European Journal of Operational Research 237 (2014) 29–49

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Discrete Optimization

A memetic algorithm for the orienteering problem with hotel selection

A. Divsalar [a,b,*], P. Vansteenwegen [a], K. Sörensen [c], D. Cattrysse [a]

[a] KU Leuven, Centre for Industrial Management/Traffic and Infrastructure, Celestijnenlaan 300A, 3001 Leuven, Belgium
[b] Faculty of Mechanical Engineering, Babol University of Technology, Babol, Mazandaran, Iran
[c] University of Antwerp, Prinsstraat 13, 2000 Antwerp, Belgium

ARTICLE INFO

Article history:
Received 13 June 2013
Accepted 3 January 2014
Available online 11 January 2014

Keywords:
Orienteering problem
Memetic algorithm
Population management
Intermediate facilities
Hotel selection

ABSTRACT

In this paper, a memetic algorithm is developed to solve the orienteering problem with hotel selection (OPHS). The algorithm consists of two levels: a genetic component mainly focuses on finding a good sequence of intermediate hotels, whereas six local search moves embedded in a variable neighborhood structure deal with the selection and sequencing of vertices between the hotels. A set of 176 new and larger benchmark instances of OPHS are created based on optimal solutions of regular orienteering problems. Our algorithm is applied on these new instances as well as on 224 benchmark instances from the literature. The results are compared with the known optimal solutions and with the only other existing algorithm for this problem. The results clearly show that our memetic algorithm outperforms the existing algorithm in terms of solution quality and computational time. A sensitivity analysis shows the significant impact of the number of possible sequences of hotels on the difficulty of an OPHS instance.

1. Introduction

The Orienteering Problem with Hotel Selection (OPHS) is a recently introduced variant of the orienteering problem (Divsalar, Vansteenwegen, & Cattrysse, 2013). In this problem, on a given complete graph $G = (V, E)$, a set of $h + n$ vertices is given. $V = H \cup N$ is composed of two subsets including h hotels, represented by numbers from 0 to $h - 1$, and n points of interests (POI), represented by numbers from h to $h + n - 1$. Hotel 0 and hotel 1 are used as the initial and the final depot respectively; the other hotels are called "extra hotels". Each POI is assigned a score S_i. The symmetric travel time needed between each pair of vertices is given by t_{ij}. These travel times can be based on Euclidean distances or a travel time matrix. An ordered set of POIs with a specific start and end hotel is called a trip. The length of each trip $d = 1, \ldots, D$ is limited by a given time budget T_d. Each of the D connected trips starts and ends in one of the h hotels. The ordered set of trips that starts in the initial depot and ends in the final depot is called a tour. Both the initial and final depot can also be used as an intermediate hotel during the tour. The objective is to find a given number of connected trips visiting each POI at most once and maximizing the sum of collected scores.

Some examples of the large number of potential applications of the OPHS are explained in Divsalar et al. (2013): a submarine performing a surveillance activity composed of consecutive missions, the design of a multi-day tourist trip through an attractive region, or a traveling salesperson who needs to select which of his possible clients to visit during his multiple day tour and also needs to choose the most appropriate hotels to stay the night.

We start this paper with an extensive literature survey on the OPHS and closely related problems. In Section 3 our heuristic algorithm is explained. Benchmark instances, experimental tests and a sensitivity analysis of the problem instance parameters are presented and discussed in Section 4 and the paper is concluded in Section 5.

2. Literature review

In the regular Orienteering Problem (OP), there are N vertices available, each with a score S_i, and the goal is to find a tour that visits some of these vertices, respects the available time limitation and maximizes the total collected score. The OP is also known as the selective traveling salesperson problem (Gendreau, Laporte, & Semet, 1998) and was introduced by (Tsiligirides, 1984). Since then, it has been considered in the literature for a number of applications such as home fuel delivery (Golden, Levy, & Vohra, 1987) and mobile tourist guides (Schilde, Doerner, Hartl, & Kiechle, 2009; Vansteenwegen, Souffriau, Vanden Berghe, & Van Oudheusden, 2011). Many (meta)heuristics and exact methods have been implemented to solve this problem. A recent survey on the OP and its variants, describing solution techniques, benchmark instances and applications can be found in (Vansteenwegen, Souffriau, & Van Oudheusden, 2011).

