Computers & Industrial Engineering 99 (2016) 189–201

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

An efficient population-based simulated annealing algorithm for the multi-product multi-retailer perishable inventory routing problem

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ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form 11 February 2016
Accepted 26 July 2016
Available online 27 July 2016

Keywords:
Inventory routing
Simulated annealing
Perishable product
Supply chain
Vendor managed inventory

ABSTRACT

This paper presents an inventory routing problem (IRP) involving perishable products with a fixed lifetime. It involves a multi-period multi-product IRP in two-level supply chains, where products are produced and delivered from a single manufacturer to several retailers utilizing multiple shipping strategies through a fleet of appropriately capacitated vehicles. The goal is to minimize total cost while ensuring that no stock out occurs. A mathematical model is presented. A population-based simulated annealing (PBSA) algorithm is proposed. This PBSA algorithm is compared with simulated annealing (SA) and genetic algorithms (GA) which shows the superiority of the PBSA algorithm. CPLEX solver, branch-and-cut method, and different relaxation methods also were used, so as to obtain upper and lower bounds. The computational experiments show the high efficiency of the PBSA algorithm.

1. Introduction

Transportation and inventory are the logistical drivers of the supply chain, and each has been the subject of numerous separate studies. Especially since the mid 1970s, though, it has been recognized increasingly that a more integrated approach can lead to significant improvement in supply chain performance. One aspect of this, and the subject of this paper, is the inventory routing problem (IRP) which arises where vendor managed inventory (VMI) systems are in operation, where a manufacturer coordinates the replenishment process of a retailer and is responsible for its in-store inventory management.

Product deterioration falls into two groups. Items such as fresh foodstuffs, human blood, and cut flowers have a maximum shelf life and are called perishable products with a fixed lifetime, while products such as alcohol and gasoline, having a demonstrably more random shelf life are called decaying products (Goyal & Giri, 2001).

This study focuses on perishable products, the starting point being the single-product model proposed by Bard and Nananukul (2009), which will be extended to incorporate multi-product perishable IRP. The objective is to present an innovative metaheuristic method for solving a multi-product multi-retailer perishable IRP by generating a conceptually near-optimal solution requiring only moderate computational time even for large problem instances.

The rest of the paper is organized as follows. In Section 2, a literature review of IRP is presented. Section 3 then details the assumptions and notations employed. Model formulation is presented in Section 4, with solution methods being described in Section 5. Computational experiments and the results obtained are set out in Section 6. Section 7 sets out the conclusions arrived at and also identify some possible directions for further research.

2. Literature review

It has been customary for researchers to classify IRP according to the importance they attach to its different elements. Baita, Ukovich, Pesenti, and Favaretto (1998) proposed seven such elements: topology, number of items, type of demand, decision domain, constraints, costs and proposed solution approaches. Kleywegt, Nori, and Savelsbergh (2002) proposed four key elements: type of demand, fleet size, length of the planning horizon, and type of delivery. Campbell and Savelsbergh (2004) in turn saw the majority of IRP research as falling into one or other of three categories: single day model, multi-day model, and permanent routing. Andersson, Hoff, Christiansen, Hasle, and Løkketangen (2010) identified seven elements in classifying IRP: length of the planning horizon, type of demand, topology, type of routing, inventory management decisions, nature of fleet composition, and fleet size. And finally, Coelho, Cordeau, and Laporte (2013) proposed

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http://dx.doi.org/10.1016/j.cie.2016.07.022
0360-8352/

two schemes: structural variants present in IRP and availability of on demand information.

As can be seen, there are a range of elements related to IRP, not all of which will be addressed here. Instead, the literature for certain elements, namely the type of products (perishable, decaying, and no deterioration), number of products, type of demand, and proposed solution approaches which are seen to be most significant for our research will be reviewed.

Brodheim, Derman, and Prastacos (1975) were among the first to work on inventory and distribution policies for perishable products; specifically they considered blood as a perishable product, and they also used Markov chain in order to model these policies. Bell et al. (1983) were among the first to investigate routing and inventory decisions simultaneously, developing a computerized optimizer which uses a Lagrangian relaxation algorithm to solve large scale mixed integer programs to near optimality.

Tarantilis and Kiranoudis (2001) presented a threshold-accepting based distribution system for fresh milk in Greece, while Zanoni and Zavanella (2007) investigated the transport-inventory system for shipping a set of perishable products in a one-to-one structure. Their objective was to minimize the sum of inventory and transportation costs, and they handled perishability constraint by stating that production, transportation and sale all occur within the corresponding expiry period. Le, Diabat, Richard, and Yih (2013) developed a column generation approach to solving perishable IRP. In their study, perishable products will never be wasted, since they envisage that a retailer never has an inventory level which is greater than the total demand in each successive planning period. Coelho and Laporte (2014) analyzed the optimal joint replenishment, delivery and inventory management policies for perishable products. They dealt with perishability constraint by two equations: one being the inventory preservation conditions for the supplier, aging the product by one unit in each planning period, and the other being that the supplier always produces fresh products.

