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Optimal Inventory Control with Consideration for LCA

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ABSTRACT

This paper proposes a new performance evaluation approach to an inventory management system based on an environmental conscious manufacturing system such as a remanufacturing system with consideration for Life Cycle Assessment (LCA). We here formulate an inventory system with single item based on newsboy problem. The system is evaluated by the total cost that includes the holding, the backlogged, the disposal and the CO₂ penalty costs. In this approach, we consider two types of inventories: one is the actual product inventory in a factory whereas the other is the LCA inventory that denotes CO₂ emission for all the life cycle of the product. This model also includes disposal and recycle rates. Using the suggested model, we can obtain the total inventory cost with consideration for the environment. Numerical examples are considered to illustrate the implementation of the methodology.

Keywords: Inventory, Life Cycle Assessment, Optimal Control.

1. INTRODUCTION

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 [16]. Wann [18] reports that an average American consumes 20 tons of materials every year. Environmentally conscious manufacturing (ECM) is mainly driven by the escalating deterioration of the environment. It has become an obligation to the environment and to the society. 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 For example, Germany has passed a regulation that requires companies to remanufacture products until the product is obsolete.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 [3-7].

Gungor and Gupta [8] reviewed the literature in the area of environmentally conscious manufacturing and product recovery. They summarized wide range of this area including industrial examples, modeling and solutions. Product recovery aims to minimize the amount of waste sent to landfills by recovering materials and parts from old or outdated products by means of recycling and remanufacturing. It should be considered in designing and managing the manufacturing systems [8-9]. Here, product recovery includes collection, disassembly, cleaning sorting, repairing bad components, reconditioning, testing, reassembling and testing. Recovered parts/products are used in repair, remanufacturing of other products and components. We focus on an inventory management system based on a remanufacturing environment with consideration for CO₂ emission.

This paper proposes a performance evaluation approach to an inventory management system based on an environmental conscious manufacturing system such as a remanufacturing system with consideration for Life Cycle Assessment (LCA). In section 2, we briefly summarize environmental conscious manufacturing background and the relevant literature. In section 3, we here formulate an inventory system with single item based on newsboy problem. The system is evaluated by the total cost that includes the holding, the backlogged, the disposal and the CO₂ penalty costs. In this approach, we consider two types of inventories: one is the actual product inventory in a factory whereas the other is the LCA inventory that denotes CO₂ emission for all the life cycle of the product. This model also includes disposal and recycle rates. In section 4, we can obtain the total inventory cost with consideration for the environment using the suggested model. Numerical examples are considered to illustrate the implementation of the methodology.

2. LITERATURE REVIEW

Our main interest is in the operational aspect of product recovery in the remanufacturing environment. Fleischmann et al. [2] define remanufacturing as a process of bringing the used products back to 'as new' condition by performing the necessary operations such as disassembly, overhaul and replacement. Remanufacturing is also referred as recycling-integrated manufacturing [10]. Similar to the conventional production systems, in remanufacturing systems, there are operational, manufacturing, inventory, distribution and marketing related decisions to be made [12]. In general, the existing methods for conventional production systems cannot be used for the remanufacturing systems. Remanufacturing environments are characterized by their highly flexible structures. Flexibility is required in order to handle the uncertainties which are likely to arise. In addition, we should recognize that the products that are used by customers would be the parts to produce new ones after collecting and recovering them.

As for the periodic review models, Cohen *et al.* [1] developed the product recovery model in which the collected products are used directly. Inderfurth [11] discussed effect of non-zero leadtimes for orders and recovery in the different model. As for continuous review models, Muckstadt and Isaac [13] 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 [17] suggested push and pull strategies for the remanufacturing system. They, however, consider that demand and procurement are independent in the inventory systems. All the above studies, however, considered the demand and procurement are independent in the systems. Nakashima *et al.* [14-15] dealt with a product recovery system with a single class of product life cycle. They proposed a new analytical approach to evaluate the system using Markov chain and gave numerical examples for various conditions. They consider the inventory which the customer has, however LCA is not included in the models.

3. INVENTORY CONTROL MODEL WITH LCA

Consider a process that produces a single item and single period inventory management system. The finished products are stocked in the retail store and are used to satisfy consumers' demands. The store makes an order of the products at the beginning of the period. If the number of product inventory is grater than the demand, the disposal cost occurs per excess inventory. On the other hand, if the number of product inventory is less than the demand, the backlogged cost is given as a penalty. In addition, we consider CO₂ emission penalty which is calculated by CO₂ inventory analysis for all the life cycle of the product. The CO₂ inventory analysis divides the emission range into five parts such as 1.material, 2.production, 3.logistics, 4.use and 5.disposal. It also considers the effect of the product recycle on the CO₂ emission (Figure 1). Table 1 shows the example of the inventory analysis of a laptop PC. The decision maker has to a number of ordering quantity of the product with consideration for LCA as well as traditional inventory costs.

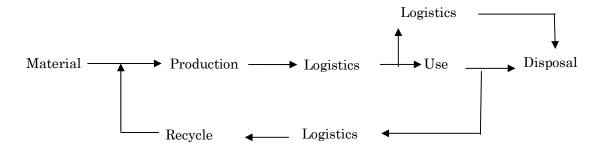


Figure 1: Concept of inventory analysis

Table 1: Example of inventory analysis

Life cycle stage	1.material	2.production	3.logistics	4.use	5.disposal	6. recycle
$CO_2(kg)$	48.3	55.9	0.36	60.4	0.07	-2.23

We use the following notation for the modeling.

d: demand W: Disposal quantity y: inventory level after delivery Td: Total CO₂ emission

x: inventory level before ordering m: CO $_2$ emission for material f(t): probability density function pr: CO $_2$ emission for product

r: recycle rate s: CO₂ emission for logistics

c: ordering cost per product u: CO_2 emission for use

h: disposal cost per product w: CO₂ emission for disposal

p: backlogged cost per product e: Recycle effect on CO_2 emission

emc: CO_2 penalty cost per unit Tc: Total cost

The total cost is given by the following equations.

$$Tc = c(y - x) + h \int_{0}^{y} (y - t) f(t) dt + p \int_{y}^{\infty} (t - y) f(t) dt + Td *emc,$$
 (1)

where

$$Td = \{m + pr + (s*2) + u + w\} * \{(y - x) * (1 - r)\} + \{e + pr + (s*2) + u + w\} * \{(y - x) * r\} + \{m + pr + (s*2) + w\} * \{W * (1 - r)\} + \{e + pr + (s*2) + w\} * (W*r).$$

$$(2)$$

4. COMPUTATIONAL RESULTS

In this section, we show the numerical results on the suggested system. The distribution of the demand is given by uniform distribution [1, 10]. The cost parameters are set as c=4, h=40, p=20 and emc=930. The recycle rate is given by r=3.9% based on the company report. Table 2 shows comparison of the two types of the inventory models with LCA. The optimal ordering number of the inventory model without recycle and that of the recycle model is 5, respectively. We can find the minimum cost of the recycle model is less than that of the no recycle model.

Table 2: Comparison of the two types of the inventory models

	No recycle model	Recycle model
Minimum cost without LCA	100	105.85
CO ₂ penalty cost	767.48	753.65
Total cost	867.81	864.50

5. CONCLUSIONS

This paper proposed a new performance evaluation approach to an inventory management system based on an environmental conscious manufacturing system such as a remanufacturing system with consideration for Life Cycle Assessment. Using the suggested model, we obtained the total inventory cost with consideration for the environment. Numerical examples were given to show the difference between the optimal ordering policy with LCA and that without it.

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