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Overview Paper

Order-first split-second methods for vehicle routing problems: A review

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ABSTRACT

Cluster-first route-second methods like the sweep heuristic (Gillett and Miller, 1974) are well known in vehicle routing. They determine clusters of customers compatible with vehicle capacity and solve a traveling salesman problem for each cluster. The opposite approach, called route-first cluster-second, builds a giant tour covering all customers and splits it into feasible trips. Cited as a curiosity for a long time but lacking numerical evaluation, this technique has nevertheless led to successful metaheuristics for various vehicle routing problems in the last decade. As many implementations consider an ordering of customers instead of building a giant tour, we propose in this paper the more general name of ordering-first split-second methods. This article shows how this approach can be declined for different vehicle routing problems and reviews the associated literature, with more than 70 references.

1. Introduction

Vehicle routing problems are widespread in various activities like distribution, waste management, city logistics, meter reading, and inspection of power lines. Their study constitutes a very active research domain in which significant advances have been realized in the two last decades. A considerable number of variants have been studied to cope with various features and constraints, like hard time windows (Repoussis and Tarantilis, 2010), soft time windows (Figliozzi, 2010), dynamic allocation of swap containers (Huth and Mattfeld, 2009), configurable vehicle capacities (Qu and Bard, 2013), or stochastic demands (Bertazzi et al., 2013).

The solution techniques are also quite diversified, including for instance branch-and-cut algorithms (Bettinelli et al., 2011), metaheuristics like tabu search (Badeau et al., 1997) and even simulation (Juan et al., 2011). As most vehicle routing problems are computationally intractable, the current limit of exact algorithms is around one hundred customers and heuristic approaches are thus required for solving the much larger instances met in many industries.

Solving vehicle routing problems involves two kinds of decisions: partitioning the customers into clusters compatible with vehicle capacity and sequencing the customers in each cluster to get a route. A classical approach for constructive heuristics dedicated to the *capacitated vehicle routing problem* (CVRP) is based on the *cluster-first route-second* principle, in which the partition is determined first. A traveling salesman problem (TSP) is then solved for each cluster, exactly or heuristically. Two good examples are the sweep algorithm, commonly attributed to Gillett and Miller (1974), and the Fisher and Jaikumar (1981), where clusters are obtained solving a generalized assignment problem.

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In the same vein, Beasley (1983) introduced *route-first cluster-second* heuristics, in which the two phases are inverted: vehicle capacity is temporarily relaxed to compute a TSP tour covering all customers, often called *giant tour*, which is then decomposed into feasible vehicle routes. Fig. 1, in which a circle symbolizes a depot while a square indicates a customer to visit, illustrates both the cluster-first route-second and the route-first cluster-second concepts for a vehicle routing problem.

Some advantages stand out in the second approach. Some users may prefer the computation of a giant tour to a clustering algorithm in the first phase. Moreover, Beasley (1983) observed that the second phase can be solved exactly as a shortest path problem in an auxiliary graph, but without reporting numerical experiments. Despite this interesting property, almost twenty years later, Laporte and Semet (2002, p. 121) wrote in a survey on CVRP heuristics: "We are not aware of any computational experience showing that route-first, cluster-second heuristics are competitive with other approaches".

Since 2002, comments have changed. In fact, the route-first cluster-second approach has led in the last decade to successful constructive heuristics and metaheuristics for node routing problems like the CVRP, but also for arc routing problems like the *capacitated arc routing problem* (CARP), where a subset of arcs or edges must be serviced. The main reasons for this growing success are a smaller solution space for metaheuristics (they search the set of giant tours instead of the much larger set of CVRP solutions), flexibility (many additional constraints can be handled) and efficiency (state of the art metaheuristics based on this approach are now available for many vehicle routing problems).

The purpose of this paper is to recall the basic route-first cluster-second approach, to show how it can be implemented efficiently, to see how it can be used in constructive heuristics and metaheuristics, and to review the literature on the numerous extensions published after Beasley's seminal article, with more than 70 papers. As we shall see, the giant tour determined in the first phase is seldom used and some algorithms rather consider an ordering of customers or a priority list before building the routes. This is why we prefer to speak about *order-first split-second methods* in the title and in the sequel. Moreover, as the ordering can be obtained in a variety of ways like heuristics, crossovers and mutation operators, the article mainly focuses on the splitting phase.

The paper is organized as follows. Section 2 describes a general frame for using splitting procedures, beyond a simple usage in constructive heuristics, underlines its advantages and introduces a classification of related published papers. Sections 3–6 are dedicated to each proposed class, with known utilizations in constructive heuristics and metaheuristics. Section 3 defines some notations, recalls the two classical capacitated routing problems (CVRP and CARP) and provides an efficient implementation of the basic splitting procedure (called *Split*) for these problems and some variants. Section 4 is devoted to simple extensions of the basic *Split*, where the construction of the auxiliary graph is affected but not the shortest path computation. More complicated versions with a different shortest path algorithm must be applied are exposed in Section 5. Some cases requiring a more general auxiliary graph are described in Section 6. The main advantages and current limitations of the approach are recapitulated in Section 7, before concluding remarks in Section 8.

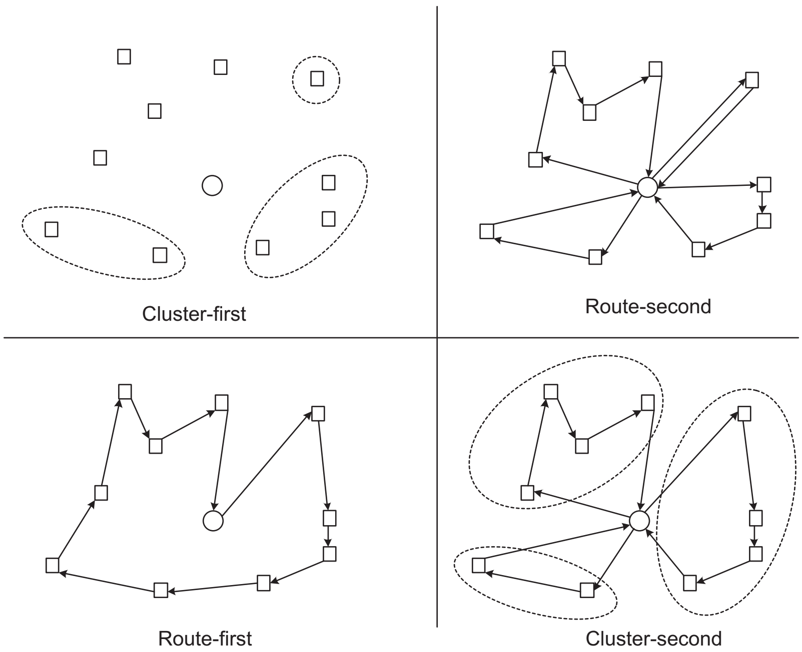

Fig. 1. Examples of two-phase procedures in vehicle routing.