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Heuristic algorithms for the vehicle routing problem with simultaneous pick-up and delivery

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Abstract

The vehicle routing problem with simultaneous pick-up and delivery is the problem of optimally integrating goods distribution and waste collection, when no precedence constraints are imposed on the order in which the operations must be performed. The purpose of this paper is to present heuristic algorithms to solve this problem approximately in a small amount of computing time. We present and compare constructive algorithms, local search algorithms and tabu search algorithms, reporting on our computational experience with all of them. In particular we address the issue of applying the tabu search paradigm to algorithms based on complex and variable neighborhoods. For this purpose we combine arc-exchange-based and node-exchange-based neighborhoods, employing different and interacting tabu lists. All the algorithms presented in this paper are applicable to problems in which each customer may have either a pick-up demand or a delivery demand as well as to problems in which each customer may require both kinds of operation.

Keywords: Vehicle routing; Distribution logistics; Heuristics

1. Introduction

Reverse distribution logistics aims at the optimization of the delivery of goods from warehouses to customers and the simultaneous collection of waste or used products from customers to warehouses or specialized recycling sites. In this framework classical routing problems such as the traveling salesman problem (TSP) and the vehicle routing problem (VRP) must be revisited taking into account simultane-

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ously both goods delivery and waste collection. For a recent review the reader is referred to the survey paper by Toth and Vigo [1].

The VRP with simultaneous pick-up and delivery (VRPSPD) is the following problem: a set of customers is located on a transportation network; each customer i requires either a delivery or a pick-up operation (or both) of a certain amount of goods (d_i) or waste (p_i) and must be visited once for both operations. The service is provided by a set of vehicles of limited capacity Q; each vehicle leaves the depot carrying an amount of goods equal to the total amount it must deliver and returns to the depot carrying an amount of waste equal to the total amount it picked-up. In each point along its tour each vehicle cannot carry a total load greater than its capacity. The goal is to minimize the overall length of the tours.

The O.R. literature is rather poor of contributions on this problem: Casco et al. [2] defined the problem and examined some basic constructive algorithms, based on the classical concept of savings introduced by Clark and Wright [3]. Mosheiov [4] considered the problem with divisible demands, in which each customer can be served by more than one vehicle; he presented greedy constructive algorithms based on tour partitioning. A related problem is the VRP with backhauls (VRPB), that is the problem in which each vehicle can both deliver goods and collect waste but it must complete all deliveries before starting to collect. Approximation algorithms have been developed by Goetschalckx and Jacobs–Blecha [5] and by Toth and Vigo [6], while optimization algorithms have been developed by Toth and Vigo [7] and Mingozzi et al. [8]. More recently Wade and Salhi [9] developed an insertion algorithm for a particular version of the VRPB, in which pick-up and delivery operations can be partially mixed, that is collections may start as soon as a given fraction of deliveries has been carried out. All these papers considered the case in which each customer has either pick-up demand or delivery demand ("simple demands" in the remainder). Dethloff [10] took into account the situation in which each customer can require both kinds of operations ("composite demands" in the remainder) and studied some parameterized constructive algorithms.

In this paper we propose several kinds of heuristic algorithms for the VRPSPD with indivisible demands, mixed pick-ups and deliveries and both simple and composite demands. We are aware that in many practical applications the primary objective is the minimization of the number of vehicles, especially if it represents the actual number of drivers to employ. In such case the overall distance travelled must be minimized after the minimum number of required vehicles has been computed. On the other hand both fleet and distance minimization can be pursued at the same time, following for instance the heuristic approach of Casco et al. [2]: a typical method consists of adding a penalty term (radial surcharge) to the cost of the arcs incident to the depot. The algorithms examined in this paper, like those illustrated by Golden et al. [11], Casco et al. [2], Mosheiov [4] and Dethloff [10], do not explicitely consider the minimization of the number of vehicles as an objective; anyway our local search and tabu search algorithms can easily take into account radial surcharges and moreover they never increase the number of vehicles of the solution they are initialized with. Constructive algorithms based on tour partitioning illustrated in the remainder are polynomial-time greedy algorithms and they do not guarantee to partition the tour into a given number of subtours; the problem of finding a feasible solution to the VRPSPD with a prescribed number of vehicles is NP-hard, since it is a generalization of the generalized assignment problem, and therefore it cannot be solved by polynomial-time algorithms unless $P = NP$. Therefore the constructive algorithms outlined hereafter can be used to model the situation in which a same vehicle must perform a set of routes; on the contrary, if the fleet must be sized in an optimal way it may be more appropriate to use bin packing algorithms to compute an initial solution with a minimal number of vehicles as a starting point for local search and tabu search. Though the number of vehicles obtained in