Expert Systems with Applications 41 (2014) 4298–4308

Contents lists available at ScienceDirect

Expert Systems with Applications

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

An integrated supply chain network design problem for bidirectional flows

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ARTICLE INFO

Keywords:
Facility location
Coordinated transportation
Lagrangian relaxation-based heuristic

ABSTRACT

Coordination among supply chains has elicited considerable attention in both academia and industry. This paper investigates an integrated supply chain network design problem that involves the determination of the locations for distribution centers and the assignment of customers and suppliers to the corresponding distribution centers. The problem simultaneously involves the distribution of products from the manufacturer to the customers and the collection of components from the suppliers to the manufacturer via cross-docking at distribution centers. The co-location of different types of distribution centers and coordinated transportation are introduced to achieve cost savings. A Lagrangian relaxation-based algorithm is then developed. Extensive computational experiments show that the proposed algorithm has stable performance and outperforms CPLEX for large-scale problems. An industrial case study is considered and sensitivity analysis is conducted to explore managerial insights. Finally, conclusions are drawn, and future research directions are outlined.

1. Introduction

Managers have come to accept that decisions concerning different levels (strategic, tactical and operational) in a supply chain must be considered simultaneously to minimize costs or maximize profits. Supply chain integration becomes one of the powerful competitive weapons in practice. In academic communities, studies on the integration and coordination of important supply chain decisions for unidirectional flow are increasingly being conducted. Comprehensive reviews can be found in Shen (2007), Fahimnia, Luong, and Marian (2008), Mula, Peidro, Díaz-Madroñero, and Vicens (2010) and Arshinder, Kanda, and Deshmukh (2011). To date, the well-studied problems include (1) the location-routing problem; (2) the inventory-routing problem; (3) the location-inventory problem; (4) the location-inventory-routing problem; and (5) the production–distribution problem. These problems combine strategic and tactical decisions in one model and implement the integrated decision. In this paper, we study an integrated facility location-distribution–collection problem for bidirectional flows. One flow refers to the distribution of final products, whereas the other refers to the collection of modules from suppliers. The coordinations between the two flows are considered to achieve system-wide cost savings.

This study is motivated by existing literature and our collaboration with an engine-making company in China. A typical diesel engine comprises several modules such as the engine body, fuel system, valve train, as well as electrical and lubrication systems. These modules are produced by this company or by the suppliers following a make and buy policy for strategic reasons. The company (manufacturer) assembles these modules to produce the diesel engine, which are later shipped to the corresponding distribution centers to satisfy customer demands. The final products are stored at the distribution centers. In addition, suppliers produce modules such as electrical systems based on procurement plans. These modules are then sent to the distribution centers instead of being directly supplied to the manufacturer because of the expensive transportation costs in China. The company establishes the procurement plans by negotiating with the suppliers to maintain a strategic partnership with them. Cross-docking operations are adopted to handle the modules at the distribution centers to achieve make-to-order manufacturing. The location of distribution centers and the assignment of customers/suppliers to these distribution centers are considered in this supply chain design problem.

A brief review of related literature is stated below. Koksalan, Sural, and Kirca (1995) discuss an application of the location-distribution problem for one company's breweries. Jayaraman and Pirkul (2001) investigate an integrated logistics model with two decisions: one involving the location of plants and warehouses, and the other involving a strategy for distribution (from plants to customers) using warehouses. Using a decomposition framework, Jang, Jang, Chang, and Park (2002) and Han and Damrongwongsiri (2005) study two supply network design problems that involve decisions regarding facility locations and production planning. Gen and Syarif (2005) address a production–distribution problem that integrates facility location decisions, distribution costs, and

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http://dx.doi.org/10.1016/j.eswa.2013.12.053

inventory management for multiple products and multiple time periods. A comprehensive review of integrated production and distribution problems can be found in Sarmiento and Nagi (1999) and in Chen (2004).

The more recent studies consider complicated settings. Vidyarthi, Çelebi, Elhedhli, and Jewkes (2007) address an integrated multi-product two-echelon location-production-inventory-distribution system design model. Gebennini, Gamberini, and Manzini (2009) present an integrated productionCdistribution model for the dynamic locationCallocation problem with control of customer service level and safety stock optimization. Gendron and Semet (2009) discuss several formulations and relaxations for a multi-echelon locationCdistribution problem arising from an actual application. Romeijn, Sharkey, Shen, and Zhang (2010) and Sharkey, Geunes, Edwin Romeijn, and Shen (2011) address a new class of integrated facility location and production planning problems that generalizes traditional facility location problems by considering the future demands of each customer. Bilgen (2010) addresses a production and distribution planning problem that involves the allocation of production volumes among different production lines in manufacturing plants as well as the delivery of products to distribution centers. Salema, Barbosa-Povoa, and Novais (2010) propose a multi-period and multi-product network model for the simultaneous design and planning of supply chains with reverse flows, covering supply, production, storage, and distribution decisions. Kanyalkar and Adil (2010) propose a robust optimization model for the aggregate and detailed planning of a multi-site procurement-production–distribution system. Bashiri, Badri, and Talebi (2012) study a strategic and tactical planning problem in a multi-echelon, multi-commodity production–distribution network. Different time resolutions are considered for strategic and tactical decisions. Fahimnia, Luong, and Marian (2012) develop a mixed integer non-linear program for a two-echelon supply network and consider a production–distribution model that integrates the decisions in production, transport, and warehousing as well as inventory management. Askin, Baffo, and Xia (in press) study a multi-commodity warehouse location and distribution planning problem with inventory consideration. Meisel, Kirschstein, and Bierwirth (2013) integrate production and intermodal transportation planning in a large-scale supply network that consists of four layers of facilities. Latha Shankar, Basavarajappa, Kadadevaramath, and Chen (2013) considers simultaneous location and distribution decisions for three-echelon supply chain network by multi-objective approaches. Barzinpour and Esmaeili (2013) study a location-distribution model for disaster management. Zhang and Xu (2014) propose a mixed-integer bi-level programming model to design a logistics network by taking intro account the order quantity of products under uncertain consumer demand pattern. Kristianto, Gunasekaran, Helo, and Hao (2014) design a reconfigurable supply chain network by optimizing inventory allocation and transportation routing.

