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Location and allocation decisions for multi-echelon supply chain network – A multi-objective evolutionary approach

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ABSTRACT

This paper aims at multi-objective optimization of single-product for four-echelon supply chain architecture consisting of suppliers, production plants, distribution centers (DCs) and customer zones (CZs). The key design decisions considered are: the number and location of plants in the system, the flow of raw materials from suppliers to plants, the quantity of products to be shipped from plants to DCs, from DCs to CZs so as to minimize the combined facility location and shipment costs subject to a requirement that maximum customer demands be met. To optimize these two objectives simultaneously, four-echelon network model is mathematically represented considering the associated constraints, capacity, production and shipment costs and solved using swarm intelligence based Multi-objective Hybrid Particle Swarm Optimization (MOHPSO) algorithm. This evolutionary based algorithm incorporates non-dominated sorting algorithm into particle swarm optimization so as to allow this heuristic to optimize two objective functions simultaneously. This can be used as decision support system for location of facilities, allocation of demand points and monitoring of material flow for four-echelon supply chain network.

1. Introduction

Supply chain (SC) is an integrated system of facilities and activities that synchronizes inter-related business functions of material procurement, material transformation to intermediates and final products and distribution of these products to customers. Supply chain management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements (Simchi-Levi, Kaminsky, & Simchi-Levi, 2000). Above definition reveals that there are many independent entities in a supply chain each of which tries to maximize its own inherent objective functions in business transactions. This is a complicated problem as too many factors are involved and needs more than one objective to be satisfied simultaneously. Such a problem is called multi-objective optimization problem and has many Pareto solutions. The final decision is made taking the total balance over all criteria into account. This balancing over criteria is called trade-off.

Since today, the success measures for the companies are thought as lower costs, shorter production time, shorter lead time, less stock, larger product range, more reliable delivery time, better customer services, higher quality, and providing the efficient coordination between demand, supply and production, the trade-off between cost investment and service levels may change over time. Hence the supply chain performance needs to be evaluated continuously and supply chain managers should make timely and right decisions (Shen, 2007).

The key issues in supply chain management can broadly be divided into three main categories: (i) supply chain design (ii) supply chain planning and (iii) supply chain control. In the supply chain design phase, strategic decisions, such as facility location decisions and technology selection decisions play major roles. It is very important to design an efficient supply chain to facilitate the movements of goods. These strategic decisions lead to costly, time consuming investment as the facilities located today, are expected to remain in operation for long time. Environmental changes during the facility's lifetime can drastically alter the appeal of a particular site, turning today's optimal location into tomorrow's investment blunder. Determining the best locations for new facilities is thus an important strategic challenge (Owen & Daskin, 1998). Once the supply chain configuration is determined, the focus shifts to decisions at the tactical and operational levels, such as inventory management decisions on raw materials, intermediate products, and end products and distribution decisions within the supply chain (Chopra & Meindl, 2005).

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In traditional supply chain management, the focus of the designs of supply chain network is usually on single objective, minimum cost or maximum profit. But the design, planning and scheduling projects are usually involving trade-offs among different incompatible goals such as fair profit distribution among all members, customer service levels, fill rates, safe inventory levels, volume flexibility, etc. (Chen & Lee, 2004). Hence real supply chains are to be optimized simultaneously considering more than one objective. Many of the problems that occur in supply chain optimization are combinatorial in nature and picking a set of optimal solutions in the case of multi-objective formulations requires a algorithm that can efficiently search the entire objective space using small amounts of computation time. Literature shows that evolutionary algorithms perform well in this respect and give good optimal results when applied to many combinatorial problems. This work proposes the utility of non-dominated sorting particle swarm optimization algorithm for simultaneous optimization of two objectives, minimizing total supply chain cost and maximizing fill rate for a four-echelon supply chain architecture so as to arrive at an efficient supply chain design and optimal transportation/shipment plan which can be used as decision support system.

