THE CAPACITATED TEAM ORIENTEERING PROBLEM: BEE COLONY OPTIMIZATION

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Abstract: *In this paper the capacitated team orienteering problem have been applied as a tool for carriers to avoid empty returns when trucks do not work with full load. The software based on bee colony optimization technique is developed for solving the problem. Numerical example is solved and the result is shown to depict the possibility of the proposed algorithm.*

Keywords*: orienteering problem, bee colony optimization, electronic auction.*

1. INTRODUCTION

Orienteering is a sport which is a mixture of cross-country running and navigation through a forest, using a map and compass. A number of control points each with an associated score are placed in the forest and their locations are marked on the competitors' maps. Competitors start at intervals of, for example, a minute and are required to visit a subset of the control points from the start point (node 1) so as to maximize their total score and return to the end point (node n) within a prescribed amount of time (Golden et al. 1987, Tsiligirides 1984).

There is analogy between sport orienteering and the problem which consists of determining a path, limited by T_{max}, that visits some of the vertices (each with a score) of a graph, in order to maximize the total collected score. Due to the analogy, the problem was named the orienteering problem (OP). In the literature (Laporte and Martello 1990, Gendreau et al. 1998) the orienteering problem is also known as the selective traveling salesman problem. In addition, the same problem in the literature (Fillet et al. 2005) can be found as a variant of the traveling salesman problem with profits in which the cost is referred to the constraint and the collected profit to the objective function. Orienteering problem (Kim et al. 2013) is the special case of team orienteering problem (TOP) in which there are teams of several competitors, each collecting scores during the same time span. The TOP is also known as the multiple tour maximum collection problem (Butt and Cavalier 1994) or the vehicle routing problem with profits. The capacitated version of TOP was studied by Archetti et al. (2009, 2010). The authors tried to develop method as a decision support when demand and offer of transportation service did not match.

In this paper the capacitated team orienteering problem is solved by applying the Bee colony optimization. The proposed algorithm is used for solving the problem when carriers try to avoid empty returns because the fleet of vehicles they own does not work with full load. The problem was successfully solved by the developed metaheuristic algorithm. The proposed algorithm might be a tool for carriers when consider bids of potential customers through the electronic auction process.

2. THE CAPACITATED TEAM ORIENTEERING PROBLEM

Given a complete undirected graph $G=(V, E)$, where $V=\{1,...,n\}$ is the vertex set and E is the edge set. Vertex 1 is a depot for m identical vehicles of capacity Q, while the remaining vertices represent potential customers. An edge $(i,j) \in E$ represents the possibility to travel from customer i to customer j. A non-negative demand d_i and a non-negative profit p_i is associated with each customer i ($d_i=p_i=0$). A symmetric travel time t_{ij} and cost c_{ij} are associated with each $(i, j) \in E$. Each vehicle starts and ends its tour at vertex 1, and can visit any subset of customers with a total demand that does not exceed the capacity Q. The profit of each customer can be collected by one vehicle at most. In the following we suppose that $t_{ij}=c_{ij}$ for each edge (i, j). In the capacitated team orienteering problem (CTOP) a subset of the potential customers available has to be selected. The objective is to maximize the total collected profit while satisfying, for each vehicle, a time limit T_{max} on the tour duration and the capacity constraint Q.

Let $\Omega=\{r_1, \dots, r_{|\Omega|}\}$ be the set of possible routes for a vehicle, that is, the set of routes starting and ending at vertex 1, visiting at most once each potential customer, satisfying the capacity constraint Q and the time limit T_{max}. Let a_{ik} = 1 if route $r_k \in \Omega$ visits customer i, a_{ik} = 0 otherwise. Let c_k be the total profit generated by route $r_k \in \Omega$: $c_k = \sum_{i \in V} a_{ik} p_i$. The CTOP can be stated as follows:

$$max \sum_{r_k \in \Omega} c_k p_k \tag{1}$$

Subject to:
$$\sum_{r_k \in \Omega} a_{ik} x_k \leq 1, \quad i \in V \setminus \{1\} \tag{2}$$

$$\sum_{r_k \in \Omega} x_k \leq m \tag{3}$$

$$x_k \in \{0,1\}, \quad r_k \in \Omega \tag{4}$$

The decision variables x_k indicate whether route $r_k \in \Omega$ is used or not. Constraints (2) ensure that each customer is visited at most once. Constraint (3) limits the number of vehicles used to m. Solving the linear relaxation of model (l)-(4) necessitates the use of a column generation technique, due to the size of Ω. Column generation is based on two components: a restricted master problem and a subproblem (Archetti et al. 2009).

