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Supporting supply process in charitable organizations by genetic algorithm ☆

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ABSTRACT

The paper concerns the optimization problem arising in charitable organizations during supply process. Such institutions are especially interested in minimizing the cost of purchase which consists of the prices at which particular products are bought as well as of the cost of their transportation. We present the formal mathematical model of the problem and the lower bound for the criterion value. We propose a genetic algorithm and the specialized list heuristic approach solving the case, which we prove is strongly NP-hard. The efficiency of implemented methods was checked in extensive computational experiments. The proposed algorithms have been integrated with the software system designed with a view of supporting charitable organizations.

1. Introduction

Scheduling theory (cf. e.g. Blazewicz, Ecker, Pesch, Schmidt, & Weglarz, 2007; Leung, 2004; Pinedo, 2008) is strictly associated with practice. Real world problems inspire proposing new scheduling models. On the other hand, scheduling theory, and more generally speaking operational research, provides approaches applicable in practice. This latter case occurred within our work on the software system supporting supply process in charitable organizations.

We investigate the problem of satisfying the demand for a set of products. Products, such as medicines, food, clothes, needed by e.g. a charitable institution, are offered by a few shops, wholesalers or donors at different prices. These suppliers are situated in different distances to the location of the institution. Charitable organizations usually pick up ordered or donated products using their own means of transportation. They often own only one vehicle. To supply the institution, one has to select depots at which products should be bought and then to construct the route for a vehicle collecting ordered goods. Similar problem appears obviously not only in charitable organizations, it can be also met in many small companies. Within the work, we propose a metaheuristic algorithm constructing a solution for the mentioned problem, which has been integrated with the web service supporting charitable organizations.

The optimization problem under consideration apparently consists of two subproblems: selecting depots providing required products at the lowest prices (order completion) and determining the shortest route (namely the shortest Hamiltonian cycle) for the selected depots (order delivery). The first subproblem is computationally easy, while the latter one is intractable, but obviously they cannot be solved separately. Actually, the problem of order completion and delivery can be considered as a variant of the travelling purchaser problem (cf. e.g. Ramesh, 1981; Ravi & Salman, 1999; Riera-Ladesma & Salazar-Gonzalez, 2006).

In the paper we provide the formal mathematical model for the mentioned problem of order completion and delivery. Due to the specificity of this case, we propose a specialized list heuristic algorithm, which efficiently constructs feasible solutions, based on different sets of depots providing products to the institution. Since we can easily obtain a set of heuristic solutions, evolutionary algorithms (Baeck, Fogel, & Michalewicz, 1997) are a natural choice for their further optimization. In the paper, we propose a genetic algorithm (cf. e.g. Holland, 1975; Sastry, Goldberg, & Kendall, 2005) based on the list heuristic for selecting depots and the minimum spanning tree heuristic for constructing a route for a vehicle (Held & Karp, 1970). The metaheuristic approach was tested in the extensive computational experiments, performed for instances reflecting the real world conditions. The efficiency of the proposed genetic algorithm was validated in terms of the improvement of the criterion value in comparison to initial solutions, as well as in terms of the distance to the lower bound proposed within the paper. Finally, a comparison to the integer programming model has been performed given the same amount of time as metaheuristic to solve the same set of instances.

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The organization of the work is as follows. In Section 2 we present the formal mathematical model for the analyzed problem and mention its computational complexity. Section 3 describes the heuristic algorithm based on a list approach solving the considered case. In Section 4, we propose the lower bound of the optimal criterion value. Section 5 presents the genetic algorithm, while Section 6 collects results of computational experiments. The paper is concluded in Section 7.

2. Problem definition

The paper concerns the problem of delivering a set of products to a single charitable institution in order to minimize the total cost, which consists of two components: the prices of products and the transportation cost. The institution (called also the customer) specifies her demand (d_j) for m types of products ($j = 1, \dots, m$). Products are available at n shops, warehouses, donors (called depots) possibly at different prices (donors offer goods at zero cost). Each depot ($i = 1, \dots, n$) is described by the unit cost (c_{ij}) and the number of units (a_{ij}) of particular products (j) available at this location. Obviously, the institution is interested in buying products at depots offering the lowest prices. Since goods have to be delivered to the location of the charitable organization, the quality of a solution is influenced also by the transportation cost. We assume that the institution collects ordered products from depots using her own means of transportation, namely – a single vehicle. The vehicle departs from the institution's location, visits all selected depots and returns to the original location. The total transportation cost is determined by the total distance travelled by the vehicle, resulting from the distances between particular locations (t_{ij}) and the unit transportation cost (T). Since we consider sellers (providing products at given prices) and donors (offering goods without any charge) as depots, we can optimize the total cost of purchasing products and picking up donated items within one tour of the vehicle collecting them. It may be profitable, from the transportation cost point of view, to buy products at more expensive shop than visiting a donor located nearby.

