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Matheuristic for a two-echelon capacitated vehicle routing problem with environmental considerations in city logistics service

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ABSTRACT

This paper addresses a two-echelon capacitated vehicle routing problem (2E-CVRP) with environmental considerations (2E-CVRP-E). A new arc-and-route-based mathematical model is constructed to formulate the problem in which the sum of drivers' wage, fuel cost, and handling cost is minimized. A matheuristic based on variable neighborhood search (VNS) and integer programming is designed to solve the 2E-CVRP-E. The integer programming in the matheuristic is used as a post-optimization technique to find better solutions missed by the VNS algorithm or to construct the least-cost first-level routes. To validate its effectiveness, the matheuristic first performs tests on 2E-CVRP instances and improves 13 current best-known solutions out of 234 instances. Then it performs tests on the 2E-CVRP-E instances modified from the 2E-CVRP. For 2E-CVRP-E instances, the total cost of the best solution found by the matheuristic is smaller than that of the best-known 2E-CVRP solution with an average relative gap of 6.37%. Computational results prove that the proposed matheuristic can find high-quality solutions for the 2E-CVRP and the 2E-CVRP-E.

1. Introduction

With industrial development and urbanization, air pollution in cities becomes increasingly serious in recent years. For example, in January 2013, China was shrouded by a large-scale lasting fog and haze covering Beijing, Shanghai, Guangzhou, and Xi'an (Cai and He, 2016). A growing number of people and governments have realized the importance and necessity of environmental protection. As motor vehicle emission is one of the main causes of fog haze weather in cities, city managers introduce legal restrictions that prevent large vehicles with heavy loads from entering urban areas. With these restrictions in place, in the express logistics industry, large vehicles are used to transport freight from the depot located on the outskirts of the city to the intermediate facilities or satellites in the vicinity of customers, and small vehicles are used to transport freight from satellites to customers, thereby forming a two-level distribution system. Moreover, to reduce air pollution and ensure environment-friendly transportation, the fuel consumption and emission of vehicles should be explicitly considered in routing decisions. Thus, this paper addresses a two-echelon capacitated vehicle routing problem (2E-CVRP) with environmental considerations (2E-CVRP-E).

The 2E-CVRP arises in a distribution system in which the freight from the depot to customers must go through one of the satellites. Direct shipments from the depot to customers are forbidden in this setting. Two levels of routing decisions should be simultaneously considered in the problem. As described in Fig. 1, the first-level routing decision determines a set of routes that start from and end at

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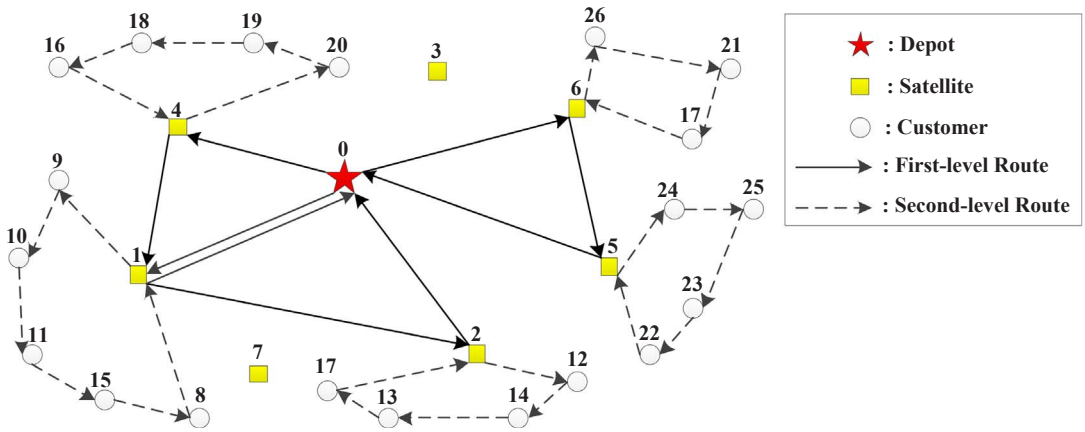

Fig. 1. Illustration of a two-level distribution system.

