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A variable neighborhood search method for the orienteering problem with hotel selection

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ABSTRACT

In this paper, we present the orienteering problem with hotel selection (OPHS), an extension of the orienteering problem (OP). In the OPHS, a set of vertices with a score and a set of hotels are given. The goal is to determine a fixed number of connected trips that visits some vertices and maximizes the sum of the collected scores. Each trip is limited in length and should start and end in one of the hotels. We formulate the problem mathematically, explain the differences with related optimization problems and indicate what makes this problem inherently more difficult.

We use a skewed variable neighborhood search that consists of a constructive initialization procedure and an improvement procedure. The algorithm is based on a neighborhood search operator designed specifically for the hotel selection part of this problem, as well as some typical neighborhoods for the regular OP.

We generate a set of 224 benchmark instances of varying sizes with known optimal solutions. For 102 of these instances our algorithm finds the optimal solution. The average gap with the optimal solution over all these instances is only 1.44% and the average computation time is 1.91 s.

1. Introduction

The orienteering problem with hotel selection (OPHS) is a new variant of the orienteering problem. Although many studies have focused on variants of the orienteering problem, this problem has not yet been discussed in the literature. In the OPHS, a set of $H+1$ hotels is given ($i=0,\ldots,H$). Also, N vertices are given and each vertex $i=H+1,\ldots,H+N$ is assigned a score S_i. Hotels have no score. The time t_{ij} needed to travel from vertex i to j is known for all pairs. The time available for each trip $d=1,\ldots,D$ is limited to a given time budget T_d which can be different for each trip. The goal is to determine a tour that maximizes the total collected score. The tour is composed of D connected trips and visits each vertex at most once. In this formulation, the number of trips, D, is a given parameter of the problem. Every trip should start and end in one of the available hotels. The initial starting and final arriving hotel of the tour are given ($i=0$ and 1, respectively). They can also be used as a hotel during the tour.

To avoid any confusion regarding the terminology used in this paper, the term "trip" refers to an ordered set of vertices with a specific starting and ending hotel. The term "tour" is used for the ordered set of trips that connect the initial departure hotel to the final arrival hotel.

As the above mentioned definition shows, the OPHS is a new and challenging problem. It is a generalization of the OP and is therefore also NP-hard. Moreover, the OPHS is much more complex than the OP, since the starting and ending location for each trip need to be optimized as well.

In order to explain the nature of the orienteering problem with hotel selection, it is helpful to consider an example. Imagine a tourist who is planning to visit a certain region with various attractions. The tourist wants to select the combination of attractions that maximizes his pleasure. The visit will last several days and only the initial departure and the final arrival location are fixed. The departure and arrival locations (hotels) during the visit should be selected in an optimal way based on the attractions that are selected. Obviously, the hotel in which the tourist ends a given day has to be the same as the starting hotel of the next day. The hotels can be selected from all suitable hotels available in the region.

A large number of practical applications can be modeled by the OPHS. For instance, a submarine performing a surveillance activity (tour) composed of consecutive missions (trips). It requires

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save zones (hotels) for provisioning between two missions. There are several possible points (vertices) to survey, but not all of them can be visited due to the limited available time. The submarine wants to maximize its benefit by selecting the most interesting combination of points. Only the initial departure and final arrival location of the whole surveillance activity are fixed. The departure and arrival save zone of each mission during the activity should be selected in an optimal way, considering the points that are selected for a visit. It is clear that when the submarine ends its current mission (trip) in a certain save zone, the next mission has to start in the same save zone.

Actually, depending on the exact practical circumstances, many of the applications for the orienteering problem (Vansteenwegen et al., 2011) or for the traveling salesperson problem with hotel selection (Vansteenwegen et al., 2012) can be modeled more appropriately by the OPHS. For example, the well-known traveling salesperson problem turns into an OPHS under (realistic) circumstances: if the traveling salesperson needs to select which of his possible clients he will actually visit during his multiple day tour and he also needs to select the most appropriate hotels to stay every night. Other examples are truck drivers with limited driving hours wanting to reach an appropriate parking space, routing maintenance technicians with several depots to pick up spare parts, etc.

In Section 2, the related problems are briefly reviewed. Then, the mathematical formulation for this new problem is presented in Section 3. In Section 4, the proposed algorithm is discussed in detail. How benchmark instances are generated is discussed in Section 5. Experimental results are presented in Section 6 and the paper is concluded in Section 7.

