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Benefit analysis of shared depot resources for multi-depot vehicle routing problem with fuel consumption

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A R T I C L E I N F O

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A B S T R A C T

Shared depot resources, which allow the route of a vehicle to start from a depot and end at any one of the depot sets, can potentially reduce delivery distance and fuel consumption because more choices are provided for route arrangement. To quantify the benefit, we define the benefit ratio between unshared and shared depots and prove that the maximum benefit ratios on route distance and fuel consumption are up to 2. Then the factors that affect the benefit ratio are analyzed by computational experiments. Computational results show that the benefit of shared depot resources depends on instance characteristics. Three characteristics are found to be significant to the relative performance, namely, depot–customer geographic distribution, maximum route distance, and number of depots.

1. Introduction

Governments and researchers have a growing awareness of the destruction caused by environmental pollution over the last decade. Carbon dioxide is the major contributor to the greenhouse effect. The International Energy Agency (2016) stated that the transportation industry is the second largest influence contributor of CO_2 emissions, accounting for 33% of the global CO_2 emissions in 2014, and almost 85% of the emissions from transportation are due to road transportation. Thus, fuel consumption and CO_2 emissions need to be reduced by optimizing vehicle routes in road transportation.

The environment-related vehicle routing problem (VRP) has received increasing interest (Xiao and Konak, 2015). This problem can be divided into three categories, namely, green VRP (GVRP), pollution-routing problem, and VRP in reverse logistics (Lin et al., 2014). The first category deals with the optimization of the energy consumption of transportation, including the analysis of fuel consumption models for road freight transportation (Demir et al., 2011; Demir et al., 2014a), and studies of VRP aimed at minimizing fuel consumption (Kuo, 2010; Xiao et al., 2012). The second category focuses on the reduction of pollution, especially carbon emissions (Bauer et al., 2010; Fagerholt et al., 2010). The third category concentrates on the distribution with reverse logistics because reuse and recycling are key processes in energy conservation and emission reduction (Kim et al., 2011; Ramos and Oliveira, 2011).

We focus on the multi-depot VRP with fuel consumption (MDVRPFC), which is related to the GVRP. In the classical multi-depot VRP (MDVRP), the route of each vehicle must end in the depot from which it starts. However, we consider a different variant of MDVRP, in which the vehicle is not required to return to the depot from which that it starts, and refer to this variant as an MDVRP under shared depot resources (MDVRPSDR). Our research motivation comes from E-commerce logistics in China. Recently, the E-commerce retail business in China is developing at a higher speed, with an annual growth of 29.4%, arriving at more than RMB

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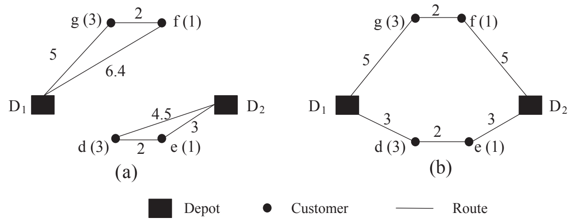

Fig. 1. Example for MDVRP under shared depot resources.

5 trillion in 2016. Multiple depots are established in large cities to serve consumers in time. For the traditional distribution centers, they only serve the customers within a fixed area. However, E-commerce logistics change the mode by the introduction of the Internet of things. Consequently, internet orders are flexibly assigned to different distribution centers, and the depot resources are shared among different distribution centers. The vehicles of a distribution center can share parking spaces of other distribution centers because drivers and vehicles can be managed by a global positioning system and an advanced information system. The drivers can go home through a convenient and fast subway system after they get off their works. Due to the pressures of increasing labor cost and fierce competition, shared depot resources are used to reduce the cost by some trucking enterprises. An example is shown in Fig. 1 and its notations are show in Table 1. The optimal routes for the MDVRP are shown in Fig. 1(a), and those for the MDVRPSDR are shown in Fig. 1(b). In Fig. 1(a), the routes are D_1-g-f-D_1 and D_2-e-d-D_2, and their total length is 22.9. In Fig. 1(b) the routes are D_1-g-f-D_2 and D_2-e-d-D_1, and their total length is 20. The routes of the next round delivery are the same as those mentioned. The costs can be saved in MDVRPSDR because more choices for the route arrangement can be provided in MDVRPSDR than in MDVRP.

Recently, Demir et al. (2014c) indicated a logistics service provider could efficiently combine its resources to reduce its transport costs in a multi-depot network by planning the deliveries from multiple depots simultaneously. Markov et al. (2016) investigated the recyclable waste collection problem and translated it into the VRP with intermediate facilities. Except for the complex realistic features, vehicle tour could start from and end at different depots. Results showed that important savings were achieved in the state of practice. Li et al. (2016) studied the mathematical model and solution method of MDVRPSDR with the objective function of minimizing the travel distance. However, two unresolved problems remain, namely, (1) how to assess the maximum benefit under shared depot resources and (2) in which situation the benefit under shared depot resources is higher. No work has been done to study these two problem for MDVRPSDR.

Therefore, considering the two problems, we focus on the MDVRPSDR in the context of fuel consumption. The maximum potential benefit is evaluated by comparing the results under shared depot resources with those under unshared condition. The circumstance that is more beneficial for sharing depots is then analyzed.

The rest of this paper is structured as follows: Section 2 presents a literature review on the VRP with fuel consumption (VRPFC). Section 3 indicates the problem description. Section 4 provides the evaluation of the maximum benefit under shared depot resources. Section 5 provides the analysis of the factors that affect the benefit ratio between unshared and shared depots. Finally, Section 6 concludes the study and indicates the proposals for future research.

2. Literature review

In this study, we only investigate the VRPFC. For the broader review on green road freight transportation, the reader is referred to Lin et al. (2014) and Demir et al. (2014a). VRPFC is separated into two categories according to the number of depots, namely, single-depot VRPFC and MDVRPFC.

Considerable attention has been paid to the single-depot VRPFC. Xiao et al. (2012) developed a model for capacitated VRP, in which fuel consumption depends on load and distance. A simulated annealing (SA) algorithm with hybrid exchange rule was then designed to solve the problem. Yang et al. (2015) further examined VRP with time windows and multiple environmental vehicle types by using an HGA. The problem was formulated as a multi-objective model to minimize costs and environmental pollution and to maximize customer satisfaction. A sensitivity analysis was also conducted to assess the impact of different type vehicles on the environment. Kuo (2010) and Qian and Richard (2016) presented a time-dependent VRP, in which travel speeds varied with time. Their objective was to minimize fuel consumption. SA algorithm and column-generation-based tabu search algorithm were adopted, respectively, to identify the effect of speed on fuel consumption. Franceschetti et al. (2013) proposed a time-dependent pollution-

Table 1
Notations of the example.

Parameter	Notation
Depots	D_1 and D_2
Customers	d, e, f, and g
Arc length	The number on the arc
Demands of customer	The number in bracket
Capacity of vehicle	4