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A heuristic method for the inventory routing and pricing problem in a supply chain

Shu-Chu Liu *, Jyun-Ruei Chen

Department of Management Information Systems, National Pingtung University of Science and Technology, Pingtung 912, Taiwan, ROC

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ABSTRACT

The inventory routing problem (IRP) in a supply chain (SC) is to determine delivery routes from suppliers to some geographically dispersed retailers and inventory policy for retailers. In the past, the pricing and demand decisions seem ignored and assumed known in most IRP researches. Since the pricing decision affects the demand decision and then both inventory and routing decisions, it should be considered in the IRP simultaneously to achieve the objective of maximal profit in the supply chain. In this paper, a mathematical model for the inventory routing and pricing problem (IRPP) is proposed. Since the solution for this model is an NP (non-polynomial) problem, a heuristic method, tabu search adopting different neighborhood search approaches, is used to obtain the optimal solution. The proposed heuristic method was compared with two other methods considering the IRPP separately. The experimental results indicate that the proposed method is better than the two other methods in terms of average profit.

1. Introduction

The inventory routing problem (IRP) in a supply chain (SC) is to determine delivery routes from suppliers to some geographically dispersed retailers and inventory policy for retailers. It is consisted of two sub-problems: inventory problem for retailers and vehicle routing problem (VRP) for suppliers. The IRP considering inventory and routing simultaneously has gained attentions since the coordination of the inventory and routing decisions between the supplier and retailers leads to a better overall performance (Vidal & Goetschalckx, 1997). According to the literature (Raa & Aghezzaf, 2009; Zhao, Wang, & Lai, 2007), the pricing and demand decisions seem ignored and assumed known in most IRP researches. Since the pricing decision affects the demand decision and then both inventory and routing decisions, it should be made in the IRP simultaneously to achieve the objective of maximal profit in the supply chain. For example, higher pricing causes lower demand and then lower order quantity and lower inventory. In contrast, lower pricing causes higher demand and then higher order quantity and higher inventory. Since the pricing decision is interrelated to inventory routing decisions, the profit may decrease when they are made separately. Hence, how to determine inventory, routing and price simultaneously becomes an important issue in supply chain management.

Because the inventory routing and pricing problem (IRPP) is a NP-hard problem (Since inventory routing decisions is a NP-hard problem (Lenstra & Rinnooy, 1981), the IRPP is more complex than the IRP.), a heuristic method is adopted to resolve this problem. Until now, there are few researches about IRPP. Hence, this paper presented a survey for two related areas: inventory routing problem and pricing problem, in the following. Bell, Dalberto, and Fisher (1983) adopted an optimization method to resolve the IRP. After that, some other optimization methods were developed to resolve the IRP (Anily & Federgruen, 2004; Dror & Ball, 1987; Gallego & Simchi-Levi, 1990; Kleywegt, Nori, & Savelsbergh, 2002; Qu, Bookbinder, & Iyogun, 1999; Yu, Chen, & Chu, 2008). Since the IRP is an NP-hard problem, heuristic methods are needed. Federgruen and Zipkin (1984) developed a nonlinear integer programming model and adopted an exchange method to resolve the IRP. Golden, Assad, and Dahl (1984) adopted an insertion method to resolve the IRP. Viswanathan and Mathur (1997) adopted a stationary nested joint replenishment policy heuristic (SNJRP) to resolve the IRP. The results show the method simultaneously making inventory and routing decisions is better than that making inventory and routing decisions separately. Campbell and Savelsbergh (2004) adopted a two-phase method to resolve the IRP. The first phase adopted an integer programming method to obtain the initial solution. The second phase adopted an insertion method to improve the initial solution. Gaur and Fisher (2004) adopted a randomized sequential matching algorithm (RSMA) to resolve the IRP. An insertion method was adopted to obtain the initial solution. Then a cross-over method was adopted to improve the initial solution. Sindhuchao, Romeijn, Akcali, and Boondiskulchok (2005) adopted a two-phase method for the IRP. The first phase adopted a column generation method to obtain the initial solution. The second phase adopted a very large-scale neighborhood search (VLSN) to improve the initial solution. Lee, Jung, and Lee (2006) adopted a tabu search method to resolve the IRP. Raa and Aghezzaf (2008) adopted a heuristic method to resolve the IRP. A column generation method was

* Corresponding author. Tel.: +886 8 7703202x7911; fax: +886 8 7740306.
E-mail address: sliu@mail.npust.edu.tw (S.-C. Liu).

