Journal of King Saud University – Engineering Sciences (2017) **29**, 29–34

King Saud University

Journal of King Saud University – Engineering Sciences

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ORIGINAL ARTICLE

A constructive heuristic for time-dependent multi-depot vehicle routing problem with time-windows and heterogeneous fleet

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Received 3 October 2013; accepted 22 April 2014
Available online 30 April 2014

KEYWORDS

Vehicle routing problem;
Time dependent;
Multi-depot;
Time windows;
Heterogeneous fleet;
Constructive heuristic

Abstract In this paper, we consider the time-dependent multi-depot vehicle routing problem. The objective is to minimize the total heterogeneous fleet cost assuming that the travel time between locations depends on the departure time. Also, hard time window constraints for the customers and limitation on maximum number of the vehicles in depots must be satisfied. The problem is formulated as a mixed integer programming model. A constructive heuristic procedure is proposed for the problem. Also, the efficiency of the proposed algorithm is evaluated on 180 test problems. The obtained computational results indicate that the procedure is capable to obtain a satisfying solution.

1. Introduction

The vehicle routing problem (VRP) is a combinatorial optimization problem seeking to service a number of customers with a fleet of vehicles in a distribution network. Since the introduction of vehicle routing problem (VRP) by Dantzig and Ramser (1959), developing real life variants of the VRP has gained increasing attention throughout the literature (El-Sherbeny, 2010). The vehicle routing problem with time windows (VRPTW) is a well-studied version of VRP in which clients impose soft or hard time windows constraints. Due to NP-hardness of VRPTW, some meta-heuristics are developed to solve it such as genetic algorithms (Cheng and Wang, 2009; Ursani et al., 2011; Vidal et al., 2013), ant colony (Ding et al., 2012; Yu and Yang, 2011), Tabu search (Belhaiza et al., 2013; Ho and Haugland, 2004), simulated annealing (Baños et al., 2013; Deng et al., 2009; Kuo, 2010; Tavakkoli-Moghaddam et al., 2007, 2011) etc.

The time dependent vehicle routing problem with time windows (TDVRPTW) is a generalization of VRPTW which is introduced by Malandraki (1989). In this problem setting, it is assumed that the time taken to travel a route is a function of the departure time. The literature on solution methods for the TDVRPTW is scant. Hashimoto et al. (2008) generalized the VRPTW by allowing both traveling times and traveling costs to be time-dependent. Ichoua et al. (2003) proposed a parallel Tabu search for TDVRP with soft time windows.

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksues.2014.04.007
1018-3639

Soler et al. (2009) solved the TDVRPTW optimally by transforming the problem into an asymmetric capacitated vehicle routing problem, so it can be solved both optimally and heuristically with known codes. Balseiro et al. (2011) proposed an ant colony algorithm hybridized with insertion heuristics for TDVRPTW. Figliozzi (2010) proposed an iterative route construction and improvement algorithm to solve VRP with soft time windows. Also he recently proposed new replicable problems for time dependent routing problems with hard time windows with a new algorithm to solve the problem (Figliozzi, 2012). Kritzinger et al. (2012) used efficient traffic data in order to develop a variable neighborhood search (VNS) to solve the problem. Recently, Nguyen et al. (2013) proposed a Tabu search meta-heuristic for the time-dependent multi-zone multi-trip vehicle routing problem with time windows.

The contribution of this paper is threefold: first, a mixed integer programming formulation is developed for the time-dependent multi-depot vehicle routing problem with heterogeneous fleet. In this problem, hard time windows and limitation on maximum number of vehicles in depots must be satisfied. The objective of this problem is to minimize the total heterogeneous fleet cost assuming that the travel time between locations depends on the departure time. This model is not considered in the past literature. Second, a constructive heuristic followed by three efficient local searches is developed for the problem. Finally, the effectiveness of the proposed method is analyzed.

The reminder of the paper is organized as follows: Section 2 describes the problem. In Section 3 we explain the proposed heuristic to obtain a satisfying solution for the problem. Computational results and performance evaluation are represented in Section 4. Finally, Section 5 contains the conclusions.