Golden et al. (1987) prove that the OP is NP-hard. The TOP is also NP-hard (Chao et al. 1996). This implies that exact solution algorithms are very time consuming and for practical applications heuristics and metaheuristics would be necessary.

There are some interesting applications of the OP and the TOP in the literature: the case when truck fleet delivers fuel to consumers on daily basis (Golden et al. 1984), application in tourism (Souffriau et al. 2008), military applications (Wang et al. 2008).

As it is said before, the CTOP was studied by Archetti et al. (2009, 2010). Several heuristics and exact algorithms for solving the problem are presented in both papers. Archetti et al. (2007) proposed two variants of a generalized tabu search algorithm and a variable neighborhood search algorithm for the solution of the TOP.

3. BEE COLONY OPTIMIZATION

The bee colony optimization metaheuristic (Teodorović 2008) was developed and used by Lučić and Teodorović (2001, 2003). Artificial bees represent agents, which collaboratively solve complex combinatorial optimization problems. Each artificial bee is located in the hive at the beginning of the search process, and makes a series of local moves, thus creating a partial solution. Bees incrementally add solution components to the current partial solution and communicate directly to generate feasible solutions. The best discovered solution of the first iteration is saved and the process of incremental construction of solutions by the bees continues through subsequent iterations.

Artificial bees perform two types of moves while flying through the solution space: forward pass or backward pass. Forward pass assumes a combination of individual exploration and collective past experience to create various partial solutions, while backward pass represents return to the hive, where collective decision-making process takes place. It is assumed that bees exchange information and compare the quality of partial solutions created, based on which every bee decides whether to abandon the created partial solution and become again uncommitted follower, continue to expand the same partial solution without recruiting nestmates, or dance and thus recruit nestmates before returning to the created partial solution. During the second forward pass, bees expand previously created partial solutions, after which they return to the hive in a backward pass and engage in the decision-making process as before. Series of forward and backward passes continue until feasible solutions are created and the iteration ends.

4. SOLVING THE CAPACITATED TEAM ORIENTEERING PROBLEM BY BEE COLONY OPTIMIZATION

Drenovac et al. (2014) developed the algorithm based on the BCO for solving the orienteering problem. The algorithm was modified and adapted for capacitated vehicle fleet. Description of the algorithm follows.

The hive with artificial bees is located in node 1. Bees bounce from the hive and begin search process of area of allowable solutions. Let V_i be the bee's benefit of choosing the i^{th} node to serve. It is accepted that the bee's benefit when selecting a node is even greater if the score is greater and the travel time is shorter. Namely, it could be presented in the following way:

$$V_i = \frac{S_i}{t_{li}} \tag{5}$$

where S_i is score in node i, t_{li} is the time required to reach node i, from the last selected node l.

Let p_i be the probability that a bee will choose the i^{th} node. Each route has to start and end at node 1. Before the node selection, a subset of those nodes that satisfy the maximal length of the route (their inclusion does not exceed the maximal length) as well as the maximal capacity (when demand of potential node is added to the partial demand, the sum does not exceed the maximal capacity of vehicle), has to be determined. Later, nodes are being chosen randomly from the subset.

Logit model was adopted as a model of choice and the probability of selection is:

$$p_i = \frac{e^{V_i}}{e^{V_1} + e^{V_2} + \ldots + e^{V_m}} \tag{6}$$

where m is the cardinal number of the subset.

During the first forward pass each bee chooses a predefined number of nodes for each route. Having returned to the hive, bees start to communicate. They calculate values of the objective function as the ratio of the total score and the total time required to visit chosen nodes and compare their partial solutions. In the proposed algorithm, the objective function of each bee comprises time because the greater route efficiency the greater number of included nodes and the greater achieved score. Then, bees make decision about their loyalty to the solution (whether to keep the solution or to abandon it).

Let Π_j be the objective function value generated by the j^{th} bee ($j=\overline{1,b}$, where b is the number of bees). Let Π_{norm_j} be the normalized value of the objective function value. It is calculated as follows:

$$\Pi_{norm_j} = \frac{\Pi_j - \Pi_{\min}}{\Pi_{\max} - \Pi_{\min}},\ \Pi_{norm_j} \in [0,1],\ j=\overline{1,b} \tag{7}$$

Where $\Pi_{\max}$ and $\Pi_{\min}$ are the minimum and the maximum value of the objective function.

The probability that the j^{th} bee will be loyal to its partial solution at the beginning of the next forward pass is calculated as follows:

$$p_j^{u+1} = e^{-\frac{\Pi_{norm_{\max}} - \Pi_j}{u}},\ j=\overline{1,b} \tag{8}$$

where u is ordinal number of the forward pass and $\Pi_{norm_{\max}}$ is maximal normalized value of the objective function.

