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A bi-objective stochastic programming model for a centralized green supply chain with deteriorating products

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ABSTRACT

In recent years consumers and legislation have been pushing companies to design their activities in such a way as to reduce negative environmental impacts more and more. It is therefore important to examine the optimization of total supply chain costs and environmental impacts together. However, because of the recycling of deteriorated items, the environmental impacts of deteriorating items are more significant than those of non-deteriorating ones.

The objective of this paper is to develop a stochastic mathematical model and to propose a new replenishment policy in a centralized supply chain for deteriorating items. In this model, we consider inventory and transportation costs, as well as the environmental impacts under uncertain demand. Several transportation vehicles producing various greenhouse gas (GHG) levels are considered. The best transportation vehicles and inventory policy are determined by finding a balance between financial and environmental criteria. In this way, we develop a linear mathematical model and present a numerical example from the real world to demonstrate its applicability and effectiveness. We then perform a sensitivity analysis and provide some managerial insights. Finally, more promising directions are suggested for future research.

1. Introduction

The issue of supply chain sustainability has been of considerable interest for the last decade both in academia and in the practitioner's world. A key subject raised in the area of sustainable supply chains is the development of green logistics and supply chains. The definition and scope of Green Supply Chain Management (GSCM) in the literature ranges from green purchasing to integrated green supply chains flowing from raw material supplier to manufacturer to customer, and reverse logistics. GSCM is defined as "integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life" (Kumar et al., 2012). Thus, in GSCM the objectives concern not only the economic impact of logistics policies on the organizations, but also the wider effects on the planet, such as the effects on the environmental pollution, fuel consumption or waste.

Concerns about depletion of the ozone layer and climate change have been increasingly discussed at international level. Transportation, many logistics activities and industrial processes have been linked to an increase in the greenhouse effect through carbon dioxide (CO_2) emissions, although the effect of other gases should not be under-estimated[1] (Harris et al., 2011). In the U.S., for instance, the predominant greenhouse gas emitted is CO_2, which accounts for 85% of the climate change potential for all human-produced emissions. Emissions from trucks increased from 42% of total transportation CO_2 emissions in 1995 to 49% in 2006 and show no signs of decreasing (Ulku, 2012).

As a result, nowadays governments are considering targets for decreased emissions and other environmental metrics. Many companies and organizations are also switching over to green logistics and measuring their carbon footprints so that they can monitor the environmental impact of their activities.

Hassini et al. (2012) represent a sustainable supply chain as wheels consisting of six spokes representing the major relevant functions within the chain: sourcing (using renewable resources

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[1] The major Greenhouse gases (GHGs) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide, (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfar hexafluoride (SF_6) (Konyar, 2001). In many cases, the predominant greenhouse gas emitted is carbon dioxide (CO_2).

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and avoiding toxic substances etc.), transformation (fair labor practices and defining sustainable practices and processes etc.), delivery (transportation, inventory and facilities location and layout etc.), value proposition (snowball effect etc.), customers (customer education etc.) and recycling (recycling or reusing products in an efficient way). Accordingly, many green functions and criteria relate directly or indirectly to the type of product that is offered by companies or supply chains. For instance, the product type may necessitate the use of specific equipment (with specific fuel with a specific level of GHG), for producing, packaging, stocking or transporting.

From the perspective of green criteria, deteriorating products are more noticeable than ones with an unlimited lifespan. Many types of products such as pharmaceuticals, agricultural products, health products, cosmetics, perfumes, radioactive substances, and many electrical, petrochemical and chemical materials are categorized as deteriorating products. Generally deterioration is defined as "decay, damage, spoilage, evaporation, obsolescence, pilferage, and loss of utility or loss of marginal value of a commodity that results in decreasing usefulness" (Wee, 1993). The importance of deteriorating products from the point of view of green criteria can be summarized as follows:

- Waste cost: the waste and recycling processes are very important for deteriorating products and many companies are trying to reduce these processes costs.
- Stocking and transporting: in most cases, specific equipment (such as refrigerated warehouses or trucks) should be used for storage and transportation of deteriorating products, to reduce the deterioration cost. There should thus be a reasonable balance between criteria like deterioration cost, energy consumption and GHGs generated.
- Risk: in the case of deteriorating products such as pharmaceutical radioactive substances, the risk for example of an accident leading to the loss of the beneficial properties of products as well as uncompensated environmental effects. So, here decreasing the risk of accidents during transportation is essential.

