# Two-Stage Sustainable Supply Chain Networks

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Supply chain networks have emerged as the backbone of economic activities in the modern world. Most of the literature on the optimization problem of transportation in supply chain networks (SCNs) considers fixed costs (FCs).

Keywords: supply chain ; network design ; two-stage ; optimization

## 1. Introduction

The supply chain network design (SCND) problem can be classified into three types: forward type of supply chain network, reverse type of supply chain network, and closed loop type of supply chain network. Researchers deal with the forward type of SCND, which is when the material flows from the supplier to the plant and then reaches the customer. There are many stages in this model (multistage), which may include warehouses and distributors. The supply chain is a network of suppliers, manufacturers, and distribution centers that transforms raw materials into usable products through several stages and distributes them to retailers in one or more stages. In the traditional transportation problem, the objective is to minimize total transportation costs by minimizing shipping costs proportional to the volume of items moved. Nevertheless, in practice, a fixed cost is incurred anytime a transportation route is established between a factory and a retailer. A fixed-cost transportation problem (FCTP) occurs when both fixed and variable costs exist simultaneously. The variable cost varies linearly with the amount carried from supply to destination, and the fixed cost is incurred anytime a product is transferred between the supply and destination points. The preceding evidence demonstrates that problems involving fixed costs are more challenging to resolve than those involving variable costs.

Typically, the FCTP is formulated as a mixed-integer programming problem and is tackled using methods comparable to those described in the literature. Several reports on the single-stage FCTP emphasize minimizing total transportation costs [1][2][3]. Molla-Alizadeh-Zavardehi et al. [4] extended the FCTP to a two-stage supply chain problem, which considers possible distribution centers with fixed capacity for each distribution center to be opened. The model optimizes overall costs by establishing the optimal number of distribution centers to meet customer demands. Panicker et al. [5] proposed a two-stage FCTP in which several plants serve products to a number of retailers via a set of unlimited-capacity distribution centers. However, the model only dealt with a single product and a single period. Similarly, Hong et al. [6] considered the FCTP in a two-stage supply chain with fixed costs for transportation routes.

In practice, it is more challenging to solve the FCTP than to solve a linear one. Numerous techniques have been proposed in the literature to solve the FCTP, such as the genetic algorithm [7][8], the simulated annealing algorithm [9], the artificial immune and genetic algorithm [4], simplex-based simulated annealing [10], and ant colony optimization for various optimization problems such as the traveling salesman problem [11]. Jawahar and Balaji [12] considered a two-stage supply chain distribution problem associated with a fixed cost. Stützle and Dorigo [13] applied ant colony optimization to solving complex cases of the FCTP. Panicker et al. [5] conducted a comparative analysis of an ant colony optimization and a genetic algorithm heuristic technique, revealing their effectiveness in solving a two-stage FCTP. Sanei et al. [14] proposed a Lagrangian relaxation heuristic for solving the problem of transporting products from sources to destinations using different transportation modes with variable and fixed costs. Lotfi and Tavakkoli-Moghaddam [1] proposed a genetic algorithm to solve FCTPs. Shen and Zhu [15] examined a two-stage FCTP under uncertainty and proposed to use the genetic algorithm and particle swarm optimization to solve the problem. Kowalski et al. [3] developed a simple algorithm for obtaining the global solution to a small-scale FCTP by decomposing the problem into a series of smaller subproblems. In the real world, the FCTP is a complicated problem, particularly in supply chain management and distribution systems. Sadeghi-Moghaddam et al. [16] presented variable and fixed costs as fuzzy numbers. Panicker and Sarin [17] and Wang et al. [18] formulated a multistage, multiperiod FCTP for multiproducts, which is solved using ant colony optimization.

## 2. One Stage FCTP

Lotfi and Tavakkoli-Moghaddam [1] proposed a genetic algorithm using priority-based encoding (pb-GA) for linear and non-linear FCTPs. Adlakha et al. [2] developed a heuristic algorithm to identify the demand destinations and the supply points to ship to. Another aspect to consider is the more-for-less (MFL) phenomenon in FCTPs. The MFL phenomenon occurs when it is possible to ship more total goods for less (or equal) total cost while shipping the same quantity or more from each origin and to each destination. LINGO 19 was used to obtain the optimal solution and the MFL solution for comparative purposes.

## 3. Two Stage FCTP

Molla-Alizadeh-Zavardehi et al. [4] considered two stages of the supply chain network: distribution centers (DCs) and customers. Customers with specific needs exist, as do prospective locations for warehouses. Each of the possible DCs can ship to any of the clients. Two different types of costs were considered: the opening cost, which is expected for opening a possible DC, and the shipping cost per unit from the DC to the clients. The proposed model picks several viable locations as distribution centers in order to meet the needs of all clients. Two algorithms, the genetic algorithm and the artificial immune algorithm, were created to address the given problem. The Taguchi experimental design approach was used to identify the best parameters with the fewest number of experiments. Different problem sizes were used, and the computational output of the algorithms was compared to one another for the purpose of performance evaluation of the suggested algorithms.

