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Multiobjective optimisation of production, distribution and capacity planning of global supply chains in the process industry

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A B S T R A C T

The performance of a supply chain should usually be measured by multiple criteria. We address production, distribution and capacity planning of global supply chains considering cost, responsiveness and customer service level simultaneously. A multiobjective mixed-integer linear programming (MILP) approach is developed with total cost, total flow time and total lost sales as key objectives. Also, two strategies to expand the formulation plants' capacities are considered in the model. The ε-constraint method and lexicographic minimax method are used as solution approaches to tackle the multi-objective problem. Finally, a numerical example is investigated to demonstrate the applicability of the proposed model and solution approaches.

1. Introduction

A supply chain contains all activities that transform raw materials to final products and deliver them to the customers. In the past decades, with the rapid globalisation, many companies' procurement, supply, production and distribution activities are located in multiple countries, even multiple continents. Dealing with the global competition, how to establish a global supply chain network with reduced cost, improved responsiveness, and higher customer service level becomes a crucial issue to multinational firms.

Cost is the most commonly used criterion for supply chain performance. The profit of a firm is directly affected by the cost of its operations. Thus, its importance and influence to the whole performance is quite obvious and is the most significant direct kind of measurement [1]. Responsiveness is regarded as an important performance metric of a supply chain in a rapid changing market environment. A firm with a responsive supply chain can meet the market demand in shorter lead times and react quickly to the customer needs. How to develop a responsive supply chain has been widely studied [2]. It is commonly regarded that responsiveness and cost-efficiency conflict with each other. A responsive supply chain usually has a higher cost, while a cost-efficient supply chain often operates at the expense of market responsiveness [3]. Another fundamental characteristic determining the performance of a supply chain is customer service level [4], which measures the percentage of customer demand satisfied on time. A low customer service level may cause lost sales or lost customers, which result in profit loss for the whole supply chain.

The above three performance metrics of supply chain are crucial to the supply chain design and planning. Erengüç et al. [5] reviewed the earlier relevant literature on production and distribution planning at each stage in the supply chain. In the past decade, a large number of new models, for supply chain design and planning in the process industry have been presented, especially those based on mathematical programming techniques. The readers can refer to the recent reviews [6–9] for more details.

Most literature models only consider single criterion for the supply chain planning and optimisation, such as cost [10,11], profit [12,13] and net present value (NPV) [14,15]. One of the earliest papers using multiobjective method for supply chain [16] proposed a multiobjective approach for vendor selection, considering three objectives including the purchases cost, number of late deliveries, and rejected units.

In the past decade, a large number of multiobjective optimisation problems and solution methods have been presented in the literature on supply chain management. Jayaraman [17] developed a weighted multiobjective model for a service facility location problem to evaluate the trade-off between demand coverage and the number of facilities. Gjerdrum et al. [18] developed a mathematical programming model to reduce operating cost, while maintaining customer order fulfilment at a high level for a supply chain network. Chen et al. [19] formulated a multiobjective mixed-integer nonlinear programming (MINLP) production and distribution planning model for a fair profit

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distribution in a supply chain network. Hugo et al. [20] proposed an optimisation-based multiobjective model for the strategic investment planning and design of hydrogen supply chains, considering both investment and environmental criteria. Amodeo et al. [21] developed a simulation-based multiobjective optimisation method for the optimisation problem of the inventory policies of supply chains considering total inventory cost and service level. Roghanian et al. [22] solved a probabilistic bi-level linear multiobjective programming problem for supply chain planning and using an adapted fuzzy programming technique [23]. Chern and Hsieh [24] proposed a heuristic algorithm to solve master planning problems for a supply chain network, with three objectives including delay penalties, outsourcing capacity usage and total cost. Pokharel [25] optimised the operation cost and delivery reliability for a supply chain network design problem using STEP algorithm [26]. Raj and Lakshminarayanan [27] considered three performance characteristics, such as customer satisfaction, back order and excess inventory. Selim et al. [28] developed a multiobjective mixed-integer linear programming (MILP) model for collaborative production–distribution planning problem using fuzzy goal programming approach. Liang [29] developed a fuzzy multiobjective linear programming (LP) model to simultaneously minimise total costs and total delivery time in a supply chain, adopting the fuzzy goal programming method [30]. Torabi and Hassini [31,32] considered multiobjective optimisation for a multi-echelon supply chain planning problem. A fuzzy goal programming-based approach was proposed, based on the literature work [33,34]. Pinto-Varela et al. [35] used an optimisation approach adapted from symmetric fuzzy linear programming [34] to solve the bi-objective MILP model for the planning and design of supply chains considering both economic and environmental aspects.

