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Simulation modelling of reverse logistics networks

S. Kara*, F. Rugrungruang, H. Kaebernick

Life Cycle Engineering and Management Research Group, School of Mechanical and Manufacturing Engineering, The University of New South Wales, Sydney NSW 2052, Australia

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Abstract

While consumers traditionally dispose of products at the end of their life cycle, product take-back legislations introduced by governments shift this responsibility from consumers to manufacturers. As a result manufacturers have to collect products at the end-of-life (EOL) and control their recovery or disposal. Product recovery, which encompasses reuse, remanufacturing and materials recycling, requires a structured reverse logistic network in order to collect products efficiently at the end of their life cycle. This paper presents a simulation model of a reverse logistics networks for collecting EOL appliances in the Sydney Metropolitan Area. The simulation results show that the model presented in this paper calculates the collection cost in a predictable manner. Moreover, it provides a tool to understand how the system behaves by carrying out "what-if" assessments and to identify which factors are most important for further more detailed analysis.

Keywords: Reverse logistics; Reuse; Recycling; Simulation modelling

1. Introduction

Due to the growing environmental concerns of today, increasing attention is given to managing the waste streams and depletion of non-renewable resources (Gungor and Gupta, 1999, Kara et al., 2003a, b). Environmental management aims primarily to reduce waste volume by moving away from one-time use and disposal to having control of the product's recovery. This encompasses of reuse, remanufacturing and materials recycling, which can be the three end-of-life (EOL) alternatives determined by the product's characteristics at the end of the product life cycle (Rose and Masui, 1998). As these concerns start to affect the customer's purchasing decisions, manufacturers are increasingly forced to consider their product's impact on the environment. This changing trend extends the responsibility of producers beyond the production and distribution to the responsibility for their products at the end of their life cycle. In order to address these problems, producers have to extend the traditional forward logistic distribution chain and consider the total environmental effects of all products and processes until they are returned at the EOL, which is also referred to as reverse logistics (Beomon, 1999, Kooi et al., 1996). Reverse logistics is gaining increasing levels of attention because of environmental factors as well as economic reasons (Ginter and Sterling, 1978; Gupta and Veerakamolmal, 2000, Haberland et al., 1997). Unfortunately, reverse logistic systems are more complex than forward logistic systems. This complexity stems from a high degree of uncertainty due to the

*Corresponding author. Tel.: +61 2 9385 5757; fax: +61 2 9663 1222.
E-mail address: S.Kara@unsw.edu.au (S. Kara).

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quantity and quality of the products (Gungor and Gupta, 1999). Although it is desirable to develop an integrated model to incorporate forward and reverse flows of new and used products, one common approach to designing reverse logistic networks is to model reverse distribution independent of forward distribution (Fleischmann et al., 2003; Ginter and Sterling, 1978; Minner, 2001; Klebber et al., 2002; Teunter and van der Lann, 2002).

In this paper, a reverse logistics network for white goods collection in the Sydney Metropolitan Area (SMA) is presented, including the corresponding simulation model. The aim of the paper is to provide a flexible model to address some of the aforementioned problems associated with reverse logistics networks. In order to achieve this, firstly, a reverse logistics network was designed to establish transfer stations, drop-off points and a disassembly plant. Secondly, a simulation model was developed by using the Arena 7.0 simulation package. Thirdly, the simulation model was tested for the white good collection process in the SMA. The certainty of the results was statistically defined using a confidence interval of 95%. The model was then justified using *t*-distribution in order to find out the number of simulation runs required so that the results are within the $\pm 5\%$. Finally, a sensitivity analysis was carried out to analyse the effect of incoming goods, the fixed and variable costs of transport, the load and unload times plus the inventory cost.

2. Design of the conceptual model

Prior to model construction with the Arena simulation package, it is first fundamental to obtain an appropriate conceptual model, by which the reverse logistics infrastructure can be described. When designing a network structure of reverse logistics, there are many factors to be considered. These factors include the number and the type of participants in the system, the number and location of the disassembly centre, collection points, characteristics of the material flow and product characteristics. It is crucial that the factors in the chain work together in order to ensure cost effectiveness of the system. The reverse logistic network in this paper is based on the existing collection structure of white good appliances in the SMA. This includes the collection and transportation of used household appliances from consumers to the final destination, which is a remanufacturing plant. The reason for using the existing collection structure is that the volume of discarded white goods in the SMA is alone too small and too wide spread to support a new reverse logistics network (Kara et al., 2003a, b).

In the SMA, the major participants who perform tasks for collecting discarded products from consumers are the 44 local councils, 4 major retailers, and 3 small business operators (SBOs). It is estimated that the proportions of white goods collected by these three collectors are 60%, 30%, and 10%, respectively (Kara et al., 2003a, b). Further assumptions for the collection strategy have been made, such that all councils and SBOs in each council area will deliver the collected products to the nearest Waste Services-New South Wales transfer station (WS-NSW). This is due to the fact that the collected white goods are mixed with other wastes, which need to be separated and batched before their transferring to the disassembly centre. The retailers will deliver the white goods directly to the disassembly centre. At the centre, the parts that can be remanufactured or recycled will be extracted and transferred either to the recycling facility or to the remanufacturing plant. The flow of collected products is illustrated in Fig. 1.

2.1. Position of disassembly centre in the system

For the integration of the disassembly activity into the system, two main concepts can be used, considering location and quantity. The first concept represents a scenario, where a sufficient number of disassembly centres are located close to collection points and recovery processing facilities (Benfield, 2000).

Certainly this is a solution in which the transportation costs can be minimized. However, there is a trade-off between disassembly fixed costs per unit and transportation costs due to a smaller number of units to be disassembled per plant. The second concept is to have a centralized disassembly centre with a high capacity for product disassembly. The second concept was more suitable for the current collection network. Therefore a centralized disassembly plant with short transport distances for used parts was chosen (Fig. 1).

A ‘‘Grid Technique’’ analysis was carried out in order to minimize the transportation costs by deciding a low cost ‘‘centre of gravity’’ with respect to incoming white goods. This centre of gravity was the geographic location for the disassembly plant. No consideration was given to the availability of