2. Prior related work

Since this work considers location decisions, allocation decisions, multi-objective optimization using particle swarm optimization algorithm, this section deals with prior work related to all these areas. Supply chain management has vast scope and encompasses the decisions about (1) where to produce, what to produce, and how much to produce at each site, (2) what quantity of goods to hold in inventory at each stage of the process, (3) where to locate plants and distribution centers etc. Out of these, location decisions may be the most critical and most difficult of the decisions needed to realize an efficient supply chain as their effect is long lasting. Both the cost of whole supply chain and the level of customer service provided by the system are significantly affected by the number, size and locations of facilities, as well as by the allocation decisions as to which customers to be served from which upstream supplier. Consequently, a significant amount of research has been devoted to the development of efficient supply chain design. The early study of location theory begin in 1909 with Alfred Weber's work on positioning a single warehouse so as to minimize the total distance between it and several customers (Weber, 1929). After that considerable work in location theory is done by Hakimi (1964), who work on locating switching centers in a communications network and police stations in a highway system. Later many researchers work on basic facility location problem formulations recognized as static and deterministic which take constant, known quantities as inputs and derive a single solution to be implemented at one point in time. These fundamental location problems are categorized into median problems (Hakimi, 1964; ReVelle, 1986), covering problems (Daskin, 1995; Church & ReVelle, 1976), center problems (Daskin, 1995), etc. Later focus is shifted to location-allocation problems which simultaneously locate facilities and dictate flows between facilities and demands. These problems are reviewed by Scott (1971). Additional variety of problems include models with multiple commodities, unreliable supply, etc. Warszawski and Peer (1973) and Warszawski (1973) are among the first to study the multi-commodity location problem. These models consider fixed location costs and linear transportation costs, and assume that each warehouse can be assigned at most one commodity. Geoffrion and Graves (1974) consider the capacitated version of the multi-commodity location problem and present a model to solve the problem of designing a distribution system with optimal location of the intermediate distribution facilities between plants and customers. The risks arising from the use of heuristics in distribution planning are discussed early on by Geoffrion and Vanroy (1979). They present three examples in the area of distribution planning demonstrating the failure of common sense methods to come up with the best solution.

In literature, another set of problems considered is called fixed charge facility location problems which consider fixed charge associated with locating at each potential facility site. There are two types of problems capacitated and uncapacitated plant location problems. Uncapacitated and capacitated plant location models are extensively dealt in Mirchandani and Francis (1990) and ReVelle, Eiselt, and Daskin (2008) and capacitated plant location models in Sridharan (1995). Also basic facility location problems are given a new orientation with integrated approach. This is due to the realization of fact that location decisions taken without considering inventory and shipment costs can lead to sub-optimality. Hence facility location models are developed considering location associated costs as well as production, inventory and distribution costs. Integrated decision making models in particular focus at coordination of any two of the three important supply chain decisions. Based on the factors considered they are catagorized into (1) location–routing (LR) models; (2) inventory–routing (IR) models; and (3) location–inventory (Li) models. These problems are extensively reviewed by Shen (2007).

Dynamic facility location models next evolved make an attempt to capture many of the characteristics of real-world location problems. Ballou (1968) first use dynamic programming to determine optimal location and relocation strategy for the planning period. Wesolowsky (1973) examines another, unconstrained, version of the single facility location problem over a finite planning horizon with explicit facility relocation costs. Scott (1971) develop multiple dynamic facility location-allocation problem. Wesolowsky and Truscott (1976) present an integer programming model to extend the analysis of multi-period node location-allocation problems, allowing facilities to be relocated in response to predicted changes in demand. Erlenkotter (1981) compares the performance of several heuristic solution approaches on a single problem formulation. He examines a dynamic, fixed charge, capacitated, cost minimization problem with discrete time intervals.

In traditional supply chain management, minimizing costs or maximizing profit is the primitive objective in most of the supply chain network design models (Cohen & Lee, 1989; Tsiakis, Shah, & Pantelides, 2001). But for a supply chain, producing products at minimum cost is not the only objective, satisfying customers is also equally important. Later some researchers start incorporating more than one competing objectives such as improving customer service and reducing cost in their models. Different methodologies found in literature for treating multiobjective optimization problems are the weighted-sum method, the ε-constraint method and the goal-programming method, fuzzy method, etc. (Azapagic & Clift, 1999; Chen & Lee, 2004; Cheng-Liang, Wang, & Wen-Cheng, 2003; Zhou, Cheng, & Hua, 2000).

Sabri and Beamon (2000) develop a model for supply chain management by combining strategic and operational design and planning decisions and solve it using an iterative procedure. They adopt multi-objective decision analysis and optimize simultaneously cost, fill rate and flexibility. Nozick and Turnquist (2001) present an optimization model which minimizes cost and maximizes service. They use a linear function to approximate the safety stock inventory cost function, which is then embedded in a fixed-charge facility location model. For a review of other multi-objective location models, publication by Shen, Coullard, and Daskin (2003) can be referred. Chen and Lee (2004) propose a model which simultaneously optimize conflicting objectives such as each participant's profit, the average customer service level, and the average safe inventory level. Guilléna, Melea, Bagajewiczb,