Transportation Research Part E 80 (2015) 142–165

Contents lists available at ScienceDirect

Transportation Research Part E

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

Economic and environmental considerations in a continuous review inventory control system with integrated transportation decisions

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ARTICLE INFO

Article history:
Received 18 February 2015
Received in revised form 2 April 2015
Accepted 6 May 2015
Available online 14 June 2015

Keywords:
Sustainability
Inventory control
Transportation
Stochastic demand

ABSTRACT

Sustainability throughout supply chains is gaining more importance and re-planning inventory operations can help companies curb emissions. In this study, we present two bi-objective integrated continuous review inventory control and transportation models with less-than-truckload and truckload carriers. Solution methods to approximate the Pareto Frontiers are proposed. Numerical studies illustrate the effects of demand variance and lead time on expected costs and carbon emissions as well as the changes in expected costs and carbon emissions due to sustainability considerations. Sample examples illustrate the use of the methods to compare different carriers in terms of not only economic but also environmental considerations.

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1. Introduction

Sustainability throughout supply chains is gaining more importance every day. Recent review papers on sustainable supply chain management document the necessity and importance of integrating sustainability with supply chain/operations management (see, e.g., Corbett and Kleindorfer, 2001a,b; Linton et al., 2007; Dekker et al., 2012). Mainly, companies are motivated to green their operations by regulatory requirements and increasing awareness of customers on climate change (Srivastava, 2007). In particular, policy makers implement environmental regulations, such as carbon taxing, carbon cap, and carbon trading as incentives for firms to increase sustainability of their operations. Aside from these regulations, companies today are able to get a competitive advantage by selling greener products (Bouchery et al., 2012). For instance, as a result of a survey among 582 European companies, Loebich et al. (2011) note that while the environmental regulations were the main reasons why companies green their operations in 2008, brand image improvement and executive board decisions were the top motivations for taking green actions in 2010. In another survey study, Kiron et al. (2012) highlight that two-thirds of 2874 managers/executives from 113 countries taking part in the survey see sustainability as a crucial factor in competition.

Aside from manufacturing; inventory holding, freight transportation, logistics, and warehousing operations are the main supply chain activities that generate emissions in many industries. Particularly, inventory control is an important activity and appears in any type of organization (Tsou et al., 2010). Inventory control policy of a company derives the level of transportation, logistics, and warehousing activities; hence, it is the key determinant of the emissions generated. It is thus not surprising that there is an increasing number of studies focusing on sustainable inventory control models. In this paper, we analyze sustainability in an inventory control system with integrated transportation decisions under stochastic demand.

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http://dx.doi.org/10.1016/j.tre.2015.05.006
1366-5545/Published by Elsevier Ltd.

From a practical point, many companies plan their inventory control and inbound transportation operations simultaneously as one affects the other. Inventory control policy, for instance, determines the frequency and amount of shipments. These, in turn, determine the transportation costs and emissions. Therefore, transportation carrier selection integrated with inventory control is an important decision that affects a company's economic and environmental performance. For instance, there might be many carriers available for outsourcing inbound transportation, which is a common business practice (see, e.g., Gurler et al., 2014); and, each carrier might have different charges. Furthermore, since different carriers operate different transportation vehicles, they will also have distinct environmental performance. Therefore, a company, who wishes to plan its inventory control and transportation operations, should compare different carriers in terms of not only costs but also environmental performance. In this study, we provide tools that can be used to compare different carriers in terms of economic and environmental performance.

Particularly, the most of the studies integrating sustainability with inventory control analyze the deterministic demand inventory control models. Nevertheless, deterministic demand assumption is very restrictive. There is a limited number of studies that focus on inventory control with environmental considerations in stochastic demand scenarios and the majority of these studies investigate single-period decisions. In this study, we investigate the continuous review inventory control model over a long planning horizon with sustainability under stochastic demand. Specifically, we analyze the (Q, R) policy, in which a retailer orders Q units whenever his/her inventory level is R. In the classic (Q, R) model, the retailer's objective is to minimize expected costs due to inventory holding, order setups, and shortages. However, as noted by Dekker et al. (2012), profit maximization (or cost minimization) is not the only objective for companies. Many studies on sustainable supply chains, therefore, consider not only economic objectives such as cost minimization or profit maximization but also environmental objectives such as emission minimization (see, e.g., Li et al., 2008; Kim et al., 2009; Ramudhin et al., 2010; Wang et al., 2011; Bouchery et al., 2012; Chaabane et al., 2012).

