European Journal of Operational Research 234 (2014) 37–48

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Discrete Optimization

The freight consolidation and containerization problem

Hu Qin [a], Zizhen Zhang [b,*], Zhuxuan Qi [c], Andrew Lim [b]

[a] School of Management, Huazhong University of Science and Technology, No. 1037, Luoyu Road, Wuhan, China
[b] Department of Management Sciences, City University of Hong Kong, Tat Chee Avenue, Kowloon Tong, Hong Kong
[c] School of Labor and Human Resources, Renmin University of China, Beijing 100872, China

ARTICLE INFO

Article history:
Received 19 August 2012
Accepted 12 September 2013
Available online 21 September 2013

Keywords:
Packing
Freight consolidation
Containerization
Memetic algorithm
Third-party logistics

ABSTRACT

In today's global free market, third-party logistics providers (3PLs) are becoming increasingly important. This paper studies a problem faced by a 3PL operating a warehouse in Shanghai, China, under contract with a major manufacturer of children's clothing based in the United States. At the warehouse, the 3PL receives textile parcel shipments from the suppliers located in China; each shipment is destined for different retail stores located across the United Sates. These shipments must be consolidated and loaded into containers of varying sizes and costs, and then sent along shipping routes to different destination ports. An express company, such as UPS and FedEx, unloads the shipments from the containers at the destination ports and distributes them to their corresponding stores or retailers by parcel delivery. The objective is to find an allocation that minimizes the total container transportation and parcel delivery costs. We formulate the problem into an integer programming model, and also propose a memetic algorithm approach to solve the problem practically. A demonstration of a good solution to this problem was a decisive factor in the awarding of the contract to the 3PL in question.

1. Introduction

The use of third-party logistics providers (3PL) has become an increasingly integral part of modern supply chain management (Marasco, 2008). Major business enterprises commonly span across several geographical locations at different sides of international borders, which makes central logistics planning difficult and inefficient. Consequently, companies prefer to employ the services of 3PLs for the storage and transportation of goods along parts of the supply chain. There are several benefits for doing so: (1) the company avoids the setup costs involved in managing the logistics in a new location; (2) 3PLs specialize in logistics and are likely to perform the required tasks more efficiently than the customer by taking advantage of economies of scale; and (3) 3PLs possess regional expertise and are therefore better able to take local conditions into account during logistics management. Furthermore, in addition to the storage and transportation of goods, 3PLs often provide other value-added services such as inbound operations, inspection, sorting, labeling, containerization, tracking and outbound operations. These and other services position 3PLs as one-stop shops for the logistical needs of their customers.

We consider the case of a major manufacturer of clothing for babies, toddlers and children. Products bearing the manufacturer's brand are sold at over 400 company-owned retailer stores as well as thousands of national department stores and some of the largest retailers across the United States. The company has outsourced some of its manufacturing needs to suppliers located in China, taking advantage of the lower costs in this rapidly developing region. As a result, they have contracted with 3PLs based in China for transporting these manufactured products to their target markets. This enables the company to focus on its core business while saving on costs without sacrificing product quality.

This study is motivated by a project awarded to our team by a 3PL that services the manufacturer via a warehouse hub in Shanghai, China. The 3PL industry in China has experienced significant and rapid growth since the economic reforms of 1978 when its borders were opened to foreign investors, and especially since its entry into the World Trade Organization in 2001. Historically, the main concern of investors with regards to logistics in China is its poor transport infrastructure (Ta, Choo, & Sum, 2000), a concern that has been addressed by the rapid development and modernization of the country in the past decades. There is therefore tremendous growth potential in the Chinese logistics market, resulting in intense competition that requires 3PLs in China to constantly seek new sources of competitive advantage (Wang, Zantow, Lai, & Wang, 2006).

* Corresponding author. Address: Department of Management Sciences, City University of Hong Kong, Tat Chee Avenue, Kowloon Tong, Kowloon, Hong Kong. Tel.: +852 69250203; fax: +852 34420189.

E-mail addresses: tigerqin@hust.edu.cn, tigerqin1980@gmail.com (H. Qin), zzzhang@cityu.edu.hk, zhangzizhen@gmail.com (Z. Zhang), zhuxuan.qi900330@aliyun.com (Z. Qi), lim.andrew@cityu.edu.hk (A. Lim).

0377-2217/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ejor.2013.09.015

The transportation process that concerns the 3PL in question is briefly described as follows. First, the suppliers send the finished goods from their manufacturing plants to the warehouse hub operated by the 3PL via domestic truck transportation. Next, the 3PL loads the goods into containers of various sizes and ships these containers to distribution hubs situated in the United States, each of which is operated by an express delivery company such as FedEx or UPS. Finally, the express company unloads the goods from the containers and distributes them to the corresponding stores or retailers by parcel delivery.

Fig. 1 illustrates the transportation network, which can be viewed as a type of hub-and-spoke network. At the warehouse hub, the 3PL provides the manufacturer with value-added services; no extra services beyond the delivery of the goods are required from the express company at the distribution hubs. The goods can be shipped to any of several distribution hubs from the warehouse hub. Therefore, there are several possible transportation routes that a shipment of goods destined for a particular store can take, as illustrated in Fig. 2. This study examines the scenario that is relevant to our client, where there is only a single warehouse hub with multiple distribution hubs. We refer to the warehouse hub in Shanghai as the *origin hub*, and the distribution hubs in the United States as *destination hubs*.

