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A multi-objective model for multi-product multi-site aggregate production planning in a green supply chain: Considering collection and recycling centers

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ABSTRACT

The present study was designed to incorporate the profit and green principles in an aggregate production planning.

It is difficult to ignore the key role of green principles in balancing environmental and economic performance for companies facing community, and competitive pressures. In this paper, a multi-objective multi-period multi-product multi-site aggregate production planning (APP) model is presented in a green supply chain considering a reverse logistic (RL) network. In the proposed model, products are scored in terms of environmental criteria such as recyclability, biodegradability, energy consumption and product risk, using analytical hierarchy process (AHP). Speaking in simple terms, the AHP concept is utilized to get one single indicator that describes environmental impact of various production alternatives. Some other green indicators including waste management, greenhouse gas (GHG) emissions arising from production methods and transportation are embedded in the model. The limited number of potential collection and recycling centers can be opened in order to produce the second-class goods. The LP-metrics method is used to consider two conflicting objectives, i.e. minimizing total losses and maximizing total environmental scores of products, simultaneously. Further, the trade-off between objectives is demonstrated by a collection of Pareto-optimal solutions. The model shows how profit and green principles can be incorporated in an APP problem. Finally, the model validity is demonstrated by a numerical example. The sensitivity analysis is carried out for GHG emission level arising from production and transportation and industrial waste level to provide some useful managerial insights, then analysis of the cost and profit in collection and recycling system, is conducted to show its performance.

1. Introduction

In the last few decades, there has been a worldwide awareness in controlling pollution to preserve the earth and its valuable resources. Given the centrality of this issue, one of the most significant current discussions in supply chain management among researchers and practitioners is green supply chain management (GSCM). For several years great effort has been devoted to the study of GSCM by a number of authors in order to consider environmental management issues. What is more, recently, researchers have shown an increased interest in GSCM models to reduce serious environmental implications associated with differing supply chain activities (see e.g. [1–10]). At the same time, with regard to the increasing importance of environmental performance, some organizations have started to apply green principles to improve business performance and create value for their end customers [11]. A variety of definitions of GSCM have been proposed in the literature. Some of these definitions are summarized in the following paragraphs.

Srivastava [12] described GSCM as "integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final products to the consumers, and end-of-life management of the product after its useful life".

GSCM has been characterized as a collection of environmental management practices which can be used to integrate environmental considerations into the forward logistics and reverse logistics [13–16].

In the last thirty years, research has provided ample support for the assertion that GSCM consists of activities such as 'green design', 'green sourcing', 'green operations', waste management and green

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manufacturing, 'green distribution, green logistics, green marketing' and 'reverse logistics' [17].

Min and Kim [18] reviewed a wide range of green supply chain studies from more than five hundred papers.

In the past few years, green and reverse logistics as a significant subsets of green supply chain management has been developed [12]. Along similar lines, Dekker, Bloemhof [19] performed a vast literature review of the research conducted on green logistics. They subscribed to the idea that when it comes to the environment, transportation lies at the heart of the discussions on supply chains. In regard to transportation, four choices such as mode choice (or modal split), fuel choice, equipment choice as well as the use of intermodal transport are investigated. Each mode of transportation, namely, transport by rail, truck, ship, and plane, enjoys differing features in relation to transportation cost, transit time, accessibility, and characteristically environmental performance. In the present study, choice method is used to take account of the environmental considerations in the model.

Rogers and Tibben-Lembke [20] described reverse logistics as 'the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal'.

The focus of reverse logistics is on getting the product back from consumption points to suppliers, after use, for possible recycling or re-manufacturing. Recently, reverse logistics has attracted much attention from researchers. Along similar lines, new objective functions and constraints are taken into consideration and recovery and valorization activities are carried out for end-of-life products [21]. Besides, organizations found that efficient RL can provide social image, as well as competitive advantage (see e.g. [22–26]). In the light of this, we considered the potential collection and recycling centers in our model to collect returned products from customers' zones and after identifying recyclable products, recycle them as the second-class products.

There is no denying the fact that aggregate production planning is one of the prominent subjects that can be discussed in GSCM. Aggregate production planning is an effective method to determine production, inventory as well as workforce levels to fulfill the demand for given capacities and resources over a planning horizon anywhere from 3 to 18 months [27,28]. Great effort has been devoted to the study of APP from several years ago (see e.g. [29–33]). Nam and Logendran [34] reviewed a number of investigations into the APP models consist of 14 books and 140 journal articles, and then divided the models into two categories, optimal and non-optimal. The current literature on aggregate production planning abounds with examples of integration of APP models with the other aspects of planning problems such as manpower planning [35], scheduling [36,37] Supplier selection and lot sizing [38] and particularly supply chain planning [39–42].

1.1. Motivation

In spite of pressure from consumers, government and the investment community, many organizations are not motivated to focus on approaches, such as cleaner production, eco-efficiency, and environmental management systems for greener management practices [3]. One question that needs to be asked, however, is whether considering green principles in decision-making processes may cause economic loss. There is increasing concern about determining the best solutions for balancing environmental and economic performance [43]. Therefore, to avoid profit reduction, many organizations make little attempt to take green criteria into consideration and improve the environmental quality.

Table 1
Environmental issues.

Issues	Description
Recyclability and Ease of disassembly	Recycling plays a key role in reducing waste of potentially useful materials. With respect to large cost of disassembly, products need to be examined not only in terms of recyclability but also in terms of ease of disassembly for an economic recycling.
Biodegradability	There is a definite need for identifying products that are capable of decomposing back into natural elements.
Energy consumption	In order to save non-renewable energy, it is important to draw a distinction between products in terms of the kind and extent of energy sources needed to be made available in their production process.
Product Risk	Product chemical or physical changes which occur during product consumption may be toxic or harmful to humans.

The main objective of this paper is to develop a new comprehensive multi-objective aggregate production planning model in a green supply chain considering a reverse logistic network to be used in many industries, including those producing steel, computers, automobiles, appliances, medical items and wood products. The other purpose is to make a trade-off between costs and green criteria. The objectives include minimizing total losses and maximizing total environmental scores of products, simultaneously. The trade-off between the conflicting objective functions is shown by a set of Pareto-optimal solutions generated by the LP-metrics method. The proposed model can be used in a systematic decision making process.

We examine the model validity by a numerical example and then analyze the results to show the performance of the collection and recycling system.

The major contributions of this paper that differentiate it from existing papers in the related literature can be summarized as follows:

- Production method: Mirzapour Al-e-hashem, Baboli [42] made attempt to limit greenhouse emission related to various modes of transportation. What is more, we assume that multiple methods could be employed to manufacture each product depending on its production system, and the greenhouse emission arising from production different methods become limited by an allowed level of emission.
- Environmental scoring of product: Mirzapour Al-e-hashem, Baboli [42] considered only specific aspects of products including the waste management and inventory. They consider a limitation to the total amount of industrial waste to safeguard the environment opposing their significant damages. A more comprehensive view is taken in the proposed model. We make a distinction between products in terms of environmental considerations including recyclability and ease of disassembly, biodegradability, energy consumption as well as product risk. The mentioned criteria are briefly presented in Table 1. Because of the different life cycle of every product, there is no disputing the fact that the criteria can be tailored to deal with the unique characteristics of each product type. An objective function is considered to maximize the total score of products in all environmental criteria. Analytical hierarchy process (AHP) has been used to quantify the criteria.
- Recently, there has been an increasing interest in reverse logistics due to growing environmental concern and economic opportunities related to cost savings and revenues of returned products. In many industries, reverse logistics can be implemented as a sustainable and profitable business strategy, to allow the