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An improved immigration memetic algorithm for solving the heterogeneous fixed fleet vehicle routing problem

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ABSTRACT

This paper deals with the heterogeneous fixed fleet vehicle routing problem (HFFVRP) which is a generalization of the classical vehicle routing problem (VRP) in the sense that the fixed fleet of vehicles is assumed to be heterogeneous. The objective of HFFVRP is to find the best fleet composition and the collection of routes such that the total costs are minimized. To address this combinatorial optimization problem, we design and implement a hybrid heuristic model integrating a genetic algorithm, a local search mechanism and an immigration strategy. Several strategies for generating the initial population of the genetic algorithm in relation with six local search heuristics are considered. An important feature of the proposed approach refers to the immigration strategy used to ensure diversification by which the level of evolution for the new immigrant individuals increases along with the evolution of the population. The proposed algorithm is tested on a set of HFFVRP benchmark instances and the preliminary results point out that our approach is an attractive and appropriate method to explore the solution space of this complex problem leading to good solutions within reasonable computational times.

1. Introduction

Problems associated with determining optimal routes for vehicles from one or several depots to a set of locations/customers are known as Vehicle Routing Problems (VRPs) and have many practical applications in the field of distribution and logistics. A wide body of literature exists on the problem (for an extensive bibliography, see Laporte [9,10] and the book edited by Ball et al. [1]).

Given a set of vehicles, a set of locations containing the depot location and the distance between each pair of locations, the VRP consists in finding the minimum cost tour for each vehicle such that all locations are visited and each vehicle returns to the depot. Because of the VRP simplicity, most attractive to many researchers have been the variations of the VRP, built on the basic VRP with extra features such as:

- The Capacitated VRP [25] in which each vehicle has finite capacity and each location has a finite demand.
- The VRP with Time Windows [19] in which there is a specified temporal window of opportunity in which to visit each location.
- The VRP with Multiple Depots [3] generalizes the idea of a depot in such a way that there are several depots from which each customer can be served.
- The Heterogeneous Fixed Fleet VRP [22] in which we have a fleet of heterogeneous (different types) vehicles using the depot as a starting base.
- The Multi-Commodity VRP [18] in which each location has a demand for different commodities and each vehicle has a set of compartments in which only one commodity can be loaded. The problem then becomes that of deciding which commodities to place in which compartments in order to minimize distance traveled.
- The Generalized Vehicle Routing Problem (GVRP) [5,15] is the problem of designing optimal delivery or collection routes, subject to capacity restrictions, from a given depot to a number of predefined, mutually exclusive and exhaustive node-sets (clusters) with the property that exactly one node is visited from each cluster.

We are concerned in this paper with the heterogeneous fixed fleet vehicle routing problem (HFFVRP) introduced by Taillard [22]. The HFFVRP is an important variant of VRP, since usually the fleets are heterogeneous in most practical situations. Various heuristic and metaheuristic algorithms have been developed for solving the HFFVRP including an algorithm based on Tabu Search, adaptive

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memory and column generation described by Taillard [22], an algorithm that extends a number of VRP classical heuristics followed by a local search procedure based on the Steepest Descent Local Search and Tabu Search introduced by Prins [16], a threshold accepting procedure implemented by Tarantilis et al. [23] where a worse solution is only accepted if it is within a given threshold (the same authors [24] later presented another threshold accepting procedure to solve the same problem). Also, a record-to-record travel algorithm was proposed by Li et al. [11] and a multi-start adaptive memory procedure combined with Path Relinking and a modified Tabu Search was developed by Li et al. [12]. More recently, Brandao [2] proposed a Tabu Search algorithm for the HFFVRP which includes additional features such as strategic oscillation, shaking and frequency-based memory while Subramanian et al. [21] described a hybrid algorithm composed by an Iterated Local Search based heuristic and Set Partitioning formulation.

In this paper, we present an efficient memetic algorithm for solving the HFFVRP, obtained by combining an immigration-based genetic algorithm with a powerful local search procedure. The genetic algorithm is endorsed by an immigration strategy designed to ensure diversification of the genetic material by inserting new individuals (called immigrants) into the population every generation. The immigrants are not random but generated based on some heuristics allowing the evolution of immigrants along with the evolution of the main population. The initialization of population takes into account several strategies for inserting the route splitters leading to four different approaches tested. The strength of the local search mechanism integrated in the evolutionary process is ensured by six local search heuristics and their diversity. Computational experiments are performed for a set of HFFVRP benchmark instances and the results are presented, analyzed and compared with existing heuristic methods. The experimental results reveal that the solutions provided by the proposed memetic algorithm are of high quality and competent to those existing in the literature.

