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A memetic algorithm for the Multi Trip Vehicle Routing Problem

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ABSTRACT

We consider the Multi Trip Vehicle Routing Problem, in which a set of geographically scattered customers have to be served by a fleet of vehicles. Each vehicle can perform several trips during the working day. The objective is to minimize the total travel time while respecting temporal and capacity constraints.

The problem is particularly interesting in the city logistics context, where customers are located in city centers. Road and law restrictions favor the use of small capacity vehicles to perform deliveries. This leads to trips much briefer than the working day. A vehicle can then go back to the depot and be re-loaded before starting another service trip.

We propose an hybrid genetic algorithm for the problem. Especially, we introduce a new local search operator based on the combination of standard VRP moves and swaps between trips. Our procedure is compared with those in the literature and it outperforms previous algorithms with respect to average solution quality. Moreover, a new feasible solution and many best known solutions are found.

1. Introduction

The well known Vehicle Routing Problem (VRP) is an $\mathcal{NP}$-hard combinatorial optimization problem where a set of geographically scattered customers has to be served by a fleet of vehicles. An implicit assumption of the VRP is that each vehicle can perform only one route in the planning horizon. This assumption is not realistic in several practical situations. For the distribution of goods in city centers, for example, small vehicles are generally preferred. Because of this capacity limitation, they daily perform several short tours. This problem is referred to as the Multi Trip VRP (also VRP with multiple use of vehicles, Taillard, Laporte, & Gendreau (1996), VRP with multiple trips, Petch & Salhi (2004) or VRP with multiple routes, Azi, Gendreau, & Potvin (2007)). In the rest of the paper it will be indicated as MTVRP.

The MTVRP is defined on an undirected graph $G = (V, E)$, where $V = \{0, 1, \ldots, n\}$ is the set of vertices and $E = \{(i, j) \mid i, j \in V, i < j\}$ is the set of edges. It is possible to travel from i to j, incurring in a travel time t_{ij}. Vertex 0 represents the depot where a fleet of m identical vehicles with limited capacity Q is based. Vertices $1, \ldots, n$ represent the customers to be served, each one having a demand q_i. A time horizon T_H exists, which establishes the duration of the working day. Overtime is not allowed. It is assumed that Q, q_i and T_H are nonnegative integers.

The MTVRP calls for the determination of a set of routes and an assignment of each route to a vehicle, such that the total travel time is minimized and the following conditions are satisfied:

(a) each route starts and ends at the depot,
(b) each customer is visited by exactly one route,
(c) the sum of the demands of the customers in any route does not exceed Q,
(d) the total duration of the routes assigned to the same vehicle does not exceed T_H.

It is also supposed that each customer i could be served by a return trip, i.e, $t_{0i} + t_{i0} \leqslant T_H$ and $q_i \leqslant Q$.

Few papers in the literature address the MTVRP and no efficient population-based algorithm were proposed. Our goal is to fill this gap proposing a memetic algorithm able to compete with previous works. Our interest in the MTVRP raises from the MODUM project,[1] where mutualized distribution in city centers is explored. The contribution of this paper is threefold:

(1) A high-performing memetic algorithm is proposed: the results found are the new state-of-the-art on classical instances for the MTVRP. Moreover, an instance has been solved for the first time, i.e., a feasible solution has been found.

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[1] http://www-lipn.univ-paris13.fr/modum.

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(2) An adaptation of the Split procedure (Prins, 2004) to segment a chromosome into a MTVRP solution is developed.
(3) A new local search (LS) operator, that combines standard VRP moves and re-assignment of trips to vehicles is introduced.

This paper is organized as follows. In Section 2 the literature on the MTVRP is reviewed. Section 3 describes the proposed algorithm. Section 4 details the *Combined* LS. Results are reported in Section 5. Conclusions and perspectives are discussed in Section 6.

2. Literature review

The well known VRP has been deeply studied in the last 50 years and many exact and heuristic methods have been proposed in the literature (see Golden, Raghavan, & Wasil, 2008; Toth & Vigo, 2002). However, exact methods remain limited to problems with restricted size, i.e., less than 100 customers. Moreover, many different variants of the problem are introduced in order to face particular constraints that arise in everyday applications. Despite that, MTVRP has been investigated only in the last two decades and the literature is still scarce.

