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# Modeling an Inventory Routing Problem for perishable products with environmental considerations and demand uncertainty

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ABSTRACT

The transition to sustainable food supply chain management has brought new key logistical aims such as reducing food waste and environmental impacts of operations in the supply chain besides the traditional cost minimization objective. Traditional assumptions of constant distribution costs between nodes, unlimited product shelf life and deterministic demand used in the Inventory Routing Problem (IRP) literature restrict the usage of the proposed models in current food logistics systems. From this point of view, our interest in this study is to enhance the traditional models for the IRP to make them more useful for the decision makers in food logistics management. Therefore, we present a multi-period IRP model that includes truck load dependent (and thus route dependent) distribution costs for a comprehensive evaluation of $CO_2$ emission and fuel consumption, perishability, and a service level constraint for meeting uncertain demand. A case study on the fresh tomato distribution operations of a supermarket chain shows the applicability of the model to a real-life problem. Several variations of the model, each differing with respect to the considered aspects, are employed to present the benefits of including perishability and explicit fuel consumption concerns in the model. The results suggest that the proposed integrated model can achieve significant savings in total cost while satisfying the service level requirements and thus offers better support to decision makers.

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## 1. Introduction

Ensuring collaborative relationships throughout a supply chain is an effective strategy to gain competitive advantage. Vendor Managed Inventory (VMI) refers to a collaboration between a vendor and its customers in which the vendor takes on the responsibility of managing inventories at customers (Hvattum and Løkketangen, 2009). The vendor decides on quantity and time of the shipments to the customers, but has to bear the responsibility that the customers do not run out of stock (Andersson et al., 2010). The VMI policy is often regarded as a win–win arrangement: 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 (Coelho et al., 2012a; Campbell et al., 1998; Raa and Aghezzaf, 2009). Due to such benefits, and the increase in availability of monitoring technologies facilitating the share of accurate and timely information among the chain partners, the VMI policy has received much attention in recent years. However, execution of the VMI policy in an effective way is not a simple task, since under this policy the vendor has to deal with an integrated problem consisting of its own vehicle routing decisions and inventory decisions of customers (Campbell and Savelsbergh, 2004; Raa and Aghezzaf, 2009). This integrated problem, especially arising in VMI systems (Yu et al., 2008), is known in the literature as the Inventory Routing Problem (IRP).

The IRP addresses the coordination of two components of the supply chain: the inventory management and the vehicle routing (Jemai et al., 2013). A generic representation of the IRP is illustrated in Fig. 1. The traditional objective is to minimize total distribution and inventory costs during the planning horizon without causing stock-outs at any of the customers (Aghezzaf et al., 2006). The supplier has to make three simultaneous decisions: (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 (Bertazzi et al., 2008; Coelho et al., 2012b). In the traditional Vehicle Routing Problems (VRPs), the supplier aims to satisfy the orders given by the customers so as to minimize total distribution cost. On the contrary, in the IRP, orders are determined by the supplier based on input on customers usage (demand). Moreover, in the IRP, the supplier aims to manage inventory of customers such that they do not experience a stock-out, whereas traditional VRPs do not have such a concern. The presence of the inventory component in the IRP adds a time dimension to the related routing problem (Bertazzi et al., 2008). The IRP is thus regarded as a medium-term problem, whereas the VRP

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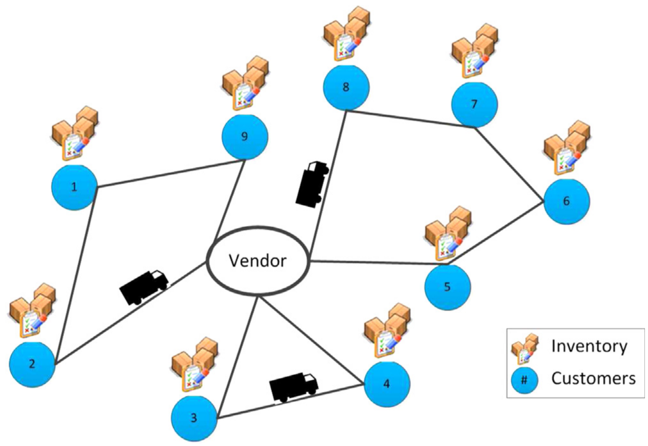


**Fig. 1.** A generic representation of the Inventory Routing Problem.

is a short term one (Moin and Salhi, 2007). Applications of the IRP arise in a large variety of industries, including the distribution of liquified natural gas, raw material to the paper industry, food distribution to supermarket chains, automobile components, perishable items, groceries, cement, fuel, blood, and waste organic oil (see respective references in Coelho and Laporte, 2013; Coelho et al., 2012b).