* Corresponding author at: KU Leuven, Faculty of Engineering, Department of Mechanical Engineering, Center for Industrial Management/Traffic & Infrastructure, Celestijnenlaan 300A Box 2422, BE-3001 Heverlee, Belgium. Tel.: +32 16 37 27 78.
E-mail addresses: ali.divsalar@cib.kuleuven.be, alidivsalar@gmail.com (A. Divsalar).

0377-2217/$ - see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ejor.2014.01.001

The hotel selection variant of the OP, studied in this paper, is closely related to a variant of the Vehicle Routing Problem (VRP) with so-called Intermediate Facilities (IF). To the best of our knowledge, (Angelelli & Speranza, 2002a) were the first to introduce intermediate facilities in a (node routing) VRP. The most important differences between their problem, the periodic VRP with Intermediate Facilities (PVRP-IF) and the OPHS are that in the OPHS each trip length is limited by a time budget and in the PVRP-IF the only time budget is the work shift applied for the whole tour and not per trip. Instead, a capacity constraint on the vehicle limits the number of customers that can be visited in each trip, while the OPHS has no capacity constraint. The tour time constraint and the fact that the number of trips is not fixed in the PVRP-IF makes it more complex to combine the trips in a tour, compared to the OPHS. Furthermore, in the PVRP-IF an empty vehicle leaves the depot and goes directly to an intermediate facility to load the goods. As a result, no customer can be visited on the way from the depot to the first facility. They propose a tabu search (TS) algorithm to solve this problem. In (Angelelli & Speranza, 2002b), the authors modify their PVRP-IF model and present a general model for waste-collection problems.

Crevier, Cordeau, and Laporte (2007) also address intermediate facilities in node routing problems with deliveries. They introduce an extension of the multi-depot VRP (MDVRP) in which vehicles may be replenished at intermediate facilities along their route. The Multi-Depot Vehicle Routing Problem with Inter-depot Routes (MDVRPI) deals with m vehicles of capacity Q. In contrast to the PVRP-IF, the MDVRPI is not a periodic problem. Moreover, a different terminology, new applications and a different solution strategy are introduced. The set of all routes assigned to a vehicle is called "rotation" which corresponds to the term "tour" in the OPHS. Based on this comparison, each route for each vehicle in the MDVRPI corresponds to a "trip" in the OPHS. There is a time limitation for a rotation of a vehicle in the MDVRPI. A rotation may be composed of "single-depot" and "inter-depot" routes which indicate if the starting and ending depot of a route are the same or different, respectively. Here again the problem differs from the OPHS in the sense that there is no explicit limitation on the length of each trip, only an implicit limitation based on the capacity of the vehicle. To solve the randomly generated instances of this problem, the authors propose a heuristic combining the adaptive memory principle, a tabu search method for the solution of sub problems, and integer programming. They apply their algorithm to a grocery distribution problem.

