Expert Systems with Applications 40 (2013) 5730–5739

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

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

A bi-objective optimization of supply chain design and distribution operations using non-dominated sorting algorithm: A case study

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ARTICLE INFO

Keywords:
Three-echelon
Supply chain
Particle swarm
Swarm intelligence
Non-dominating sorting
Bi-objective

ABSTRACT

This paper considers simultaneous optimization of strategic design and distribution decisions for three-echelon supply chain architecture consisting of following three players; suppliers, production plants, and distribution centers (DCs). 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 distribution centers, so as to minimize the combined facility location, production, inventory, and shipment costs and maximize fill rate. To achieve this, three-echelon network model is mathematically represented and solved using swarm intelligence based Multi-objective Hybrid Particle Swarm Optimization algorithm (MOHPSO). This heuristic incorporates non-dominated sorting (NDS) procedure to achieve bi-objective optimization of two conflicting objectives. The applicability of proposed optimization algorithm was then tested by applying it to standard test problems found in literature. On achieving comparable results, the approach was applied to actual data of a pump manufacturing industry. The results show that the proposed solution approach performs efficiently.

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1. Introduction

In today's industrial environment, the rapid technological advancements, together with increased economic uncertainty and the globalization of economic activities have resulted in tough competition, and chaotic, demanding customers. There is a need to focus on revenue growth, asset utilization, cost reduction, short and reliable delivery time, increased customer satisfaction so as to balance customers' demands with the need for profitable growth. Realizing that supply chain (SC) can be a strategic differentiator in this direction, market leaders keep refining their SCs so as to gain competitive advantage (Cohen & Roussel, 2005).

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 (SCM) 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 across the entire SC. (Simchi-Levi, Kaminsky, & Simchi-Levi, 2001). Thus SC consists of many independent organizations each of which tries to focus on its own inherent objectives in business for better profitability. Many of the interests of these organizations will be conflicting. Such a problem which tries to optimize many conflicting objectives simultaneously is called multi-objective optimization problem and has many optimal solutions. In such a situation, analyzing the system using traditional optimization techniques such as weighted objective method leads to subjective and sub-optimal results. The ideal situation is that the decision maker should be presented with a vector of optimal solutions. The final decision is made among them by taking the total balance over all criteria into account. This balancing over criteria is called trade-off. The trade-off level may change over time due to uncertainty and global competitiveness. Hence the SC performance needs to be evaluated continuously and SC managers should make timely and right decisions (Shen, 2007).

Real SCs are to be optimized simultaneously considering more than one objective. This is because design, planning and scheduling projects are usually involving trade-offs among different conflicting goals such as customer service levels, fill rates, safe inventory levels, volume flexibility etc. (Chen & Lee, 2004). In this work a bi-objective mixed-integer non-linear programming model is formulated that accounts for major characteristics of SC, such as material cost, production cost, inventory cost, fill rate etc. Two conflicting objectives considered are, (1) Minimizing total SC operating cost of production, inventory, and distribution. (2) Maximizing fill

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http://dx.doi.org/10.1016/j.eswa.2013.03.047

rate. The problem is then solved using NDS based MOHPSO algorithm. The proposed approach is illustrated through a live case study of a pump manufacturing industry. This bi-objective model when solved results in Pareto-optimal curve that reveals the trade-off between the total SC operating costs and fill rate. The solution simultaneously predicts the optimal network design, facility location, SC operating cost, inventory control, and logistics management decisions. The cost values obtained are compared with actual industrial data.

Rest of the paper is organized as follows. Section 2 deals with the work that is done previously in the related field. Section 3 explains modeling and mathematical formulation of design-distribution network considered. Section 4 deals with Hybrid MOPSO methodology adopted to solve bi-objective design-distribution problem. A systematic application of the proposed algorithm is demonstrated in Section 5. Section 6 includes results and discussions, which is followed by concluding Section 7 where in future work is outlined.

2. Prior related work

In traditional supply chain management, the focus of the integration of SCN is usually on single objective such as minimizing cost or maximizing profit (Jayaraman & Pirkul, 2001; Jayaraman & Ross, 2003; Syarif, Yun, & Gen, 2002; Yan, Yu, & Cheng, 2003). Since a decade, researchers started incorporating more than one competing objectives such as each participant's profit, the average customer service level, and the average safe inventory level. Different methodologies found in literature for treating multi-objective optimisation problems are the weighted-sum method, the -constraint method, goal-programming method, fuzzy method etc. (Azapagic & Clift, 1999; Chen & Lee, 2004; Chen, Wang, & Lee, 2003; Zhou, Cheng, & Hua, 2000).

