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A biased random-key genetic algorithm for the two-stage capacitated facility location problem

Fabrício Lacerda Biajoli*, Antônio Augusto Chaves, Luiz Antonio Nogueira Lorena

Univ Fed São Paulo, São José dos Campos 12231-280, Brazil

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ABSTRACT

This paper presents a new metaheuristic approach for the two-stage capacitated facility location problem (TSCFLP), which the objective is to minimize the operation costs of the underlying two-stage transportation system, satisfying demand and capacity constraints. In this problem, a single product must be transported from a set of plants to meet customers demands passing out by intermediate depots. Since this problem is known to be NP-hard, approximated methods become an efficient alternative to solve real-industry problems. As far as we know, the TSCFLP is being solved in most cases by hybrid approaches supported by an exact method, and sometimes a commercial solver is used for this purpose. Bearing this in mind, a BRKGA metaheuristic and a new local search for TSCFLP are proposed. It is the first time that BRKGA had been applied to this problem and the computational results show the competitiveness of the approach developed in terms of quality of the solutions and required computational time when compared with those obtained by state-of-the-art heuristics. The approach proposed can be easily coupled in intelligent systems to help organizations enhance competitiveness by optimally placing facilities in order to minimize operational costs.

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1. Introduction

Facility location problems have numerous practical applications and have been studied extensively in the most active fields in Operations Research. In industrial engineering, the location analysis is one of the most important challenges, since it deals with the decision of optimally placing facilities in order to minimize operational costs. Decisions about facility location are strategic and belong to the core of any planning and management process, regardless of the industry involved. These decisions can influence the relation between the industrial sectors, the supply chain network and their customers.

Although solved in several practical situations by intuitive methods, optimal facility location decisions usually demand more in-depth studies (Fernandes et al., 2014) due of its importance. Different models have been proposed to solve the facility location problem in many real-world applications. For example, the single-stage capacitated facility location problem have been successfully analyzed, as can be seen in the review publications by Klose and Drexl (2005).

In a classic facility location problem, management decision makers have to decide which sites should be chosen to establish new facilities from a set of available candidate sites, while constraints are met in order to minimize the total cost and to guarantee that the demands of all customers have to be met, the capacity limits of the suppliers and facilities must be respected, etc. The cost includes fixed costs to open facilities and variable costs associated with transportation.

The two-stage capacitated facility location problem (TSCFLP) is a variant of classic facility location problem and can be defined as follows: a single product manufactured in plants is delivered to depots, both having limited capacities. Then the products storage in depots are delivered to customers to satisfy their demands. The use of the plants and depots apply a fixed cost, while transportation from the plants to the customers through the depots results in a variable cost, depending on the quantity transported. The objective is identify what plants and depots to use, as well as the product flows from the plants to the depots and then to the customers such that the demands are met at a minimum cost.

TSCFLP has attracted researchers attention, since in many situations more than one type of facilities are considered simultaneously. Due to the intractability of the TSCFLP, it is hard to obtain optimal solutions for a large-sized instance. Therefore, some researchers focused on heuristics rather than mathematical modeling in solving the TSCFLP (Guo, Cheng, & Wang, 2017).

* Corresponding author.
E-mail addresses: fabricio.biajoli@unifesp.br (F.L. Biajoli), antonio.chaves@unifesp.br (A.A. Chaves).

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Although the TSCFLP has some variants (e.g., Keskin & Üster, 2007; Klose, 2000; Tragantalerngsak, Holt, & Ronnqvist, 2000), this paper will focus on the same version as presented by Litvinchev and Ozuna (2012), who proposed some Lagrangian relaxations for the problem. The Section 2 describes the mathematical model of the TSCFLP presented by the authors.

The same version is also considered in Fernandes et al. (2014) and Rabello, Mauri, and Ribeiro (2016). In the first paper a genetic algorithm (GA) was used to determine which plants and depots should be opened and obtained the flow values between plants and customers through the depots by solving a minimum cost flow problem. The authors also proposed two different constructive heuristics, one of them based on a pure greedy criterion and the other one on rounding linear relaxations of the problem formulation after iteratively fixing some of its variables. Rabello et al. (2016) proposed a hybrid method based on Simulated Annealing (SA) plus Clustering Search (CS) to determine the opened plants and depots, and a mathematical model to solve the transportation problem. The exact solver CPLEX v12.6 was used by them to obtain the solution of this mathematical model.

Recently, Guo et al. (2017) proposed a hybrid evolutionary algorithm framework with extreme machine learning fitness approximation for delivering solutions. Genetic operators (i.e., selection, crossover and mutation) are adopted to perform the search process as well as restarting strategy and a local search is used to refine the best solution found in the population. The authors also considered the same version as proposed by Litvinchev and Ozuna (2012).

