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A robust inventory routing policy under inventory inaccuracy and replenishment lead-time

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A B S T R A C T

In this paper, we study an inventory routing problem under replenishment lead-time and inventory inaccuracy, which exist extensively in distribution systems for fresh products, but are often ignored in existing research. To solve the problem, a robust inventory routing policy is developed in three steps. At first, we propose the methods of updating the probability of the current net inventory and predicting those in future periods. For each candidate route, we develop a *Robust TQL Algorithm* to optimize the replenishment time, replenishment quantity and replenishment stage length. Finally, a genetic algorithm-based method is developed to optimize the delivery route.

1. Introduction

In the context of the vendor-managed inventory (VMI), for a distribution system that are composed of a vendor and several geographically dispersed retailers, the ideal management ensures that merchandises are distributed in the right quantities, to the right locations, and at the right time, in order to minimize the system-wide cost, while satisfying the service level requirement. The vendor needs to decide when to visit the retailers, how many items to deliver to each of them, and how to plan the delivery routes. This problem is known as the inventory routing problem (IRP), which dates back three decades (Coelho et al., 2014). In IRPs, transportation management and inventory control are combined together. By considering both inventory control and routing, integrated approaches can be developed to obtain mutual benefit. The IRP has received considerable attention in the last decade (Coelho and Laporte, 2013), and researchers have contributed a lot in this field. However, two significant and realistic factors are often ignored, they are inventory inaccuracy and replenishment lead-time.

Inventory inaccuracy means the discrepancy between the inventory record and the physical net inventory. DeHoratius and Raman (2008) showed that inventory inaccuracy cost retailers as much as 10% of their profit. It has been reported in the literature that inventory inaccuracy may considerably worsen the performance of inventory management. For example, Kang and Gershwin (2005) pointed out that very severe out-of-stock might be caused by a very small rate of undetected stock loss. However, for IRP, inventory inaccuracy has not been taken into consideration yet. In IRP, the vendor needs to make an integrated decision according to the inventory status of all the retailers in the distribution system. All the retailers face inaccurate inventory records, which surely hinder the optimal decision on distribution time, replenishment quantity and routing. Therefore, an entirely new approach needs to be developed to solve the problem, which is the first motivation of this research.

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Another motivation for this work is that we find in existing research on IRP, the time taken in transportation is often ignored. For example, in the basic model of IRP (Coelho et al., 2014), all the items reach the retailers in the same period that they are delivered from the vendor. However, in certain situations, transportation time cannot be ignored. For example, in China Wal-Mart has 11 fresh products distribution centers that are in charge of delivering fresh products to about 400 stores in 160 cities. Each center covers a large area. Due to the short life cycle and high loss rate of fresh products, for avoiding the stock out and reducing the unnecessary loss in the inventory, transportation time in the decision process is very important and cannot be ignored. If the transportation time is considered, different routes may lead to different lead-times for replenishment, which makes the decisions on replenishment quantity and routing depend on each other more tightly.

In this paper, by considering a multiple-retailers, multiple-product type distribution system with inaccurate inventory records and replenishment lead-time, we aim to design a robust myopic replenishment and routing policy which can hedge against inventory inaccuracy in the distribution systems, and is easy to implement in practice.

The rest of this paper is organized as follows: In Section 2, a literature review of the existing research on inventory inaccuracy and IRP is given. In Section 3, an IRP with inventory inaccuracy and lead-time for replenishment is described and formulated mathematically. In Section 4, we develop a robust inventory routing policy for this IRP. In Section 5, numerical experiments are conducted to examine the performance of the proposed robust policy. In Section 6, the main contributions of this research are summarized, with remarks on some recommendations for future research.

2. Literature review

In this section, we give a brief review on the work related to this research from two perspectives, i.e. inventory inaccuracy and the inventory routing problem.

2.1. Inventory inaccuracy

Inaccurate record is widespread in inventory systems. DeHoratius and Raman (2008) found that inventory inaccuracy exists in 65% of the nearly 370,000 inventory records observed across 37 retail stores. At present, most research on inventory inaccuracy focuses on the replenishment problem of a retailer, examining how to manage the inventory of a retailer with inaccurate inventory records. Generally speaking, there are three main ways for dealing with inventory record inaccuracy:

(1) *Obtain accurate net inventory by audits, and then eliminate the impact of inaccuracy temporarily.* For example, Kök and Shang (2014) considered a serial supply chain and proved that it is more effective to conduct more frequent audits at the downstream stage. Agrawal and Sharda (2012) employed a simulation model to investigate the relationship between the stock loss and the frequent alignment of physical inventories and information system inventories.

(2) *Develop inventory management policies in the context of inaccurate inventory record.* DeHoratius et al. (2008) developed a Bayesian inventory record accounting method and corresponding replenishment policy so that the cost caused by inventory inaccuracy was compensated to a large extend. Rekik (2011) constructed a general framework for addressing inventory inaccuracy issues and found a connection between these issues and the random yield problem. Sahin and Dallery (2009) modeled a Newsvendor supply chain with inventory inaccuracy and assess the impact of inventory inaccuracy quantitatively. Mersereau (2013) modeled an inventory system with inventory inaccuracy as a partially observed Markov decision process (POMDP) and proposed a forward-looking replenishment policy. Some researches considered the integration of the above two ways. For example, Kök and Shang (2007) and Rekik and Sahin (2012) investigated the combined inspection and replenishment policies for a system with inaccurate inventory records.

(3) *Eliminate inventory inaccuracy based on automatic product identification technologies such as radio-frequency identification (RFID).* Heese (2007) and Rekik et al. (2009) found that RFID technology could solve the inventory inaccuracy problem to some extent. However, due to the expensive prices of the RFID devices, Chang et al. (2010) pointed out that the employment of RFID systems needs to be evaluated carefully. Moreover, RFID devices cannot eliminate inventory inaccuracy completely. For example, Metzger et al. (2013) investigated the measurement errors due to the limitations of radio frequency communications (i.e., imperfect read rates) and evaluated the impact on the performance of RFID-based shelf inventory control policies. To our knowledge, inventory inaccuracy has not been taken into consideration in inventory routing problems.

Although we accept that above three approaches are not exclusive and their integration is meaningful, our focus in this paper is primarily on the second approach mentioned above. Therefore, we investigate a robust inventory routing policy that can hedge against inventory inaccuracy.

2.2. Inventory routing problem

The study of IRP is rooted in the paper of Bell et al. (1983). Dror et al. (1985) gave a precise definition of the inventory routing problem (IRP). The most prominent feature of an IRP is the trade-off between the inventory and transportation cost and the risk of stock-out. Andersson et al. (2010) provided a good review of IRP and classified the literature in the time dimension, reflecting the planning periods used: *instant*, *finite* and *infinite*. This classification is adopted in this subsection in reviewing the research on IRP in recent years. In *instant time horizon* models, the planning horizon is so short that at most