One of the earliest works on multi-objective location problems is by Ross and Soland (1980). According to them practical problems involving the location of public facilities are multi-criteria problems. They modeled cost and service as general criteria and developed an interactive approach to the resolution of multi-criteria location problems. Lee, Green, and Kim (1981) presented the application of integer goal programming to the facility location and products allocation problem with multiple, competing objectives. Fernandez and Puerto (2003) presented an exact and an approximate approach to obtain the set of non-dominated solutions for discrete multi-objective un-capacitated plant location problem. The two approaches resort to dynamic programming to generate in an efficient way the non-dominated solution sets. Sabri and Beamon (2000) formulated a model that incorporates production, delivery and demand uncertainty and provides a multi-objective performance vector for entire SC network. They adopted multi-objective decision analysis and optimized simultaneously cost, fill rate and flexibility. Nozick and Turnquist (2001) presented an optimization model which minimized cost and maximized service. They used a linear function to approximate the safety stock inventory cost function, which was then embedded in a fixed-charge facility location model. They solved the problem heuristically. Shen, Coullard, and Daskin (2003) proposed a joint location-inventory problem involving a single supplier and multiple retailers with variable demand. They presented computational results on several instances of sizes ranging from 33 to 150 retailers.

Chen and Lee (2004) proposed a model which simultaneously optimizes conflicting objectives such as each participant's profit, the average customer service level, and the average safe inventory level. Guilléna, Melea, Bagajewiczb, Espuñaa, and Puigjanera (2004) formulated the SCN design problem as multi-objective stochastic Mixed Integer Linear Programming model for SC design, which was solved by using the standard -constraint method, and branch and bound techniques. This formulation takes into account SC profit and customer satisfaction level, considering uncertainty by means of the concept of financial risk. Shen (2006) addressed profit-maximizing SC design model where in a company can choose whether to satisfy a customer's demand.

Work of Bouzembrak, Allaoui, Goncalves, and Bouchriha (2011) captured a compromise between the total cost and the environment influence. They simultaneously optimized two objective functions; total cost and total CO_2 emission in entire SC. Their work helped to take strategic decisions such as warehouses and DCs location, building technology selection and processing/distribution planning. Classical GA was improved by Prakash, Felix, Chan Liao, and Deshmukh (2012) who presented a knowledge based genetic algorithm (KBGA) for the network optimization of SC. Their methodology considered three new genetic operators – knowledge based: initialization, selection, crossover, and mutation. The results showed that their methodology improved the performance of classical GA by obtaining the results in fewer generations. Research by Amin and Zhang (2012) proposed an integrated model for general closed loop supply chain network. Their model considered supplier selection, order allocation, and closed loop supply chain network configuration, simultaneously. Liu and Papageorgiou (2013) considered three objectives; cost, responsiveness and customer service level for integrating production, distribution, capacity planning of a global SC. The authors solved their model using e-constraint method. A multi-objective Harmony Search algorithm approach for the efficient distribution of 24-h emergency units is considered by Landa-Torres, Manjarres, Salcedo-Sanz, Del Ser, and Gil-Lopez (2013). They applied this to a realistic case in two regions of Spain and showed that the proposed algorithm is robust and provides a wide range of feasible solutions.

Particle swarm optimization (PSO) is one of the evolutionary computation techniques and is originally proposed by Kennedy as a simulation of social behavior. It is initially introduced as an optimization method in 1995 (Kennedy & Eberhart, 1995). The algorithm initializes in the beginning of search a population of particles which survive for all generations till end of search. Each particle has memory using which it keeps track of best position it has acquired so far and best position any other particle acquired so far within the neighborhood. The particle will then modify its direction based on components towards its own best position and towards the overall best position. This kind of systematic acceleration finally leads to convergence to the target. PSO can be easily implemented and it is computationally in expensive, since its memory and CPU speed requirements are low (Eberhart, Simpson, Dobbins, & Dobbins, 1996). Also, it does not require gradient information of the objective function, but needs only its values (Kennedy & Eberhart, 1995).

Until 2002 PSO had only been applied to single objective problems, and was giving promising solutions efficiently and effectively. In single objective PSO, the swarm population is fixed and are only adjusted by their pbest and the gbest. But, to facilitate Multi-objective approach to PSO a set of non-dominated solutions must replace the single global best individual in the standard single objective PSO. This task of picking suitable global best (gbest) and personal best (pbest) to move the particles through search space is much difficult in Multi-objective Particle Swarm Optimization (MOPSO). According to Coello (1999), a good MOPSO method must obtain solutions with a good convergence and diversity along the Pareto-optimal front. In 2002, break through studies on inception of multi-objective PSO (MOPSO) were published (Coello & Lechuga, 2002; Fieldsend & Singh, 2002; Hu & Eberhart, 2002; Parsopoulos & Vrahatis, 2002). Each of these studies implements MOPSO in different ways. Later publications incorporate several

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