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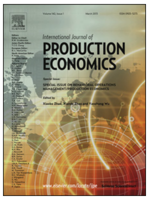

Multi-product multi-period Inventory Routing Problem with a transshipment option: A green approach

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ABSTRACT

This paper addresses a multi-product multi-period Inventory Routing Problem (IRP) where multiple capacitated vehicles distribute products from multiple suppliers to a single plant to meet the given demand of each product over a finite planning horizon.

The demand associated with each product is assumed to be deterministic and time varying. In this supply chain, the products are assumed to be ready for collection at the supplier site when the vehicle arrives. A transshipment option is considered as a possible solution to increase the performance of the supply chain and shows the impact of this solution on the environment. A green logistic issue is also incorporated into the model by considering the interrelationship between the transportation cost and the greenhouse gas emission level. The proposed model is a mixed-integer linear program and solved by CPLEX. We provide a numerical study showing the applicability of the model and underlining the impact of the transshipment option on improved supply chain performance.

1. Introduction

Because global warming is recognized as one of the greatest challenges of this century, Greenhouse gas (GHG) emissions are increasingly becoming a focus of attention. Global warming results from increased GHG concentrations in the atmosphere. In response to this challenge, a number of organizations are applying ‘green’ principles such as using environmentally friendly raw materials and recycled paper for packaging and reducing their use of fossil fuels. These green principles have been expanded to many areas, including supply chains (Chung and Wee, 2008; Zhu et al., 2008; Lin et al., 2011; Wang et al., 2012). Adding the ‘green’ concept to the ‘supply chain’ concept creates a new paradigm where the supply chain has a direct relation to the environment (e.g., Diabat and Govindan, 2011; Wang et al., 2011; Zhu and Sarkis, 2011; Eltayeb et al., 2011).

Globalization, with its increasing industrial trend towards outsourcing, has caused transportation to become the most visible sector that has increased GHG emissions over the last two decades. Transportation activities are therefore one of the primary contributors to global warming (Fig. 1), leading to the recent expansion of green logistics investigating as a subset of the green supply chain (Srivastava, 2007; Sheu, 2008; Bai and Sarkis, 2010; Yeh and Chuang, 2011; Mirzapour Al-e-hashem et al., 2013). A comprehensive review of the studies on green logistics can be found in Dekker et al. (2012). Logistics are now widely recognized as value-adding components in organizations. The primary objective of logistics is to coordinate activities such as freight transport, storage, inventory management and materials handling. One of the well-known topics typically addressed in this regard is the Inventory Routing Problem (IRP).

The IRP in a supply chain simultaneously determines the optimal inventory levels, delivery routes, and vehicle scheduling based on the minimal cost criterion (Moin et al., 2011). In the past, this cost has been assessed solely in economic terms. Due to the increasing of environmental concerns, companies must better account for the external costs of logistics associated with global warming such as air pollution, noise, vibrations and accidents (Quariguasi et al., 2009). This study attempts a novel approach of reducing GHG emissions in IRPs to achieve a balance between economic and environmental objectives.

In Section 2, we review previous studies on the IRP in existing literature. We describe the Inventory Routing Problem under study in Section 3; its mathematical formulation is then provided in Section 4. A numerical study, as well as the managerial insights, is provided in Section 5 and Section 6 concludes the paper and proposes further research in this field.

2. Literature review

Transportation and inventory management are two key logistic drivers of Supply Chain Management (SCM). The coordination of

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these two drivers, often known as the IRP, is typically the issue at hand in vendor-managed inventory systems (VMI) (Zachariadis et al., 2009).

VMI is the state of the art in value-added logistics. This practice constitutes a win/win approach to inventory management; the suppliers make replenishment decisions based on specific inventory and supply chain policies (saving on distribution and production costs by combining and coordinating demands and shipments for different customers), while the buyers gain by not allocating resources to controlling and managing inventories (Coelho et al., 2012).

Andersson et al. (2010) presented a classification and comprehensive literature review of Inventory Routing Problems. Another review of studies on IRPs can be found in Moin and Salhi (2007). IRPs can be broadly categorized according to the following criteria: finite or infinite planning horizons (Anily and Federgruen, 1990; Archetti et al., 2007), single or multiple periods (Moin et al., 2011), single or multiple customers (Bertazzi and Speranza, 2002; Sindhuchao et al., 2005; Archetti et al., 2007), single or multiple items (Sindhuchao et al., 2005; Huang and Lin, 2010), identical (homogeneous) or non-identical vehicles (Persson and Gothe-Lundgren, 2005), and deterministic or stochastic demand (Kleywegt et al., 2002; Kleywegt et al., 2004; Bertazzi et al., 2013; Chen and Lin, 2009). Several other variants of IRPs can also be found, depending on the underlying assumptions in the models such as IRPs with direct deliveries (Mishra and Raghunathan, 2004) or with transshipment options (Nonas and Jornsten, 2005, 2007; Coelho et al., 2012).