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Nomenclature

c_{rjl}	distance from j to l for route r
A	ordering cost per order
a_i	intercept value for the demand pattern of retailer i
b_i	slope of the demand pattern of retailer i
C	supplier capacity
v	vehicle capacity
ψ	vehicle dispatching cost
w	working days in the planning period
δ	production cost per unit
cm	traveling cost per unit distance
h	holding cost per period
i	index of retailers
r	index of routes (or vehicles)
j	index of retailers ($1 \leqslant j \leqslant N$) or supplier ($j = N + 1$)
l	index of retailers ($1 \leqslant l \leqslant N$) or supplier ($l = N + 1$)
R	route (or vehicle) number
N	retailer number
T_r	replacement time of route r
V_r	retailer set for route r ($1 \leqslant r \leqslant R$)
q_{imax}	upper bound for demand of retailer i per day
q_{imin}	lower bound for demand of retailer i per day
y_{imax}	upper bound for demand of retailer i in the planning period (=$w \times q_{imax}$)
y_{imin}	lower bound for demand of retailer i in the planning period (=$w \times q_{imin}$)
q_i	demand of retailer i per day
y_i	demand of retailer i in the planning period (=$w \times q_i$)
p_i	sales price of retailer i in the planning period
X_{rjl}	1, if point j immediately precedes point l on route r; 0, otherwise

adopted to find the initial solution. Then a saving heuristic method was adopted to improve the initial solution. Zhao et al. (2007) adopted a heuristic method to resolve the IRP. The initial solution was generated randomly. Then a tabu search method adopting the GENI neighborhood search was used to improve the initial solution. Zhao, Chen, and Zang (2008) adopted a variable large neighborhood search (VLNS) method to resolve the three-echelon (suppliers, distributors, retailers) IRP. The results show the proposed method is better than the tabu search method. In summary, tabu search (TS) adopting the GENI neighborhood search approach and VLNS have been adopted to find the optimal solution for the inventory routing problem effectively and efficiently (Gaur & Fisher, 2004; Lee et al., 2006; Zhao et al., 2007; Zhao et al., 2008). Hence, they will be adopted to resolve the IRP sub-problem in IRPP in this paper. As for the pricing problem, some researchers (Jung & Klein, 2006; Kotler, 1971; Lau & Lau, 2003; Ray, Gerchak, & Jewkes, 2005) determined the prices and demands using calculus according to the known demand function based on the maximal profit criterion. Nachiappan and Jawahar (2007) adopted a genetic algorithm (GA) method to find the prices and demands based on the maximal profit criterion in a supply chain. The pricing problem is a nonlinear integer programming (NIP) problem. Searching for the optimal solution is an NP problem. According to the literature (Costa & Oliveria, 2001; Exler, Antelo, Egea, Alonso, & Banga, 2008; Schlüter, Egea, & Banga, 2009; Yin & Wang, 2008), genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO) and tabu search (TS) have been adopted to resolve the NIP problem. Since tabu search is adopted to resolve the IRP sub-problem in IRPP mentioned above, if GA, PSO or ACO is adopted to resolve the pricing sub-problem in IRPP, the IRPP would be resolved separately by different methods. Hence, tabu search is adopted to resolve the IRPP simultaneously in this paper.

2. Model formulation for the inventory routing and pricing problem

2.1. Assumptions and notations

2.1.1. Assumptions

According to the literature survey, there are no other researches available for the IRPP. Hence, the used assumptions in this paper are selected from two related research areas: the inventory routing model (Raa & Aghezzaf, 2009; Zhao et al., 2007) and the pricing model (Nachiappan & Jawahar, 2007). The details are as follows:

A supplier serves retailers which are geographically dispersed in a given area.
A homogenous fleet of vehicles is considered with the same capacity.
A single product is considered and distributed to retailers.
Each retailer is served by exactly one vehicle.
The total demand on each route is less than or equal to the vehicle capacity.
Each route begins and ends at the same supplier.
No vehicle loading and unloading cost is considered.
No supplier ordering and inventory cost is considered.
Demand lies between a specific range and the validity of the assumption of linear demand function holds very well within this range.
The pricing can not be zero.

2.2. Model formulation

Before the model for the inventory routing and pricing problem is formulated, the relevant information is discussed first.

2.2.1. Revenue

Demand function defines the price and demand quantity relationship. The planning horizon is usually 1 year or half year. The demand function for retailer i: $p_i = a_i - b_i y_i$ (The linear demand function is the most popular in the related research (Lau & Lau, 2003; Nachiappan & Jawahar, 2007)). Since $y_i = w \times q_i$, the demand function becomes as follows: $p_i = a_i - b_i w q_i$. Hence, the revenue per day $p_i q_i = a_i q_i - b_i w q_i^2$.

2.2.2. Supply chain cost

2.2.2.1. Transportation cost. The transportation cost includes the traveling cost plus the vehicle dispatching cost, Ψ. The detailed computation is as follows: transportation cost per day = $\sum_{r=1}^{R}\sum_{j=1}^{N+1}\sum_{l=1}^{N+1}\frac{c_{rjl}\times cm+\psi}{T_r}$.

2.2.2.2. Production cost. The production cost includes material cost and manufacturing cost. The detailed computation is as follows: production cost per day = $\sum_{r=1}^{R}\sum_{i\in V_r}\delta \times q_i$.

2.2.2.3. Inventory cost. The inventory cost includes ordering cost and holding cost. The detailed computation for these costs is as follows: (1) ordering cost per day $= \sum_{r=1}^{R}\frac{A}{T_r}$. (2) holding cost per day $= \sum_{r=1}^{R}\sum_{i\in V_r}\frac{T_r\times q_i\times h}{2}$.