Int. J. Production Economics 145 (2013) 683–695

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Environmental performance—Impacts of vendor–buyer coordination

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ARTICLE INFO

Article history:
Received 8 December 2011
Accepted 18 May 2013
Available online 29 May 2013

Keywords:
Green supply chain
Utility functions
Synchronization
Multiple buyers
Multi-objective programming

ABSTRACT

Effective coordination is a hallmark of successful supply chain management. Without such coordination, vendors and buyers will act independently to make decisions that optimize their own objectives (e.g., maximize their respective profits or minimize their costs). This non-coordinated approach is unlikely to be optimal when one considers the supply chain as a whole. Most vendor–buyer coordination research concentrates only on an objective of minimizing total system costs; but with the increasing environmental awareness in business and the general public, many organizations acknowledge that strategies and practices which incorporate environmental considerations are essential to acquire a competitive advantage. The objectives of this research are concerned not only with the economic impact of vendor–buyer coordination on the organizations involved, but also with the wider effects on society, such as the effects of pollution on the environment. This research demonstrates how to effectively incorporate environmental issues into vendor–buyer coordination. First, we study the impacts of cost-minimizing vendor–buyer coordination models on environmental performance when compared with independent (non-coordinated) optimization. Second, we develop a single-vendor multi-buyer coordination model that includes both costs and environmental performance measures in its objective function. A numerical example and a real case study show how both the total system cost and the environmental performance can be simultaneously improved.

1. Introduction

Coordination among parties in a supply chain system is essential in today's business environment to acquire and maintain a competitive advantage. How best to achieve effective coordination between vendors and buyers is both a current managerial concern and an important research issue. However, most literature on vendor–buyer coordination concentrates only on an objective of minimizing the total system costs. With the increasing environmental awareness in the general public, the advent of new environmental organizations and the implementation of new legislation in some countries, there is increased pressure for enterprises to improve environmental performance. Hence, incorporating environmental impacts into vendor–buyer coordination is of vital importance.

Since the mid-1990s, there has been increasing awareness of the linkages between public health and environmental conditions. Supply chain practitioners and researchers began to perform research related to environmental issues, known as "green supply chain management" (GSCM). Beamon (1999) carried out an intensive (qualitative) study on GSCM to investigate and identify essential environmental factors for a green supply chain system. Hervani and Helms (2005) carried out similar, but more updated and intensive research on identifying performance metrics and measures for GSCM. Recently, there has been much research with a range of techniques and industries on identifying and evaluating green performances measures, including Life Cycle Assessment (LCA) (Dias et al., 2004; Yung et al., 2009), gap analysis (H'Mida and Lakhal, 2007) and factor analysis (Zhu and Sarkis, 2004; Zhu et al., 2008). Application-oriented research has addressed package printing industries (Vachon and Klassen, 2006; Vachon, 2007), US health care systems (Ford and Scanlon, 2007), the Taiwanese electronics industry (Chien and Shih, 2007), and the integration of green supply chain and reverse logistics (Marsillac, 2008). Researchers have also addressed "green" aspects for the transportation decision (Kim and Goyal, 2009) and comprehensive models of transportation and inventory control (Viau et al., 2009). Azevedo et al. (2011) studied the relationship between green practices of supply chain management and supply chain performance in the automotive industry in Portugal and Large and Thomsen (2011) constructed a structural model to show that green collaboration with purchasing can have a positive influence on the environmental performance.

Dekker et al. (2012), Sbihi and Eglese (2010), and Srivastava (2007) surveyed the extensive literature on mathematical models

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http://dx.doi.org/10.1016/j.ijpe.2013.05.023

and techniques used in modeling GSCM, including reverse logistics, waste management, and vehicle routing and scheduling. For GSCM publications with mathematical models, the objective mainly has mainly been to minimize the total cost, instead of directly optimizing environmental performance, and there is limited research on the environmental performance, including air pollution, in supply chain coordination models. To simultaneously attain economic and environmental goals it requires that the vendor and the buyers compromise on ordering and delivery schedules to benefit all parties involved. Such collaborative decisions can only be achieved via vendor–buyer coordination. In the past three decades, significant advancement has been achieved on vendor–buyer coordination research, including Goyal (1976), Monahan (1984), Banerjee (1986), Lee and Rosenblatt (1986), Goyal and Gupta (1989), Banerjee and Burton (1994), Lu (1995), Chan et al. (2003, 2006), Chan and Kingsman (2007), Sarmah et al. (2008), Sinha and Sarmah (2010), and Hariga et al. (2013).

There is also some empirical research that emphasizes both economic and environmental measures, such as Rao and Holt (2005), Ferretti et al. (2007), Holt and Ghobadian (2009), and Thun and Müller (2010). Most of the research reveals that while companies are willing to engage in green activities, cost reduction remains a top-rated consideration. Intuitively, there is a tradeoff between environmental impact and supply chain cost. Motivated from the above, we propose a synchronized green supply chain coordination model in which both the total system cost and the environmental performance can be simultaneously improved when compared with independent optimization. The objectives of this research are concerned not only with the economic impact of vendor–buyer coordination on the organizations involved but also with the wider effects on society, such as the effects of air pollution on the environment.