the depot while visiting the satellites that are the origins and destinations of the second-level routes; the second-level routing decision generates a set of routes that start from and end at the same satellite while visiting the assigned customers. A satellite is allowed to be visited by more than one first-level vehicle, and a customer is required to be serviced exactly once by one second-level vehicle, i.e., split deliveries are allowed at the first level but not at the second level. In addition to the total travel cost of first- and second-level routes, the handling cost proportional to the freight quantity shipped through the satellites is incurred. Therefore, the 2E-CVRP aims to find two sets of first- and second-level routes with the minimum sum of travel cost and handling cost while satisfying the given constraints. Moreover, if the handling cost per unit of freight is different for satellites, the total handling cost has influence on the delivery routes; otherwise, the total handling cost is a constant which can be ignored in the objective function.

In practice, carbon dioxide equivalent (CO_{2e}) emissions are crucial considerations for city managers in building an environment-friendly society. The total amount of CO_{2e} emissions is proportional to the amount of fuel consumed (Franceschetti et al., 2013). Therefore, in order to respond to the call to environmental protection, express logistics companies should reduce the amount of fuel consumed during transportation. The travel speed of vehicle and the load on vehicle mainly determine the fuel consumption and emission (Soysal et al., 2015). The former changes depending on the traffic density at a given time and location; the latter is associated with the visiting sequence of customers. Hence, incorporating such environmental considerations into the objective function complicates the 2E-CVRP. In the literature, researchers pay more attention to the single-echelon vehicle routing problem (VRP) with fuel consumption or emission considerations (Maden et al., 2010; Demir et al., 2011, 2012; Qian and Eglese, 2016) than the 2E-CVRP-E. Soysal et al. (2015) first construct a comprehensive mixed integer linear programming model for the 2E-CVRP-E but do not develop an approach to it. Therefore, this paper focuses on designing an efficient matheuristic to address the 2E-CVRP-E.

The remainder of this paper is organized as follows. Section 2 reviews the literature on the 2E-CVRP and the 2E-CVRP-E. Section 3 describes the model of the proposed problem. Section 4 presents the matheuristic. Section 5 reports the computational results. Section 6 gives the conclusions and future research directions.

2. Literature review

In this section, we first review the exact and heuristic algorithms for the 2E-CVRP and then present the research on environmental considerations in the 2E-CVRP.

Feliu et al. (2007) construct a commodity-flow model for the 2E-CVRP and use a branch-and-cut (B & C) algorithm to solve it. Later, Perboli et al. (2010, 2011) propose new families of valid inequalities to enhance the performance of the B & C algorithm. Jepsen et al. (2013) develop a B & C algorithm with feasibility test and specialized branching scheme to solve the symmetric 2E-CVRP. Baldacci et al. (2013) design an exact algorithm that decomposes the 2E-CVRP into a set of multi-depot capacitated VRPs with side constraints. Santos et al. (2013) develop two branch-and-price (B & P) algorithms on the basis of different route relaxations to solve the problem. Furthermore, Santos et al. (2015) incorporate valid inequalities into their B & P algorithm to develop a branch-and-price-and-cut algorithm for the problem.

The abovementioned papers focus on exact algorithms for the 2E-CVRP. Various heuristics are also developed for this problem. Crainic et al. (2011) present a multi-start heuristic that first separates the depot-to-satellite delivery and the satellite-to-customer delivery and then iteratively solves the two resulting sub-problems. Hemmelmayr et al. (2012) propose an adaptive large neighborhood search (ALNS) heuristic with problem-specific destroy and repair operators to solve the problem. Crainic et al. (2013) design a meta-heuristic based on greedy randomized adaptive search procedure (GRASP) with path relinking to address the problem. Zeng et al. (2014) combine the GRASP with the variable neighborhood descent (VND) algorithm to solve the 2E-CVRP. Breunig et al. (2016) develop a large neighborhood search (LNS) heuristic for the problem. Grangier et al. (2016) design an ALNS heuristic for the 2E-CVRP with multi-trip and satellite synchronization. Wang et al. (in press) propose a genetic algorithm to solve the 2E-CVRP with stochastic demands.

The 2E-CVRP has attracted significant attention in the research community (Cuda et al., 2015). However, only taking travel cost