Computers & Industrial Engineering 109 (2017) 204–210

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

An effective zero-inventory-ordering policy for a single-warehouse multiple retailer problem with a modified all-unit discount

Ching-Ter Chang *

Department of Information Management, Chang Gung University, 259 Wen-Hwa 1st Road, Kwei-Shan, Tao-Yuan, Taiwan, ROC
Department of Thoracic Medicine, Chang Gung Memorial Hospital at Linkou Taoyuan, Taiwan, ROC
Department of Industrial Engineering and Management, Ming Chi University of Technology, Taiwan, ROC

ARTICLE INFO

Article history:
Received 3 September 2016
Received in revised form 25 January 2017
Accepted 4 May 2017
Available online 6 May 2017

Keywords:
Cross docking
Supply chain management
Discount cost structure
Transportation model

ABSTRACT

A warehouse is an important value-added service hub between a supplier, a retailer and a customer in a supply chain system. In order to encourage the retailer to purchase a large volume of goods and save in transportation costs, a modified all-unit discount cost structure is often used by warehouses. However, Chan, Muriel, Shen, and Simchi-Levi (2002) noted that the modified all-unit discount cost structure is an NP-hard problem. It is difficult to obtain the optimal solution for this problem. Therefore, Chan et al. developed a novel heuristic algorithm to solve a single-warehouse multiple retailer problem with a modified all-unit discount cost structure that was close to the optimal solution. This paper proposes an exact strategy to deal with the same problem that gives the optimal solution in polynomial time, without the need for binary variables, and regardless of the number of breakpoints. The proposed solution is also successfully demonstrated and can be extended to solve arbitrary piecewise linear functions.

1. Introduction

Supply Chain Management is an important element of operational efficiency (Bani-Asadi & Zanjani, 2017). Modern supply chains rely heavily on warehouses to rapidly fulfill customer demands and increase satisfaction with E-business, retailers, web-based business, catalogue channels and others. Recently, sustainability is considered as a leading topic in supply chain (Asadi & Sadjadi, 2017; Kausar, Garg, & Luthra, 2017). Warehouse is a service hub in the supply chain and operates in a reactive mode. That is, the role of the warehouse is changing from the traditional passive role of serving as a buffer to mitigate variations in demand in supply chains to the more active role of providing value-added services, such as consolidation, deconsolidation, assembling and kitting (Sainathuni, Parikh, Zhang, & Kong, 2014). The effective management of inventory/distribution systems (**I/DS**) has recently become one of the most challenging issues for both practitioners and scholars of supply chain management. Chan, Muriel, Shen, Simchi-Levi, and Teo (2002) noted that cost savings in supply chains can be achieved by integrating inventory control and transportation policies. Real practical examples of the use of I/DS are Coca-Cola, Wal-Mart, 7-Eleven and Amazon. A typical example of the use of I/DS in academia is the popular single-warehouse multiple retailer (**SWMR**) configuration, as shown in Fig. 1 (Chan, Muriel, Shen, & Simchi-Levi, 2002; Chan, Muriel, Shen, Simchi-Levi, Teo, 2002; Hill & Galbreth, 2008; Rieksts, Ventura, & Herer, 2009). Ene, Küçükoğlu, Aksoy, and Öztürk (2016) derived a genetic algorithm for minimizing energy consumption in warehouses using order picking routes. Pan, Shih, Wu, and Lin (2015) proposed a genetic algorithm for a pick-and-pass warehousing system. A single warehouse replenishes N retailers' and customers' demands, by ordering goods from manufacturers and suppliers. In the SWMR system, the retailers only order goods from the warehouse. This is a typical centralized SWMR system.

However, it can be difficult to determine the optimal solution for an SWMR problem in a centralized environment, particularly in cases where there are various transportation modes, such as a Truckload (**TL**) transportation mode, or a Less-than-truckload (**LTL**) transportation mode. Therefore, most studies have been restricted to stationary policies in a centralized environment (Graves & Schwarz, 1977; Maxwell & Muckstadt, 1985). For simplicity and tractability, many transportation cost structures are modeled in a linear form, which is often far from accurate in practice (LeBlanc, Hill, Greenwell, & Czesnat, 2004; Ng, Li, & Chakhlevitch, 2001). Typically, the I/DS relies on third parties for the transportation of goods from suppliers, through a warehouse and then to retailers, which is referred to as an SWMR system. In this situation, large shipments from a supplier to a warehouse

* Address: Department of Information Management, Chang Gung University, 259 Wen-Hwa 1st Road, Kwei-Shan, Tao-Yuan, Taiwan, ROC.
E-mail address: chingter@mail.cgu.edu.tw

http://dx.doi.org/10.1016/j.cie.2017.05.005
0360-8352/

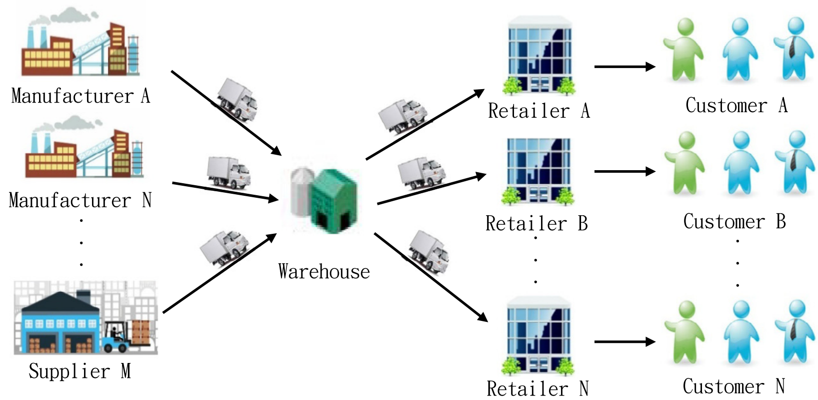

Fig. 1. I/DS configuration.

