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METAHEURISTICS SET

Volume 3

Metaheuristics for Vehicle Routing Problems

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Metaheuristics for Vehicle Routing Problems

Notations and Abbreviations

Here is a non-exhaustive list of the most common notations and abbreviations used in the book.

Notations

A : set of arcs.

c_{ij} : traveling cost between nodes i and j.

d_i : demand of customer i.

E : set of edges.

$f(S)$: cost of solution S.

G : a complete graph.

K : set of identical vehicles.

n : number of customers.

$N(S)$: subset of solutions close to S in term of structure (neighborhood).

Q : vehicles capacity.

R_i : route i.

S : a solution.

T : tour or sequence of customers.

V : set of nodes.

Abbreviations related to problems

CARP : capacitated arc routing problem.

CCVRP : cumulative capacitated vehicle routing problem.

CVRP : capacitated vehicle routing problem.

DARP : dial-a-ride problem.

HFVRP : heterogeneous fleet vehicle routing problem.

IRP : inventory routing problem.

LRP : location-routing problem.

LRP-2E : two-echelon location-routing problem.

MDVRP : multi-depot vehicle routing problem.

OVRP : open vehicle routing problem.

PCARP : periodic capacitated arc routing problem.

PDPTW : pick up and delivery vehicle routing problem with time windows.

PVRP : periodic vehicle routing problem.

RCPSP : resource-constrained project scheduling problem.

SCP : set covering problem.

SPP : set partitioning problem.

SDVRP : vehicle routing problem with split deliveries.

TOP : team orienteering problem.

TSP : traveling salesman problem.

TTRP : truck and trailer routing problem.

VRP-2E : two-echelon vehicle routing problem.

VRPs : family of vehicle routing problems.

VRPTW : vehicle routing problem with time windows.

Abbreviations related to methods

ACO : ant colony optimization.

ALNS : adaptive large neighborhood search.

ELS : evolutionary local search.

GA : genetic algorithm.

GLS : guided local search.

GRASP : greedy randomized adaptive search procedure

GTS : granular tabu search (also guided tabu search).

HGSADC : hybrid genetic search with adaptive diversity control.

ILS : iterated local search.

LNS : large neighborhood search

LS : local search.

MA : memetic algorithm.

MA|PM : memetic algorithm with population management.

PSO : particle swarm optimization.

PR : path relinking.

RVNS : reduced variable neighborhood search.

SA : simulated annealing.

SS : scatter search.

TS : tabu search.

VND : variable neighborhood descent.

VNS : variable neighborhood search.

VLSN : very large scale neighborhood search.

Introduction

Unlike heuristics, which are problem-dependent techniques which try to take full advantage of the features of the problem at hand but which usually get trapped in a local optimum when followed by a local search, metaheuristics can be defined as solution methods that control the exploration of a solution space by problem-independent techniques with higher level strategies. This allows them to explore the solution space more extensively with the aim of escaping from local optima and thus a hopefully obtain a better solution. These approaches include any scheme that resorts, for example, to one or more neighborhood structures, building or destroying procedures or combining components of several solutions. Notwithstanding their general structure, it is necessary to adapt the techniques according to the problem to solve by some fine-tuning of their intrinsic parameters. Metaheuristic methods have proved to be particularly effective for solving many types of complex problems.

This book is dedicated to these methods developed to one of the most important and studied categories of combinatorial optimization problems: the family of vehicle routing problems (VRPs). The aim of the basic version also called capacitated VRP (CVRP) is to determine the optimal set of routes to be performed by a fleet of capacitated vehicles to serve the demand of a given customer set.

More than 15 years have elapsed since Dantzig and Ramser introduced the problem in 1959 [DAN 59], and the number of models and solution methods has experienced a strong growth as exposed in [LAP 09]. Although the CVRP still attracts researchers, many variants are now investigated. This interest is motivated by two main concerns:

– this class of problems has a high practical relevance;

– it is challenging to solve given its considerable difficulty.

