer and a downstream retailer. It is found that the incentive contract can perfectly coordinate the distribution channel in the product design problem.

For issues in the greening process, Nahmias and Rivera (1979) have studied an EPQ variant of Schrady's model (1967) with a finite recovery rate. Koh et al. (2002) assumed an infinite production rate and finite recovery rate. They did not limit the recovery rate. White et al. (2003) presented a generalized overview of product recovery. The purpose of their paper described the recovery of computers as a step-by-step process, and framed an environmental research agenda for recovery management of computer industry. Bonney et al. (2003) examined some of the changes that are occurring in manufacturing companies and in the market. Changes include the product design process, reduction in product design time, new technology, new materials and production methods, the availability of better quality data, organization change including changes in techniques and tools used for planning and control. De Brito (2004) provided an extensive literature reviews while Bayındır et al. (2006) investigated the level of the desired recovery effort when the recovery process is not perfect. Tagaras and Zikopoulos (2008) assumed that demand is satisfied only by remanufactured items and studied a single period model with return in which inspection/sorting schemes are incorporated. Nenes et al. (2010) investigated alternative policies for a system where both demand of new products and returns of used products are stochastic. The expected cost of each policy for a real application problem is computed and the best policy is proposed.

Finally, there are numerous researches on just-in-time implementation with closer collaboration of the supplier–buyer integration as one of the keys to successful JIT implementation. Considerable researches have been done on the integrated inventory model and the JIT implementation. Banerjee (1986) derived a joint economic lot size model for a single vendor, single buyer system with the finite vendor's production rate. Hill (1999) and Kim and Ha (2003) presented a cooperative policy for multiple deliveries. The phenomenon of deterioration is prevalent and should not be neglected in the integrated model development. Deterioration is defined as decay, damage, spoilage, evaporation, obsolescence, pilferage, and loss of entity or loss of marginal value of a commodity that results in decreasing usefulness from the original one (Wee, 1993). Bhunia and Maiti (1998) studied the deteriorating inventory model with shortages and time-dependent demand, and considered functional relations of the replenishment rate and the on-hand inventory. Yang and Wee (2002) developed an integrated deteriorating inventory model considering multiple buyers. Balkhi and Benkherouf (2004) presented an inventory model for deteriorating items with stock dependent and time-varying demand rates for a finite time planning horizon. Lin et al. (2006) studied a production-inventory model with continuous deterioration. The problem of the paper is to schedule multiple products to be manufactured on a single machine repetitively over an infinite planning horizon. He et al. (2010) examined the issue of the selling season between geographically dispersed markets with an insightful production-inventory model of a deteriorating items manufacturer selling goods to multiple-markets with different selling seasons. Therefore, the factor of deterioration cannot be neglected in an inventory model development.

This study considers green product design and remanufacturing with re-usage concept by the development of an integrated production inventory model with short life-cycle. This study is organized as follows: In Section 2, assumptions and notation are provided for model development. In Section 3, the study develops an integrated buyer–supplier deteriorating model considering JIT deliveries, design costs for product function and gas emission, reverse-manufacturing costs and other costs. A simple algorithm to derive an optimal solution is also provided. A numerical example is presented in Section 4. Conclusion and remarks are shown in Section 5.

## 2. Notation and assumptions

### 2.1. Notation for the forward manufacturing

#### 2.1.1. Notation for the supplier

| | |
|---|---|
| $P$ | production rate |
| $D$ | demand rate |
| $B$ | production lot size per cycle time |
| $T_1$ | production time interval (year) |
| $T_2$ | time interval after production time (year) |
| $\Psi_{S1}(t_1)$ | inventory level during the production period |
| $\Psi_{S2}(t_2)$ | inventory level after the production period |
| $I_{Sm}$ | maximum inventory level during the production period |
| $C_S$ | the supplier's setup cost per cycle time |
| $C_{Is}$ | the supplier's unit item cost |
| $F_S$ | the cost of less flexibility per cycle time |
| $C_{if}$ | fixed inspection cost per year |
| $C_{i0}$ | variable inspection cost per setup per year |
| $U_{inv}$ | the unit variable inspection cost per year |
| $H_S$ | holding cost per unit per unit time |
| $TC_S$ | the total cost function of the supplier |

#### 2.1.2. Notation for the buyer

| | |
|---|---|
| $I_B(t)$ | the buyer's inventory level |
| $H_b$ | holding cost per unit per unit time for the buyer |
| $T_b$ | delivery cycle time per batch for the buyer (year) |
| $O$ | ordering cost per production cycle for the buyer |
| $N$ | the number of deliveries per cycle time |
| $q$ | delivery size per delivery |