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Modeling a green inventory routing problem for perishable products with horizontal collaboration

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ABSTRACT

Increasing concerns on energy use, emissions and food waste requires advanced models for food logistics management. Our interest in this study is to analyse the benefits of horizontal collaboration related to perishability, energy use (CO_2 emissions) from transportation operations and logistics costs in the Inventory Routing Problem (IRP) with multiple suppliers and customers by developing a decision support model that can address these concerns. The proposed model allows us to analyse the benefits of horizontal collaboration in the IRP with respect to several Key Performance Indicators, i.e., emissions, driving time, total cost comprised of routing (fuel and wage cost), inventory and waste cost given an uncertain demand. A case study on the distribution operations of two suppliers, where the first supplier produces figs and the second supplier produces cherries, shows the applicability of the model to a real-life problem. The results show that horizontal collaboration among the suppliers contributes to the decrease of aggregated total cost and emissions in the logistics system. The obtained gains are sensitive to the changes in parameters such as supplier size or maximum product shelf life. According to experiments, the aggregated total cost benefit from cooperation varies in a range of about 4–24% and the aggregated total emission benefit varies in a range of about 8–33% compared to the case where horizontal collaboration does not exist.

1. Introduction

Vertical and horizontal collaboration are the two main modes of collaboration commonly applied in logistics. Vertical collaboration involves companies operating at different levels of the supply chain, e.g., cooperation between a wholesaler and a retailer, whereas horizontal collaboration involves companies from the same level of the supply chain, e.g., cooperation between two wholesalers [16]. Relatively more attention has been given to vertical collaboration in logistics literature and the research on horizontal logistics collaboration is accordingly in its infancy [21,35,48]. The approach of applying only vertical collaboration to a supply chain has been challenged by new drivers such as increased energy costs, stricter government transport regulations and a broader focus on sustainability [7]. This transition has raised the importance of taking both collaboration opportunities into account simultaneously while tackling logistics problems. One of the problems in the literature that incorporates both vertical and horizontal collaboration opportunities is a variant of the Inventory Routing Problem (IRP) where multiple suppliers and customers exist.

The IRP addresses the coordination of inventory management and vehicle routing in a supply chain [27]. The variant of the IRP tackled here concerns the transportation of products between a number of suppliers and customers [6]. This problem requires vertical collaboration among suppliers and customers, and horizontal collaboration among suppliers. The vertical and horizontal collaboration enables us to have a centralized system in which suppliers collectively act as a single entity in their logistics operations and take on the responsibility of managing inventories at customers. Suppliers decide on quantity and time of the shipments to the customers, but have to bear the responsibility that the customers do not run out of stock [6]. Such a system offers potential logistics efficiency gains to suppliers through jointly using vehicles. Moreover, suppliers can better coordinate deliveries to customers, since the vehicle routes can be based on the inventory levels observed at the customers rather than the replenishment orders coming from the customers, and customers do not have to dedicate resources to inventory management [17,15,41].

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The IRP in this study comprises a 3PL which serves as a rental vehicle company, and multiple suppliers and customers. Fig. 1 shows a generic representation of the problem. Suppliers provide several product types with fixed shelf lives to customers. The problem has multiple periods and customer demand is not known in the beginning of the planning horizon. The main decisions involved are (1) when to deliver to each customer, (2) how much to deliver to each customer each time it is served, and (3) how to combine customers into vehicle routes [13,18]. The traditional objective is to minimize total distribution and inventory costs during the planning horizon without causing stock-outs at any of the customers [1,38].

Traditional OR models for the IRP focus mainly on the key logistical aim of cost reduction. However, the need to reduce transportation energy use, emissions, and product waste require extension of the key logistical aims [49]. Regarding energy use, the traditional approaches often rely on distance-based cost calculation, whereas fuel consumption and therefore cost can change based on e.g. vehicle load, which is dependent on the visiting order of the customers [31,33,51,36], vehicle speed or vehicle characteristics [43]. Ignoring explicit fuel consumption may lead to missed opportunities to reduce operational cost and emissions. Regarding perishability, the traditional approaches often assume that products have unlimited shelf lives, whereas this is not always the case, especially for food supply chains. Ignoring perishability thus restricts the use of traditional approaches in supply chains for perishable products. The need for decision support tools that can incorporate these additional key logistical aims as well as traditional cost concerns has accordingly increased.

