Computers & Industrial Engineering 110 (2017) 175–190

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Solving multi-region multi-facility inventory allocation and transportation problem: A case of Indian public distribution system

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ARTICLE INFO

Article history:
Received 25 August 2015
Received in revised form 25 January 2017
Accepted 29 May 2017
Available online 31 May 2017

Keywords:
Inventory allocation and transportation problem
Multi-region multi-facility
Indian PDS
MILP
Heuristic

ABSTRACT

In this paper, we study an inventory allocation and transportation problem in a supply chain consisting of multiple storage facilities (warehouses) located in different regions of a large geographic area, which is motivated by the case of the Indian public distribution system. The procurement in each region is known and the item procured within a region needs to be allocated for storage in the warehouses of the same region. The demand of each region is satisfied by the warehouses located in the respective regions. Consideration of region-wise aggregated demand/procurement over multiple facilities located in each region makes the proposed study different from the existing literature. There is a mismatch in procurement, demand, and available storage capacity of warehouses across all the regions. Therefore, the problem is to determine an optimal plan for holding inventory at different storage facilities and to satisfy the demand of all regions without shortages by transporting items between different storage facilities. A mixed integer linear programming model is formulated to minimize the total relevant costs over a finite planning horizon. A heuristic devising activity based decision rules is proposed to solve the problem by decomposing the problem into sub-problems. The performance of the proposed approach is compared with the exact solutions obtained using Cplex for several problem instances. The results of the computational analysis reveal that the proposed solution approach is computationally efficient and gives good quality solutions with an average cost deviation from the optimal solution of less than 6%.

1. Introduction

Due to the economic integration, interdependence, and globalization, an efficient logistics management is the essence of any private or government organization to retain the competitive edge. Transportation and inventory are the two major components of logistics in supply chain management and contribute for around one half and one third of the total logistics cost, respectively (Robinson, 2015). In many cases, these two important aspects of logistics are practiced in a decoupled fashion, which may lead to sub-optimal performance of the overall system. Hence, the need for close coordination between transportation planning and inventory control is highlighted in the literature (Kim & Kim, 2000; Zhao, Wang, Lai, & Xia, 2004). The policy of frequent shipments in small lot sizes lowers the inventory carrying cost at increased transportation cost and vice-versa. Therefore, it is important to determine an optimal plan for holding inventory at different storage facilities and to meet the demand in a timely manner by transporting items between different storage facilities in supply chain.

The present study is motivated by the case of foodgrain distribution in the Indian public distribution system (PDS). PDS is practiced for the distribution of essential commodities, particularly foodgrains, at subsidized prices for people with lower income to ensure the affordability of food. There is a basic difference in the objective of traditional supply chains and PDS. The former has the objective to make profit while the latter is driven by the social obligations even if it results in a loss. However, the challenge to optimize the performance by improving the operational efficiency is common in both. The supply chain of the Indian PDS has some special characteristics. It consists of multiple storage facilities (warehouses) located across the country to store the foodgrain to meet the demand of the different regions. Because of the limited available storage capacity, the major challenge includes the storage of a large amount of foodgrain procured during a specific season in different warehouses. The other challenge is the transportation of the foodgrain from regions with a surplus to regions with a deficit over a notably large geographic area. At present, these issues are solved separately, resulting in a higher operational cost and

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http://dx.doi.org/10.1016/j.cie.2017.05.037
0360-8352/

substantial wastage of foodgrain (on average 20,000 metric ton per year, Mathew, 2015). Therefore, we propose an integrated approach to coordinate the inventory and inter-facility transportation decisions in the Indian PDS considering the trade-off between the inventory holding and transportation costs.

The present problem is related to the two different problems studied in literature: multi-plant capacitated lot sizing problem (MPCLSP) and multi-site production-distribution planning problem. Discounting the decisions related to production/procurement planning, the problem under consideration can be presented as a MPCLSP with storage and inter-plant transfer. Moreover, the supply chain under consideration consists of multiple regions with multiple storage facilities in each region, which is analogous to the supply chain structure of multi-site production-distribution planning problem. Therefore, the literature is reviewed considering the research articles dealing with the above mentioned problems.

