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Bi-objective orienteering for personal activity scheduling

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ABSTRACT

We propose and solve a rich, bi-objective extension of the orienteering problem with time windows (OPTW) to model a combined routing and scheduling problem. Our research is motivated by the problem faced by mobile freelancers who have to integrate irregular appointments and tasks into their daily routines. Those people have a number of tasks which they need to perform at various locations (e.g. meetings with different clients), subject to varying time constraints (e.g. opening hours), and with different levels of importance or urgency (e.g. submitting a deliverable versus cleaning the home office). Furthermore, sets of related tasks may be subject to precedence relations and time dependencies. We explicitly consider the trade-off between planning more tasks and enjoying more free time by means of a bi-objective model. The extension of the OPTW and the bi-objective formulation result in the Personal Planning Problem (PPP). We present a mathematical formulation of the PPP and a metaheuristic based on Large Neighborhood Search (LNS) is developed to generate a set of non-dominated solutions to the problem. Solution quality is analyzed on real-world-inspired test instances. Exact reference sets based on a linear single-commodity flow model are used as benchmarks. Extensive computational experiments show that the proposed metaheuristic generates near-optimal solution sets and scales well to larger instances.

1. Introduction

The present study originates from a research project which aims at investigating the optimal planning of flexible activities and complex trip sequences, and at developing a personal schedule optimizer with built-in routing functionality. The problem to be solved is motivated by the challenges faced, for example, by mobile freelancers with complex routines of multiple projects and different clients. People in this target group have a variety of activities which they may need to perform at various locations (e.g. meetings with different clients, project work at different venues). These activities may be subject to timing constraints (e.g. arranged appointment times, opening hours), and they may have varying priorities or urgency (e.g. submitting a deliverable versus cleaning the home office). Hence, those people need to plan their time wisely to strike a balance between their professional activities and their private leisure time.

If many activities of private and professional nature need to be performed at diverse locations within varying time frames, determining when, where, and in what order to plan them can be overwhelming for a person due to the large number of possibilities. A sophisticated schedule optimizer can help to overcome this complexity by filtering out inefficient options and presenting only a few of the most streamlined plans. If trip sequences and daily schedules are improved, a better use of leisure time as well as an increase in the number of performed activities can be achieved. This can lead to a better quality of life and satisfaction by facilitating a better work-life balance. Thus, a personal activity scheduler should offer suggestions for where, when, and in which order activities can efficiently be planned. Four aspects need to be considered: potential locations of an activity (where to perform an activity), potential time windows for an activity (when to perform the activity), the sequence of activities (does another activity have to be performed before or after this activity, and does a time lag have to be respected), and the travel times between locations.

We propose to model this problem with an extension of the well-known orienteering problem with time windows (OPTW) (Kantor and Rosenwein [1]). We consider a graph, with nodes and directed arcs, where the nodes are used to represent the activities and their locations, the profits at the nodes correspond to the relative importance of these activities, and the service times measure how much time the activities require. The arcs in the graph

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represent the travel time between two nodes depending on the given mode of transport.

Several extensions to the classic OPTW are needed to model additional real-life aspects. First, activities may be performed at one of several possible locations. For example, groceries can be bought at various supermarkets, eating out is possible at different restaurants, and packages can be sent from any post office. Moreover, efficient schedules should not be short-sighted and should be based on a planning horizon longer than just one day. As a result, tasks and locations may have multiple time windows during the planning horizon. For instance, a pharmacy may be open only on weekdays, and its opening hours may be split due to a midday break. Similarly, tasks such as having lunch at noon may have their own time windows independent of their potential locations. In addition, sets of tasks may be connected by precedence relations. For example, the subsequent stages of a project (e.g. music composition, practice, and recording), may be done individually at any time, but not in any order. Finally, it may be necessary to respect a certain time delay between related tasks. For example, if the person wishes to exercise three times per week, they may wish to allocate a day of rest between each session. This can be modeled by imposing a minimum time delay constraint between the individual sessions. Similarly, a maximum time delay constraint may be added to ensure that tasks are not too far apart (e.g. buying groceries and bringing them home into the fridge).

The subjective quality of a schedule depends not only on its profit in terms of the tasks planned, but also on the efficiency of their timing and routing. These two apects are conflicting, and people may also have varying individual preferences with regard to the trade-off between professional activities and leisure. This means that two conflicting objectives have to be considered when determining optimal schedules: (i) the profit of planned activities and (ii) the amount of leisure time. For these reasons, we solve a bi-objective formulation of the problem, where the aim is to find a set of Pareto-optimal compromise solutions, i.e. solutions for which it is impossible to improve either objective without worsening the other. This allows the decision makers to choose among a set of diverse schedules the one which best matches their preferences.