This paper proposes a Biased Random-key Genetic Algorithm (BRKGA) to solve the TSCFLP. A local search for the transportation flow is also proposed in order to investigate and improve the best results found out by BRKGA. Computational results demonstrate that the BRKGA is competitive with state-of-the-art approaches (Fernandes et al., 2014; Guo et al., 2017; Rabello et al., 2016), providing better solutions for some instances developed by Fernandes et al. (2014).

This study contributes to the literature of TSCFLP by presenting an efficient approach to support and guide the process of placing facilities in order to minimize costs. In addition, it can help researchers, decision makers, developers of expert systems, and anyone else who requires these type of approaches. The main contributions are listed below:

- The literature about TSCFLP is limited and most approaches are supported by exact models that require a solver to execute. The proposed approach presents an independent and efficient method that can be easily coupled in expert systems.
- For the first time, the BRKGA is used to solve the TSCFLP. In particular, a simple and effective decoder is introduced for the problem and used as part of BRKGA metaheuristic.
- In addition, a new local search for TSCFLP is proposed. This method can be used to improve a TSCFLP solution generated by any heuristic approach.

The remainder of this paper is organized as follows. The Section 2 presents the mathematical formulation for the TSCFLP. In Section 3 the BRKGA algorithm is briefly introduced and in Section 4 the proposed BRKGA to solve TSCFLP is described in detail. The computational experiments are presented in Section 5 followed by the conclusions and points out future research in Section 6.

2. Mathematical model for TSCFLP

To describe the problem, let I be the index set of potential plants, J the index set of potential depots and K the index set of customers. Let binary variables y_i $(i \in I)$ and z_j $(j \in J)$ which indicate, respectively, whether a plant or depot is opened (value equal to 1) or closed (value equal to 0). Let x_{ij} be a real variable which indicate the amount of products transported from plant $i \in I$ to depot $j \in J$. Similarly, let s_{jk} be a real variable which indicate the amount of products transported from depot $j \in J$ to customer $k \in K$. Finally, the parameters of this problem are defined as follows:

- f_i is the fixed cost associated to plant $i \in I$;
- g_j is the fixed cost associated to depot $j \in J$;
- c_{ij} is the transportation cost of one unit of the product between plant $i \in I$ and depot $j \in J$;
- d_{jk} is the transportation cost of one unit of the product between depot $j \in J$ and customer $k \in K$;
- q_k is the demand of customer $k \in K$;
- b_i is the capacity of plant $i \in I$; and
- p_j is the capacity of satellite $j \in J$.

Thus, the mathematical model of the TSCFLP can be formulated as:

$$Minimize \quad z = \sum_{i \in I} f_i y_i + \sum_{j \in J} g_j z_j + \sum_{i \in I} \sum_{j \in J} c_{ij} x_{ij} + \sum_{j \in J} \sum_{k \in K} d_{jk} s_{jk} \tag{1}$$

subject to:

$$\sum_{j \in J} s_{jk} \geq q_k, \qquad \forall k \in K \tag{2}$$

$$\sum_{i \in I} x_{ij} \geq \sum_{k \in K} s_{jk}, \qquad \forall j \in J \tag{3}$$

$$\sum_{j \in J} x_{ij} \leq b_i y_i, \qquad \forall i \in I \tag{4}$$

$$\sum_{k \in K} s_{jk} \leq p_j z_j, \qquad \forall j \in J \tag{5}$$

$$y_i \in \{0, 1\}, \qquad \forall i \in I \tag{6}$$

$$z_j \in \{0, 1\}, \qquad \forall j \in J \tag{7}$$

$$x_{ij} \in \mathbb{R}^+, \qquad \forall i \in I, \forall j \in J \tag{8}$$

$$s_{jk} \in \mathbb{R}^+, \qquad \forall j \in J, \forall k \in K \tag{9}$$

The objective function (1) minimize the total fixed cost associated with opening plants and depots plus the cost associated with both transportation stages. Constraints (2) is the demand constraint (for each customer, the demand must be met), (3) are conservation constraints (the total amount of products transported from a depot must be at most the total transported to it from the plants), (4) and (5) represent capacity limits for plants and depots, respectively. Finally, constraints (6) and (7) are assigned to flow variables, and constraints (8) and (9) impose binary values for the respective variables.

3. Biased random-key genetic algorithm

A biased random-key genetic algorithm (BRKGA) is a general search metaheuristic proposed in Gonçalves and Resende (2011) and based on random-key genetic algorithm (RKGA), which was first introduced by Bean (1994) for solving combinatorial optimization problems involving sequencing. The chromosomes of a RKGA are represented as vectors of randomly generated real numbers in the interval [0, 1]. A deterministic algorithm, called

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