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A genetic algorithm for solving the fixed-charge transportation model: Two-stage problem

K. Antony Arokia Durai Raj, Chandrasekharan Rajendran*

Department of Management Studies, Indian Institute of Technology Madras, Chennai 600036, India

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ABSTRACT

Transportation of goods in a supply chain from plants to customers through distribution centers (DCs) is modeled as a two-stage distribution problem in the literature. In this paper we propose genetic algorithms to solve a two-stage transportation problem with two different scenarios. The first scenario considers the per-unit transportation cost and the fixed cost associated with a route, coupled with unlimited capacity at every DC. The second scenario considers the opening cost of a distribution center, per-unit transportation cost from a given plant to a given DC and the per-unit transportation cost from the DC to a customer. Subsequently, an attempt is made to represent the two-stage fixed-charge transportation problem (Scenario-1) as a single-stage fixed-charge transportation problem and solve the resulting problem using our genetic algorithm. Many benchmark problem instances are solved using the proposed genetic algorithms and performances of these algorithms are compared with the respective best existing algorithms for the two scenarios. The results from computational experiments show that the proposed algorithms yield better solutions than the respective best existing algorithms for the two scenarios under consideration.

1. Introduction

A supply chain refers to the flow of material through different facilities, starting with raw-materials and ending with finished products delivered to final consumers. A multi-stage distribution problem is a typical problem for firms with supply chain networks [15]. A two-stage transportation problem involves the freight transportation network from plants to customers through distribution centers (DCs) or warehouses. A firm may have constraints with respect to opening or operating a DC. These DCs are generally assumed to have capacitated or uncapacitated storage facilities. In this paper, a two-stage transportation problem with two different scenarios is considered. The first scenario considers the per-unit transportation cost and the fixed cost associated with every route, and unlimited capacity at every DC (or a warehouse). The second scenario reckons with the opening cost of a DC, per unit transportation cost from a plant to a DC and also from a DC to a customer.

The presence of fixed costs results in the objective function being a step function [1]. The fixed-charge transportation problem (FCTP) is NP-hard, hence heuristic methods have been proposed in the past to solve multi-stage transportation problems by considering different scenarios in the supply chain (e.g. [19,25,8,15,2]). The research on fixed-charge transportation problem (FCTP) has centered mostly on single-stage distribution problems and there is a need to develop efficient algorithms to solve two-stage distribution problems [15]. In this paper, two-stage transportation problems with two scenarios are considered, and a genetic-algorithm-based solution technique (genetic algorithm coupled with an improvement scheme, called TSGA) is proposed. Subsequently, the uncapacitated two-stage fixed-charge transportation problem (Scenario-1 problem) is represented as a single-stage FCTP. This single-stage transportation problem is solved using the proposed genetic algorithm, called SSGA (single-stage GA). The performance of the proposed methods and the best existing methods in the respective two scenarios are compared by making use of benchmark problem instances available in the literature.

2. Literature review

The fixed charge problem was first formulated by Hirsch and Dantzig [14] (see [17]). Balinski [3] formulated the fixed charge transportation problem, explained the special properties of FCTP, and proposed an approximate method to solve the FCTP. Many researchers developed solution techniques to solve the single-stage fixed-charge transportation problems in the past (e.g. [17,5,22,18,20]). All exact algorithms are computationally intractable in view of the problem being NP-hard [23].

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* Corresponding author. Tel.: +91 44 2257 4559; fax: +91 44 2257 0509.
E-mail address: craj@iitm.ac.in (C. Rajendran).

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Nomenclature

l	number of plants
m	number of DCs
n	number of customers
C_{ij}	cost per unit of transportation from plant i to DC j
F_{ij}	fixed charge associated with the shipment from plant i to DC j
T_{jk}	cost per unit of transportation from DC j to customer k.
G_{jk}	fixe dcharge associated with the shipment from DC j to customer k
S_i	supply available at plant i
W_j	capacity available at DC j (applicable only to Scenario-2; in case of Scenario-1, the capacity of a DC is assumed to be unlimited)
D_k	demand requirement at customer k
H_j	fixed-cost for operating (i.e., or opening) DC j (applicable only to Scenario-2; in case of Scenario-1, the cost does not exist)
U	an upper limit on total number of DCs to be opened

Variables

X_{ij}	quantity shipped from plant to DC i to DC j
Y_{jk}	amount of product shipped from DC j tocustomer k
Q_{ijk}	quantity shipped from plant through DC j to customer k

Many researchers attempted to solve the FCTP using metaheuristics such as tabu search or genetic algorithms to solve such hard optimization problems [28,23,7,6]. The use of genetic algorithms (GA) for solving linear and nonlinear transportation problems is well discussed (e.g. [16,28,11,10,7]). Vignaux and Michalewicz [28] introduced the permutation representation and the matrix representation of chromosomes. Another way of representing a chromosome is through the use of Prüfer numbers (see [7]).