After making decisions about the loyalty to their solutions, bees gather in the dance floor area. The bees that decide to keep their partial solutions start dancing and thus recruit uncommitted bees. Uncommitted followers choose which of the loyal bees to follow in the next forward pass.

During the search process time is updated and when bees can no longer expand the solution, the search ends. Having coming back to the hive after an arbitrary forward pass, the bees can create partial as well as final solutions. Despite of that, all of them participate in information exchange, evaluation of solutions and decision-making concerning the loyalty to solutions.

If the number of loyal bees is equal to r before the next forward pass, the probability that the uncommitted bee will join the k^{th} loyal bee in the next forward pass is equal to:

$$p_k = \frac{e^{\Pi_{norm_k}}}{e^{\Pi_{norm1}} + e^{\Pi_{norm2}} + \ldots + e^{\Pi_{norm\,r}}},\ k=1,\ldots,r \tag{9}$$

Based on these probabilities, uncommitted bees are coupled with committed bees. Bees then start a new forward pass flying together to the last node of partial solutions generated by committed bees. After that, each bee individually extends its partial solution.

Each iteration gives a particular solution containing tours for vehicles. The best solution obtained during the pre-specified number of iterations is selected.

5. NUMERICAL EXAMPLE

Spreading of markets forces carriers to look for customers wider than their traditional service area. Usually, long-term contracts are settled through electronic auctions (using the Internet), where selected set of carriers submit a bid to cover a given set of lanes. The aim of carriers is to reduce their costs and to decrease seasonal effects when fleet of vehicles is non-optimally used (when trucks travel without any load or have a partial load). Carriers have to make effort to expand their market area and to attract new customers. Through the web carriers can find a number of spot loads to fill up trucks or to avoid empty returns. They decide whether to pick up or not according to the compatibility with the remaining capacity of a truck. The additional cost for serving the customer must be compensated by profit. For planning potential customers the entire fleet of vehicle has to be considered (Archetti et al., 2009).

This problem can be modelled as a routing problem with profits where a fleet of capacitated vehicles is given as well as a set of customers that have to be served. In addition, a set of potential customers is available. The problem is to decide which of these potential customers to serve and how to construct routes for vehicles in such a way that a suitable objective function is optimized. In this paper the objective is the maximization of the collected profit, given limited time available for vehicles.

In order to demonstrate the proposed metaheuristic approach, the following numerical example was solved. The benchmark problem, 21-node network was taken from the following internet address and modified: www.mech.kuleuven.be/cib/op. A time limit on the tour duration is 22. The capacity constraint is 25. Demands equal to 5 are associated with the nodes except node one, which is the depot and has demand equal to 0. The 21st node is replaced by the coordinates of the first node in order for each vehicle to start and to end its route at the depot. Nodes from 6 to 13 represent long-term contracts. There are three vehicles. Each vehicle starts and ends its tour at depot. Solving vehicle routing problem of regular customers gives the following result:

Table 1. Tours with regular customers

	tour	tour length	demand	score
Vehicle 1	1, 7, 6, 13, 1	7.9968	15	120
Vehicle 2	1, 12, 10, 8, 1	11.5067	15	
Vehicle 3	1, 11, 9, 1	10.0119	10	

It could be seen that all of vehicles are poorly exploited as well as the time available for service. Nodes from 2 to 5 and from 14 to 20 are potential customers that might be considered to serve. Regular customers that need to be visited are modelled with scores 10 times bigger than real ones. Solution obtained by the proposed algorithm is given in table 2.

Table 2. Tours containing both regular and new customers

	tour	tour length	demand	score
Vehicle 1	1, 11, 10, 9, 17, 14, 1	21.2215	25	290
Vehicle 2	1, 13, 12, 8, 2, 4, 1	20.0413	25	
Vehicle 3	1, 7, 6, 5, 3, 20, 1	20.1056	25	

It could be seen that all regular customers are included in tours. Remaining, unvisited nodes are 15, 16, 18, 19. Capacity of vehicles are fully used and the available time is almost completely used, while the score is higher. It could be said that the new, better transportation plan for carriers could be obtained by the proposed algorithm.

6. CONCLUSION

In this paper capacitated team orienteering problem is solved by applying the Bee colony optimization. Here the problem is considered when the carrier has a fleet of capacitated vehicles for the set of customers but it does not completely use the time available for the service or capacity of vehicles. Finding new customers may be modelled with the CTOP. The developed algorithm, used for solving capacitated team orienteering problem for the first time, yields acceptable results. It might be considered as a support tool for decision making of carriers when choosing new customers from databases available on the Internet.

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