Similar to Bouchery et al. (2012), we formulate a sustainable continuous review inventory control model by considering two objectives: cost minimization and emission minimization. Multi-objective continuous review inventory control models have been analyzed in the literature for the classical (Q, R) settings (see, e.g., Agrell, 1995; Puerto and Fernandez, 1998; Tsou, 2008, 2009). To the best knowledge of the authors, the current study is the first that introduces an environmental objective into a continuous review inventory control model. Furthermore, we contribute to the sustainable inventory control models by analyses of stochastic demand inventory systems with integrated transportation decisions.

Specifically, a major share of greenhouse gas (GHG) emissions comes from the transportation sector. According to ECOFYS (2010), around 15% of 2010 global GHG emissions resulted from transportation, including passenger and freight transportation. For instance, EEA (2013) data shows that 25% of France's GHG emissions, 17% of Germany's GHG emissions, and 20% of the U.K.'s GHG emissions in 2010 were generated from transportation sector. In the European Union (EU), approximately 25% of the total GHG emissions was due to transportation in 2010 (EU, 2013). In the U.S., transportation sector generated 27% of the total GHG emissions in 2011 (EPA, 2013). While the passenger transportation is the major player in transportation GHG emissions, freight transportation significantly contributes to transportation GHG emissions. Among freight transportation modes, the major contributor to GHG emissions is the road transportation. For instance, in 2010 in the EU, more than 70% of transportation emissions comes from road transportation including light-duty and heavy-duty vehicles (EU, 2013) and almost 19% and 22% of 2010 U.S. transportation emissions were generated by light-duty and medium/heavy-duty trucks, respectively (EPA, 2013). The statistics on the fact that freight trucks are the main contributors to GHG emissions of freight transportation are not surprising as freight trucks are the most common transportation mode. Furthermore, considering the anticipated increases in freight transportation in both European countries and the U.S. (see, e.g., Toptal and Bingol, 2011; FHWA, 2008), it is important to consider freight trucks in transportation integrated with inventory control decisions to accurately model sustainable inventory control decisions.

To this end, we consider the proposed sustainable (Q, R) model with two different common types of road freight transportation: less-than-truckload (LTL) transportation and truckload (TL) transportation. In LTL transportation, the retailer is charged on the number of units (or volume or weight units) shipped. The settings of the (Q, R) model with LTL transportation are, therefore, parallel to the classical (Q, R) model. On the other hand, in TL transportation, the retailer is charged on the number of trucks used for transportation, which requires explicit transportation modeling. TL transportation has been integrated with inventory control decisions in the supply chain and logistics literature (see, e.g., Aucamp, 1982; Lee, 1986; Toptal et al., 2003; Toptal and Çetinkaya, 2006; Toptal, 2009; Toptal and Bingol, 2011; Konur and Toptal, 2012). Following the modeling approach in these studies, we model TL transportation explicitly by taking per truck costs and per truck capacities into account.

Furthermore, as noted previously, trucks are the main contributors to freight transportation emissions; hence, to accurately model the carbon emissions in the case of TL transportation, we include TL transportation emissions explicitly in modeling the retailer's emissions. We note that Hoen et al. (2014a) and Pan et al. (2012) define similar functions to model carbon emissions functions due to freight transportation. In order to minimize carbon emissions within a supply chain network, Pan et al. (2012) formulate a transportation problem with two modes of transportation (rail and trucks). Specifically, Pan et al. (2012) note that a piecewise discontinuous carbon emissions function is observed in TL and rail transportation. Recently, Konur (2014) and Konur and Schaefer (2014) model carbon emissions from trucks considering truck characteristics.

This study presents two bi-objective (Q, R) models: one for LTL transportation and one for TL transportation. For each of these models, we focus on approximating a set of Pareto efficient (Q, R) policies, i.e., a Pareto Frontier, among which the retailer can select a policy regarding his/her sensitiveness to the environment and/or how much he/she is willing to pay