Geoffrion and Graves [9] were the first to study the two-stage transportation problem, and they proposed a Bender′s decomposition algorithm to solve the multi-commodity distribution problem. Many researchers attempted to solve multi-stage transportation problems using exact algorithms and heuristics (e.g. [19,13,27,24,25]). Syarif and Gen [25] proposed a hybrid genetic algorithm with a chromosome for each stage represented by Prüfer numbers.

Recently, Jawahar and Balaji [15] proposed a genetic algorithm to solve a two-stage transportation problem by considering the per-unit transportation cost, fixed cost associated with each route and uncapacitated DCs or warehouses. This type of two-stage transportation problem is referred to as Scenario-1 problem in our paper. Jawahar and Balaji considered a chromosome to represent a candidate solution from DCs to customers; the other part of the solution (i.e., distribution plan from plants to DCs) is obtained by applying the well-known Least Cost Method (LCM) that uses a cost called equivalent cost, per-unit transportation cost and the fixed cost associated with a route. The GA by Jawahar and Balaji appears to be the best existing method, as of then, for the two-stage transportation problem considering both per-unit transportation cost and fixed cost associated with a route. Later, Balaji and Jawahar [2] developed a simulated annealing (SA) based algorithm to solve Scenario-1 two-stage transportation problems. The performance of the SA is compared with a lower bound as well as with the solution obtained by solving the problem as a linear programming problem that uses the approximated per-unit transportation cost. The authors found that their simulated annealing algorithm produced solutions closer to lower bounds and better than the solutions obtained by solving problems using approximate methods. This SA appears to be the best existing method, up to now, for two-stage distribution problems (i.e., Scenario-1 two-stage transportation problem).

As for the two-stage transportation problem considering the opening cost of a DC, Gen et al. [8] proposed a genetic algorithm using a priority-based encoding procedure to solve the two-stage transportation problem. They dealt with a two-stage transportation problem by considering the per-unit transportation cost, cost of opening a facility and by limiting the number of DCs to be opened. This type of transportation problem is referred to as Scenario-2 problem in our paper. Such two-stage transportation problems are NP-hard [8]. It appears that their GA using the priority-based encoding is the best method to solve the two-stage transportation problem when the opening cost of a facility and per-unit transportation cost are considered.

As an outcome of the literature review, it appears that there is scope to develop efficient metaheuristics to solve the two-stage transportation problems by considering the fixed cost associated with each route or the cost of opening a facility (called Scenario-1 and Scenario-2, respectively, in this paper). In this work an attempt is made to develop a genetic algorithm, and compare the performance of the proposed genetic algorithm with the respective best existing algorithm in two scenarios by solving benchmark problem instances. For this purpose, the GA proposed by Jawahar and Balaji [15] and the SA by Balaji and Jawahar [2] are compared with the proposed GA (called TSGA) to solve the two-stage transportation problem by considering the per unit transportation cost, fixed cost associated with a route and uncapacitated capacity at every DC (Scenario-1). The genetic algorithm designed by Gen et al. [8] is compared with the performance of our proposed GA (TSGA) to solve the two-stage transportation problem by considering the per-unit transportation cost and the opening cost of a DC (Scenario-2). Subsequently we represent the two-stage fixed-charge transportation problem in Scenario-1 as a single-stage FCTP, and solve it using the single-stage genetic algorithm, called SSGA. The proposed and the best existing methods in the respective two scenarios are evaluated using the respective benchmark instances available in the literature.

3. Scenario-1: consideration of per-unit transportation cost and fixed cost along a route

Scenario-1 problem considers an uncapacitated two-stage fixed-charge transportation problem with the consideration of per-unit transportation cost and fixed cost associated with each route between facilities of a supply chain (see [15] for details).

The objective in the two-stage FCTP is to minimize total transportation cost, given by

$$Z=\sum_{i=1}^{l}\sum_{j=1}^{m}C_{ij}X_{ij}+\sum_{i=1}^{l}\sum_{j=1}^{m}F_{ij}\delta_{ij}+\sum_{j=1}^{m}\sum_{k=1}^{n}T_{jk}Y_{jk}+\sum_{j=1}^{m}\sum_{k=1}^{n}G_{jk}\lambda_{jk}, \qquad (1)$$