The rest of paper is structured as follows: the definition of the HFFVRP is presented in Section 2; the proposed memetic algorithm is described in Section 3 focusing on the general framework of the genetic algorithm (solution representation, fitness function, genetic search operators and strategies for population initialization), the immigration techniques integrated in the algorithm and the local search procedure; computational experiments and results are discussed in Section 4 and the conclusions of the study are depicted in Section 5.

2. Definition of the problem

Formally, the HFFVRP is defined on a directed graph $G=(V,A)$ with $V=\{0,1,2,\dots,n\}$ as the set of nodes, the set of arcs $A=\{(i,j)|i,j\in V, i\neq j\}$ and a nonnegative distance c_{ij} associated with each arc $(i,j)\in A$. The set of nodes consists of vertex $v=0$ which represents the depot and the vertices $v=1,\dots,n$ which represent the customers. Each customer has a certain non-negative amount of demand. There exists a fleet of heterogeneous (different types) vehicles that are using the depot as a starting base. We denote by v_t the variable cost per distance unit of a vehicle of type t and by Q_t its carrying capacity and we suppose that the number of vehicles of each type is fixed.

The HFFVRP consists in finding the minimum cost collection of routes starting and ending at the depot, such that a single vehicle supplies the demand of each customer and the sum of all the demands of any route does not exceed the capacity of the assigned vehicle to it.

An illustrative scheme of the HFFVRP and a feasible collection of routes is shown in Fig. 1.

The HFFVRP reduces to the classical Capacitated Vehicle Routing Problem (CVRP) when all the vehicles have the same capacity. As a consequence HFFVRP is *NP*-hard because it includes the Capacitated Vehicle Routing Problem as a special case.

3. An improved immigration memetic algorithm for solving the HFFVRP

Memetic algorithms have been introduced by Moscato [14] to denote a family of metaheuristic algorithms that use a population-based approach with separate individual learning or local improvement procedures for problem search. Therefore, a memetic algorithm is a genetic algorithm (GA) hybridized with a local search procedure to intensify the search.

Genetic algorithms are not well suited for fine-tuning structures which are close to optimal solutions. Therefore, incorporating local improvement operators into the recombination step of a GA is essential in order to obtain a competitive GA.

We propose an effective heuristic based algorithm for solving the HFFVRP which is an immigration memetic algorithm combining the power of genetic algorithms with that of local search and the immigration techniques. The general scheme of the proposed heuristic is depicted in Fig. 2.

As shown in the presented scheme, in order to improve a current generation we use an immigration technique (described in Section 3.2), a local search procedure (described in Section 3.3) and in addition we eliminate the duplicate solutions.

3.1. The genetic algorithm

We use a natural, compact and efficient encoding of solutions for HFFVRP similar to that described by [15] in the case of the GVRP. Specifically, 0 represents the depot and each customer is tagged with a non-duplicated natural number from 1 to n. We represent a chromosome by a variable length array so that the gene values correspond to the nodes selected to form the collection of routes which are delimited by 0 representing the depot.

The corresponding chromosome representation of the feasible solution of the HFFVRP presented in Fig. 1 is

(6 2 10 1 7 0 11 3 9 4 0 8 5 12),

where the values $\{1,\dots,12\}$ represent the customers while the depot denoted by 0 is the route splitter. Route 1 begins at the depot then visits customers 6–2–10–1–7 and returns to the depot. Route 2 starts at the depot and visits the customers 11–3–9–4 and finally, in route 3 are visited the customers 8–5–12.

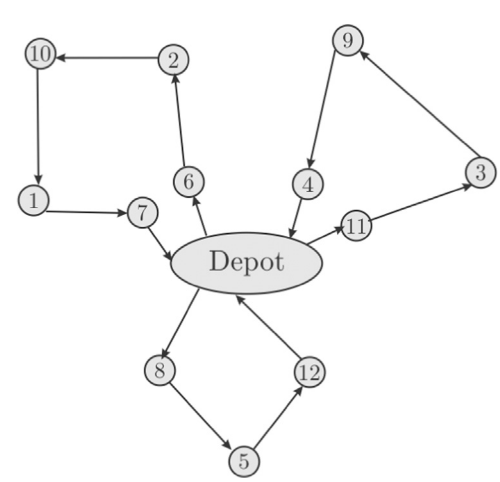

Fig. 1. An example of a feasible solution of the HFFVRP.