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Heuristics for the time dependent team orienteering problem: Application to tourist route planning☆,☆☆

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ABSTRACT

The Time Dependent Team Orienteering Problem with Time Windows (TDTOPTW) can be used to model several real life problems. Among them, the route planning problem for tourists interested in visiting multiple points of interest (POIs) using public transportation. The main objective of this problem is to select POIs that match tourist preferences, taking into account a multitude of parameters and constraints while respecting the time available for sightseeing in a daily basis and integrating public transportation to travel between POIs (Tourist Trip Design Problem, TTDP). TDTOPTW is NP-hard while almost the whole body of the related literature addresses the non-time dependent version of the problem. The only TDTOPTW heuristic proposed so far is based on the assumption of periodic transit service schedules. Herein, we propose efficient cluster-based heuristics for the TDTOPTW which yield high quality solutions, take into account time dependency in calculating travel times between POIs and make no assumption on periodic service schedules. The validation scenario for our prototyped algorithms involved the transit network and real POI datasets compiled from the metropolitan area of Athens (Greece). Our TTDP algorithms handle arbitrary (i.e. determined at query time) rather than fixed start/end locations for derived tourist itineraries.

1. Introduction

In the Team Orienteering Problem with Time Windows (TOPTW) [25] we are given a set of nodes each associated with a profit, a visiting time and a time window, as well as a travel time between each pair of nodes; the objective is to find a fixed number of disjoint routes from a starting node to a destination node, each not exceeding a given time limit, that maximize the overall profit collected by visiting the nodes in all routes without violating their time windows. The TOPTW applies to several real-life problems. In this paper, we focus on the Tourist Trip Design Problem (TTDP) [28] which refers to a route-planning problem for tourists interested in visiting multiple points of interest (POIs). Solving the TTDP we derive daily tourist tours comprising ordered sets of POIs that match tourist preferences, thereby maximizing tourist satisfaction, while taking into account a multitude of parameters and constraints (e.g., distances among POIs, time estimated for visiting each POI, POIs' opening hours) and respecting the time available for sightseeing in daily basis. The problem is further complicated when considering the complexity of metropolitan transit networks commonly used by tourists to move from a POI to another. In this case, the required travel time depends on the departure time from the origin POI; hence, the TTDP can be modeled as a Time Dependent TOPTW (TDTOPTW) i.e. as a TOPTW with time dependent travel time between each pair of nodes.

The TOPTW and the TDTOPTW are NP-hard. While a significant number of heuristic approaches have been proposed in the literature for tackling the TOPTW (for a survey see [10,26]), to the best of our

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knowledge, the only TDTOPTW heuristic has been recently proposed by Garcia et al. [9]. The algorithm of Garcia et al. is based on the assumption of periodic service schedules which is clearly not valid in realistic transportation networks, wherein arrival/departure frequencies typically vary within the service's operational periods.

Herein, we propose two novel randomized metaheuristic approaches based on the technique of iterated local search [18], the Time Dependent CSCRoutes (TD_CSCR) and the Time Dependent Slack CSCRoutes (TD_$S\ell$CSCR) algorithms which address the above described shortcoming of the existing TDTOPTW approach. The main incentive behind our approaches is to motivate visits to topology areas featuring high density of 'promising' (i.e. highly profitable) candidate vertices, while taking into account time dependency (i.e. multimodality) in calculating travel times from one vertex to another; the aim is to derive high quality routes (i.e. maximizing the total collected profit) and minimize the time delays incurred in transit stops, while not sacrificing the time efficiency required for online applications. The two algorithms favor solutions with increased number of walking over public transit transfers (the latter are considered costly and typically less attractive to tourists than short walking transfers). Both algorithms are extended to tackle the case which involves arbitrary (i.e. determined at query time) rather than fixed starting/destination locations for derived tourist itineraries.

In addition to the TD_CSCR and TD_$S\ell$CSCR algorithms, we have also implemented the Average travel times CSCRoutes (AvgCSCR) algorithm which uses average (rather than time dependent) travel times between POIs. In effect, the AvgCSCR algorithm reduces the TDTOPTW to TOPTW. Having obtained a TOPTW solution, AvgCSCR employs two additional steps to ensure route feasibility and further improve the solution's quality.

Our prototyped algorithms have been tested in terms of various performance parameters (solutions' quality, execution time, percentage of transit transfers over total transfers, etc.) upon real test instances (i.e. set of POIs and accommodation facilities) compiled from the wider area of Athens, Greece; the calculation of time dependent travel times has been carried out over the Athens metropolitan transit network. The performance of the TD_CSCR, TD_$S\ell$CSCR and AvgCSCR algorithms has been compared against a time dependent extension of the most efficient known TOPTW heuristic (Vansteenwegen et al. [27]) as well as the approach proposed by Garcia et al. [9] using precalculated average travel times between POIs.

