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The vehicle routing problem: A book review

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Abstract. We review the recent book, edited by Paolo Toth and Daniele Vigo, *The Vehicle Routing Problem*, SIAM Monographs on Discrete Mathematics and Applications 2002, ISBN: 0-89871-498-2, price: 95 USD.

1 Introduction

In a short paper (Dantzig and Ramser 1959) published in Management Science in October 1959 Dantzig and Ramser wrote:

> *This paper is concerned with the optimum routing of a fleet of gasoline delivery trucks between a bulk terminal and a large number of service stations supplied by the terminal (omissis). A procedure based on a linear programming formulation is given for obtaining a near optimal solution.*

This is the first paper on the Vehicle Routing Problem. A few years later (1964) Clarke and Wright proposed an effective greedy heuristic that improved on the Dantzig-Ramser approach (Clarke and Wright 1964). Since these two seminal papers hundreds of models and algorithms have been proposed for solving optimally or approximately various versions of the VRP. Vehicle Routing Problems (VRPs) are among the most important Combinatorial Optimisation problems, because of their difficulty as well as because of their practical relevance. Indeed they not only model the problems of collection and delivery of goods, but, more generally, appear as a key ingredient in many transportation systems, such as those for solid waste collection, street cleaning, bus routing, dial-a-ride systems, routing of maintenance units, transports for handicapped. Another area in which very similar problems play a relevant role is modern telecommunication networks, even if here we find "routing" and not "vehicle routing" problems. Many commercially available software packages exist. Exact algorithms are in general able to handle up to about 50 customers whereas effective heuristics are needed for larger instances.

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For the sake of simplicity let us concentrate on the classical distribution of goods problem. We are then concerned, in a given time period, with a set of customers to be served with a set of vehicles, located in one or more depots, operated by drivers, using an appropriate road network. The solution requires determining a set of routes, one for each vehicle starting and finishing at its depot, so that all requirements of the customers are fulfilled, all operational constraints are satisfied, and the transportation cost is minimised.

The road network is described trough a graph G (directed, undirected or mixed). Each arc of G is associated with a cost (often proportional to the length of the corresponding route) and a travel time, which may depend on the type of vehicle and/or on the travelling period. Each customer is characterised by (a subset of) the following connotations: the vertex of G in which it is located, the amount of goods (demand) it requires, the period of the day (time window) it wants to be served, the time required for the service (loading or unloading times), and the subset of the set of available vehicles suitable for serving it. Typical characteristics of the vehicles are: its home depot (to which it must return or not), its capacity (expressed in various ways, such as maximum weight or volume, number of pallets, etc.), the subset of arcs of G which can be traversed by that vehicle, and the costs associated to its utilisation.

The book edited by Toth and Vigo aims at covering the state-of-the-art in both exact and heuristic algorithms for VRPs.

The two editors are among the leading experts in this field and they write indeed three out of the 14 chapters of the book. They have secured the contribution of a formidable group of colleagues in order to take care of the other parts of the book: virtually every author is well known in the scientific community for his/her contributions in the field.

2 Contents

The book is divided in three parts preceded by an introductory overview. The first part surveys with its 5 chapters exact and heuristic approaches to the classical Capacitated VRP. In the overview constituting the first chapter, Toth and Vigo review the basic notation, definitions and models of VRPs. In the second chapter they address Branch-and-Bound (B&B) algorithms for the Capacitated VRP. Branch-and-Cut (B&C) approaches to this problem are the topic of the third chapter by Naddef and Rinaldi. B&B is still the most successful approach to solve VRPs exactly. As pointed out at the end of third chapter, the use of B&C to solve these problems is still in its infancy. A better understanding of the underlying polytope is needed together with better separation routines. This field of research is very active around the world, exploring also the possibility that other formulations could provide different polytopes thus opening new views on the polyhedral characterisation of the Capacitated VRP and its variants. Simchi-Levi and Bramel survey in the fourth chapter the set-covering-based approaches. These are characterised by

strong LP lower bounds, but also by heavier computational requirements. In a very interesting last section the two authors analyse the reasons for this behaviour of the set-covering formulation.