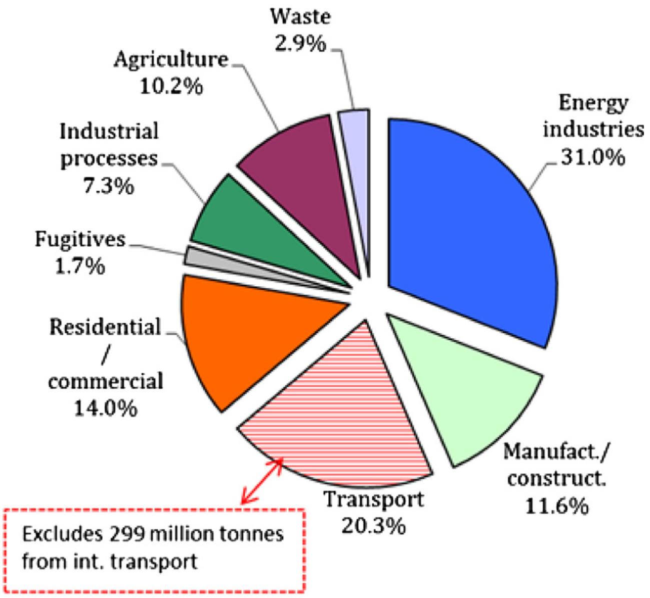


Fig. 1. Total GHG emissions by sector in the EU-27, 2011. (European Environment Agency, 2013).

To the best of our knowledge, this study is among the first to consider the concept of “green logistics” in IRP models. We consider green logistics through incorporating a decision variable that would enable the proposed model to select the appropriate vehicle by considering the greenhouse gas emission levels, vehicle capacity and transportation cost.

This paper also considers a transshipment option within the proposed Inventory Routing Problem. Under this policy, a vehicle may either provide a specific product for an assembly plant directly from the supplier which produces the product or from other suppliers which temporarily stored this product from previous trips (Nonas and Jornsten, 2007). More discussion about transshipment option can be found in the studies of Herer et al. (2002), Burton and Banerjee (2005), Lee et al. (2007), Tiacci and Saetta (2011), Chen et al. (2012), Hochmuth and Köchel (2012). From a practical point of view, the use of a transshipment option improves the performance of a supply chain through lead time reduction; in this study, the impact of transshipment on GHG emissions is also discussed.

3. Problem description

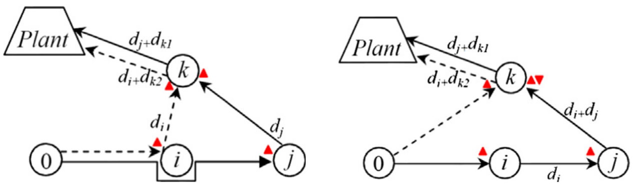
Assume that a company consists of one assembly plant (Node F) and a set of suppliers {1, 2, …, *N*}; each supplier provides one product type for the assembly plant. The company has an internal contract with a rental truck company (Depot) that ships the products from the suppliers to the assembly plant in each period. This rental truck company has several types of trucks, each one is characterized by its own capacity, fixed and variable transportation cost rate and its GHG emission index.

The optimization problem must find the best configuration of the vehicle types, routes, pickups, deliveries and transshipments in each period in a manner that minimizes the total cost of the supply chain, including the inventory holding cost and transportation cost, while satisfying all constraints.

Allowing the vehicles to temporarily store pickups during their trips at a supplier storage area located along their itinerary is known as transshipment-enabled IRP. As previously mentioned, our research is developed on the premise that the use of a transshipment option improves supply chain performance through lead time reduction. To explain this premise we consider a simple illustrative example.

Fig. 2 illustrates the case of 3 suppliers and 2 periods to discuss the possible reduction in travel distance by transshipment-enabled IRP.

In solution (a), nodes *j* and *k* are visited by the vehicle in period 1 (solid arrows). The vehicle picks up d_j and d_{k1} (cf. the table) units of product type *j* and *k*, respectively. In the next period (dashed arrows), node *j* has no demand, so the vehicle only visits nodes *i* and *k* and picks up d_i and d_{k2} units of product type *i* and *k*, respectively.



Solution (a)		Solution (b)	Demand		
			Node	***period$_1$***	***period$_2$***
Trips in period 1 →	Load ▲		***i***	-	d_i
Trips in period 2 - -→	Unload ▼		***j***	d_j	-
Supplier ○			***k***	d_{k1}	d_{k2}

Fig. 2. How transshipment can reduce travel distances.

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