The remainder of this paper is organized as follows: Section 2 overviews the related work while in Section 3 our novel cluster-based heuristics for the TDTOPTW are presented. An algorithmic solution for the TTDP is presented in Section 4. The experimental results are discussed in Section 5 while Section 6 concludes our work.

2. Related work

The TOPTW is an extension of the Orienteering Problem (OP) [24,26] also known as the Maximum Collection Problem. In the OP, several locations with an associated profit have to be visited within a given time limit. The goal of the problem is to maximize the overall score collected on a single tour starting from and ending at a depot node. The OP is NP-hard [12,15]. The team orienteering problem (TOP) [3] extends the OP considering multiple routes while the TOP with time windows (TOPTW) [25] considers visits to locations within a predefined time window. The TOPTW is NP-hard, since it extends OP, hence exact solutions for the TOPTW can be applied only to instances with a limited number of nodes. As a result, the main body of the TOPTW literature exclusively involves heuristic algorithms [8,14,13,17,19,23,27]. ACS [19], Enhanced ACS [8] and the approach of Tricoire et al. [23] are known to yield the highest quality solutions. The most efficient known heuristic is based on Iterated Local Search (ILS) [27], offering a fair compromise with respect to execution time versus deriving routes of reasonable quality [26]. However, the ILS approach treats each POI separately, thereby commonly overlooking highly profitable areas of POIs situated far from current location considering them too time-expensive to visit. In [11] CSCRatio and CSCRoutes, two cluster-based extensions to ILS, have been proposed to address the aforementioned weakness. The main incentive behind these approaches is to favor visits to topology areas featuring high density of good candidate nodes. This is achieved through a clustering phase which groups nodes based on geographical criteria, and encouraging visiting topology areas, even distant ones.

Erkut and Zhang in [6] considered the Maximum Collection Problem with Time Dependent Rewards (MCPTDR) where each node's profit decreases linearly over time, and the objective is to maximize the sum of the rewards collected in a single tour. The problem may find applications in cases where there is a time-dependent penalty for delays in service. The authors proposed a mixed integer programming formulation, and a penalty-based greedy heuristic algorithm and an exact branch-and-bound algorithm for solving the MCPTDR. In [22] the problem of scheduling technicians for planned maintenance of geographically distributed equipment is formulated as a Multiple Tour Maximum Collection Problem with Time-Dependent rewards (MTMCPTD). In the MTMCPTD, the rewards are assigned to the tasks based on the "urgency" for completing a task on a given day and the objective is to determine a set of tours, each corresponding to a technician's schedule on a particular day, such that the total reward collected during the scheduling horizon is maximized. The authors introduced a tabu-based search heuristic for solving the MTMCPTD. The Orienteering Problem with Variable Profits was introduced by Erdogan and Laporte [5] as a variant of the OP in which the percentage of the collected profit at each node depends either on the number of discrete passes or in an alternative model, on the continuous amount of time spent at the node. Yu et al. recently [30] presented a mixed integer programming approach for solving a more general problem that allows multiple starting nodes (depots) and the profit collected at each node is characterized by some non-decreasing function over the time spent at this node. Their method is extended to the case of multiple tours.

The previous paragraph referred to variants of the OP and TOP with time dependent rewards. The Time Dependent OP (TDOP) considering time dependent travel costs, was first introduced by Formin and Lingas in [7]. TDOP is MAX-SNP-hard since a special case of the TDOP, the time-dependent maximum scheduling problem is MAX-SNP-hard [21]. Fomin and Lingas [7] give a $(2+\epsilon)$ approximation algorithm for rooted and unrooted TDOP. Verbeeck et al. [29] suggested a mathematical formulation of the TDOP and proposed a fast local search based metaheuristic to tackle the problem. This algorithm is inspired by an ant colony system (ACS) and utilizes a speed-up time-dependent local search procedure equipped with a local evaluation metric. Abbaspour et al. [1] investigated a variant of the Time Dependent OP with Time Windows (TDOPTW) in urban areas, and proposed a genetic algorithm for solving the problem. The work of Garcia et al. [9] is the first to address algorithmically the TDTOPTW. The authors presented two different approaches to solve TDTOPTW, both applied on real urban test instances (POIs and bus network of San Sebastian, Spain). The first approach involves a pre-calculation step, computing the average travel times between all pairs of POIs, allowing reducing the TDTOPTW to a regular TOPTW, solved using the insertion phase part of ILS. In case that the derived TOPTW solution is infeasible (due to violating the time windows of nodes included in the solution), a number of visits are removed. The second approach uses time-dependent travel times but it is based