Classical heuristics are presented by Laporte and Semet in the fifth chapter, whereas metaheuristics for the Capacitated VRP are the subject of the sixth chapter by Gendreau, Laporte and Potvin. The famous saving heuristic for the VRP appeared more than 35 years ago. A comparison of the many classical heuristics proposed since then is difficult, especially because of too many unknown implementation features. It is now clear however that, in terms of solution quality, classical heuristics based on simple construction and a subsequent descent improvement phase do not compete with, say, some of the best Tabu Search methods. Because of this fact, even considering that one of the strengths of classical heuristics is their ease of adaptation to variants of the Capacitated VRP, Laporte and Semet express the view that little room is left for improvement in the area of classical heuristics. Even if Tabu Search as of now emerges as the most effective metaheuristic for the Capacitated VRP, the potentiality of Genetic Algorithms or Ant Systems (or, more recently, ACO, Ant Colony Optimisation (Dorigo and Di Caro 1999) is not yet fully explored, particularly when combined with an effective Local Search phase. Metaheuristics are however much more time consuming than classical heuristics and existing benchmarking instances do not allow to test what happens when really large problem instances have to be solved. The development of simpler methods capable of quickly providing good quality solutions is badly needed: the Granular Tabu Search algorithm suggested by Toth and Vigo is an important step in this direction (Toth and Vigo 2003).

The second part of the book addresses the most important variants of the VRP: VRP with Time Windows (VRPTW) (chapter 7 by Cordeau et al.), VRP with Backhauls (VRPB) (chapter 8 by Toth and Vigo), and VRP with Pick-up and Delivery (VRPPD) (chapter 9 by Desaulniers et al.). In VRPTW the success of both exact as well as approximate methods suggests that hybrid methods could be an important area in which we can expect further progress. VRPTW is important also because it constitutes the backbone of more complex models for applications such as fleet-planning, crew-scheduling, and crew-rostering problems. In VRPB problems the customer set is partitioned into two subsets, the first requiring goods to be delivered, the second requiring that goods be picked up: this is a very frequent situation in practice. The chapter on VRPB surveys exact as well as heuristic approaches for this very important variant. As far as VRPPD problems are concerned, perhaps because of the fact that most practical instances are of high dimensionality, more sophisticated heuristics do not perform as satisfactory as for other variants. Much remains to be done also as far as exact algorithms are concerned, in particular exploiting the special structure of the problem. Moreover a satisfactory benchmark problem set, such as that available for VRPTW, has not yet been developed for VRPPD, probably because of the multitude of variants considered in the literature. Recent

telecommunication progresses (e.g. real-time information through satellites) also suggest interesting new variants, for instance including vehicle diversion.

The third part presents some large-scale applications and case studies. VRPs for industries in solid waste, beverage, food, dairy (by Golden et al.) are dealt with in chapter 10. The experience of the city of Philadelphia, where vehicles have to consider site dependencies in the network is reported in chapter 11 (by Sniezek et al.). Chapter 12 (by Campbell et al.) is devoted to inventory routing. Chapter 13 (by Hadjiconstantinou and Roberts) addresses routing problems under uncertainty. The last chapter is by Baker and is devoted to the evolution of microcomputer-based software for VRPs. The power and speed of microcomputers have increased dramatically in recent years: VRP packages of today can be used to optimise the entire logistic supply chain from purchase of materials, through manufacturing, to the final delivery of the product to customers. However their cost has increased substantially and can arrive at hundreds of thousands of dollars.

Each chapter is provided with an up-to-date list of references and a comprehensive analytical index can be found at the end of the book.

3 Conclusions

This book is more than welcome: it presents, in fact, from the perspective of VRPs, a complete overview of the effective use of the most important techniques proposed up to date to cope with hard Combinatorial Optimisation problems. It does so in depth and with a lucid style, which makes most chapters a pleasure to read. Indeed the first two parts of this text would be perfectly suited for a course on VRPs. I found the third part less coherent, even if this had to be expected. The only serious complain is the lack of an overview of available software packages: the last chapter in fact presents only microcomputer-based VRP software. Another minor criticism is the absence of consideration of robustness: it is expected that the future will see more attention given to this, comparatively recent, criterion of optimality (Kouvelis and Yu 1996).

With this book the SIAM Monographs on Discrete Mathematics and Applications series adds another very valuable text to its small but already extremely interesting list. I think we must be grateful to Editor-in-Chief Peter Hammer and to Editors Toth and Vigo and their collaborators for having provided another valuable teaching and research tool for the CO community.

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