From this point of view, our interest in this study is to analyse the benefits of horizontal collaboration in the IRP with multiple suppliers and customers by developing a decision support model that can address the concerns for perishability of goods, explicit energy use (CO_2 emissions) from transportation operations, logistics cost and demand uncertainty. To the best of our knowledge, such an attempt has not yet been made for the IRP. The rest of the paper is structured as follows. The next section presents a review of the relevant literature on the IRP and clarifies the contribution of our work. The subsequent section presents the formal description of the problem and related optimization model. This section is followed by computational results for a real life distribution problem. The last section presents conclusions and future research directions.

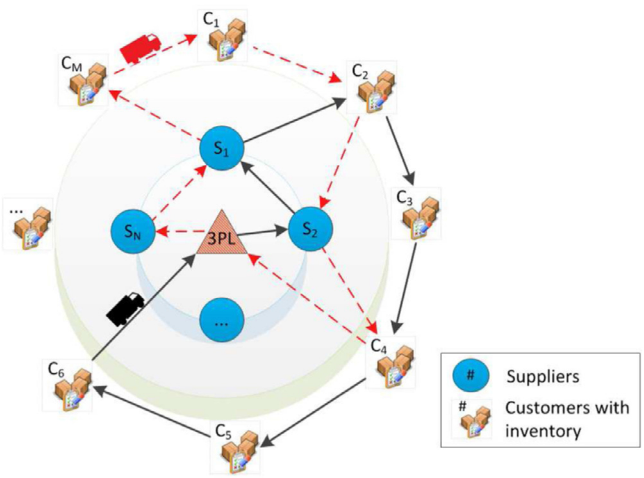

Fig. 1. A generic representation of the Inventory Routing Problem with multiple suppliers and customers.

2. Related literature review

The IRP literature describes mainly three types of distribution networks according to the number of suppliers and customers involved: (1) one-to-one: one supplier serves one customer, (2) one-to-many: one supplier serves a set of customers which is the most common case, and (3) many-to-many: several suppliers serve a set of customers [18]. Our problem is classified as a many-to-many structure, which is the least studied variant in the literature [18,44]. Table 1 presents the overview of the related literature on IRP. As shown in this table, the studies on IRP with a many-to-many structure manage either a single product (e.g., [8,46]) or multiple products (e.g., [45,42]). All studies on the IRP with many-to-many structure do not consider perishability and explicit energy use. These attempts, therefore, regard only distance while calculating distribution costs and address management of only non-perishable products. Moreover, none of these studies has discussed the effects of horizontal logistics collaboration on logistics Key Performance Indicators (KPIs).

Our review on variants of the IRP shows that only few studies have introduced new KPIs to the proposed models (see

Table 1
Overview of the related literature on IRP.

Studies	Perishability		Fuel or emissions considerations			Demand uncertainty	Product #	Distribution structure
	Shelf life	Waste	Traveled dist.	Load	Speed			
Federgruen et al. [25]	√	√	–	–	–	√	Single	One-to-many
Bard et al. [8]	–	–	–	–	–	√	Single	Many-to-many
Ronen [45]	–	–	–	–	–	√	Multiple	Many-to-many
Persson and Gothe-Lundgren [40]	–	–	–	–	–	-	Multiple	Many-to-many
Al-Khayyal and Hwang [2]	–	–	–	–	–	-	Multiple	Many-to-many
Savelsbergh and Song [46]	–	–	–	–	–	-	Single	Many-to-many
Savelsbergh and Song [47]	–	–	–	–	–	-	Multiple	Many-to-many
Benoist et al. [12]	–	–	–	–	–	-	Single	Many-to-many
Ramkumar et al. [42]	–	–	–	–	–	-	Multiple	Many-to-many
Treitl et al. [52]	–	–	√	√	√	-	Single	One-to-many
Mirzapour Al-ehashem and Rekik [37]	–	–	√	–	–	-	Multiple	Many-to-one
Le et al. [34]	√	–	–	–	–	-	Single	One-to-many
Alkawaleet et al. [4]	–	–	√	–	–	-	Single	One-to-many
Al Shamsi et al. [3]	√	–	√	√	√	-	Single	One-to-many
Coelho and Laporte [20]	√	√	–	–	–	-	Single	One-to-many
Jia et al. [29]	√	√	–	–	–	-	Single	One-to-many
Soysal et al. [50]	√	√	√	√	√	√	Single	One-to-many
This study	√	√	√	√	√	√	Multiple	Many-to-many