Apart from the solution methods mentioned above, the ε-constraint method has widely been used in the literature to generate Pareto-optimal solutions for multiobjective supply chain planning problem. Sabri and Beamon [36] developed an integrated multiobjective model for simultaneous strategic and operational planning of a supply chain, taking into account cost, customer service level, and delivery flexibility as objectives. Guillén et al. [37] used NPV, demand satisfaction and financial risk as objectives in the proposed two-stage MILP stochastic model for a supply chain design problem under demand uncertainty. You and Grossmann [38] proposed multi-period MINLP model for supply chain design and planning under both responsive and economic criterion with demand uncertainties. Franca et al. [39] proposed a multiobjective stochastic model considering both profit and raw material obtained defects of the supply chain.

As to the global supply chain planning problem, a large number of papers have addressed it. Vidal and Goetschalckx [40] presented a literature review of strategic production–distribution models of global supply chain. Schmidt and Wilhelm [41] reviewed the literature for strategic, tactical and operational decisions related to multi-national logistics networks. Then, Goetschalckx et al. [42] presented a review for modelling and design of global logistics systems. Meixell and Gargeya [43] reviewed the literature decision support models for the global supply chain design problem.

There are a number of literature models on the global supply chain optimisation. Nagurney et al. [44] proposed a network equilibrium model for a three-level global supply chain. Oh and Karimi [45] presented an MILP model for capacity-expansion planning and material sourcing problem in global chemical supply chains. A static MILP model was proposed by Tsiakis and Papageorgiou [46] to formulate a strategic optimal planning problem for multi-echelon supply chain networks, taking into account some financial aspects. Das and Sengupta [47] presented a two-level MILP approach for strategic and operational planning of a strategic business unit in a global supply chain. Bassett and Gardner [48] developed a multi-period MILP model for the optimal supply chain network design and production–shipping operations of an agrochemical company. Sousa et al. [49] developed an MILP model and two decomposition algorithms for a global pharmaceutical supply chain planning problem.

From the above literature review, we can see that little work has done to consider these three important measure criteria, cost, responsiveness and customer service level, simultaneously. In this work, we address the production, distribution and capacity planning of a global process supply chain, with cost, responsiveness, and customer service level as the objectives. The purpose is to develop a multiobjective MILP formulation for this problem and adapt two solution approaches to solve the model; the ε-constraint method and the lexicographic minimax method. To the best of our knowledge, the lexicographic minimax method has not been used in the multiobjective supply chain optimisation.

The remainder of this paper is organised as follows: the multiobjective supply chain planning problem statement is described in Section 2. The detailed mathematical formulation is shown in Section 3. In Section 4, two solution approaches, ε-constraint method and lexicographic minimax method, are presented. The details of a numerical example are given in Section 5. Section 6 presents and discusses the computational results of the case study. Finally, some concluding remarks are made in Section 7.

2. Problem statement

The global supply chain network of an agrochemical company consists of one active ingredient (AI) production plant, several formulation plants in different regions and a number of market regions. The products are divided into several product groups. Each plant can produce products in suitable product groups.

The production and transportation costs of AI are included in the raw material cost, which also includes the cost of other ingredients. In the plants, the final products are formulated. Transportation costs and times occur when the products are shipped from plants to market regions for sale. When the products arrive to the market, duties are also charged. It is assumed that all inventories are held at the markets. The supply chain network is illustrated in Fig. 1.

In this problem, we consider the production, distribution and capacity planning of the supply chain. It is assumed that the original capacities of formulation plants will not satisfy the requirement of rapidly increased demand. So, the capacity planning is also considered here. There are two optional capacity expansion strategies: proportional and cumulative capacity expansion. For the proportional capacity expansion (PCE), the maximum capacity increment

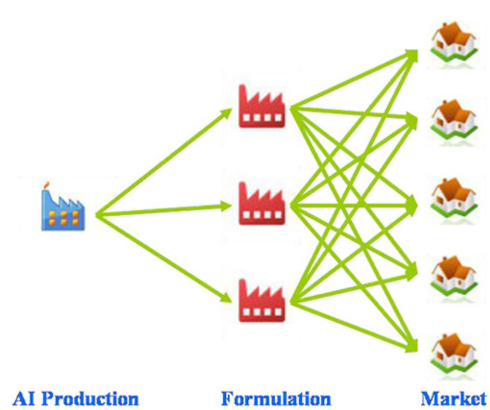

Fig. 1. Supply chain network of an agrochemical company.