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Considering lost sale in inventory routing problems for perishable goods ☆

Samira Mirzaei [a], Abbas Seifi [b,*]

[a] Cluster for Operations Research and Logistics, Department of Economics and Business, Aarhus University, Aarhus, Denmark
[b] Department of Industrial Engineering and Management Systems, Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

This paper presents a mathematical model for an inventory routing problem (IRP). The model is especially designed for allocating the stock of perishable goods. It is assumed that the age of the perishable inventory has a negative impact on the demand of end customers and a percentage of the demand is considered as lost sale. The proposed model balances the transportation cost, the cost of inventory holding and lost sale. In addition to the usual inventory routing constraints, we consider the cost of lost sale as a linear or an exponential function of the inventory age. The proposed model is solved to optimality for small instances and is used to obtain lower bounds for larger instances. We have also devised an efficient meta-heuristic algorithm to find good solutions for this class of problems based on Simulated Annealing (SA) and Tabu Search (TS). Computational results indicate that, for small problems, the average optimality gaps are less than 10.9% and 13.4% using linear and exponential lost sale functions, respectively. Furthermore, we show that the optimality gaps found by CPLEX grow exponentially with the problem size while those obtained by the proposed meta-heuristic algorithm increase linearly.

1. Introduction

Inventory routing problem (IRP) is a major concern in supply chain management. The aim is to integrate the transportation activities and inventory management along the supply chain and avoid the inefficiency caused by solving the underlying vehicle routing and inventory subproblems separately.

Recent studies assume that an indefinite number of stock items can be stored to meet future customers' demand. However, the impact of perishability cannot be ignored for certain types of goods that deteriorate over time and may become partially or entirely unsuitable for consumption (Shen, Dessouky, & Ordonez, 2011). Deteriorating items refer to items that get damaged, spoiled, dried, invalid, or degraded over time (Li, Lan, & Mawhinney, 2010) and can be classified into two groups: perishable products and decaying products. Items such as meat, green vegetables, human blood, medicine, flowers, and films that have a maximum usable lifetime are known as perishable products. Commodities like alcohol and gasoline that have no shelf-life are known as decaying products (Goyal & Giri, 2001).

Although the life of the perishable products can be prolonged by advanced cooling equipment, these products lose their quality over time and this will cause a decrease in the demand for these products.

If perishable products are not delivered to retailers on a daily basis, due to the limited lifetime and possible degradation of these products, some customers will refrain from purchasing them. Thus, the demand for the products is affected by the age of the perishable inventory.

In IRP literature, some models consider shortage, stock out, or backorder costs (see for instance: Abdelmaguid & Dessouky, 2006; Abdelmaguid, Dessouky, & Ordóñez, 2009; Herer & Roundy, 1997; Jaillet, Bard, Huang, & Dror, 2002). Modeling IRP with deteriorating products and the associated cost of lost sale has not been explicitly considered in the literature. In this paper, we specifically calculate the cost of lost sale in the supply chain for perishable goods to avoid overstocking such items in an attempt to reduce transportation cost.

This paper formulates a multi-period inventory routing problem for perishable goods in which the end customers' demand depends on the age of the inventory. The proposed model includes vehicle routing decisions as well as delivery and inventory decisions over a specific planning horizon. It is a non-linear mixed

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* Corresponding author at: Department of Industrial Engineering and Management Systems, Amirkabir University of Technology (Tehran Polytechnic), P.O. Box 15875-4413, Tehran, Iran. Tel.: +98 64545377; fax: +98 66954569.

E-mail address: aseifi@aut.ac.ir (A. Seifi).

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integer programming model which is linearized to be solvable efficiently. The objective function is to minimize the total cost of transportation, lost sale, and holding inventories. In addition to the usual inventory routing constraints, we consider a nonlinear constraint that defines the inventory age as a function of delivery date. The lost sale is assumed to be a linear or an exponential function of the inventory age. The mathematical model with both linear and exponential lost sale functions is solved up to optimality for small to medium size problems. It is also used to find some lower bounds for larger instances. Since such problems are *NP*-hard due to the underlying vehicle routing problem (VRP), we develop a heuristic algorithm within a metaheuristic framework for solving larger problem instances.

The rest of this paper is organized as follows. Section 2 reviews the literature on inventory management and vehicle routing problems for perishable goods. In Section 3, the problem is formulated as a mathematical model using two different lost sale functions. The metaheuristic algorithm is described in Section 4, followed by the results of computational experiments in Section 5. Conclusions and some directions for future research are described in Section 6.