Hong et al. [6] focused on the problem of distribution allocation in a supply chain with two stages and fixed costs. His challenge was to identify a distribution network's manufacturing facilities, wholesalers, and retailers' supply chain arrangements. The issue was modeled using an integer-programming approach. The mathematical model includes fixed costs for facility opening and fixed costs for transportation routes, as well as unit transportation costs between entities. The model's goal was to reduce the overall expenses of supply chain management associated with assigning retailers to distribution centers and distribution centers to production facilities. For the purpose of solving the model, an ant colony optimization (ACO)-based heuristic was created. On a range of produced problem sizes, the heuristic was tested.

Panicker et al. [5] focused on an issue of distribution allocation in a supply chain with two stages and fixed costs. To handle the problem of a fixed transportation cost for a route, an algorithm based on ant colony optimization was suggested. A numerical analysis of examples of benchmark problems was performed. The proposed algorithm's outcomes were contrasted with those of the genetic algorithm-based heuristic. The design and management of supply chains were found to be the key concerns for managers of industrial and service organizations in today's fiercely competitive business environment. Allocating customers to a manufacturing company's various supply chain partners is a crucial choice that influences value addition, degree of customer service, and prices.

Sanei et al. [14] introduced the step fixed-charge solid transportation problem, in which products are transported using a combination of unit and step fixed-charges from sources to destinations. It offers a dual decomposition method that can handle larger cases and relies on Lagrangian relaxation. Lotfi and Tavakkoli-Moghaddam [1] proposed a priority-based genetic algorithm to solve both linear and nonlinear FCTPs that includes novel crossover and mutation operators. Shen and Zhu [15] examined the two-stage fixed-cost transportation problem in an unpredictable environment. Demands, supply, availability, fixed costs, and transported amounts were all regarded as uncertain factors because there are so many unknowns. The goal was to maximize overall profit in unpredictable circumstances. Based on the structure of the problem, the genetic algorithm and particle swarm optimization were suggested to solve the equivalent forms of the models.

Kowalski et al. [3] presented a simple method to find the overall solution to an FCTP on a small scale. By breaking the problem down into a number of smaller subproblems, the suggested approach solved FCTP. To solve the small-scale FCTP, a straightforward and quick branching approach was suggested. Until a perfect solution is found, the subproblems can be divided into even smaller subproblems. This approach offers a substitute for quickly using computer tools to solve small-scale problems. As a result, it can be used as a pedagogical tool in a classroom setting to achieve educational objectives. Sadeghi-Moghaddam et al. [16] presented variable and fixed costs as fuzzy numbers. They used both priority-based representation and Prüfer numbers based on spanning trees to propose novel techniques in solution algorithms. Additionally, the Taguchi method was employed to ensure the accurate calibration of parameters and the proper operation of algorithms. Additionally, a number of instances of various sizes were produced to evaluate the effectiveness of the algorithms and available software in the context of real-world cases. Keshavarz et al. [19] considered a fixed-charge transportation problem with fuzzy shipping costs where the shipping costs of routes are fuzzy intervals with increasing linear membership functions, fixed costs, supplies, and demands are deterministic numbers.

## 4. Multistage FCTP

In addition to the variable cost, the majority of practical applications of a transportation network have a fixed cost. For a scenario involving multiple products, the problem is described as a multistage, multiperiod fixed-charge transportation problem (MPFCTP). Panicker and Sarin [17] modeled the problem with the use of an optimization modeling tool named “A Mathematical Programming Language,” and the BONMIN solver provides the answer. Finding the best solution for a huge problem size that is seen in practice typically requires more precise algorithms and longer computation times. A heuristic based on ant colony optimization was suggested for these operational problems, where process speed is just as crucial as solution quality. Using datasets created at random, the solution produced by the suggested heuristic was contrasted with that of accurate approaches. For a scenario involving many products, a simple MPFCTP model was created. The computational analysis shows that even though the solution reached using exact methods is the best, the computational time required to solve a mathematical model is substantial. The ant colony optimization approach was suggested to solve the model since the exact methods become less effective as the problem size increases. Both approaches are the subject of a computational investigation, and the outcomes of the precise method and the ACO were compared. It is known that ACO provides a solution that is close to optimal in a lot less time than exact approaches.

A market area receives a variety of products from the supply chain over time. The model takes into account where manufacturers and retailers are located and makes the assumption that customer behavior is probabilistic and based on an attraction function that is affected by both the location and the quality of the retailers. In order to maximize supply chain profit in a competitive economy, Wang et al. [18] studied a model of a supply chain network with pricing competition. They built the supply chain with capacity constraints. A model of mixed integer nonlinear programming was used to formulate the issue. Simulated annealing search (SA) and particle swarm optimization (PSO) were the two heuristic techniques they suggested. The results based on solving designed datasets demonstrated that simulated annealing is more effective than particle swarm optimization in terms of both solution quality and CPU times. Kungwalsong et al. [20] proposed a two-stage stochastic programming model for a four-echelon global supply chain network design problem, considering possible disruptions at facilities. A modified simulated annealing (SA) algorithm was developed to determine the strategic decision at the first stage.

