Ant colony optimization for real-world vehicle routing problems
From theory to applications

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Abstract Ant colony optimization (ACO) is a metaheuristic for combinatorial optimization problems. In this paper we report on its successful application to the vehicle routing problem (VRP). First, we introduce the VRP and some of its variants, such as the VRP with time windows, the time dependent VRP, the VRP with pickup and delivery, and the dynamic VRP. These variants have been formulated in order to bring the VRP closer to the kind of situations encountered in the real-world.

Then, we introduce the basic principles of ant colony optimization, and we briefly present its application to the solution of the VRP and of its variants.

Last, we discuss the applications of ACO to a number of real-world problems: a VRP with time windows for a major supermarket chain in Switzerland; a VRP with pickup and delivery for a leading distribution company in Italy; a time dependent VRP for freight distribution in the city of Padua, Italy, where the travel times depend on the time of the day; and an on-line VRP in the city of Lugano, Switzerland, where customers’ orders arrive during the delivery process.

Keywords Ant colony optimization · Ant colony system · Vehicle routing problem · Dynamic VRP · Rich VRP · Real-world VRP

1 Introduction

The vehicle routing problem (VRP) concerns the transport of items between depots and customers by means of a fleet of vehicles. Examples of VRPs are: milk delivery, mail delivery, school bus routing, solid waste collection, heating oil distribution, parcel pick-up and delivery, dial-a-ride systems, and many others. Although finding the most cost efficient
way to distribute goods across the logistic network is the main objective of supply-chain systems, only in the early '90s enterprise resource planning software vendors started to integrate tools to solve the VRP in supply chain management software (a review of software for supply chain management can be found in Aksoy and Derbez 2003).

The practical interest of the VRP has spawn a number of studies, which tackled the problem from many sides. Yet, the VRP is combinatorially complex and, therefore, as the size of the problem increases, it becomes harder and harder to obtain an exact solution for it in a reasonable amount of time. Thus, even the most advanced exact solution methods impose particular constraints on the problem instance, which are often violated when dealing with real-world vehicle routing problems, leaving practitioners unsatisfied with the performance and applicability of the algorithms.

Given the shortcomings of exact solution methods, researchers in the field of operations research (OR) started to develop metaheuristics (Blum and Roli 2003), heuristic methods that can be applied to a wide class of problems. One of the advantages metaheuristics have over traditional optimization algorithms is their ability to produce a good suboptimal solution in short time. The integration of optimization algorithms based on metaheuristics, such as tabu search (Glover and Laguna 1997), simulated annealing (Kirkpatrick et al. 1983), ant colony optimization (Dorigo et al. 1996, 1999), and iterated local search (Lourenço et al. 2003), with advanced logistic systems for supply chain management opens new perspectives for operations research applications in industry. In particular, for the solution of VRP and its variants, a number of metaheuristics have been successfully applied, such as: simulated annealing (Osman 1993), tabu search (Gendreau et al. 1994; Taillard et al. 1997), granular tabu search (Toth and Vigo 2003), genetic algorithms (Van Breedam 1996), guided local search (Kilby et al. 1999), variable neighborhood search (Bräysy 2003), greedy randomized adaptive search procedure (Resende and Ribeiro 2003), and ant colony optimization (Gambardella 1999; Reimann et al. 2003).

In this paper we focus on ant colony optimization (ACO) (Dorigo and Stützle 2004), a metaheuristic inspired by the foraging behavior of ant colonies. ACO has been used for the approximate solution of a number of traditional OR problems, among which the job shop scheduling problem, the quadratic assignment problem, the sequential ordering problem, the graph coloring problem, and the shortest common supersequence problem (Dorigo and Stützle 2004). More recently, ACO has been employed in a number of open shop scheduling problems (Blum 2005), in optimal product design (Albritton and McMullen 2007), and has also been used in some environmental problems, such as the design of a water distribution network (Zecchin et al. 2007) or the planning of wells for groundwater quality monitoring (Li and Chan Hilton 2007), thus proving its adaptability to very different domains of application.

The flexibility of the ACO metaheuristic allowed its application to many vehicle routing problems where heterogeneous vehicle fleets, limitations on customer accessibility, time windows, and the order imposed by pick-ups and deliveries considerably complicate the problem formulation. These kinds of problems have been labeled as rich vehicle routing problems (Hartl et al. 2006). Yet, real-world problems are even more complex; for instance, travel times may be uncertain and may depend on traffic conditions, and not all customers’ orders may be perfectly known in time and dimension. These problem variants have been called dynamic VRP and they are currently attracting a lot of research efforts, because of their closeness to real-world traffic and distribution models (Zeimpekis et al. 2007). The objective of this paper is to describe how ant colony optimization can be successfully used to solve a number of VRP variants, both for some of the basic problem instances (the capacitated VRP, the VRP with time windows, the VRP with pickup and delivery) and for some