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An evolutionary approach for multi-objective optimization of the integrated location–inventory distribution network problem in vendor-managed inventory

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ABSTRACT

Vendor-managed inventory (VMI) is one of the emerging solutions for improving the supply chain efficiency. It gives the supplier the responsibility to monitor and decide the inventory replenishments of their customers. In this paper, an integrated location–inventory distribution network problem which integrates the effects of facility location, distribution, and inventory issues is formulated under the VMI setup. We presented a Multi-Objective Location–Inventory Problem (MOLIP) model and investigated the possibility of a multi-objective evolutionary algorithm based on the Non-dominated Sorting Genetic Algorithm (NSGA2) for solving MOLIP. To assess the performance of our approach, we conduct computational experiments with certain criteria. The potential of the proposed approach is demonstrated by comparing to a well-known multi-objective evolutionary algorithm. Computational results have presented promise solutions for different sizes of problems and proved to be an innovative and efficient approach for many difficult-to-solve problems.

1. Introduction

Recently, two generic strategies for supply chain design have emerged: efficiency and responsiveness. Efficiency aims to reduce operational costs; responsiveness, on the other hand, is designed to react quickly to satisfy customer demands. A crucial question in the supply chain is the design of distribution networks and the identification of facility locations. Ballou and Masters (1993) put forward four strategic planning areas in the design of a distribution network system, as shown in Fig. 1. The first issue deals with customer service levels. The second one deals the placement of facilities and demand assignments made to them. The third deals with inventory decisions and policies that involve inventory control. The fourth deals with transportation decisions of how transport modes are selected, utilized, and controlled. All four of these areas are inter-related and the customer service level is determined by the other three decision areas. There are practical challenges for firms when they try to simultaneously reduce operating costs (for efficiency) and customer service (for responsiveness). In traditional supply chain network design, the optimization focus is often placed on minimizing cost and maximizing profit as a single objective. However, very few distribution network systems should be considered as intrinsically single objective problems. It is not always desirable to reduce costs if this results in a degraded level of customer service. Thus, it is necessary to set up a multi-objective network design problem.

Research on integrated location–inventory distribution network systems is relatively new. Jayaraman (1998) developed an integrated model which jointly examined the effects of facility location, transportation modes, and inventory-related issues. However, Jayaraman's study did not contain any demand and capacity restrictions. Erlebacher and Meller (2000) formulated an analytical joint location–inventory model with a highly nonlinear objective function to maintain acceptable service while minimizing operating, inventory and transportation costs. Nozick and Turnquist (2001) proposed a joint location–inventory model to consider both cost and service responsiveness trade-offs based on an uncapacitated facility location problem. Miranda and Garrido (2004) studied a MINLP model to incorporate inventory decisions into typical facility location models. They solved the distribution network problem by incorporating a stochastic demand and risk pooling phenomenon. Sabri and Beamon (2000) presented an integrated multi-objective, multi-product, multi-echelon model that simultaneously addresses strategic and operational planning decisions by developing an integrated two sub-module model which includes cost, fill rates, and flexibility. Gaur and Ravindran (2006) studied a bi-criteria optimization model to represent the inventory aggregation problem under risk pooling, finding out the tradeoffs in costs and responsiveness.

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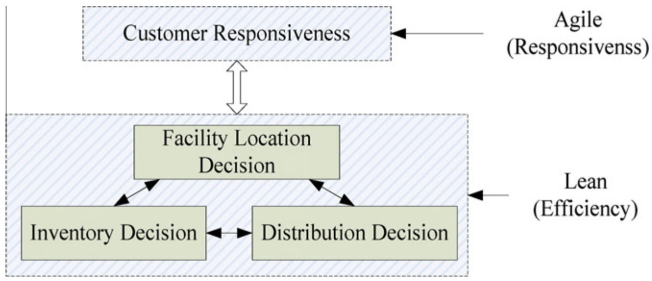

Fig. 1. Four strategic planning issues in distribution network design.

Recently, Daskin, Coullard, and Shen (2002) and Shen, Coullard, and Daskin (2003) introduced a joint location–inventory model with risk pooling (LMRP) that incorporates inventory costs at distribution centres (DCs) into location problems. LMRP solved the problem in two special cases: deterministic demand and Poisson demand. It assumed direct shipments from DCs to buyers which extended the uncapacitated fixed-charge problems to incorporate inventory decisions at the DCs. The uncapacitated assumption at DCs is usually not the case in practice. Shu, Teo, and Shen (2005) solved LMRP with general stochastic demand. Shen and Daskin (2005) extended the LMRP model to include the customer service component and proposed a nonlinear multi-objective model including both cost and service objectives. In contrast to LMRP and its variants that consider inventory cost only at the DC level, Teo and Shu (2004) and Romeijn, Shu, and Teo (2007) proposed a warehouse-retailer network design problem in which both DCs and retailers carried inventory. These are actually the two major streams of integrated distribution network design problems.

