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Routing with time-windows for multiple environmental vehicle types

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ABSTRACT

With the goal of reducing cost, improving customer satisfaction and controlling the environmental pollution, a environmental routing optimization problem with time windows and multiple vehicle types is proposed by considering the concept of low-carbon logistics. A multi-objective vehicle routing problem (VRP) model with soft time-windows for multiple environmental vehicle types is presented, and a hybrid genetic algorithm (GA) is designed. Based on the experiments, the effectiveness of the algorithm is examined. With Pareto analysis, the relationship among the three objectives (distribution cost, customer satisfaction and environmental pollution) is examined. Sensitivity analysis is conducted to identify the influence of different type vehicle on the environmental performance. The results shows that the vehicle speed has strong correlation with the operation cost and environmental pollution, while the load capacity affects the operation cost, customer satisfaction and environmental pollution.

1. Introduction

With the development of social economy, the progress of science and technology, and the expansion of production scale, energy consumption, waste pollution and CO_2 emissions and many other environmental problem arose. In such a period of sharp contradictions between economic growth and environment deterioration, saving energy and controlling energy consumption become global issues. In 2010, the tertiary industry in China consumes approximately 16% of the whole society energy (Xiang, Xu, & Sha, 2013). Particularly, the modern logistics industry (transportation and warehousing activities) has consumed almost 80% of the energy of the tertiary industry. To improve the energy utilization rate and alleviate the pressure of energy requirement, researchers focus on the logistics optimization to control the environmental pollution. Cooper, Browne, and Peters (1994) proposed the concept of "Green Logistics", and put forward the framework of green logistics by improving vehicle design, increasing highway tolls and encouraging the transport combination. With the prevailing concept of low-carbon logistics, more and more attentions have been paid to the study on the low-carbon vehicle routing problem (VRP) (Ćirović, Pamučar, & Božanić, 2014; Erdoğan & Miller-Hooks, 2012; Zhang, Thompson, Bao, & Jiang, 2014). This problem is a heterogeneous fleet vehicle routing problem, which is a NP-hard problem. We proposed an environmental vehicle routing model to study the influence of low-carbon vehicles on the green logistics.

2. Literature review

Nowadays, many models and solution algorithms have been proposed quite extensively for the vehicle scheduling problem with one type vehicles in literature. Meanwhile, multi-vehicle scheduling problem and its variations are paid many attentions, as well as the vehicle routing problem (VRP) with time windows. Karunoa and Nagamochib (2003) presented a nearly linear time 2-approximation algorithms for the multi-vehicle scheduling problem considering the release and handling times. Tütüncü (2010) discussed a visual interactive approach based on a new greedy randomized adaptive memory programming search (GRAMPS) algorithm to solve the heterogeneous fixed fleet vehicle routing problem (HFFVRP). Each vehicles is restricted in a load capacity under the constraints with variable traveling costs. For multi-yard vehicle scheduling problem in the logistics distribution, Zhong and He (2005) proposed two handling methods, designed a Tabu algorithm according to the specific constraints of capacity, time windows and multi-type vehicle. Based on the research of the combined transportations of multi-warehouse, Jing and Zhang (2006) established a new optimization model that was solved by a GA implemented by Matlab software. Some traditional VRP with time window (VRPTW) variants are studied. By proposing new adaptive mechanisms for encoding, crossover and mutation operations, Bin and Fu (2003) constructed an improved GA to solve the

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VRP with soft time window (VRPSTW), and compared the algorithms performance with other GAs. Dondo and Cerdá (2007) discussed the influence of multi-depot situation on VRPTW, Figliozzi (2012) introduced the benchmark problems in time-dependent VRPTW, Archetti, Bouchard, and Desaulniers (2011) studied an VRPTW with split deliveries based on an enhanced branch and price and cut method.

In the researches of VRP, carbon emission and green preferences of different custom have been taken into consideration, which affect the environmental performance of the VRP optimization results. Based on a green logistics case study, Ubeda, Arcelus, and Faulin (2011) established the VRP model considering the fuel consumption and routes' distances, and minimizing CO_2 emissions from the economic and ecological perspectives, respectively. Harris, Naim, Palmer, Potter, and Mumford (2011) considered the strategic and operational level decisions simultaneously. They established a multi-objective optimization model to assessing the impact of CO_2 emissions on the cost. And designed the logistics network to improve the vehicle utilization rate, which is beneficial to reduce the logistics cost and energy consumption. Besides the model analysis, some heuristic algorithms are utilized in VRPs. Repoussis and Tarantilis (2010) proposed a novel adaptive memory programming (AMP) solution approach for the fleet size and mix vehicle routing problem with time window (FSMVRPTW), which is to determine the heterogeneous fleet of vehicles with different capacities and fixed costs, with the goal of minimizing the total transportation costs and fleet composition. Ceder (2011a) considered the association between the characteristics of each trip (urban, peripheral, inter-city, etc.) and the vehicle type required for the particular trip, and proposed a heuristic algorithm for timetable and vehicle scheduling optimization (Ceder, 2011b). Ai and Kachitvichyanukul (2009) presented a particle swarm optimization (PSO) to solve the capacitated vehicle routing problem (CVRP). In the optimization, the vehicle routes are constructed based on a customer priority list and vehicle priority, which are represented by the decoding method. Brandão (2011) proposed a tabu search algorithm for HFFVRP, and tested some benchmarks in which the number of customers ranges from 50 to 360.