## References


1. Lotfi, M.M.; Tavakkoli-Moghaddam, R. A genetic algorithm using priority-based encoding with new operators for fixed charge transportation problems. Appl. Soft Comput. J. 2013, 13, 2711–2726.
2. Adlakha, V.; Kowalski, K.; Vemuganti, R.R.; Lev, B. More-for-less algorithm for fixed-charge transportation problems. Omega 2007, 35, 116–127.
3. Kowalski, K.; Lev, B.; Shen, W.; Tu, Y. A fast and simple branching algorithm for solving small scale fixed-charge transportation problem. Oper. Res. Perspect. 2014, 1, 1–5.
4. Molla-Alizadeh-Zavardehi, S.; Hajiaghaei-Keshteli, M.; Tavakkoli-Moghaddam, R. Solving a capacitated fixed-charge transportation problem by artificial immune and genetic algorithms with a Prufer number representation. Expert Syst. Appl. 2011, 38, 10462–10474.
5. Panicker, V.V.; Vanga, R.; Sridharan, R. Ant colony optimisation algorithm for distribution-allocation problem in a two-stage supply chain with a fixed transportation charge. Int. J. Prod. Res. 2013, 51, 698–717.
6. Hong, J.; Diabat, A.; Panicker, V.V.; Rajagopalan, S. A two-stage supply chain problem with fixed costs: An ant colony optimization approach. Int. J. Prod. Econ. 2018, 204, 214–226.
7. Raj, K.A.A.D.; Rajendran, C. Fast heuristic algorithms to solve a single-stage Fixed-Charge Transportation Problem. Int. J. Oper. Res. 2009, 6, 304–329.
8. Raj, K.A.A.D.; Rajendran, C. A genetic algorithm for solving the fixed-charge transportation model: Two-stage problem. Comput. Oper. Res. 2012, 39, 2016–2032.
9. Jawahar, N.; Gunasekaran, A.; Balaji, N. A simulated annealing algorithm to the multi-period fixed charge distribution problem associated with backorder and inventory. Int. J. Prod. Res. 2012, 50, 2533–2554.
10. Yaghini, M.; Momeni, M.; Sarmadi, M. A Simplex-based simulated annealing algorithm for node-arc capacitated multicommodity network design. Appl. Soft Comput. J. 2012, 12, 2997–3003.
11. Dorigo, M.; Member, S.; Gambardella, L.M. Ant Colony System: A Cooperative Learning Approach to the Traveling Salesman Problem. IEEE Trans. Evol. Comput. 1997, 1, 53–66.

12. Jawahar, N.; Balaji, A.N. A genetic algorithm for the two-stage supply chain distribution problem associated with a fixed charge. Eur. J. Oper. Res. 2009, 194, 496–537.
13. Dorigo, G.E.M.; Di Caro, G.; Stützle, T. Special Issue on Ant Algorithms. 1999. Available online: http://polymorphe.free.fr/cours/ia/antlab/FGCS-Editorial-final.pdf (accessed on 16 October 2022).
14. Sanei, M.; Mahmoodirad, A.; Niroomand, S.; Jamalian, A.; Gelareh, S. Step fixed-charge solid transportation problem: A Lagrangian relaxation heuristic approach. Comput. Appl. Math. 2017, 36, 1217–1237.
15. Shen, J.; Zhu, K. An uncertain two-echelon fixed charge transportation problem. Soft Comput. 2020, 24, 3529–3541.
16. Sadeghi-Moghaddam, S.; Hajiaghaei-Keshteli, M.; Mahmoodjanloo, M. New approaches in metaheuristics to solve the fixed charge transportation problem in a fuzzy environment. Neural Comput. Appl. 2019, 31, 477–497.
17. Panicker, V.V.; Sarin, I.V. Multi-product multi-period fixed charge transportation problem: An ant colony optimization approach. IFAC-Pap. 2019, 52, 1937–1942.
18. Wang, J.; Wang, X.; Yu, M. Multi-Period Multi-Product Supply Chain Network Design in the Competitive Environment. Math. Probl. Eng. 2020, 2020, 8548150.
19. Keshavarz, E.; Mahmoodirad, A.; Niroomand, S. A Transportation Problem Considering Fixed Charge and Fuzzy Shipping Costs. Decis. Mak. Adv. 2023, 1, 115–122.
20. Kungwalsong, K.; Cheng, C.Y.; Yuangyai, C.; Janjarassuk, U. Two-stage stochastic program for supply chain network design under facility disruptions. Sustainability 2021, 13, 2596.