Application of Greedy Algorithms in Supply Chain Design for Two-Echelon Single-Product Systems

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Abstract

This paper addresses a supply chain design problem based on a two-echelon single-product system. In the first echelon, plants transport the product to distribution centers. In the second echelon, the distribution centers transport the product to customers. Several transportation channels are available between nodes in each echelon, with different transportation costs and times. The decision variables are the opening of distribution centers from a discrete set, the selection of transportation channels, and the flow between facilities. The problem is modeled as a bi-objective mixed-integer program. The cost objective aggregates the opening costs and transportation costs. The time objective considers the longest transportation time from the plants to the customers. An implementation of the classic epsilon-constraint method was used to generate true efficient sets for small instances of the problem, and approximate efficient sets for larger instances. A greedy algorithm was developed to solve the problem, as the major contribution of this work. The greedy algorithm iteratively selects the locally optimal choice at each stage with the hope of finding a global optimum. The large instances were solved with the greedy algorithm, and a comparison was made in time and quality with the epsilon-constraint based algorithm. The results were favorable to the greedy algorithm for large instances of the problem.

Introduction

In recent years, Supply Chain Design has been addressed by many authors, and several reviews have been published. The decisions imply strategic aspects related to location, capacities, and technology selection, and tactical aspects like product allocation and transportation flows. In this paper, we address a previous work where a supply chain design problem based on a two-echelon single-product system was introduced. The problem considers the location of facilities, the selection of transportation channels, the calculation of the flows between facilities, and the time-cost tradeoff. The selection of transportation channels produces a bi-objective optimization problem where cost and lead time must be minimized. The objective in this new research was to develop a greedy algorithm to solve the problem. The problem belongs to the NP-Hard type, hence it is necessary to use a heuristic method to solve large instances. The greedy algorithm proposed here makes locally optimal choices at each stage with the aim of finding a global optimum. This type of approach, although simple, can yield good solutions for complex problems like supply chain design.

Literature Review

One characteristic that differentiates the problem introduced by previous works from others in the literature is the study of the tradeoff between lead time and cost in supply chain design, related to transportation choices. The review by Current et al. (1990) makes evident that the balance of these criteria had not been extensively studied. Arntzen et al. (1995) addressed the supply chain design problem for a company that handled the cost-time tradeoff. This case study builds on these concepts by applying a greedy algorithm, a method less frequently explored in this context.

Problem Description and Mathematical Model

The problem introduced previously was a two-echelon distribution system for one product in a single time period. A set of manufacturing plants produce and send the product to distribution centers in the first stage. Later, the distribution centers transport the product to the customers. The number and location of plants and customers, along with demands and capacities respectively, are known. The distribution centers must be selected from a discrete set of potential locations. The problem can be formulated as a mixed-integer program with two objectives: minimizing total costs (opening and transportation costs) and minimizing the longest transportation time.

Greedy Algorithm Approach

The greedy algorithm developed for this problem follows these steps:

1. **Initialization**:
    - Begin with no open distribution centers and no assigned transportation channels.
2. **Selection Criteria**:
    - At each step, select the distribution center and transportation channel that results in the lowest incremental cost and time, balancing both objectives.
3. **Iteration**:
    - Add the selected distribution center and transportation channel to the solution.
    - Update the flow of products accordingly.
4. **Termination**:
    - The algorithm terminates when all customers are served, and all plants have their products dispatched.
5. **Evaluation**:
    - The solution is evaluated based on the total cost and the longest transportation time.

Computational Evaluation

Experiments were conducted to compare the greedy algorithm with the epsilon-constraint method. Small instances were solved using the epsilon-constraint method to obtain true efficient sets. For larger instances, the greedy algorithm was employed due to its scalability. The largest instance solved with the greedy algorithm had 50 plants, 50 potential distribution centers, and 100 customers. The greedy algorithm showed significant improvements in computational time while providing comparable solution quality.

Conclusion

The process of supply chain design involves decisions over several aspects. The most treated decisions in the literature are facility location, transportation flows, production levels, supplier selection, and inventory levels. This case study incorporates the selection of transportation channels that produce a cost-time tradeoff. The greedy algorithm proved to be effective in handling large instances of the problem, providing a viable alternative to traditional methods like the epsilon-constraint method.

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