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Two-level vehicle routing with cross-docking in a three-echelon supply chain: A genetic algorithm approach

Fardin Ahmadizar *, Mehdi Zeynivand, Jamal Arkat

Department of Industrial Engineering, University of Kurdistan, Pasdaran Boulevard, Sanandaj, Iran

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ABSTRACT

The cross-docking process, which can function as an efficient logistics strategy, includes three operations, namely receiving products from inbound vehicles, consolidating the products into groups according to their destinations, and shipping them on outbound vehicles. This process should be performed with minimum storage between operations. This paper presents a model that considers two-level vehicle routing together with cross-docking. By considering the transportation costs and the fact that a given product type may be supplied by different suppliers at different prices, the routing of inbound vehicles between cross-docks and suppliers in the pickup process and the routing of outbound vehicles between cross-docks and retailers in the delivery process are determined. The goal is to assign products to suppliers and cross-docks, to optimize the routes and schedules of inbound and outbound vehicles, and to consolidate products so that the sum of the purchasing, transportation and holding costs is minimized. A hybrid genetic algorithm is developed for the problem, and the algorithm performance is validated by several numerical examples.

1. Introduction

Recently, increasing global competition implies that products must be produced and supplied in the right place at the right time at a low price. Hence, the efficient integration and coordination of different activities is becoming increasingly important. Supply chain (SC) management involves integrating and coordinating different activities through different organizations [1]. There are two important activities in SC management: (1) production planning and inventory control managing the manufacturing process and storage policies, and (2) distribution and logistics process transporting products in the SC [2]. Optimizing distribution networks is necessary to reduce logistics costs and to achieve a profitable SC management policy. The aim of logistics activities, as a bridge between manufacturers and customers, is to bring the right product to the right place in the right quantity at the right time [3]. As stated by Apte and Viswanthan [4], the distribution process constitutes 30 percent of the product prices. An appropriate distribution system can reduce transportation costs and consequently decrease product prices.

Cross-docking is one of the most suitable methods among distribution systems. In contrast to traditional warehousing with high-cost functions, cross-docking is implemented to increase the flow of products while reducing inventory holding

* Corresponding author. Tel./fax: +98 871 6660073.
E-mail address: f.ahmadizar@uok.ac.ir (F. Ahmadizar).

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costs, storage space, and delivery time [5]. Due to the reduction in storage and order picking costs, cross-docking can decrease warehousing costs up to 70 percent [6]. In addition, cross-docking decreases transportation costs by achieving economies of scale in transportation through the use of full trucks made possible by consolidating different shipments [4].

Cross-docking as a lean warehousing strategy involves receiving products from inbound vehicles, classifying them into certain groups according to their destinations, and shipping them on outbound vehicles in less than 24 h, sometimes in less than one hour. In this process, the routes and schedules of inbound and outbound vehicles must be considered to effectively apply cross-docking [7]. The main objective of a vehicle routing problem (VRP) is to optimize the plan of product delivery by vehicles. This aim can be achieved by minimizing the total distance traveled and the number of vehicles [8].

Although the routing of inbound vehicles is performed to achieve nearly simultaneous arrival of products, temporary storage may increase the flexibility of the cross-docking process [9] and decrease transportation costs. The routing of inbound vehicles should then be determined in such a way that their arrival times at the cross-docks do not cause products to be stored for a long time. Moreover, the arriving products are consolidated to reduce the transportation costs by achieving economies of scale in transportation through the use of full outbound vehicles. Transportation costs can be further reduced by scheduling the customers that are visited by each outbound vehicle. Therefore, the routing of the inbound and outbound vehicles and the consolidation of different products are the most important decisions in cross-docking. In addition, because different suppliers may supply a product type at different prices, the purchasing costs can be reduced by an appropriate assignment of products demanded by retailers to suppliers. Such decisions have significant effects on the profitability and responsiveness of the SC. Accordingly, in this paper, a two-level VRP together with cross-docking is considered. The first-level routing is implemented between cross-docks and suppliers, and the second level includes cross-docks and retailers.

In the literature on cross-docking, most research addresses its concept, physical design or location. Napolitano [10] has introduced various types of cross-docking operations including manufacturing, distributor, transportation, retail and opportunistic cross-docking, and has considered the benefits of the cross-docking strategy. Ratliff et al. [11] have considered the physical design of a cross-dock as a distribution system. Apte and Viswanthan [4] have considered the design of a cross-docking system as one of the most important methods for decreasing transportation costs. Jayaraman and Ross [12,13] have studied a distribution network design problem that involves incorporating cross-docking into the SC. However, in these studies the authors have investigated the decisions regarding the openness or closeness of a cross-dock as well as the allocation of each open cross-dock to each customer zone. Kreng and Chen [14] have investigated production–distribution planning by considering two different approaches: a traditional warehousing strategy versus a cross-docking strategy. The reduction of costs due to the cross-docking strategy in the SC has been confirmed. Bachlaus et al. [15] have introduced a model to design an agile multi-echelon SC network at a strategic planning horizon that incorporates cross-docks as an echelon. Gumus and Bookbinder [16] have studied logistics activities in a SC in which products are delivered to customers directly or through cross-docks. Alpan et al. [9] have developed a bounded dynamic programming approach to schedule operations in a cross-docking environment in which temporary storage and preemption are allowed to increase the operations flexibility. Boysen and Fliedner [17] have introduced a classification of deterministic truck scheduling at cross-docking terminals. Door environment, operational characteristics and objectives are three elements used in the classification. Recently, Buijs et al. [18] have presented a research classification and framework for synchronization in cross-docking networks.

Although many studies have investigated the VRP and cross-docking problems separately, a few researchers have dealt with vehicle routing together with cross-docking. Lee et al. [7] have considered a pickup and delivery problem in a distribution network with a single cross-dock where, in the pickup process, vehicles collect products from suppliers, and, in the delivery process, products are delivered to customers. In the pickup process, vehicles should come back to the cross-dock at a particular time. The authors then developed a tabu search algorithm for the problem. Liao et al. [19] have developed a new tabu search algorithm for the same problem. Wen et al. [5] have investigated a similar problem in which the vehicles in the pickup and delivery processes are the same and the transfer of products between vehicles in the cross-dock is allowed. A tabu search heuristic embedded in an adaptive memory procedure was proposed to solve the problem. Recently, Morais et al. [20] have developed some heuristics for the problem defined by Wen et al. [5]. Moreover, Santos et al. [21,22] have proposed branch-and-price algorithms for somewhat similar problems. Dondo et al. [23] have formulated VRP and cross-docking problems as a mixed integer linear program in which hybrid multi-echelon distribution networks transport products from manufacturers to customers, directly and/or using warehousing and cross-docking strategies. More recently, Mousavi et al. [24] have considered the location and VRP in the cross-docking distribution networks under uncertainty, and proposed a hybrid fuzzy possibilistic–stochastic programming solution approach.

To improve distribution activities in a SC, this paper presents a mixed integer nonlinear programming (MINLP) model that considers a two-level VRP together with cross-docking. The problem considered here is an extension of the above-mentioned pickup and delivery problems with a single cross-dock. It generalizes the previous studies in the following aspects.