In the last two decades, food supply chain management has evolved due to various reasons such as demand for safe and high quality food products, increasing health consciousness of consumers, growth of world population, climate change, limited natural resources and escalating sustainability awareness. More specific, food logistics systems have seen the transition from a focus on traditional supply chain management to food supply chain management, and successively, to sustainable food supply chain management (Soysal et al., 2012). This transition has brought new key logistical aims besides the cost minimization objective: (i) the ability to control product quality in the supply chain and deliver high quality food products in various forms to final consumers by incorporating product quality information in logistics decision making, (ii) the ability to collaborate in the supply chain network to reduce food waste and (iii) the ability to reduce environmental and societal impacts of operations (Soysal et al., 2012). The aforementioned developments have stimulated companies and researchers to consider multiple Key Performance Indicators (KPIs) such as cost, food waste and transportation emissions in food logistics management projects (e.g., Zanoni and Zavanella, 2012; Soysal et al., 2014).

Some traditional assumptions in the IRP literature restrict the usage of the proposed models in current food logistics systems. These assumptions, which can be regarded as doubtful from the practical point of view, are summarized as follows. First, IRP models often assume that distribution costs between nodes are known in advance and are constant (e.g., Vidović et al., 2014; Qin et al., 2014). However, fuel consumption and therefore cost can change based on vehicle load which is dependent on the visiting order of the customers (Kara et al., 2007; Kuo and Wang, 2011). The literature for a number of VRPs shows that an explicit consideration of fuel consumption in logistics operations can help us to reduce relevant operational costs and environmental externalities (e.g., Bektaş and Laporte, 2011; Franceschetti et al., 2013). Second, a common assumption of an unlimited product shelf life in the IRP models is restrictive in that it does not allow for the consideration of quality decay of products. This is one of the main obstacles for the application of the basic IRP models in food logistics management. Third, a widespread tendency is to assume that customer usages are known in advance in the beginning of the planning horizon, which is clearly not the case in reality. These are the main weaknesses of the basic IRP models to be improved.

From this point of view, our interest in this study is to enhance the traditional models for the IRP to make them more useful for the decision makers in food logistics management. In order to achieve that improvement, we do not rely on all common assumptions of the basic IRP models. Therefore, in our problem setting, distribution costs between nodes are not known in advance and can change according to the routing schedule employed, the product is subject to quality decay because of the perishability nature and customer usage is not known a priori. Moreover, we estimate fuel consumption and emissions based on a comprehensive emissions model that allows us to incorporate transportation cost and emissions more accurately and explicitly. Consequently, we develop a comprehensive chance-constrained programming model for the multi-period IRP that accounts for perishability, explicit fuel consumption and demand uncertainty. The proposed model manages relevant KPIs of total energy use (emissions), total driving time, total routing cost, total inventory cost, total waste cost, and total cost, simultaneously. 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. Section 2 presents a review of the relevant literature on the IRP and clarifies the contribution of our work. Section 3 defines the problem and presents the optimization model. Section 4 presents three different variations of the proposed model, which are employed to show the benefits of including perishability and explicit fuel consumption considerations in the model. Section 5 presents a simulation for the problem to evaluate the solutions of the optimization models. Section 6 presents computational results on a real life distribution problem. The last section presents conclusions and future research directions.

## 2. Related literature review

The traditional IRP without perishability and sustainability concerns has been extensively studied in the literature. The interested reader is referred to the reviews by Moin and Salhi (2007), Andersson et al. (2010) and Coelho et al. (2012b) on the topic. Our focus here is on attempts aimed to incorporate additional KPIs to the IRP. Relatively few studies on the IRP have bothered to introduce new KPIs to the proposed models. We can subdivide the related literature into two groups: (i) studies with perishability considerations and (ii) studies with environmental or societal considerations.

First, we review the studies on IRP with perishability considerations. Federgruen et al. (1986) study the IRP for a perishable product with a fixed lifetime during which it can be used and after which it must be discarded, e.g., human blood, food and medical drugs. They distinguish two age classes, fresh and old, based on the product remaining lifetime and discard the product that reaches the maximum age in inventory. Le et al. (2013) and Al Shamsi et al. (2014) study the IRP for a perishable product with a fixed lifetime as well. Both studies restrict the total amount of time that products can be stored in facilities and do not allow product wastes. Coelho and Laporte (2014) integrate an age tracking approach to the IRP of a perishable product with a fixed shelf life. The age tracking approach ensures to distinguish products according to their shelf lives and has also been used in the literature for other logistics problems such as inventory problems (Haijema, 2013), and production and distribution problems (Rong et al., 2011; Van Elzakker et al., 2014). Jia et al. (2014) incorporate quality time windows (shelf life limit) to the IRP of a perishable product with the same objective as the age tracking approach: controlling deteriorating item's quality which has a fixed shelf life.

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