The majority of IRP models have been analyzed by considering single products. For example, in Kleywegt et al. (2002), Campbell and Savelsbergh (2004), Zhao, Wang, and Lai (2007), Archetti, Bertazzi, Laporte, and Speranza (2007), Zhao, Chen, and Zang (2008), Le et al. (2013), and in numerous other papers. However, a number of authors also have considered multiple products, for example Speranza and Ukovich (1994), Bertazzi (2008), Moin, Salhi, and Aziz (2011), and Coelho and Laporte (2013).

Few papers hitherto have been devoted to IRP with stochastic demands. Hvattum and Løkketangen (2009) dealt with by using scenario trees and the progressive hedging algorithm. Solyalı, Cordeau, and Laporte (2011) introduced an IRP under demand uncertainty, and Bertazzi, Bosco, Guerriero, and Demetrio (2013) considered stochastic IRP with stock out. Conversely, several other papers have considered deterministic demands, for example in Zhao et al. (2007), Solyalı and Süral (2011), Le et al. (2013), and Coelho and Laporte (2013).

Since IRP includes VRP as one segment and, according to Lenstra and Rinnooy Kan (1981), VRP is NP-hard, it follows that IRP also is NP-hard. Therefore the optimal solution for the majority of IRPs probably is unreachable, due to problem complexity. For this reason almost all recent authors have introduced heuristic approaches. Abdelmaguid, Dessouky, and Ordóñez (2009) and Stålhane et al. (2012) developed constructive and improvement heuristics for IRP in order to reach an approximate solution. Zhao et al. (2008) developed a variable large neighborhood search algorithm and they also proposed fixed partition and power-of-two strategy. Bard and Nananukul (2009) presented a comparative analysis of a series of heuristics for IRP in a manufacturing supply chain. Zhong and Aghezzaf (2011) developed a combined DC-programming and branch-and-bound approach within a steepest descent hybrid algorithm. Coelho and Laporte (2013) proposed a branch-and-cut algorithm for IRP with multiple products and multiple vehicles. Adulyasak, Cordeau, and Jans (2013) proposed a branch-and-cut algorithm, and they presented an adaptive large neighborhood search heuristic to determine initial solutions.

3. Assumptions and notations

The following assumptions and notations are used throughout this paper.

Assumptions:

- There is a bi-level supply chain which comprises one manufacturer and several retailers that work under the VMI system.
- This IRP is multi-product, with known and deterministic demand with the objective of minimizing total cost. Products are perishable and have a fixed lifetime.
- Storage capacity both of the manufacturer and the retailers is limited and no stock out is allowed.
- The manufacturer's capacity is limited and is known in advance for each production period.
- Products are delivered through a fleet of capacitated vehicles (which differ only in delivery costs) according to multiple shipping strategies.
- Split deliveries are not permitted.
- Perishability is assumed to dominate physical storage capacity considerations. Consequently, the upper bound inventory levels of retailers are determined only by the perishability constraints.
- It is assumed that deliveries from the manufacturer to the retailers are always of new or freshly processed product.

Indices

i, j	indices for retailers or manufacturer, where 0 corresponds to the manufacturer ($i,j \in \{0,1,2,\ldots,N\}$)
v	index for vehicles ($v \in \{1,2,\ldots,m\}$)
t	index for planning periods ($t \in \{1,2,\ldots,T\}$)
p	index for products ($p \in \{1,2,\ldots,k\}$)

Parameters

N	number of retailers
m	number of vehicles
T	number of planning periods
k	number of products
f_t	production setup cost in period t
c_{ijvt}	cost of product transportation between node i and retailer j by vehicle v in period t
h_{pjt}	holding cost per unit of product p at manufacturer or retailer j in period t
α_p	inventory capacity utilization rate of product p
β_p	production capacity utilization rate of product p
d_{pjt}	demand for product p at retailer j in period t
Q_v	capacity of vehicle v
$I^j_{\max}$	inventory capacity of manufacturer or retailer j
$P^t_{\max}$	production capacity in period t
$L^p_{\max}$	maximum shelf life of product p

Decision variables

w_{pjvt}	delivery quantity of product p to retailer j by vehicle v in period t
I_{pjt}	inventory level of product p at manufacturer or retailer j at the beginning of period t
x_{vjt}	total number of visiting retailers by vehicle v before