The inventory of the stores is replenished periodically, and each store may demand goods from one or several suppliers. For each period, the manufacturer aggregates the demands of its stores and places orders with suppliers. In most cases, the total volume of demanded goods for a single store in one time period is much less than the capacity of a single container, which is one Twenty-foot Equivalent Unit (TEU); hence, consolidating goods for different stores into one container becomes necessary for reducing transportation cost. In order to facilitate the consolidation process, the manufacturer stipulates that the suppliers must send their goods to the origin hub within a predetermined time window that ranges from one day to several days. Since there is only one origin hub in our problem, the cost of truck transportation is fixed and we can assume that all goods have already arrived at the origin hub. The goods heading to the same store are combined into one shipment at the origin hub, so a single shipment may consist of one or several items. To simplify some store operations such as tracking and receiving goods, it is required that all items in one shipment must be transported along a single route, but they are allowed to be loaded into different containers.

In this study, we investigate the *freight consolidation and containerization problem* (FCCP). It models the task faced by the 3PL, which requires the assignment of shipments to routes as well as items to containers, with the objective of minimizing the total cost

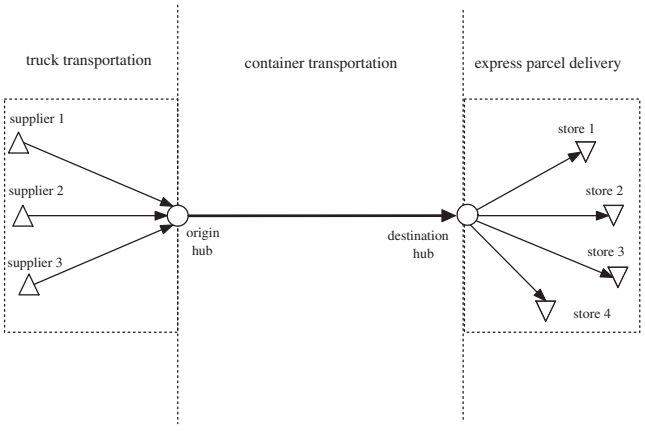

Fig. 1. Overall transportation process.

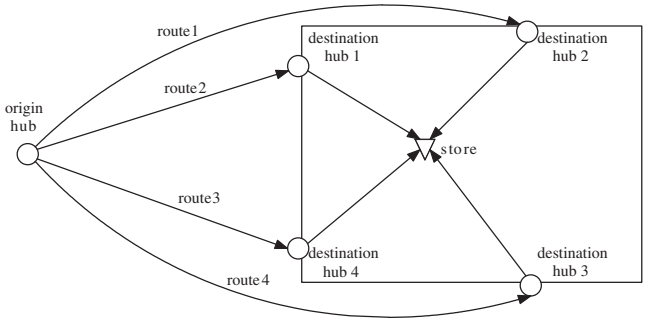

Fig. 2. Multiple routes for a single store.

of two transportation modes, namely container transportation and parcel delivery. We assume that each item transported by the 3PL is an indivisible textile package that must be loaded into only one container. Moreover, the flexibility and non-fragility of textiles allow us to treat the process of loading items into containers as a variable sized bin packing problem (VSBPP). The main difficulty lies in managing the tradeoff between container transportation cost and parcel delivery cost: on one hand, if we send every shipment to the destination hub with the cheapest associated parcel delivery cost, the containers may be underutilized; on the other hand, if we try to minimize container cost by loading each container as fully as possible, then higher parcel delivery costs may be incurred for some shipments.

The FCCP models an actual problem that combines goods consolidation and containerization (i.e., container loading). In contrast to other typical services such as inspection and tracking, a good solution to this problem translates directly into cost savings that can be passed onto the customers, which provides the 3PL with a competitive advantage. In fact, a demonstration of this capability was a decisive factor in the awarding of the contract by the manufacturer to the 3PL in question. Furthermore, consolidation and containerization often exist in tandem in the logistics industry, and the FCCP is likely to be applicable in a variety of practical scenarios. To the best of our knowledge, this problem has not been investigated in the existing literature.

The contributions of this paper are twofold. Firstly, we formally define the problem examined in this article, and also provide an integer programming (IP) model for it. Secondly, the problem is easily shown to be NP-hard. To solve it practically, we focus our efforts on devising an efficient heuristic approach that provides high quality solutions within a reasonable amount of computing time. Consequently, we propose a memetic algorithm (MA) for the FCCP that combines genetic algorithm operations, local search, and a heuristic for the VSBPP. The effectiveness of our algorithm was verified via extensive experiments on a large number of generated test instances.

The remainder of this paper is structured as follows. In Section 2, we give an overview of the relevant research in existing literature. We provide a formal description of the problem in Section 3, along with a mixed integer formulation and a brief discussion of the computational complexity of the problem. Section 4 describes the details of our MA approach. We evaluate our approach using a large set of generated test instances, which are described in Section 5 along with the computational results. Finally, we conclude our article in Section 6 and suggest some possible directions for future research.

2. Literature review

Freight consolidation, which is an important practice in logistics management, has been investigated extensively. The related