In MPCLSP, the objective is to determine when, where and how many items to produce (lot sizing) so that the total relevant cost is minimized to meet the demand on each plant. A decision is to be taken in each period, whether a plant will produce the required item, carry over the inventory for the subsequent periods or allow other plants to produce and get the item transferred to meet the period-wise demand. Sambasivan and Schmidt (2002) studied the MPCLSP for the case of a US based large steel manufacturer and presented a heuristic procedure with lot-shifting and lot-splitting techniques to solve the problem. Later, Sambasivan and Yahya (2005) studied the same problem and proposed a Lagrangian based heuristic solution approach to obtain a better solution. Nascimento, Resende, and Toledo (2010) proposed a greedy randomized adoptive search procedure to obtain a quick solution for the MPCLSP. Deleplanque, Kedad-Sidhoum, and Quilliot (2013) extended the same problem by incorporating transportation and storage capacity constraints and proposed a decomposition technique based on a Lagrangian relaxation approach. Recently, Carvalho and Nascimento (2016) proposed a hybrid Lagrangian heuristic with path relinking which outperforms the other established techniques to solve the MPCLSP. In an industrial context, Aghezzaf (2007) studied the MPCLSP for mold transfers in a production facility. Also, Guimaraes, Klabjan, and Almada-Lobo (2012) presented an application of the MPCLSP for the beverage industry where each plant has a set of filling lines capable of bottling and packing a certain family of products. They presented a heuristic to solve the problem. In the literature of the MPCLSP, production lot sizing is considered a prime decision for different plants to meet the demand at each plant. However, in reality there can be multiple regions and the demand of each region can be satisfied from multiple production/storage facilities located in the respective regions. This means that demand can be considered for each region rather than an individual facility (plant/warehouse).

The second stream of literature concerns multi-site production, inventory and transportation planning in supply chains. This considers manufacturing/storage facilities located in different regions within a geographic area or in different countries. Wilkinson, Cortier, Shah, and Pantelides (1996) studied a production and distribution scheduling problem for a fast moving consumer goods (FMCG) company which has a set of manufacturing facilities to meet the demand of different European countries from a single warehouse in each country. Timpe and Kallrath (2000) proposed a generic multi-site production-distribution problem with inter-facility transportation, which is motivated by the case of a chemical industry. They considered a single manufacturing facility and a set of retail outlets at each site. The decision involves production, inventory and inter-facility transportation quantities over a finite planning horizon. Similar studies in the literature include applications like FMCG Company (Kanyalkar & Adil, 2007), thin film transistor and liquid crystal display manufacturer (Lin & Chen, 2007), multi-national pharmaceutical companies (Susarla & Karimi, 2012), wheat distribution (Asgari, Farahani, Rashidi-Bajgan, & Sajadieh, 2013), soft-drink manufacturer (Sel & Bilgen, 2014), offshore air transport (Hermeto, Ferreira Filho, & Bahiense, 2014). A comprehensive review of tactical planning models for supply chains can be found in Esmaeilikia et al. (2014).

In the literature of the multi-site production, inventory and transportation planning problems, the selection of sites for production is considered as an inherent decision to satisfy either aggregate demand of all the regions or the demand of individual facilities in each region. However, region-wise aggregate demand/production/procurement over multiple facilities located in each region is not considered in the literature. In some cases production/procurement activity can be possible only during a specific season, and the related planning of when, where and how much to produce/procure may not be under the control of decision makers. In such situation, the decision makers are concerned with the optimization of logistics related costs. For example, an organization dealing with the supply chain of seasonal agricultural produce (fruits, foodgrains, sugarcane, etc.) is bounded to procure the available produce in the marketing season from the stakeholders (farmers/growers), and subsequently to transport and store the products at different storage locations to meet the annual demand of different regions. This aspect is also neglected in the literature.

In the present study, we consider a supply chain consisting of multiple storage facilities (warehouses) located in different regions of a large geographic area, where each region has a procurement and demand strategy that is aggregated over all the warehouses located in that region. Consequently, it is necessary to decide in which warehouse to store the procured item and when to withdraw the item to meet the demand of each region. Further, in order to ensure availability of the item in regions with a deficit, the item is required to be transported from regions with a surplus. The problem is formulated as a multi-region multi-facility inventory allocation and transportation problem to minimize the inventory and transportation costs. A heuristic is proposed to solve the problem by decomposing the problem into sub-problems.

The rest of the article is organized as follows. The problem description is presented in the next section. In Section 3, the model formulation is presented. The solution methodology is discussed in Section 4. The results of the computational experiments are presented in Section 5. Finally, Section 6 concludes the paper.

2. Problem description

In the Indian PDS, foodgrain (mainly wheat and rice) is procured from farmers at a predetermined price (called minimum support price) and distributed to around 813.5 million beneficiaries at a subsidized price through a large network of retail outlets called fair price shops (FPS). To make the PDS work, Food Corporation of India (FCI), a public sector undertaking of the government of India, carries out the activities of procurement, storage and transportation of foodgrain across different states (regions) of India. Presently, there are 29 states and seven union territories in India. Foodgrain is procured by FCI during the marketing season at the marketplaces located in the foodgrain producing states. Major foodgrain producing states are located in the northern part of the country. The marketing seasons for wheat and rice are April-June and October-February, respectively, due to their different cultivation periods. Average annual procurement of wheat and rice during 2010–14 has been 28.1 and 33.6 million metric ton (MMT), respectively. The procured foodgrain is preferably stored in the warehouses of the respective procuring states. Otherwise, it is kept in open space