2. Literature review

In this section, we review the literature related to inventory management and vehicle routing problems with regards to perishable goods. Due to the importance of assumption on retailers' orders in modeling the inventory of perishable goods, researchers have studied a variety of constant demand, time-varying demand, stock dependent and price dependent demand (see Goyal & Giri, 2001; Li et al., 2010; Raafat, 1991; Shah & Shah, 2000). Many researchers have developed inventory models for deteriorating items with time varying end customer demand using linearly or exponentially decreasing demand (see, for instance: Chung & Ting, 1993; Dave & Patel, 1981; Giri & Chaudhuri, 1997; Hariga & Benkherouf, 1994; Sachan, 1984; Wee, 1995; Xu & Wang, 2003). This paper also assumes that the demand of end customers is a linearly or an exponentially decreasing function of the age of perishable goods.

Tarantilis and Kiranoudis (2001) proposed a threshold-accepting algorithm to solve a fresh milk distribution problem for a dairy company in Greece. They focused on a routing problem using heterogeneous vehicles. Tarantilis and Kiranoudis (2002) solved the distribution of fresh meat products in Greece using an open multi-depot VRP. They did not consider any additional constraints reflecting the perishable nature of those commodities. Hsu, Hung, and Li (2007) developed a stochastic VRP model to obtain optimal delivery routes, loads, fleet dispatching and departure times for distribution of perishable food. Their objective function was to minimize the cost of dispatching vehicles transportation as well as the inventory, energy and penalty costs for violating the time window constraints. Osvald and Stirn (2008) developed a heuristic algorithm for the problem of distributing fresh vegetables in which the impact of perishability of the goods was considered as a part of the overall distribution cost. However, since additional cost of distribution of perishable goods is insignificant compared to the transportation cost, we do not consider such details in our modeling of the VRP subproblem. This is in agreement with the practical consideration reported by Tarantilis and Kiranoudis (2001) and Tarantilis and Kiranoudis (2002).

Federgruen, Prastacos, and Zipkin (1986) are among the pioneering scholars who integrated the routing and inventory allocation in a single period problem assuming random retailers' demand for perishable products. They classified perishable products into old and fresh items. Old items would perish in the present period while other goods would be considered fresh for at least one period before becoming outdated. Le, Diabat, Richard, and Yih (2012) presented a multi-period IRP model for perishable products with a fixed shelf life in which the customer demand was deterministic and unsold goods with no value were discarded. A path flow formulation for this problem was proposed and a lower bound for the problem was obtained using column generation. In addition to the regular IRP constraints, they added another constraint guaranteeing that a retailer should not have an inventory greater than the total demand in the next consecutive time periods based on maximum shelf life of the perishable goods.

Furthermore, due to the nature of perishable products, some researchers integrated production planning or facility location problem with the VRP or IRP for perishable products (see Karaesmen, Scheller-Wolf, & Deniz, 2011). For example, Chen, Hsueh, and Chang (2009) considered the production schedule and delivery routes decisions simultaneously in order to maximize the expected profit of the supplier. Seyedhosseini and Ghoreyshi (2014) integrated production and distribution planning in an IRP model to determine product quantities, the number of distribution centers to be visited, and the quantities of perishable products to be delivered. Hiassat and Diabat (2011) proposed a model for deteriorating items in which the inventory location problem was integrated with the routing decisions for deterministic demand. We do not, however, take the production program or facility location into consideration in this paper and we focus on IRP for perishable goods. We have not found any literature that includes the cost of lost sale explicitly in the formulation of IRP for perishable goods as considered in our paper.

3. Problem definition

We consider a two-echelon supply chain involving a depot, a set of retailers, and a fleet of capacitated homogenous vehicles. A central depot (supplier) serves a set of geographically scattered retailers having deterministic demand. Perishable items are transported from the depot to the retailers in such a way that out-of-stock situations never occur. The problem is a multi-period routing and inventory planning problem with a finite time horizon. Retailers have limited storage capacities and their demand in each period is assumed to be known and should be met by the end of each period. It is also assumed that the end customer's demand is a linearly or exponentially decreasing function of the age of the perishable goods and any inventory unsold by the time of the next delivery is considered as lost sale. We propose a mixed integer nonlinear programming model whose objective function is the sum of the transportation cost, and the cost of inventory holding and lost sale. In addition to the usual inventory routing constraints, we consider a nonlinear constraint that defines the inventory age as a function of the delivery date. The lost sale is then expressed as either a linear or an exponential function of the inventory age. The assumptions on the VRP subproblem are the same as the ones in the classical models. Each vehicle starts its tour from the central depot and returns to the central depot after delivering the goods to a set of retailers assigned to that vehicle. A retailer is served only once and by one vehicle in each period.

3.1. Model formulation

In this section, we develop a mixed integer non-linear programming model for the IRP with lost sale (named as IRPLS) and linearize it to make it solvable using CPLEX. First, the following sets, constants, parameters, and decision variables are introduced: