Solution methods for the Time-Dependent Orienteering Problem

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1 Problem definition

The orienteering problem (OP) is defined on a graph in which scores are assigned to the vertices and a travel time is assigned to each edge linking two vertices. The objective of the OP is to select a subset of vertices and determine the order in which they are visited so that the total collected score is maximized while the maximum total travel time is not exceeded. In addition, a feasible OP solution should start and end at a predetermined vertex.

Orienteering problems are typically used in logistic planning tools and they serve as the basic problem formulation of personalized touristic trip planners.

This research focuses on developing metaheuristics to obtain solutions within a few seconds of computation time for time-dependent orienteering problems (TD-OP) which means that the travel time between two vertices depends on the departure time at the first vertex. This specific problem formulation allows us to tackle congestion related issues in routing problems. To the best of our knowledge, a solution method for this problem is only provided in journal papers by Abbaspour et al. (2011) and Garcia et al. (2013).

2 Solution method

To obtain solutions within a few seconds of computation time, metaheuristics are advised as solution methods since the TD-OP(TW) is NP-hard. therefore, a metaheuristic, based on the principles of an ant colony system (ACS), is implemented to tackle the TD-OP(TW). This choice was motivated by the fact that generally very complex problems require simple solution frameworks and by former successful implementations of the framework for the OP and the time dependent vehicle routing problem (TD-VRP). More specifically, our solution approach is based on a time-dependent local search procedure and a fast local evaluation metric. This procedure iteratively tries to insert non-included vertices into an existing solution, thus improving its total score. To prevent a time-consuming evaluation of the whole solution after each insertion attempt, we store for every included vertex the maximum amount of time that this vertex can be postponed before the solution becomes infeasible.

The first benchmark instances were developed by combining the benchmark datasets of the OP with a speed model used for the TD-VRP (Donati et al., 2008), which simulates congestion patterns by using arc categories and time slots. The travel time is determined by defining a speed level for every combination of a time slot and arc category. To resemble a real live road network, congestion patterns imitating the real situation on a road network (e.g. realistic morning and evening peaks between city centers and living areas), were inserted in the existing datasets of the orienteering problem.

2.1 Implementing a realistic road network

In these benchmark datasets every single vertex is connected to every other vertex with one direct arc, constructing a complete graph. This is a simple representation of a road network that enables a practical way of working but it is not suited for congested realistic road networks. For example, only one congestion pattern could be assigned to one arc, however in reality a route between two vertices consists of an concatenation of arcs each with their own congestion characteristics. We removed this restriction by using the realistic road information available in Open Street Maps (OSM). Notwithstanding the high quality results on the artificial datasets, displayed in Section 3, the algorithm needed further improvement to deal with larger datasets with a realistic road structure.

2.2 Incorporating time windows

Incorporating time windows and service times makes the problem not only more realistic but it is a necessary addition to the orienteering problem as the resulting waiting times directly affect the travel times in a time-dependent problem context. Therefore the ACS algorithm was adapted to solve time-dependent orienteering problems with time windows

(TD-OPTW). An ant constructs a solution based on greedy information about the aptitude to go from the last visited vertex to another feasible vertex. This greedy information consists of the score of the new vertex, the extra distance needed to travel to it and a time window urgency factor. During the construction of an initial solution waiting is allowed which is beneficial to the insert local search procedure providing ample time to insert other vertices. A new local search move which makes use of the local evaluation metric, replace was implemented and replaces a vertex from the current solution with a non-included vertex with a higher score. Finally, a basic swap local search procedure that swaps solution members in order to save travel time was also employed.

3 Results

A way to obtain larger TD-OP instances with known optimal solutions was developed. First, all instances were solved first as time-*independent* OPs using a commercial exact solver. Following this optimization, the optimal time-*independent* solutions (sequence of vertices) are used to modify the original time-dependent instances in such a way that slightly modified time-dependent instances with known optimal solution are created. More specifically, for each arc included in the optimal time-independent solution, the travel speed is set to its maximal value, but only during the time periods these arcs are traversed. Since the travel speed is only modified in some of the time periods of these arcs, these arcs still have time-dependent travel times. The time dependent travel times on all other arcs are not modified. In this way, it is ensured artificially that the time-independent optimal solution is also an optimal solution to the modified time-dependent instance.

Table 1 presents a summary of the results for the TD-OP on 59 instances. This table proves the high performance quality of the solution method, since the average gap, 1.4% is very low and the optimal solution could be found for 24 out of 59 instances. Studying the computation time leads to the conclusion that the ACS is very fast, as on average only one second is required to solve a problem instance. The maximum observed CPU time was 1.6 seconds, which is more than fast enough for most application purposes. Therefore, it can be concluded that the ACS is able to deliver a high performance requiring a minimal computational effort. We also tested and improved the algorithm for the TD-OPTW on 27 Open Street Maps instances. These results again prove the high performance quality of the ACS, since the average gap is very low, 1.5%. Furthermore, the known optimal solution could be found for 8 out of 27 test instances. Studying the computation time leads to the conclusion that the ACS is also very fast in solving the TD-OPTW, as on average only 0.7 seconds are needed to obtain a solution. An extensive sensitivity analysis shows that the performance of the algorithm is insensitive to small changes in its parameter settings. The strength of the algorithm lies in the interaction effect between the swap, insert and replace local search procedures.

Table 1: % gap (best, average, worst) and average CPU time per dataset

	TD-OP					TD-OPTW			
N	best % gap	avg % gap	worst % gap	CPU s	N	best % gap	avg % gap	worst % gap	CPU s
21-33	0.0	0.1	0.3	0.1	20	0.2	0.2	0.2	0.2
64-66	0.7	1.1	1.9	0.5	50	0.9	2.5	3.8	0.6
100-101	2.5	3.4	4.5	1.1	100	0.6	1.8	3.8	1.6
overall maximum	5.0	6.1	9.0	1.4		3.8	5.0	7.4	2.1
overall average	1.0	1.4	2.0	0.5		0.6	1.5	2.6	0.8
% optimal	61.0	44.1	44.1			77.8	29.6	29.6	

4 Conclusions

This paper presents a local search based metaheuristic for the time-dependent orienteering problem and its extension with time windows. This metaheuristic is inspired by an ant colony system and the local search moves themselves represent a time-dependent insertion and replacement procedure. These trial-and-error procedures are fastened by a local evaluation metric. Moreover, realistic time-dependent test instances are developed based on the open source database OpenStreetMap in combination with a well performing speed model. Our metaheuristic obtains high quality results on the proposed benchmark instances within a few seconds of computation time. Furthermore, solving the time-dependent variant of the team orienteering problem (TD-TOPTW) is very interesting as it allows to optimize the routing of a fleet of vehicles, instead of one vehicle only, which is certainly useful for logistic companies.

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