Compared to the considerable amount of literature on the location-distribution problems in unidirectional flow, fewer studies have been conducted on problems for bidirectional flows except in the field of closed-loop supply chains, which normally involve only the cooperation and collaboration between forward flow (new products) and reverse flow (returned products). In closed-loop supply chains, problems concerning facility location (Amin & Zhang, 2012; Hasani, Zegordi, & Nikbakhsh, 2012; Sahyouni, Savaskan, & Daskin, 2007; Sasikumar & Haq, 2011), performance assessment (Olugu & Wong, 2012; Tseng, Lin, Lin, Chen, & Tan, 2014), lot sizing (Pan, Tang, & Liu, 2009), as well as integrated facility location and inventory (Kannan, Haq, & Devika, 2009; Zhang, Berenguer, & Shen, 2013) have been studied recently.

The main contributions of this paper are twofold. From a modeling viewpoint, an integrated facility location and product distribution–collection model for bidirectional flows is proposed to achieve the benefits of integrated decisions. The unique characteristics of this model include the following: (1) to the best of our knowledge, ours is the first study on location-distribution–collection problems for bidirectional flows; and (2) coordinated transportation between the bidirectional flows is considered, which yields cost savings. Cost savings attributed to joint distribution centers are also considered. From an algorithm viewpoint, we develop an efficient Lagrangian relaxation-based heuristic to address the proposed model. Extensive computational experiments show that the proposed approach outperforms CPLEX in terms of solution quality in most of the instances. Several interesting managerial insights are reported from numerous computational experiments.

The remainder of the paper is organized as follows: Section 2 describes the supply chain structure in detail, after which a nonlinear mixed integer program is proposed. The solution approach is given in Section 3. In Section 4, numerous computational experiments are conducted, after which an industrial case study is examined, and managerial insights are explored. Finally, conclusions are drawn and future research directions are outlined in Section 5.

2. Problem statement and formulation

We consider a supply chain network design problem for bidirectional flows (Fig. 1). The operational processes of the network are as follows:

- Distribution flow: The manufacturer ships the final products to the regional distribution centers (RDCs), which hold the final products needed to satisfy customer demand. Based on the forecast of customer demands (sales plans during T periods), the final products are then shipped to the corresponding customers.
- Collection flow: Based on the procurement plans (T periods), the suppliers ship the modules to the corresponding distribution centers. One supplier provides only one type of model. The modules are stored in standard transport cases at the distribution centers and then shipped to the manufacturer. Cross-docking operations are adopted, which indicates that the modules are immediately shipped to the manufacturer (the handling time in a distribution center is normally less than 12 h). Either a dedicated vehicle or a vehicle previously used to ship the final product (to a distribution center) is utilized to ship the modules from the distribution centers to the manufacturer.

RDCs are of three types. The first type is a distribution regional distribution center (DRDC), which is only used for distribution flow. The second is a collection regional distribution center (CRDC), which is a cross-docking station that is only used for collection flow. The third type, a joint RDC (JRDC), is constructed if a DRDC

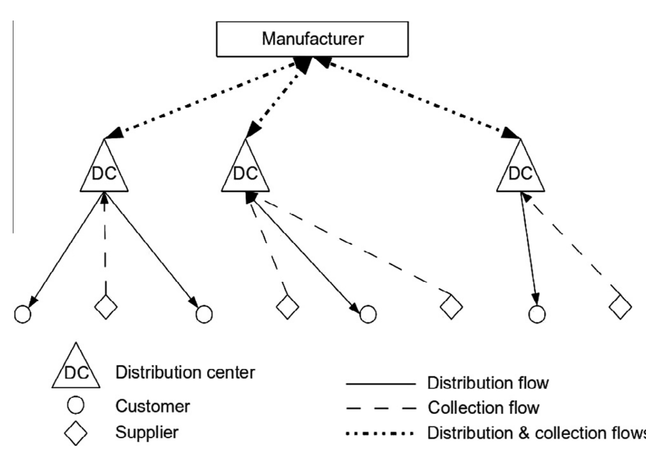

Fig. 1. Schematic structure of the supply chain network.