Despite the abundant activity on VRPs, the current exact methods are limited to problems of about 100 customers [BAL 08a], while real cases can reach 1,000 clients.

Therefore, a large number of metaheuristics have been proposed to solve very different problems of vehicle routing, as stated by the surveys periodically published on the subject. From procedures with tabu to hybrid approaches combining heuristic and exact methods, metaheuristics remain the favorite methods for dealing with realistic cases.

Several books are available on either metaheuristics [DRÉ 03, SIA 14] or VRPs [TOT 02] but, to the best of our knowledge, the only books addressing these two topics simultaneously are published PhD dissertations [EUC 12] or books with contributed chapters [GOL 08]. The aim here is more to provide a book for people wishing to discover and quickly master metaheuristics dedicated to VRPs. The particularity is to combine a tutorial with algorithms, examples, and a quick overview of the state-of-the art for such methods developed in the last decades for the CVRP and some of its main variants.

The key points are to present:

– a progressive approach, from the basics to several recent and efficient methods;

– different metaheuristics for the same VRP and, conversely, the way of adapting the same metaheuristic template to several problems;

– algorithms allowing the readers to implement the methods on a computer;

– an up-to-date bibliography focusing on the references which have a real interest.

The book consists of five chapters. After this introduction, the first chapter gives a general presentation that intends to make the readers more familiar with the related fields of logistics and combinatorial optimization.

This preamble is followed, in Chapter 2, with a description of significant heuristic methods classically applied to provide feasible solutions quickly, and local improvement moves widely used to search for enhanced solutions. The overview of these fundamentals allows appreciating the core of the work devoted to an analysis of metaheuristic methods for VRPs. Those methods are exposed according to their feature of working either on a sequence of single solutions, or on a set of solutions, or even by hybridizing metaheuristic approaches with other kinds of methods (mixed integer programs, mathematical decompositions, etc.).

Thus, Chapter 3 begins with the class that works on a single solution at a time, making it evolve through a particular iterative process. This kind of exploration requires us to define at least one neighborhood to jump from an incumbent solution to another area of the solution space. Eight approaches are presented in this chapter, namely simulated annealing, greedy adaptive search procedure, tabu search, variable neighborhood search, iterated local search, guided local search, adaptive large neighborhood search and transitional forms such as evolutionary local search.

Chapter 4 exposes methods operating on a set of solutions. Their feature is to generate new solutions by either combining existing ones or by making agents cooperate through a learning process. Two main variants are put forward: those that combine solutions selected from a population such as genetic algorithms, memetic algorithms, scatter search and path relinking; the ones that make cooperate homogenous agents in their environment such as particle swarm optimization and ant colony optimization.

Chapter 5 is devoted to two main classes of hybrid methods: either by combining components from several stand alone metaheuristics, or by crossing exact algorithms with metaheuristics (leading to the so called matheuristics). The main motivation of this trend is to take advantage of the complementarity of different optimization strategies and cooperate in synergy.

Finally, the Conclusion closes the book and draws up some perspectives of the research on VRPs. In the three chapters detailing the different class of metaheuristics, several selected implementations of methods dedicated to typical VRPs are given as illustrative examples.

Contents

1

General Presentation of Vehicle Routing Problems

Vehicle routing problems (VRPs) represent an important family of problems encountered in the fields of logistics, as well as in many other applications. In general, a number of customers have to be served with a fleet of vehicles. They can be modeled as an integer programming problem, solved by combinatorial optimization tools. However, exact methods cannot solve instances that consider a large set of customers, as encountered in most real cases. It is, therefore, often necessary to resort to approximate paradigms generally carried out through metaheuristics.

This first chapter introduces what the logistics management and the combinatorial optimization are, before giving a formal definition of the CVRP, with notations useful throughout the remainder of the book.

1.1. Logistics management and combinatorial optimization

In the last few decades, a great interest has grown up in the area of logistics among both industry and academia, for different reasons [BRA 98]. First, companies are facing fierce competition in today's global markets. They need to innovate to keep their position, and they realize the savings that can be achieved by a better planning and management of their logistic systems.