2. Literature review

The OPHS is closely related to the regular orienteering problem (OP), the team orienteering problem (TOP), and the traveling salesperson problem with hotel selection (TSPHS). Since the OPHS is a new problem, we will explain the similarities and differences with each of these problems. In the regular OP (Tsiligirides, 1984) a set of N vertices i is given, each with a score S_i. The initial and final vertices are fixed. The time t_{ij} needed to travel from vertex i to j is given for all vertices. Because of the time limitation ($T_{\max}$), not all vertices can be visited. The goal is to find a single route with maximum score, respecting the time limitation $T_{\max}$. Each vertex can be visited at most once. The OP is also known as the selective traveling salesperson problem (Gendreau et al., 1998), the maximum collection problem (Butt and Cavalier,1994) and the bank robber problem (Arkin et al.,1998). Moreover, the OP can be formulated as a special case of the resource constrained TSP, a TSP with profits or as a resource constrained elementary shortest path problem (Vansteenwegen et al., 2009a). A number of challenging practical applications were modeled as orienteering problems and many exact and heuristic solution approaches were developed to solve this problem (Vansteenwegen et al., 2011).

When there are several routes allowed to visit vertices and all of them start and end at the same vertex, we are dealing with a team orienteering problem (TOP) (Chao et al.,1996a). A comprehensive survey about the (T)OP can also be found in Vansteenwegen et al. (2011).

Although the OP and the TOP have been studied in numerous papers, the OPHS has not been considered before. The OPHS has more than one trip and from this point of view it is comparable to the TOP. The main difference between the TOP and the OPHS is that in the TOP all trips have to start and end in the same vertex and no hotels need to be selected.

A recent publication by Vansteenwegen et al. (2012) discusses the traveling salesperson problem with hotel selection (TSPHS). In the TSPHS, a number of hotels are available as well as a number of vertices. Each vertex is assigned a visiting time, and the required times to travel between all pairs of vertices are known. The available time that each trip takes is limited to a time budget, and the goal is to first minimize the number of connected trips and then minimize the total length of the tour (Vansteenwegen et al., 2012), while visiting all vertices. Two obvious differences with the OPHS are that in the TSPHS all the vertices have to be visited and that the objective is to minimize the number of trips and the total travel time. For a discussion about the similarities and differences between the TSPHS and other routing problems (multiple TSP, multi-depot VRP, location routing problems, etc.), we refer to the literature review in Vansteenwegen et al. (2012).

3. Mathematical formulation

Making use of the notation in the first section, the OPHS can be formulated as a mixed-integer linear problem ($x_{i,j,d}=1$ if, in trip d, a visit to vertex i is followed by a visit to vertex j, 0 otherwise; $u_i=$ the position of vertex i in the tour).

$$\text{Max} \sum_{d=1}^{D}\sum_{i=0}^{H+N}\sum_{j=0}^{H+N} S_i x_{i,j,d}$$

$$s.t. \tag{0}$$

$$\sum_{l=1}^{H+N} x_{0,l,1}=1 \tag{1}$$

$$\sum_{k=0}^{H+N} x_{k,1,D}=1 \tag{2}$$

$$\sum_{h=0}^{H}\sum_{l=0}^{H+N} x_{h,l,d}=1 \quad d=1,\dots,D \tag{3}$$

$$\sum_{h=0}^{H}\sum_{k=0}^{H+N} x_{k,h,d}=1 \quad d=1,\dots,D \tag{4}$$

$$\sum_{k=0}^{H+N} x_{k,h,d}=\sum_{l=0}^{H+N} x_{h,l,d+1} \quad d=1,\dots,D-1 \quad h=0,\dots,H \tag{5}$$

$$\sum_{i=0}^{H+N} x_{i,k,d}=\sum_{j=0}^{H+N} x_{k,j,d} \quad k=H+1,\dots,H+N \quad d=1,\dots,D \tag{6}$$

$$\sum_{d=1}^{D}\sum_{j=0}^{H+N} x_{i,j,d}\le 1 \quad i=H+1,\dots,H+N \tag{7}$$

$$\sum_{i=0}^{H+N}\sum_{j=0}^{H+N} t_{i,j}x_{i,j,d}\le T_d \quad d=1,\dots,D \tag{8}$$

$$u_i-u_j+1\le (N-1)\Big(1-\sum_{d=1}^{D} x_{i,j,d}\Big) \quad i=H+1,\dots,H+N \quad j=H+1,\dots,H+N \tag{9}$$

$$u_i\in 1,\dots,N \quad i=H+1,\dots,H+N \tag{10}$$

$$x_{i,j,d}\in\{0,1\} \quad \forall i,j=1,\dots,H+N \,|\, i\ne j \quad d=1,\dots,D \tag{11}$$