Fleischmann (1990) was the first to address the problem in his working paper in 1990. He proposes a modification of the savings algorithm and uses a bin packing (BP) problem heuristic to assign routes to the vehicles. In Taillard et al. (1996), VRP solutions are generated using a tabu search (TS) algorithm with adaptive memory (Taillard, 1993). The routes forming the VRP solutions are stored in a list. From that list a subset of routes is selected and a MTVRP solution is constructed using a BP heuristic. A benchmark of instances (constructed from VRP instances) is proposed. It will be used as efficiency comparison for all the authors that have developed a solution method for the MTVRP. Curiously, Taillard et al. (1996) provide values only when the algorithm fails in finding a feasible solution, introducing an arbitrary penalization factor $\theta = 2$ for the overtime. Next papers follow the same scheme except Salhi and Petch (2007) (Olivera & Viera (2007) do not provide exact values, but just a *GAP* measure from a reference value as it will be explained in Section 5). Petch and Salhi (2004) propose a multi-phase algorithm with the minimization of the overtime as objective function. A pool of solutions is constructed by the parametrized Yellow's savings algorithm Yellow (1970). For each solution in the pool, a MTVRP solution is constructed using a BP heuristic. The MTVRP solutions are improved using 2-opt, 3-opt moves, combining routes and reallocating customers. In Salhi and Petch (2007), as in Petch and Salhi (2004), the maximum overtime is minimized. A genetic algorithm is proposed. In this method the plane is divided in circular sectors. Each sector is defined by an angle measured with respect to the depot and the x axis. A chromosome is the sequence of such angles in non-decreasing order. Clusters are created by assigning each customer to the sector it occupies. In each cluster, the Clarke and Wright savings heuristic is used to solve a smaller VRP problem. The resulting routes are packed using a BP heuristic. Olivera and Viera (2007) use an adaptive memory approach to tackle the MTVRP. A memory M is constructed with different routes that form VRP solutions generated with the sweep algorithm. Each route is labeled with its overtime value and its cost and are sorted using a lexicographic order. New VRP solutions are generated by probabilistically selecting routes in M and improved by a TS algorithm. New VRP solutions are used to update M. From the best VRP solution a MTVRP solution is obtained using a BP heuristic. Recently, Mingozzi, Roberti, and Toth (2012) propose an exact method for the MTVRP based on two set partitioning-like formulations. 52 instances with up to 120 customers and with a known feasible solution (without overtime) are tackled and in 42 cases the optimal solution is found.

Alonso, Alvarez, and Beasley (2008) consider the site-dependent periodic MTVRP. Each customer has to be served up to t times in a planning horizon of t periods. Moreover, not every vehicle can serve all the customers. To each customer is assigned a delivery pattern and it is assigned to a vehicle using GENIUS heuristic (Gendreau, Hertz, & Laporte, 1992). If the insertion violates time or capacity constraints a new route is initialized. Two moves are used to improve the solution: customers are moved from a route to another and different patterns are assigned to a customer.

The MTVRP with time widows (MTVRPTW) is addressed as well. Several exact methods are proposed Azi et al., 2007; Hernandez, Feillet, Giroudeau, and Naudi, 2011. Instances with 100 customers and 1 vehicle (Azi et al., 2007) and with 50 customers and 4 vehicles (Hernandez et al., 2011) can be solved to optimality.

Different studies facing practical cases envisage to perform several trips during the working day. For example, Brandão and Mercer (1997) consider a MTVRPTW that raises from the biscuit distribution of a British company. Vehicles have different capacities, in case of need they can be hired from the company and the access to some customers is restricted to particular vehicles. Drivers' schedule must respect the maximum legal driving time per day. Legal time breaks and unloading times are taken into account. Real instances including 45–70 customers and the use of 11 vans and 11 tractors are considered. In their subsequent work, Brandão and Mercer (1998) adapt the algorithm to compare the results with those obtained by Taillard et al. (1996). A two phases TS is performed. In the first phase, a solution is allowed to become infeasible regarding travel time constraints, but in the second phase, only feasible solutions are accepted. Insert and swap moves are considered. Battarra, Monaci, and Vigo (2009) consider the MTVRPTW and different commodities that cannot be transported together. The objective is to minimize the number of used vehicles. The problem is decomposed in simpler subproblems, one for each commodity. A set of routes is then generated for each commodity and packed by means of a BP heuristic in order to obtain a solution. Data comes from real-world instances where goods are delivered to supermarkets placed in a regional territory. The concept of multi-trips is also addressed by Cornillier, Laporte, Boctor, and Renaud (2009) and Gribkovskaia, Gullberg, Hovden, and Wallace (2006). The former paper concerns the petrol distribution to gas stations, while the latter proposes a model for the livestock collection.

The idea of multi-trip is found in the context of city logistics as well. For example, Taniguchi and Shimamoto (2004) propose a model to evaluate the impact of advanced information system in urban areas and they assume that vehicles are allowed to perform multiple trips per day. Browne, Allen, and Leonardi (2011) present the case of supplies company operating in the City of London. From a micro-consolidation urban center, electrically assisted cargo tricycles and electric vans perform deliveries. Due to the small size of tricycles and electric vans, they perform several trips during each day.

3. A memetic algorithm for the MTVRP

Genetic algorithms (GA) are adaptive methods inspired from the natural evolution of biological organisms. An initial population of individuals (*chromosomes*) evolves through generations until satisfactory criteria of quality, a maximum number of iterations or time limits are reached. New individuals (*children*) are generated from individuals forming the current generation (*parents*) by means of genetic operators (*crossover* and *mutation*). The principles of genetic procedure were firstly formalized by Holland (1975) and have been successfully used in different contexts (Neri & Cotta, 2012). The papers of Prins (2004) and Vidal, Crainic, Gendreau,