However, the previous researches of VRP mostly focused on the loading capacities and vehicle speed, rarely considered the environmental performance of different vehicles. Dessouky, Rahimi, and Weidner (2003) presented a method for the joint optimization of cost, service and life-cycle environmental consequences in vehicle routing and scheduling, and discussed the relationship among environmental sustainability, operation cost and service delay. Zhang and Huo (2006) established a simulation model to analyze the impact of the quantity and speed of vehicles on the delivery performance. The results showed that the quantity configuration should be allocated dynamically according to the loading and unloading time, however the speed increasing not necessarily accelerates the efficiency of delivery. There are few scholars study the customer satisfaction, logistics cost and carbon emission simultaneously.

Based on the concept of low-carbon logistics, this paper improves the basic heterogeneous fleet vehicle routing problem, aiming at minimizing cost, improving customer satisfaction and controlling environmental pollution. Considering the balance among the three objectives, the multi-type environmental vehicles are used to reduce the quality of carbon dioxide emission. According to different customer demands with time windows, different vehicle combinations varying in speed, loading capability and environmental pollution level are assigned, and the influence of vehicle with different environmental performance on routing optimization are analyzed. The optimal model has significance in increasing logistics efficiency, improving logistics service and promoting low-carbon economy.

3. Problem definitions

The heterogeneous fleet vehicle routing problem (HFVRP) is often encountered in the logistics operation management. The general objective of HFVRP is to decide the routes, load capability, speed, and vehicle type of the fleet to satisfy different customers' demands with a proper cost. Moreover, we also consider the environmental performance of the vehicles used for the logistics. Thus, we study two key points of HFVRP: one is to decide the type of the vehicles to improve the environmental influence, and another is to schedule the distribution routes to satisfy the demands and optimize the cost.

In this paper, considering the constraints on customer demands, vehicle capability, time windows of demand, vehicle type and carbon emissions, the vehicle routing problem with multiple vehicle types is discussed. This VRP can be defined in a logistics distribution network with a depot and n demand nodes, in which the node set is $N = \{1, 2, ..., n, n+1, n+2\}$, and the customer node set is N^C, $N^C = N \setminus \{1, n+2\}$. The depot is represented by the two nodes 1 and $n+2$. All feasible vehicle routes start from depot nodes and end at customer nodes. Each customer node i, $i \in N^C$, is associated with a given distribution demand D_i, and bounded within a time window $\left[T_i^L, T_i^U\right]$, which means that the earlier vehicle arrival leads to waiting, and later to delaying. The service of customer node i must start within its time window, and the service time is denoted as T_i^S.

The vehicle type set is $V^T = \{1, 2, \ldots, t\}$, and vehicle set is $V^N = \{1, 2, \ldots, k\}$. Each vehicle of type t has five attributes, maximum traveling speed v_t, loading capability c_t, operation cost per unit time c_t^t, environmental indicator e_t, and fixed cost c_t^f. The transport time of a vehicle of type t from customer demand node i to j is $T_{t,i,j}$. While the logistics network has a upper limit of total carbon emission L_e. An example of the network is shown in Fig. 1, where one depot node and 20 customer demand nodes and three vehicles types (environmental vehicle, sub-environmental vehicle and general energy-consumption vehicle) are involved. The four cycles in Fig. 1 represent the four routes, indicating that in the network 4 vehicles and 3 types are used, for details, there are two environmental vehicles, one sub-environmental vehicle and one general vehicle.

The proposed multi-objective model minimizes the total network cost including fixed vehicle cost and traveling cost, maximizes the customer satisfaction degree which is measured by the arrival time deviation degree to the time window, and minimizing

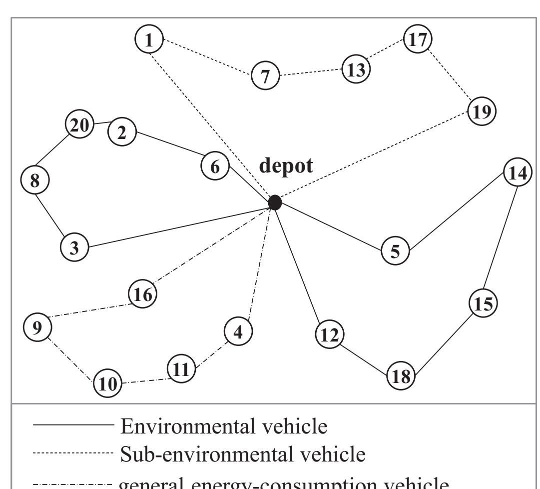

Fig. 1. Vehicle routing problem with multiple vehicle types.