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Quota traveling car renter problem: Model and evolutionary algorithm

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A B S T R A C T

The quota traveling car renter problem is the quota variant of the traveling car renter problem. A graph is given where a bonus is associated with each vertex. The bonus is collected at every visited vertex. Several cars are available to travel the edges of the graph, each of which associates weights with the edges. The problem involves finding a cycle on a subset of vertices such that a predefined minimum sum of bonuses is obtained at least. The objective is to minimize the cost of the tour using the available cars. In this study, we propose an integer programming model for the problem, which is solved, and we present optimal solutions for 24 instances. We propose an evolutionary algorithm with a plasmid operator, which we compare with a memetic algorithm. We also present the results obtained based on computational experiments with 72 instances.

1. Introduction

The problem considered in this study is within the same family as the traveling salesman problem (TSP). Given an edge-weighted graph $G = (V, A)$, where V is the set of vertices, $|V| = n$, and A is the set of arcs, $|A| = m$, the objective of the TSP is to find a spanning cycle C in G such that its cost, which is given by the sum of the weights of the edges in C, is minimized. The TSP is a classical NP-hard problem with innumerous practical applications [24]. Several interesting generalizations and variations of the TSP have been proposed, among which two are the main focus of this study: the quota TSP (QTSP) [3,4,48] and the traveling car renter problem (CaRS) [21]. In the QTSP, a benefit is associated with each vertex of G and the Hamiltonian constraint is no longer required, but instead a minimum sum of quotas is collected from the vertices visited. CaRS generalizes the TSP by allowing several cars with different costs to be available for use during the salesman's tour. The quota CaRS (q-CaRS) is defined in this context. q-CaRS is a generalization of the QTSP where a set of cars with different costs is available to the salesman. Practical applications of q-CaRS include tourism and sales. In many cases, tourists cannot visit all of the existing attractions in a given region. Thus, it is interesting to consider the satisfaction obtained by visiting the most attractive places. In this context, points of interest can be treated as the vertices of a graph and their corresponding quotas are associated with some degree of satisfaction after visiting them. Several modes of transportation are

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available to tourists at any point, so the objective is to reach a predefined total degree of satisfaction by visiting attractive points with the lowest cost possible during the tour. In recent years, several applications have become available for tourism purposes such as those described by [7,29,44]. According to [27], mobile device applications are valuable as tools to facilitate the personal selection and routing of attractions to spread tourism throughout regions. Recently, increased numbers of studies have modeled and solved problems related to tourism [44] and a recent survey of tourist trip design problems (TTDPs) was presented by [15]. Analogous situations can occur for sales representatives, where the quota is associated with the revenue related to each location. Thus, the problem of the sales representative is selecting a subset of locations where a minimum revenue is achieved with the minimum travel expenses.

The problem addressed in this study is a generalization of the QTSP where a set of cars is available to the salesman. The QTSP is a variant of the TSP where a quota is associated with each vertex and the objective is to minimize the travel costs given the requirement that the collected quota is not less than a preset value [10]. No penalty is associated with unvisited vertices. q-CaRS was introduced by [30] who referred to it as the prize collecting car renter problem (pCaRS). We rename the problem because the penalty associated with unvisited vertices, which is a characteristic of the prize collecting TSP, is not computed, and thus the *quota* type is more suitable. A mathematical formulation of q-CaRS is presented and solved to optimality based on a set of 40 instances with up to 16 vertices. To generate the lower bounds, quadratic constraints are linearized using the reformulation-linearization technique (RLT). We compare our results with those presented by [30] who used standard linearization. We also present a hybrid evolutionary algorithm and the results of its application to instances with up to a 100 vertices. A computational experiment based on 72 instances is reported, where we compare the proposed algorithm with the memetic algorithm (MA) described by [30], as well as the results obtained with a solver.

The remainder of this paper is organized as follows. The problem and the proposed mathematical formulation are presented in Section 2. The fundamentals of the proposed algorithm are presented in Section 3. The proposed algorithm is presented in section 4 and the results of computational experiments based on 72 instances are reported in Section 5. Finally, we give our conclusions in Section 6.

2. Problem definition

The problem addressed in this study is a CaRS version of the QTSP called q-CaRS. The QTSP is presented in Section 2.1. Other models related to q-CaRS, including those with applications in the tourism sector, are presented in Section 2.2. The issues addressed in these initial sections provide the background for the Q-CaRS presented in Section 2.3.

2.1. Quota TSP

Let $G = (V, A)$ be a complete graph, where $V := \{v_1, \dots, v_n\}$ is the set of vertices and $A = \{(v_i, v_j) : v_i, v_j \in V, i < j\}$ the set of edges. A non-negative quota is associated with each vertex $v_i \in V$ and a weight c_{ij} is associated with each edge $(v_i, v_j) \in A$. The QTSP involves finding a Hamiltonian cycle on a subset V' of V, such that the travel costs are minimized and a collected quota constraint is satisfied. This problem has several relevant applications, including those in tourism. For example, [41] reported an application that allows tourists to deal with insufficient time or financial resources to visit all cities. Applications associated with the QTSP and other routing problems in the tourism sector are being explored increasingly. These *TTDPs* [42] and are considered in Section 2.2.

2.2. Related problems

Most previous studies of the computation of touristic tours are based on variations of the orienteering problem [23] and they neglect the cost of transportation. They consider the time spent traveling between successive points of interest and maximizing the sum of the benefit value associated with each location. Some of these studies considered the time needed to visit each touristic attraction. Given a set of locations as vertices of a graph a score is associated with each to denote its attractiveness. The weight associated with each edge $(v_i, v_j) \in A$ denotes the time required to travel from v_i to v_j. The objective of the orienteering problem is to maximize the sum of the scores for the selected locations when restricted to a given time budget. A survey of heuristic and metaheuristic approaches for TTDPs was presented by [15]. A dynamic tour guide for the Goerlitz region in Germany was presented by [25,27], where a greedy algorithm was used to tackle the optimization problem. A variant of the orienteering problem was used to model a practical problem in [40], where they associated a weight to each vertex to denote the time needed by the tourist to visit each location. The score associated with each location was computed with information retrieval techniques and guided local search was applied to the problem. A practical implementation of the system was presented for the city of Ghent. This study was extended by [39] by considering the weather, opening hours, crowded places, and personal preferences. The base model was the team orienteering problem, but it differed from the orienteering problem according to the requirement for the construction of a given number of routes restricted to a time budget. A greedy randomized adaptive search procedure (GRASP) with path relinking was applied to the optimization problem. The bi-objective version of the problem addressed in [40] was also investigated in [35], where two different benefit values were assigned to each city. Ant colony and variable neighborhood algorithms hybridized with path relinking were applied to the single and bi-objective instances. In addition, to existing benchmark instances, the algorithms were applied to real-world instances created using data from Austrian regions and the city of Padua in Italy. GRASP was