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

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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.

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

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 Fleischmann 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, Fleischmann 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.
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, and reusable product recovery. Insights about the sensitivity of high-level decisions to 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 Guittouni 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 Guittouni 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 Kekälä [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 consensus 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.
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