A Memetic Algorithm Solving the VRP, the CARP and General Routing Problems with Nodes, Edges and Arcs

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This research presents a memetic algorithm (MA) for solving a new vehicle routing problem that generalizes two classics, the VRP and the CARP. The *VRP* (*Vehicle Routing Problem*) is the main node routing problem, with important applications in distribution networks. It consists of building a set of vehicle trips of least total cost, to service a set of customers located on the nodes of an undirected network. The *CARP* (*Capacitated Arc Routing Problem*) is a similar problem, but in arc routing: the tasks to be performed by the vehicles consist of servicing some edges. Its applications include winter gritting and municipal waste collection.

Both problems are NP-hard but the best metaheuristics available obtain very good solutions in practice. Despite this success, it is clear that these two academic models are insufficient for many applications. Consider for instance urban waste collection. Although most tasks consist of servicing streets, the problem cannot be modeled as a pure CARP because of punctual accumulations of waste that must be modeled as required nodes, e.g., hospitals or schools.

Moreover, the undirected graph tackled by the VRP and the CARP can only model 2-way streets whose both sides are collected in parallel and in any direction (*zigzag* or *bilateral* collection, a practice reserved to low-traffic residential areas). In reality, a street can be a 2-way street with bilateral collection (giving an edge in the modeled network), a 2-way street with two sides collected independently (giving two opposite arcs), or even a 1-way street (giving one arc).

An extended model is introduced: the *NEARP* (*Node, Edge and Arc Routing Problem*). It is defined on a mixed graph with required nodes, edges and arcs and contains the VRP and the CARP as particular cases. A common data structure shared by all algorithms is proposed for coding NEARP instances. The first algorithms developed are three simple heuristics that are used to initialize the initial population of the MA. The third heuristic, a tour splitting method, plays also a key-role in chromosome evaluation.

A memetic algorithm for the NEARP is developed. It manipulates chromosomes corresponding to sequences of tasks, without trip delimiters, allowing adaptations of simple crossovers like OX or LOX. The tour splitting technique designed for the third heuristic is used to split the chromosomes into trips. We show that this splitting is optimal (subject to chromosome sequence) and that there exists at least one optimal chromosome.

To check if it is pertinent to use one common MA for the VRP and the CARP, the simple heuristics and the MA undergo a preliminary testing on 37 standard VRP and CARP benchmarks from the literature. The results show that the MA can compete with the best metaheuristics published for these two particular cases of the NEARP, even if one single setting of parameters is used. In particular, we know that a majority of CARP instances are solved to optimality, because some tight lower bounds are reached.

A random generator of NEARP instances is developed. It is intended to produce planar mixed graphs imitating the shape of real street networks. The generator is used for building 23 large-scale NEARP instances with 11 to 150 nodes, 29 to 311 links, 3 to 93 required nodes, 0 to 94 required tasks and 0 to 149 arc-tasks. The full paper describes these instances in more details and reports the solution values achieved by the three simple heuristics and by the MA.

Of course, no published algorithm is available for comparison on this new problem. However, since the MA retrieves many proven optima or best-known solutions when executed on VRP and CARP instances, we think its solutions are quasi-optimal for the NEARP and we invite other researchers interested in vehicle routing to try to find better solutions.

In spite of its encouraging results, more research is required on the MA, for instance to improve the running time (on average, 13 minutes on a 1 GHz PC for the NEARP instances). We have observed that the local search procedure called by the MA works well when the required links are predominant, but performs a slow descent with many small improvements on node routing problems. Clearly, better neighborhoods should be designed to accelerate the descent and decrease the overall running time.

Our work is one more example of the power and flexibility of memetic algorithms. It is a step towards more realistic and generic models in vehicle routing, that could lead to a new generation of optimization software in this domain of logistics.