Our model builds upon the initial LMRP model but with some differences. First, a capacitated version of a similar model is established. Second, to make an original contribution, the proposed model incorporates two extra performance metrics corresponding to customer service. With these considerations, we present a capacitated Multi-Objective Location–Inventory Problem (MOLIP) which results in a Mixed-Integer Non-Linear Programming (MINLP) formulation. Some noteworthy innovative research aspects that are incorporated in our research include: (i) *Multi-Objective Location–Inventory Problem*. Very few studies have addressed this problem; (ii) *multi-objective evolutionary algorithms* (MOEAs). Most previous works have focused on traditional optimization techniques, but few have performed these techniques successfully and efficiently. In contrast, MOEAs have been successfully developed for various optimization problems, creating potential for the proposed MOLIP.

This study is organized as follows: Section 2 describes our research problem and details the model formulation. Section 3 proposes a hybrid evolutionary algorithm with a heuristic procedure for MOLIP. Section 4 illustrates our experimental results including (i) the computational results of a *base-case* problem (ii) scenario analysis (iii) computational evaluation of the proposed algorithm for MOLIP. Finally, conclusions and suggestions for the direction of future research are provided in Section 5.

2. Designing an integrated location–inventory distribution network model

In this section, we present a mathematical model which provides the foundation for our research.

2.1. Problem description

2.1.1. VMI coordination mechanism

Vendor-managed inventory (VMI) is one of the most widely discussed coordination mechanisms for improving multi-firm supply chain efficiency. Evidence has shown that VMI can improve supply chain performance by decreasing inventory costs for the supplier and buyer and improving customer service levels, such as reduced order cycle times and higher fill rates (Waller, Johnson, & Davis 1999). Fig. 2 indicates the system diagram of a VMI system includes its incurred material and information flows. Since the supplier is responsible for managing the inventories at the buyer's DC, including ordering and inventory holding, the supplier ought to receive the information about demand directly from the market. Since the supplier determines ordering instead of receiving orders from buyers, there is no information flow of the buyer's orders in the VMI system.

The main feature of VMI indicates the centralized system within, with which the supplier as a sole decision maker decides the order quantity based on information available from both buyers and suppliers to minimize the total cost of the whole supply chain system. The supplier has full authority over inventory management at the buyer's DC to pay all costs associated with the supplier's production cost, both the buyer's and the supplier's ordering cost, the inventory holding cost and distribution cost. The supplier monitors, manages and replenishes the inventory of the buyer. Thus, the decisions on order replenishment quantity and order shipping are given to the supplier in the VMI system, rather than to the buyer as in tradition systems. Fig. 3 presents the operational cost structure between the partners in the VMI system. The proposed model is mainly based this cost structure.

2.1.2. Overview of our research problem

In general, suppliers and distributors route their products through DCs. In practice, there are many cases in which each supplier has its own set of DCs. Consider a distribution network configuration problem where a single supplier and DCs are to be established to distribute various products to a set of buyers and both the DCs and buyers are geographically dispersed in a region. In this problem, each buyer experiences demands for a variety of products, which are provided by the supplier. A set of DCs must be located in the distribution network from a list of potential sites. The DCs act as intermediate facilities between the supplier and the buyers and facilitate the shipment of products between the two echelons. The supplier wishes to decide the supply chain distribution network for its products such as to determine the subsets of DCs to be opened and to design a distribution network strategy that will satisfy all capacity and demand requirements for the products imposed by the buyers.

However, our problem jointly considers both *strategic* and *tactical* decisions in the supply chain system. The strategic decision involves the *location* problem, which determines the number and the locations of DCs and assigns buyers to DCs, whereas the tactical decision deals with the *inventory* problem which determines the levels of safety stock inventory at DCs to provide certain service levels to buyers. The integrated problem is called a *location–inventory* distribution network problem. The centralized inventory policy is considered under the vender managed inventory (VMI) mode (Waller et al., 1999) which refers to the holding safety stocks aggregated at DCs. This inclusion acquires especial relevance in the presence of high inventory holding costs and high variability of demands. Fig. 4 shows the overall schematic diagram of the hierarchy of the model considered in our study.

2.2. Model assumptions and notations

Basic assumptions are used when modeling our problem. It is assumed that all the products are produced by a single supplier and one specific product for a buyer should be shipped from a single DC. Reverse flows, in-transit inventory, and pipeline inventory are not considered. All the buyers' demands are uncertain and the