Tarantilis, Zachariadis, and Kiranoudis (2008) define the VRP with intermediate replenishment facilities (VRPIRF). In the VRPIRF, the goal is to determine optimal routes for a fleet of vehicles that can renew their capacity at intermediate replenishment stations. The VRPIRF is a special case of the MDVRPI in which one of the depots is called the central depot and the others being intermediate replenishment depots. The vehicles start and end their trips at the central depot. The part of the route of a vehicle between two consecutive depots is called a "route segment" and the total demand of the customers visited in each route segment is limited by the capacity of the vehicle. The duration of the whole route for a vehicle cannot exceed a given upper bound. Beside the non-periodic characteristic of the VRPIRF, the problem is very similar to the PVRP-IF except for a small difference: in the PVRP-IF the vehicles leave the central depot empty and immediately go to an intermediate facility and also have to visit an IF immediately before going back to the main depot at the end of their tour. This is not the case in the VRPIRF. Tarantilis et al. (2008) suggest a three-step algorithm to solve the VRPIRF. Their algorithm consists of a cost-saving construction heuristic to create the initial solution, improving it using a tabu search within a variable neighborhood search methodology, and applying guided local search to eliminate low-quality features from the final solution. They apply their algorithm to benchmark instances in the literature as well as to new classes of the VRPIRF benchmark instances. They also mention some applications such as waste-collection when waste disposal is done to multiple dump sites, winter road maintenance when it is done by spreading chemicals and abrasives, and snow plowing.

Kim, Kim, and Sahoo (2006) present algorithms for a commercial waste collection VRP with time windows with consideration of multiple site locations and drivers' lunch break. They characterize this problem as a VRP with time windows and intermediate facilities (VRPTW-IF). In this specific waste collection application, a vehicle that is full needs to go to the closest available disposal facility and this may happen several times per day. There are two capacity constraints: one for the vehicle and another one for the route. The route capacity includes maximum number of stops and lifts, and maximum volume and weight that a driver can handle per day. Kim et al. (2006) take the minimization of route compactness and the workload balance into account besides the two common objective functions of VRPs: minimizing the number of vehicles and the travel time. These authors also state that considering disposal trips is not a simple task. An extended insertion algorithm of Solomon (Solomon, 1987) to consider multiple disposal trips and drivers' break, and a clustering-based waste collection VRPTW algorithm are proposed.

Kek, Cheu, and Meng (2008) introduce two new distance-constrained capacitated VRPs (DCVRP) and show the potential benefit of assigning start and end depots in a flexible way. The DCVRP_Fix is their first problem in which both vehicle capacity and maximum distance constraints are imposed as well as additional service and travel time constraints. It also considers the minimization of vehicle utilization and is applicable to both symmetric and asymmetric problems. In their second problem, the DCVRP_Flex, which is a relaxation of the first variant, the vehicles are allowed to start and end their tour at different depots and to visit any depot for reloading. In the definition of this problem, each vehicle route can pass through any number of depots any number of times as long as range constraints on the total length of any vehicle route are met. Their problem is structurally very similar to the MDVRPI. The main difference is that in the DCVRP_Flex a distance-constrained capacitated version of the VRP is considered to have intermediate facilities available. They solved both the DCVRP_Fix and the DCVRP_Flex problems to optimality using four case studies in Singapore and show the positive benefits of flexible assignment in practice. Comparing the definitions, one can find the similarities between the second version of the problem introduced by Kek et al. (2008) and the OPHS in the sense that in both problems the initial and the final depot are allowed to act as an intermediate depot as well. This is also the case for the MDVRPI. The difference is that in the OPHS the constraint of having a fixed start and end depot should still be satisfied while in the other mentioned problems (the MDVRPI and the DCVRP_Flex) it is relaxed. Moreover, the main difference is still the same: in the DCVRP_Flex, there is no time budget between each two consecutive depots in the route.

Time windows, driver breaks, and multiple disposal facilities in a waste collection VRP are also considered in Benjamin and Beasley (2010). They propose two metaheuristic algorithms using tabu search and variable neighborhood search as well as an algorithm based on variable neighborhood tabu search where the tabu search is used to search the neighborhood. As these authors mention, their problem is a collection problem with disposal facilities and it differs from the delivery problem with replenishment facilities in the sense that, in the collection problem, a vehicle visits a disposal facility to empty itself immediately prior to returning to the depot.

Since the OPHS is a node routing problem, arc routing problems with intermediate facilities (Ghiani & Federico, 2001; Ghiani, Guerriero, Laporte, & Musmanno, 2004; Ghiani, Laganà, Laporte, & Mari, 2008) are not discussed in detail here.