In this paper we examine the first two issues. The third one will be dealt with in our future research. For this purpose, we consider a two-echelon centralized supply chain with a single retailer and a single supplier, which is faced with an uncertain demand from external customers. Generally, for considering uncertain demand in the decision-making process, there are four main approaches: *fuzzy programming, robust optimization, stochastic dynamic programming and stochastic programming.* Sahinidis (2004) has discussed each approach in detail.

In a problem where uncertainty and time play a key role, the decision model should be designed to allow the decision maker (DM) to adopt a decision policy that can respond to events as they unfold. Specific decisions depend on three main factors: (i) what information is available to the DM, (ii) when the information is available and (iii) what actions can be taken by the DM. The multi-stage stochastic programming (MSP) approach has been proposed to deal with multi-period optimization problems with dynamic stochastic data throughout the planning horizon (Kazemi Zanjani et al., 2010). Accordingly, since in our study we consider a multi-period centralized supply chain in which the end customer's demand is uncertain, we apply the multi-stage stochastic programming approach to decision making based on present resources, future uncertainties and possible actions in the future. This approach has been employed by several researchers and its applicability for modeling multi-period supply chains with uncertain demand has been verified (for example see Escudero, 1993; Brandimarte, 2006).

In the multi-stage stochastic programming approach, there are two different techniques to describe uncertainty: (i) the distribution-based approach which is applied where a continuous range of potential future outcomes can be anticipated, and (ii) the scenario-based approach which is applicable when the uncertainty is illustrated by a set of discrete scenarios forecasting how the uncertainty might take place in the future. Each scenario is associated with a probability level signifying the decision makers′ expectation of the occurrence of a particular scenario (Mirzapour Al-e-Hashem et al., 2012). In this paper we apply the scenario-based approach that is practicable when a continuous range of future outcomes is not available.

The rest of the paper is organized as follows: in the next section we review some of the main related researches in green supply chain management. The motivation of this paper and the problem are then described in Sections 3 and 4, respectively. In Sections 5 and 6 the mathematical model developed is explained in the form of a multi-stage stochastic programming and a two-stage stochastic programming model respectively. Section 7 presents the solution procedure. A real case study and sensitivity analysis are presented in Sections 8 and 9, respectively. The paper ends with concluding remarks and some directions for future research, in Section 10.

2. Literature review

In recent decades, there has been a growing amount of research on green logistics and supply chains. Several attempts have been made to analyze greenhouse gas emissions resulting from logistics activities (Carlsson-Kanyama, 1998; Konyar, 2001; Gielen et al., 2002; Lehtila et al., 2005; Hirschberg, 2005; Weisser, 2007; Rizet et al., 2010; Bocken et al., 2011; Thanarak, 2012).

A number of studies have taken a mathematical approach to deal with GHG emissions in green logistics and supply chains. GHG emissions can mainly be seen in two forms in the models developed: (i) costs of GHG gases; and (ii) GHG emission levels. Paksoy et al. (2010) have considered GHG emissions in a mathematical model in terms of their associated costs. They studied a closed-loop supply chain and developed a mathematical model in the form of a linear programming formulation to identify each product that had been transported and the mode of transport used, to make a trade-off between various costs, including emission costs and transportation of commodities within the chain. Zhao et al. (2012) have used the game theory to analyze the strategies selected by manufacturers to reduce life cycle environmental risk of materials and carbon emissions. In their model, the strategic choices of the manufacturers were influenced by government penalties or incentives.

Moreover, some researchers have considered GHG emission levels directly in mathematical models. Wang et al. (2011) studied a supply chain network design problem by applying a bi-objective optimization model to consider the environmental investment decision in the strategic supply network design phase. They considered total costs in the first objective function and total CO_2 emissions in all the supply chains in the second one, and determined facilities locations, material flows and environmental protection levels in each facility. Harris et al. (2011), using a simulation method on a European case study from the automotive industry, considered strategic and operational level decisions simultaneously. They showed that the optimum design based on costs does not necessarily equate to an optimum solution for CO_2 emissions. Zhang et al. (2012) describe an empirical study of nearly one hundred questionnaires of various Chinese iron and steel companies. Then, by a regression analysis, they showed that although some CO_2 reduction activities can improve environmental performance, their impacts on the economic performance are less clear.