To define the problem under consideration in the more formal way, we use the following parameters mentioned above:

- m – the number of required products (types of products),
- d_j – the demand for product j, i.e. the number of units of product j required by the institution/the customer ($j = 1, \dots, m$),
- n – the number of depots offering products,
- c_{ij} – the cost of one unit of product j offered by depot i ($i = 1, \dots, n, j = 1, \dots, m$),
- a_{ij} – the number of units of product j available at depot i ($i = 1, \dots, n, j = 1, \dots, m$),
- t_{ir} – the distance between depots i and r ($i = 1, \dots, n, r = 1, \dots, n$), ($t_{0i}$ and t_{i0} denote the distance from the institution to depot i and from depot i to the institution respectively; taking into account real world conditions the distances between locations do not need to be symmetric e.g. due to existence of one-way roads),
- T – the unit transportation cost.

To find a solution of the problem, we determine two types of decision variables. They correspond to two subproblems of selecting a set of depots selling products to the institution and forming a tour from selected depots:

- x_{ij} – the non-negative integer variable representing the number of units of product j delivered to the customer from depot i ($i = 1, \dots, n, j = 1, \dots, m$),
- y_{ik} – the binary variable, which takes value 1, if depot i is at position k in the route ($i = 1, \dots, n, k = 1, \dots, n+1$) and 0 otherwise (where $y_{i,n+1} = 0$, for $i = 1, \dots, n$).

Based on the provided notation, the case under consideration can be formulated as the following integer programming problem.

Minimize

$$\sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij}c_{ij} + \tag{1}$$

$$T\left(\sum_{i=1}^{n} y_{i1}t_{0i} + \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n-1} max\{0, y_{ik} + y_{j,k+1} - 1\}t_{ij} + \sum_{i=1}^{n}\sum_{k=1}^{n}\left(y_{ik}\left(1 - \sum_{r=1}^{n} y_{r,k+1}\right)\right)t_{i0}\right) \tag{2}$$

under constraints:

$$\sum_{i=1}^{n} x_{ij} = d_j, \quad j = 1, \dots, m, \tag{3}$$

$$x_{ij} \leqslant a_{ij}, \quad i = 1, \dots, n, \quad j = 1, \dots, m, \tag{4}$$

$$x_{ij} \geqslant 0 \ \text{and integer}, \quad i = 1, \dots, n, \quad j = 1, \dots, m, \tag{5}$$

$$\sum_{k=1}^{n} y_{ik} = min\left\{1, \sum_{j=1}^{m} x_{ij}\right\}, \quad i = 1, \dots, n, \tag{6}$$

$$\sum_{k=1}^{n} y_{ik} \leqslant 1, \quad i = 1, \dots, n, \tag{7}$$

$$\sum_{i=1}^{n} y_{ik} \leqslant 1, \quad k = 1, \dots, n, \tag{8}$$

$$\sum_{i=1}^{n} y_{i,k+1} \leqslant \sum_{i=1}^{n} y_{ik}, \quad k = 1, \dots, n-1, \tag{9}$$

$$y_{ik} \in \{0, 1\}, \quad i = 1, \dots, n, \quad k = 1, \dots, n+1, \tag{10}$$

Constraints (3) ensure that the institution's demand is satisfied. Formulas (4) guarantee that the number of product units taken from the depot does not exceed the availability of this product at the location, while constraints (5) ensure that this number is a non-negative integer. According to formulas (6), the position in the route for a vehicle is assigned only to those depots which deliver any product to the customer. Constraints (7) and (8) ensure that each depot can be assigned to at most one position in the route and each position is occupied by at most one depot. Thanks to formulas (9) the position numbers given to depots form continuous sequence. Constraints (10) ensure that the decision variables are binary ones.

Constraints (3)–(5) model the problem of selecting depots delivering products to the customer at the minimal cost, while constraints (6)–(10) model the problem of constructing the shortest tour containing all selected depots exactly once, i.e. the subproblem equivalent to the travelling salesman problem.

The criterion function describing the quality of a solution consists of two components. The first one (1) corresponds to the total cost of products delivered from particular depots. The latter one (2) shows the transportation cost expressed as the total distance multiplied by the unit transportation cost. The total distance is determined as the sum of the distance from the institution to the first