Omega 39 (2011) 558–573

Contents lists available at ScienceDirect

Omega

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

A multicriteria decision making model for reverse logistics using analytical hierarchy process

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ARTICLE INFO

Article history:
Received 5 October 2009
Accepted 9 December 2010
Processed by B. Lev
Available online 17 December 2010

Keywords:
Reverse logistics
Decision making models
Product recovery
Sensitivity analysis
AHP

ABSTRACT

Product recovery activities such as recycling, refurbishing and direct reuse are becoming integral to manufacturing supply chains. This study presents a multicriteria decision making model for reverse logistics using analytical hierarchy process (AHP). The AHP model evaluates a hierarchy of criteria and subcriteria, including costs and business relations, for critical decisions regarding network design. Using sensitivity analysis with AHP, the work provides insights into the preference ordering among eight alternative network configurations. For instance, the choice of test sites is largely dependent on the potential for cost savings on testing procedures and transportation of scrap, and this decision is not sensitive to the importance of business relations. By contrast, the choice of collection sites is largely determined by the relative importance of business relations considerations vs. cost considerations. As well, the processing location decision favors a third-party reprocessor if there is little need to protect proprietary product knowledge and cost savings is very important. The model is demonstrated using three case studies of real-world applications.

1. Introduction

In today's manufacturing climate, producers are paying increased attention to the need for product recovery activities. Producers are looking for efficient ways to integrate reverse logistics into their supply chains, primarily to recover economic value from returned products, and to reduce disposal costs for non-recoverable waste [1].

What are the critical decisions facing producers? According to Fleischmnn et al. [2]:

> In particular, companies need to choose how to collect recoverable products from their former users, where to inspect collected products in order to separate recoverable resources from worthless scrap, where to reprocess collected products to render them remarketable, and how to distribute recovered products to future customers [2, p. 65].

This paper presents a multicriteria decision making model for conceptual decisions in reverse logistics network design using analytical hierarchy process (AHP). The AHP model provides a way to detect interactions between various high-level decision factors, some of which are not easily quantifiable. This work also applies the AHP model to three case studies together with sensitivity analysis that provides insights across industries about the trade-offs among preferences to high-level decisions in network design.

A number of facility location models have been presented to determine facility locations and transportation network details [3–15]. Facility location models seek to minimize transportation and processing costs while determining an optimal network design. Given a set of candidate facility locations and associated costs, these models produce the best locations and network layout at the least cost.

However, it is important for the producer who is just beginning to consider reverse logistics to make critical conceptual design decisions first. Should collection be done directly from customers or should the collection system include other manufacturers' products as well as their own? Would it be better to have a third-party recycle the returns, or should the returns be reprocessed in-house? What testing needs to be done? Is it best to test at a central location and save costs on testing, or to test out in the field and prevent excess transportation costs to ship unnecessary scrap?

Conceptual design decisions have been explored by a number of researchers. In a review of quantitative models for reverse logistics, Fleischmnn et al. [16] in 1997 enumerated considerations for network design questions, and these network design questions were the basis for later conceptual models. The design questions included: who are the entities performing reverse logistics (e.g., collectors, reprocessors, etc.), which functions need to be carried out and where, and whether the forward and reverse flows should be integrated or separate.

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doi:10.1016/j.omega.2010.12.002

Seminal work in reverse logistics includes Thierry et al. [17], who categorized networks by type of product recovery options: (i) direct reuse and resale, (ii) repair, refurbishing, remanufacturing, cannibalization and recycling, and (iii) waste disposal. As well, Goggin and Brown [18] developed a generic typology of resource recovery as a basis for problem-solving to help original equipment manufacturers (OEMs) determine whether to implement recovery and how it would operate; their typology defines the complexity of types of recovery and provides insights into the requirements for material reclamation, component reclamation, and remanufacturing product recovery.

In 2000, Fleischmann et al. [19] proposed a conceptual model based on the network design questions in [16]. Using common characteristics of several case studies, product recovery networks were classified into three types: (i) bulk recycling networks, (ii) assembly product remanufacturing networks, and (iii) reusable item networks. Each type of network had its own characteristics, including degree of centralization, integration with existing supply chain operations, and whether products would be returned to the manufacturer for reprocessing or to an outside entity. The result is a descriptive conceptual model that distinguishes among network types based on product function – recycling, remanufacturing, or reusing – and then proposes specific network design considerations for each network type.

In 2003 DeBrito et al. [20] presented a descriptive framework for reverse logistics, which discusses structures for reuse, remanufacturing, and recycling networks in 24 case studies. Their work encompassed the following observations: (i) successful reuse networks rely on matching supply and demand of returned items at the same time; (ii) optimal remanufacturing depends on the location of the remanufacturing facility, ensuring a steady return product volume and minimizing the impact of uncertainty in return supply, and (iii) recycling is primarily done through public government-sponsored networks, driven by environmental objectives, and is likely to be centralized due to expense of facilities.