are often delivered in a TL transportation mode, the cost which can be approximated by piecewise linear concave functions (e.g., a fixed-charge cost structure). In contrast, for the retail, grocery and electronics industries, LTL transportation is the most frequently used mode for the movement of goods from a warehouse to many different retailers on one truck. The advantage of LTL is that the price of sending a shipment using LTL is significantly lower than that for a TL carrier. In this instance, the carrier usually offers an all-unit discount policy, to encourage large shipments that fill the entire truck. The all-unit discount is the most common condition in many markets and industries (Chan, Muriel, Shen, Simchi-Levi, Teo, 2002; Munson & Rosenblatt, 1998). In fact, the all-unit discount is used not only for wholesale pricing by vendors, but also by common carriers (Knowles & Pantumsinchai, 1988; Toptal, 2009). For a warehouse order of Q units, this cost structure, as described in Fig. 2, implies a transportation cost structure.

$$G(Q)=\begin{cases}0, & \text{if } Q=0,\\ c, & \text{if } 0<Q\leqslant M_1\\ \alpha_j Q, & \text{if } M_j\leqslant Q\leqslant M_{j+1}, \quad j=1,2,\ldots,m-1\end{cases}$$

where $\alpha_1>\alpha_2>\cdots>\alpha_m>0$ and $\alpha_1 M_1=C$. Therefore, C denotes a minimum charge for shipping a small volume, where $Q\leqslant M_1$, and the dashed lines indicate that the associated solid lines originate at point (0,0). In practice, when a shipper plans to ship Q units, the transportation cost is calculated as $F(Q)=\min\{G(Q), G(M_{j+1})=\min\{\alpha_j Q,\alpha_{j+1}M_{j+1}\}$. This structure is denoted by the heavy solid line in Fig. 3, which is termed a modified all-unit discount (**MAUD**) cost structure (Chan, Muriel, Shen, Simchi-Levi, 2002; Chan, Muriel, Shen, Simchi-Levi, Teo, 2002). Therefore, for a warehouse order of Q units, the MAUD cost structure is:

$$G(Q)=\begin{cases}0, & \text{if } Q=0,\\ c, & \text{if } 0<Q\leqslant M_1\\ \alpha_j Q, & \text{if } M_j\leqslant Q\leqslant M_{j+1}, \quad j=1,3,\ldots\\ \alpha_{j+1}M_{j+1}, & \text{if } M_j\leqslant Q\leqslant M_{j+1}, \quad j=0,2,\ldots\end{cases}$$

where $\alpha_1>\alpha_3>\cdots>0$ and $\alpha_0=\alpha_2=\cdots=0$ are unit shipping costs that depend on quantity, Q. C is a minimum (fixed) charge for shipping a small volume $Q\leqslant M_1$, and M_j are the cutoff quantities to qualify for each unit shipping cost. A well-known example of MAUD is the industry standard transportation-rating engine, which is termed CZAR (Southern Motor Carrier's Complete Zip Auditing and Rating engine) (Chan, Muriel, Shen, Simchi-Levi, 2002; Chan, Muriel, Shen, Simchi-Levi, Teo, 2002; Hill & Galbreth, 2008). Chan, Muriel, Shen, Simchi-Levi (2002) showed that the MAUD cost structure cannot be represented by the piecewise linear cost structures that are used in capacitated models because of two properties: (i) *it is a non-decreasing function of the amount shipped* and (ii) *the cost per unit is non-increasing in the amount shipped*. This adds significant complexity to the I/DS problem. Therefore, a heuristic algorithm was proposed to solve this complicated problem that is understood as being close to optimal

Ertogral, Darwish, and Ben-Daya (2007) noted that the impact of complex shipping costs has not been adequately addressed in the literature. Obviously, when using traditional methods, the SWMR transportation optimization problem with a MAUD cost structure often requires a mixed integer formulation, which can be very time-consuming to solve (Hill & Galbreth, 2008). SWMR is also an NP-hard problem, even if all transportation cost structures are fixed-charge cost functions (Arkin, Joneja, & Roundy, 1989). These problems have been the subject of much study in

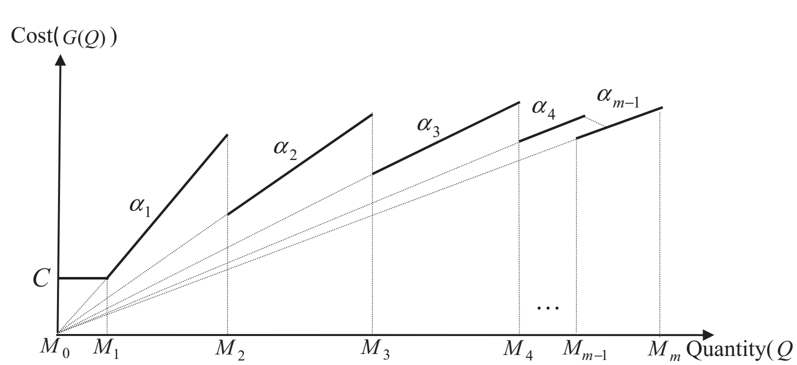

Fig. 2. All unit discount cost structure.