This research shows one way to incorporate environmental issues into vendor–buyer coordination. We first study the impacts of cost-minimizing vendor–buyer coordination on environmental performance when compared with independent (non-coordinated) optimization. Then, we develop a single-vendor multi-buyer coordination model that includes both costs and environmental performance measures as objectives. The model is formulated as a multi-objective programming model that is of a type widely adopted in supply chain coordination models (e.g., Sabri and Beamon, 2000; Mula et al., 2010; Jazemi et al., 2011).

The remainder of the paper is organized as follows: Section 2 provides brief background on the independent policy model and the synchronized cycles model, respectively. Section 3 describes the environmental performance issues and formulates the proposed green supply chain model. Section 4 presents the results of a numerical example and a real case study, and is followed by the conclusion in Section 5.

2. Independent optimization and the coordination model

2.1. Independent policy

In this paper, we consider a supply chain with one vendor that produces a product throughout the whole planning horizon and delivers the product to multiple buyers with deterministic demand. We assume that each of the n buyers faces a deterministic demand at rate d_i per unit time, incurs an ordering cost A_i each time it places an order and incurs an inventory holding cost h_i per unit per unit time held. If the buyers and the supplier operate independently, then each buyer will order a quantity Q_i at time intervals of T_i units apart, which are determined only on the basis of the costs and demands of the ith buyer. The total costs per unit time for the ith buyer can thus be expressed as

$$B_i = \frac{A_i}{T_i} + \frac{h_i d_i T_i}{2} \tag{1}$$

and $Q_i = d_i T_i$. This is the simple standard EOQ model so that the costs per unit time are minimized when

$$T_i = \sqrt{\frac{2A_i}{h_i d_i}} \tag{2}$$

The vendor is faced with orders from each of the n buyers based on demand rates of $d_1, d_2, \ldots, d_n$ per unit time. Thus the vendor has to satisfy a demand that occurs at an average rate of D per unit time, where

$$D = d_1 + d_2 + \ldots + d_n. \tag{3}$$

The vendor produces new items at a rate P $(P > D)$ per unit time. We assume that the vendor incurs a setup cost S_v for each production run, a holding cost of h per unit held per unit time and an order processing and shipment cost C_i for delivery to buyer i. If the vendor operates independently of the buyers and aims to satisfy the average demand rate D per unit time, then we have the simple EBQ model where the vendor starts a production run every T_v units of time and produces a total lot size of Q_v where $Q_v = DT_v$. The costs per unit time for the vendor are given by

$$V^{IND} = \frac{S_v}{T_v} + \frac{hDT_v}{2}\left(1 - \frac{D}{P}\right) + \sum_{i=1}^{n} \frac{C_i}{T_i} \tag{4}$$

The last term in Eq. (4) covers the order processing and fixed shipment costs in supplying the order quantities $Q_i = d_i T_i$ to each of the buyers. Optimization of the total cost (4) yields the simple EBQ model where the costs of the vendor per unit time are minimized by

$$T_v = \sqrt{\frac{2S_v}{hD(1 - \frac{D}{P})}} \tag{5}$$

2.2. Vendor–buyer coordination model

Coordinating the timing of deliveries to the buyers with the production policy of the vendor may enable a reduction in the inventory needed in the system to avoid stockouts. Banerjee and Burton (1994) and others proposed that the buyers all adopt a common order cycle of placing orders every T periods apart, where the vendor uses a production cycle that is an integer multiple of T, say NT. However, it would be more economical to have long cycle times for the low demand buyers and short cycle times for the high demand buyers. This can be achieved by having some basic cycle time, T, and insisting that each buyer use an integer multiple of that basic cycle time, say $k_i T$ for the ith buyer. Let the vendor production cycle time be denoted by NT, where N is also an integer.

For simplicity we assume that delivery to the buyers is instantaneous at regular intervals T apart. The result of the coordination will be a set of demands $D_1, D_2, \ldots, D_N$ over the NT periods of the vendor production cycle, where each demand is some subset of the buyers' order quantities. If buyer i, who orders every $k_i T$ time units apart, places its orders as early as possible in each of its order cycles, Chan and Kingsman (2007) showed that the total relevant cost of the coordinated vendor–buyer system is

$$\frac{S_v}{NT} + \sum_{i=1}^{n}\left(\frac{A_i}{k_i T} + \frac{1}{2} d_i h_i k_i T + \frac{C_i}{k_i T} + d_i\left[\frac{D}{P} - \frac{1}{2}\right] h k_i T\right) + \left[\frac{hD}{2} - \frac{hD^2}{2P}\right] NT. \tag{6}$$

The first term is the vendor's setup cost. The first two terms in the summation are the buyers' ordering cost and the buyers'