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UCT in Capacitated Vehicle Routing Problem with traffic jams

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ABSTRACT

In this paper a dynamic version of the Capacitated Vehicle Routing Problem (CVRP) which takes into account traffic jams is considered. Traffic jams occur randomly according to predefined intensity and length distributions. In effect, static CVRP is transformed into a non-deterministic scheduling problem with high uncertainty factor and changing in time internal problem parameters. Our proposed solution to CVRP with traffic jams (CVRPwTJ) relies on application of the Upper Confidence Bounds applied to Trees (UCT) method, which is an extension of the Monte Carlo Tree Search algorithm. The most challenging issue here is finding a suitable mapping of the CVRPwTJ onto a tree-like problem representation required by the UCT. Furthermore, in order to prevent the size of the tree from explosive growth, an efficient mechanism for child nodes selection is proposed. UCT-based approach is compared with four other methods showing promising results and offering prospects for its wider applicability in the domain of stochastic optimization problems.

1. Introduction

Vehicle Routing Problem (VRP) [10], along with its numerous variants, is a widely known combinatorial optimization task. The problem was formulated in 1959 [10] and subsequently proved to be NP-hard in 1981 [29]. In short, the problem consists in assigning a number of homogeneous vehicles to a number of clients, where each client has a certain 2D location and a certain demand of (homogeneous) goods. The optimization objective is to deliver the demanded goods to all clients while minimizing the sum of vehicles routes' costs (lengths). Additionally, each client must be served by exactly one vehicle and each vehicle's route must start and end in the depot (defined by its 2D coordinates). For practical reasons, the upper limit on vehicles' capacity is often imposed, leading to the Capacitated Vehicle Routing Problem (CVRP) formulation.

Since VRP/CVRP is NP-hard, no polynomial method of solving the problem is known and the exact solutions can only be obtained for relatively small-size problems. Among the exact algorithms one can distinguish the following three main approaches: full tree search (e.g. spanning tree and shortest path relaxations method [7]), dynamic programming (e.g. [14] in the case of problems with a priori known number of required vehicles) and integer programming (e.g. three-index vehicle flow formulation [17]).

There are also multiple approximation algorithms for VRP/CVRP, most of them designed to address specific problem formulations, e.g. multi-trip [5] or multi-compartment [1] versions of the problem, variants with certain delivery time-windows [19] or dynamically defined requests [34], combined pickup and delivery problem formulations [35], ecology-

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oriented Green VRP [31,51], and others. The area of VRP is broad and fast-growing. Due to space limits, we are unable to provide a more in-depth characteristics of this field. Please consult an excellent book [49], the recent survey paper [42], or the recent special issue [48] for an overview of the current developments and challenges in the domain, and [15] for the VRP taxonomy.

A particular variant of CVRP considered in this paper, which we call CVRP with Traffic Jams (CVRPwTJ), introduces a high degree of uncertainty to the problem specification by means of traffic jams (TJ), which may dynamically occur on particular edges of the planned vehicles' routes. The existence of a traffic jam increases the cost of traversing a certain edge, usually to the extent that requires some re-modeling of the currently planned route. In the proposed solution, these dynamic changes are handled on-line by appropriate actions taken to alleviate their impact.

Our proposed solution to CVRPwTJ relies on the Upper Confidence Bounds Applied to Trees (UCT) method [4,26], which is currently a state-of-the-art approach in game playing domain. UCT is particularly applicable to games for which compact and easily computable position assessment function is not known. Typical examples of such games/game frameworks are Go [4,18] or General Game Playing [44,45,50].

The main advantage of using UCT in games is its adaptability to the changing game situation and long-term reliability of position assessment. An additional asset of UCT is its "knowledge-free" nature [32,33] which is understood as the lack of the requirement for providing any domain-specific knowledge, except for the formal game definition, which is indispensable in the move generation process and for detection and evaluation of the final states of the game.

In the view of the above-listed UCT qualities, we conducted research on possible ways of applying the modified form of this algorithm to solving CVRPwTJ. In particular, the presented research aims at verification of the UCT capability to flexibly address the *exploration vs. exploitation dilemma* in CVRPwTJ, i.e. the issue of balancing the usage of discovered best solutions vs. finding the new ones with respect to highly variable problem parameterization (stochastic changes of TJ intensities). Such a *plasticity* of the solution method seems to be indispensable for efficient solving stochastic optimization problems, in particular CVRPwTJ.

Since, to the best of our knowledge, this paper presents the first approach to solving the CVRPwTJ by means of the UCT method, we had to make several decisions related to particular implementation and usage of the method in a new application domain. The main issue was related to the CVRPwTJ problem representation in the form of a graph (which is a desirable representation for the UCT tree-search method), and definition of the set of UCT actions (possible "moves" in a given state of a partial solution) as well as their interpretation per analogy to game moves.

The efficacy of the proposed approach is compared with two versions of Genetic Algorithms (GA) implementations and with Tabu Search (TS) and Ant Colony Optimization (ACO) metaheuristics showing its upper-hand under the same time and resource availability. Several differences in which UCT and the above-mentioned metaheuristic methods tackle the problem have been pointed and discussed.

The rest of the paper is organized as follows: in the next section a formal definition of the CVRPwTJ is provided, followed by a discussion of the related work. Sections 3 and 4 summarize the UCT method and the way we propose to apply it to solving CVRPwTJ, respectively. In Section 5, evolutionary methods used for comparison with the proposed UCT approach are introduced. Section 6 is devoted to presentation of an experimental setup, simulation results and their comparison with the above-mentioned metaheuristic approaches. A summary of the main contribution and directions for future research conclude the paper.

2. Capacitated Vehicle Routing Problem with Traffic Jams (CVRPwTJ)

In CVRP, a fleet $V = \{v_1, \dots, v_n\}$ of n vehicles is to deliver cargo to a set of m clients $C = \{c_1, \dots, c_m\}$ each of them having a demand of size $size_i, i = 1, \dots, m$. Vehicles are homogeneous, i.e. have identical $capacity \in \mathcal{R}$. The cargo is loaded in a pre-defined *depot* (denoted by c_0 in our implementation).[1] Each customer as well as the depot have certain location $loc_j \in \mathcal{R}^2, j = 0, \dots, n$.

The travel distance $\rho_{i,j}$ is the Euclidean distance between loc_i and loc_j in $\mathcal{R}^2; i, j = 0, \dots, m$. For each vehicle v_i the $r_i = (i_0, i_1, \dots, i_{p(i)})$ is a permutation of indexes of requests/customers assigned to v_i to be visited by the vehicle, which defines the route of the ith vehicle. The first and the last elements in r_i always denote a depot, i.e. each route must start and end in a depot.

The goal is to serve all clients (requests) with minimal total cost (travel distance), with routes/vehicles starting from the depot, fulfilling the trucks' capacity constraint, visiting each client only once (i.e. for each customer cargo must be delivered in one service) and returning to the depot afterwards. Formally, the goal is to find a set $R = \left\{r_1^*, r_2^*, \dots, r_n^*\right\}$ of permutations of requests that minimizes the following cost function:

$$COST(r_1, r_2, \dots, r_n) = \sum_{i=1}^{n} \sum_{j=1}^{p(i)} \rho_{i_j i_{j-1}} \tag{1}$$

[1] In some CVRP formulations more than one depot is considered, however, the version with one depot is the most popular in the literature.