Furthermore, the evolution of lifestyles is significant. Modes of consumption are changing and expectations of consumers switch to products with short lifecycles, and the advancement in communications and transportation technologies, such as mobile communication and overnight delivery, motivates continuous development of the management of logistic systems.

These changes attract attention of the academic community, whose approach consists of determining characteristics of the problems and developing solution methodologies, as well as providing specific guarantees of effectiveness.

1.1.1. *History of logistics*

Logistics is not a recent trend in managing the flow of goods from an origin to a destination, with the aim to meet some requirements. Logistics made an important stride during the construction of the pyramids in ancient Egypt, for example. It played a key role in global sea trade with the invention of rowing vessels around 300 B.C. Logistics was also one of the main factors for the victory of most wars throughout history.

In military context, logistics is responsible for supplying the troops. It deals with the inventory management and transportation. However, this type of requirement also predominates in carriers and wholesalers activities. Thus, it is natural that modern logistics appears in industry.

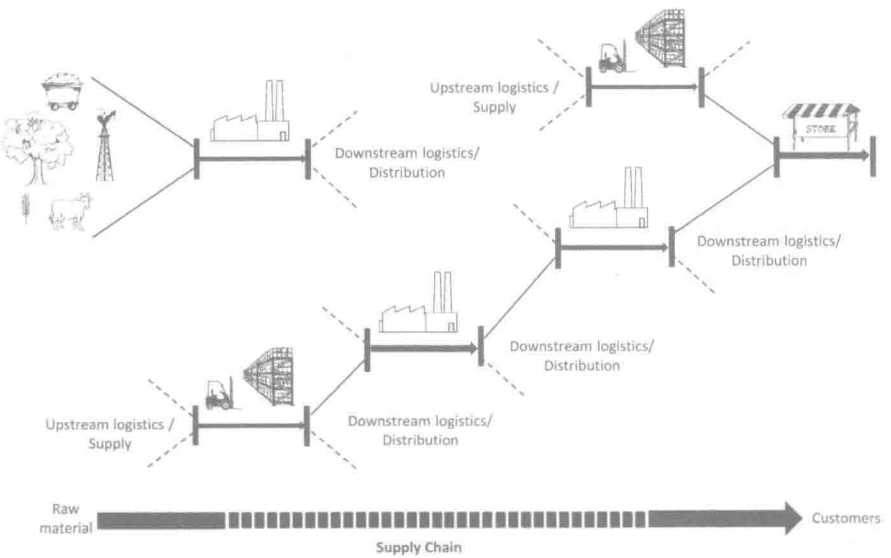

Figure 1.1. *Example of a supply chain*

Nowadays, the function extends from production to distribution, leading to the supply chain (Figure 1.1). In this chain, upstream activities take place prior to a particular link, when the latter orders for material to suppliers in the aim to bring its

added value. On the contrary, downstream activities involve the sale of a material to other businesses, governments or private individuals. The extreme link in the upstream part usually concerns raw materials, while the extreme downstream link is related to the final customer. However, each other link in the midstream is both customer of predecessor actors and supplier of successors. Midstream can be a manufacturer, a cooperative warehouse, a regional consolidation center, a city hub, local depot, etc.

Most of the freight transport in the chain is carried in containers, although bulk transport is used more for large volumes of durable goods. The reason is that this option is often the most efficient and cost-effective way to supply the products. However, for the smaller quantities generally required at the final destination, the supply chain is often less efficient. This characteristic is known as the "last mile problem", which can represent up to 28% of the total cost to move goods. In addition, if transport plays an important role in economic growth and globalization, it causes air pollution and a large amount of traffic. Hence, a good transport planning is essential to control the costs, as well as the flow and limit nuisances.