2. Problem description

Assume that a fleet of heterogeneous vehicles with different capacities and different travel costs is available to serve the transportation requests. Also, the travel time between locations is assumed as a function of departure time. Furthermore, the vehicles do not have to return to a central depot, although maximum number of vehicles in depots is restricted to prevent the aggregation of vehicles in some depots. All locations have to be visited within a specific time window. If the vehicle reaches one of these locations before the beginning of the time window, it has to wait.

The time-dependent multi-depot vehicle routing problem studied in this paper involves finding distinct feasible tours in order to minimize the total cost for operating the tours. A feasible tour of a vehicle is a journey starting from a depot and ending at the same or different depot, passing some costumers such that time windows, capacity constraints and limitation on maximum number of vehicles in depots hold.In sequence, assume the problem represented in a graph $G = \{N, A\}$ where the set of nodes, N, represents locations (customers and depots) and the set of arcs, A, represents routes between locations. Also, there is no arc between depots. The set of nodes, N, are numbered from 1 to n, which $W = \{1,\ldots, m\}$ are depots and $V = \{m + 1,\ldots, n\}$ are customers. The fixed request of a customer i is denoted by q_i; $i = m + 1,\ldots, n$, while request of depots is assumed zero, $q_i = 0$; $i = 1,\ldots, m$. Number of vehicle types is assumed P. Number of available heterogeneous vehicles before routing at each depot is assumed to be arbitrarily large for each vehicle type, while maximum number of vehicles after routing at each depot is assumed Q. However, assuming that each vehicle serves only one customer, an upper bound on the number of vehicles at each depot is $P(n - m)$ at worst case. In doing so, we will have maximum $K = mP(n - m)$ vehicles in the network.

To take into account time dependency the time horizon is divided to U time intervals. In this study, a stepwise function of speed distribution is assigned to each arc and then the time distribution is obtained by integration (Fleischmann et al., 2004). In doing so, we can get continuous function of link travel time. This method ensures the network has FIFO property (Ichoua et al., 2003). A model with a FIFO property guarantees that if a vehicle leaves customer i to go to customer j at any time t, any identical vehicle with the same destination leaving customer i at a time $t + \varepsilon$, where $\varepsilon > 0$, will always arrive later. This is an intuitive and desirable property though it is not present in all models.

We have the following notations for the problem:

N set of nodes of graph representing the locations, indexed by i and j
A set of arcs of graph representing the potential routes between locations
W set of depots $W \subset N$; indexed by i and $j = 1,\ldots, m$
V set of customers $V \subset N$, $W \cap V = \emptyset$, $W \cup V = N$; indexed by i and $j = m + 1,\ldots, n$
F set of heterogeneous vehicles, indexed by $k = 1,\ldots, K$
P number of vehicle types
Q maximum number of vehicles in each depot after routing
I set of time intervals, indexed by $u = 1,\ldots, U$
q_i request of customer i
s_i service time of customer i
$[a_i , b_i]$ time window of customer i
C_k capacity of vehicle k
cf_k fixed cost of vehicle k
cv_k variable cost of vehicle k per unit traveled distance
d_{ij} distance between locations i and j
c_{ij}^k travel cost between locations i and j with vehicle k; $c_{ij}^k = d_{ij} \times cv_k$
t_{ij}^k travel time between locations i and j with vehicle k (time distribution which is a continuous function of departure time)
T_u upper limit of u^{th} time interval
Z objective function
x_{ij}^{ku} 1; if vehicle k travel between locations i and j in time interval u
0; otherwise (binary decision variable)
y_i^k service start time of customer i (real decision variable) served by vehicle k

Notice that, the decision variable y_i^k allows for waiting at customer i; service start time may not necessarily be the same as arrival time. Using the above notation, the problem can be mathematically formulated as follows:

$$\min Z = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{K}\sum_{u=1}^{U} c_{ij}^k x_{ij}^{ku} + \sum_{i=1}^{m}\sum_{j=m+1}^{n}\sum_{k=1}^{K}\sum_{u=1}^{U} cf_k x_{ij}^{ku} \quad (1)$$