We call this problem the Personal Planning Problem (PPP). We present a metaheuristic based on Large Neighborhood Search (LNS) in order to generate solutions within very short computation times. We analyze solution quality on real-world-inspired test instances. For this purpose, we also formulate the problem as a mixed-integer linear programming model based on single-commodity flows and solve it with CPLEX embedded in an epsilon-constraint framework. The sets of solutions generated by our LNS are compared to the exact solutions and evaluated with different performance measures for multi-objective optimization.

The remainder of the article is organized as follows. In the next section, a literature review is presented. In Section 3, a detailed mathematical formulation for the PPP is provided. In Section 4, the solution approach is introduced and explained. Different computational experiments are presented in Section 5 to show the effectiveness of our solution approach. Concluding remarks are given in Section 6.

2. Literature review

A growing body of research has been published on the Orienteering Problem (OP) and its variants. A recent review is presented in Vansteenwegen et al. [2]. The OP is related to the traveling salesman problem with profits (TSPP), of which a slightly older review is provided by Feillet et al. [3]. As noted by Vansteenwegen et al. [2], not much research has been published specifically on the OPTW originally proposed by Kantor and Rosenwein [1], but the team orienteering problem with time windows (TOPTW) is a generalization that has been given notable attention.

2.1. Single-objective OPs

An exact solution method to orienteering problems including the TOPTW is proposed in Boussier et al. [4]. However, due to the problem's difficulty and the instance sizes of real-life applications, most research on the TOPTW has focused on heuristic approaches [2]. Vansteenwegen et al. [5] propose a fast and deterministic Iterated Local Search (ILS) to solve the TOPTW within a few seconds and introduce a set of benchmark instances. Following this paper, more elaborate algorithms are introduced (in order of publication) in Montemanni and Gambardella [6] (Ant Colony Optimization, ACO), Montemanni et al. [7] (enhanced ACO), Labadie et al. [8] (GRASP+variable neighborhood descent), Labadie et al. [9] (granular variable neighborhood search), and Lin and Yu [10] (simulated annealing). Most authors report a set of new best solutions at the time of publication. To the extent of our knowledge, the most recent contribution is that of Hu and Lim [11], who combine heuristic and exact methods within an iterative three-component heuristic which finds 35 new best solutions and appears to outperform previous methods in terms of average performance.

Some rich extensions to the OP have also been proposed. Tricoire et al. [12] model the combined problem of route planning and scheduling for field workers and sales representatives to visit both regular and potential new clients. The authors introduce the multi-period OP with multiple time windows (MuPOPTW), and solve it with an exact algorithm embedded within a variable neighborhood search (VNS). The VNS in Tricoire et al. [12] also produces high quality results on the (T)OPTW benchmark instances. Another rich variant is presented by Souffriau et al. [13], who introduce the multi-constraint TOP with multiple time windows (MCTOPMTW). This approach considers resource constraints. By doing so, a number of usual constraints are tackled, for instance multiple time windows. Souffriau et al. [13] are motivated by a tourism application where the different attributes can for instance represent entry costs (to limit total spend) or point-of-interest categories (to accommodate "max-*n*-type constraints" such as visiting at most *n* museums).

2.2. Multi-objective OPs

Despite interest in orienteering problems in general, multi-objective formulations of the problem have only received attention in the last ten years. This is somewhat unexpected since the OP is characterized by an inherent conflict between the profit collected and the distance traveled. Most researchers solve the problem in a single-objective way, with a hard constraint on a resource (usually time), while some approaches maximize the difference between profit and cost [3].

Jozefowiez et al. [14] develop a multi-objective evolutionary algorithm for the traveling salesman problem with profits (TSPP). An exact method for the bi-objective TSPP, based on the ϵ-constraint framework, is introduced in Bérubé et al. [15]. Another exact approach, following the two-phase method, is provided by Filippi and Stevanato [16]. In a following article, the same authors provide an approximation method which enumerates a subset of the Pareto set (Filippi and Stevanato [17]).

A different bi-objective orienteering problem is introduced by Schilde et al. [18], with applications in the tourism sector. The objectives refer in this case to the different categories of points of interest (e.g. culture, leisure, dining), with each such point offering different degrees of benefits for each category. The aim is to find a variety of tours offering different degrees of focus on