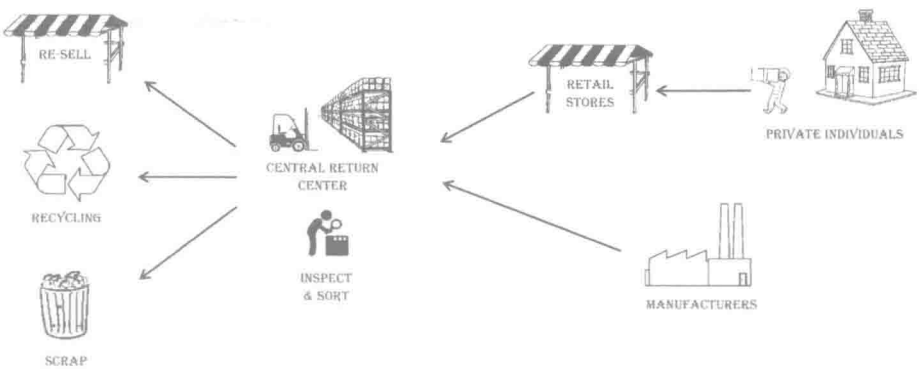

Figure 1.2. *Possible outline of a reverse logistics chain*

In an even more global view, the network also integrates reverse flows. These cover all operations related to the recycling of products and materials thrown away by the public or by industries (obsolete products, mixed waste and even hazardous). The so-called *reverse logistics* brings together the movements of products from consumers to producers through a distribution chain (Figure 1.2). The growing concern for integrating environmental requirements into green supply chain management concepts and practices makes it even more relevant. The reverse logistics process refers to activities undertaken to reduce, manage and dispose of waste from industrial activities. It meets the need to decommission the products after use and treat the destruction, by transforming or recycling in order to reduce costs,

and valuing the recovered products. Several related activities, therefore, involve: collecting waste, the location of recycling points/storage, inventory management and integration of products from the collection at the related industries. It also includes the optimization of the Ecodesign to facilitate future recycling.

Other issues have arisen recently about *city logistics* which are obviously related to the last mile problem described before. In fact, the freight distribution in urban area has to deal with several aspects. First, traffic may be difficult because of congestion at some rush hours, which makes the travel time dependent on the time of the day. Another particularity is the accessibility constraint. It might be quite complicated to deliver the goods in some areas because of the lack of parking for example, or because of city restrictions on the use of trucks in favor to smaller vehicles. In the same vein, economic and environmental problem concerns might lead to choose alternative types of transport for urban freight distribution (such as electric vehicles), as well as to adopt new commercialization behaviors. For example, the growth of e-commerce brings new questions and some retail companies have studied the use of drones to deliver online purchased goods to consumers.

Hence, many activities are involved in the supply chain, from the network design, to logistics of transportation, passing through warehouse management, international commerce or information systems. Transportation is one of the main parts of logistics. It can be made through several modes such as air, rail, road, water, cable, pipeline and space and may require particular infrastructures (Figure 1.3). These include links in the network (roads, railways, canals or pipelines, for instance) and terminals such as airports, railway stations, warehouses and depots. A wide range of issues emerges in this context, sweeping topics as diverse as the routing, inventory, cross-docking or network structure.

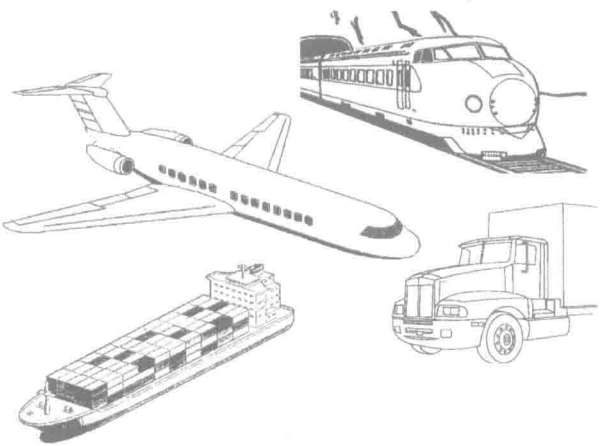

Figure 1.3. *Example of transportation modes*