Some research has approached the reverse logistics network design problem through the study of network configurations and the impact of related factors on network design. Francas and Minner [21] studied a multi-product network design problem that looked at two network configuration choices for remanufacturing: an integrated network in which manufacturing and remanufacturing are done at the same facility with pooled capacity, and a decentralized network with manufacturing and remanufacturing carried out at separate facilities. They also studied two design methodologies: sequential design in which product recovery was added to an already existing network design, and simultaneous design in which the network was redesigned entirely to include product recovery and new product production. Their work investigated capacity planning and the advantages of the different network configurations for remanufacturing.

Barker and Zabinsky [22] developed a conceptual framework with eight possible network configurations, through case study analysis of 40 case studies that addresses a wide variety of industries. The conceptual framework is composed of a set of high-level decisions and their associated considerations impacting the choice of network configurations. The decisions govern how to collect the return product, where testing will be performed, and if processing will be done at the original plant or at a secondary facility, and the considerations include factors such as the cost of testing, the strength of customer relationships, whether a government mandate exists for recycling or return product, etc. This research looked at the complete cycle of product recovery, from collection through processing and associated the network design decisions.

While prior research has identified many characteristics of reverse logistics networks and possible network configurations, existing conceptual frameworks are not quantitative. This paper extends the non-quantitative conceptual framework in Barker and Zabinsky [22] into a quantitative decision model.

High-level decisions for reverse logistics are influenced by a multitude of factors that interact with each other resulting in trade-offs between cost savings and other factors such as direct customer relationships and proprietary knowledge. According to Evans [23] and Guitouni and Martel [24] most decision problems, especially location problems, involve balancing inherent trade-offs rather than optimizing a single objective such as cost. As well, the parameters for high-level decisions in a mixed-integer linear program are not easily quantifiable, making the models in Fleischmann et al. [2] and others not immediately applicable in this context. Thus analytic hierarchy process was selected as the decision making methodology.

As a multicriteria decision making method (MCDM), AHP balances the interactions among decision criteria and synthesizes the information into a vector of preferences among the alternatives [25,26]. AHP has been used in a wide variety of contexts for decisions that incorporate hard-to-quantify decision factors, including risk assessment in overland petroleum pipelines [27] and watershed management in the U.S. [28]. AHP satisfies the selection criteria suggested in Hobbs [29]: appropriateness, ease of use, and validity. Further, AHP satisfies the guidelines in Guitouni and Martel [24]: (i) structuring the decision process, (ii) articulating and modeling the preferences, (iii) aggregating the alternative evaluations (preferences) and (iv) making recommendations.

In reverse logistics research AHP has been used by Staikos and Rahimifard [30] to develop a decision model for product recovery of shoes. Their model consists of criteria in three areas: environmental factors based on life cycle analysis (LCA), economic factors from cost-benefit analysis, and qualitative technical factors from a secondary AHP analysis. Kannan et al. [31] created a multicriteria decision making model using AHP and fuzzy analytical hierarchy process to evaluate collection centers for product recovery in the tire manufacturing industry in India. In another study, Fernández and Kekäle [32] proposed a conceptual model using Delphi and AHP as an illustration of model-building under multiple conflicting priorities. The Delphi method was used to develop concensus among reverse logistics practitioners to determine which variables caused reverse logistics success and what cause-and-effect sequence impacted these successes. AHP was then applied to determine the relationships among the variables and their relationships to the recovery options. A closely related methodology, analytic network process (ANP) was used by Ravi et al. [33] to evaluate alternatives for end-of-life computers, connecting diverse and hard-to-quantify decision factors including financial and non-financial factors and tangible and intangible factors. Efendigil et al. [34] used fuzzy AHP to determine selection of third-party logistics providers in the presence of vagueness. Pochampally and Gupta [35] also used fuzzy AHP in a reverse supply chain network study to select the most economical product to reprocess, identifying potential recovery facilities, and determining locations to minimize cost.

In summary, the model in this study is a generalized model for reverse logistics network design that addresses conceptual design questions posed by earlier researchers and quantifies the design considerations and the trade-offs between decision choices. The model also provides sensitivity analysis to explore the dependencies of network configuration decisions on a variety of factors, including the strength of customer relationships and the degree of cost savings that can be achieved. The model and sensitivity analysis are demonstrated with three case studies: medical device refurbishing, residential carpet recycling, and commercial carpet recycling. Insights about the sensitivity of high-level decisions to the decision factors are provided through the results from these three case studies.