Expert Systems with Applications 41 (2014) 3748–3760

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Vehicle routing problem with a heterogeneous fleet and time windows

Jun Jiang *, Kien Ming Ng, Kim Leng Poh, Kwong Meng Teo

Department of Industrial and Systems Engineering, National University of Singapore, Singapore

ARTICLE INFO

Keywords:
Vehicle routing problem with time windows
Heuristics
Reporting

ABSTRACT

In this paper, a problem variant of the vehicle routing problem with time windows is introduced to consider vehicle routing with a heterogeneous fleet, a limited number of vehicles and time windows. A method that extends an existing tabu search procedure to solve the problem is then proposed. To evaluate the performance of the proposed method, experiments are conducted on a large set of test cases, which comprises several benchmark problems from numerous problem variants of the vehicle routing problem with a heterogeneous fleet. It is observed that the proposed method can be used to give reasonably good results for these problem variants. In addition, some ideas are presented to advance the research in heuristics, such as fair reporting standards, publication of benchmark problems and executable routines developed for algorithmic comparison.

1. Introduction

This paper is motivated by the last mile urban transportation and unmanned airborne vehicle (UAV) path planning applications. The last mile problem is valued in regions where land-use patterns have moved tremendous jobs and people to low-density suburbs. UAVs are widely utilized in military and civilian applications, such as surveillance and firefighting. The routing problems in these real-world applications can be classified into different problem variants of the vehicle routing problem (VRP), which has wide applicability in the fields of transportation, distribution and logistics (Toth & Vigo, 2001). VRP calls for the determination of the optimal set of routes to be taken up by a fleet of vehicles serving customers. VRP can be categorized into problem variants, such as VRP with a limited number of vehicles, VRP with time windows, and VRP with multiple depots. Many algorithms have been proposed for each problem variant in the literature. However, in system implementations, a real problem could be a generalization of various problem variants. Thus, it is difficult to evaluate the performance of algorithms for specific problem variants on real-world problems.

In this paper, a problem variant, the vehicle routing problem with a heterogeneous fleet and time windows (VRPHETW), is defined to generalize the vehicle routing problem with time windows and a limited number of vehicles (m-VRPTW), fleet size and mix vehicle routing problem with time windows (FSMVRPTW) and vehicle routing problem with a heterogeneous fleet (VRPHE). A tabu-search algorithm, which extends an existing tabu search specially designed for the m-VRPTW (Lau, Sim, & Teo, 2003), is proposed to solve the VRPHETW.

It is also observed that researchers frequently encounter problems when conducting experiments and reporting computational results. Firstly, the size of the parameter space expands in an exponential manner for an algorithm with a large number of parameters, which impedes the search for a good set of parameters. Secondly, fair comparisons are not easy to make (Silberholz & Golden, 2010). In particular, it is difficult to have access to the results and the executable routines. Thus, researchers are not able to run the algorithms and find out the details of the solving process. Thirdly, using only the best solutions, as is often done in the literature, may create a false picture on the real performance of an algorithm (Bräysy & Gendreau, 2005).

In order to overcome these problems, our proposed method is designed to contain as few parameters as possible. Meanwhile, the test cases used and executable routines developed can be provided to facilitate comparisons. The experiments are conducted on a large set of test cases to evaluate the algorithm's performance. In the literature, the VRPHETW is less studied than other problem variants. Also, most of the papers focus on the real applications and so the test cases and results are not comparable. As such, we have evaluated our proposed algorithm on the FSMVRPTW instances, which have heterogeneous fleet, time windows and unlimited number of vehicles, as well as instances from several other problem variants of the VRP with a heterogeneous fleet. The aim of illustrating the ability of the proposed algorithm to solve numerous problem variants is to assess its potential in solving real-world problems as a real-world problem could be a generalization of various problem variants in practice.

Our contribution is in proposing an effective method to solve the VRPHETW which is able to provide reasonably good results for numerous problem variants. This is an advancement over existing work where most of the relevant algorithms would tend to

* Corresponding author.
E-mail addresses: g0800228@nus.edu.sg (J. Jiang), kienming@nus.edu.sg (K.M. Ng), pohkimleng@nus.edu.sg (K.L. Poh), kwongmeng@nus.edu.sg (K.M. Teo).

0957-4174/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2013.11.029

solve a specific VRP variant effectively but may not perform as well for other problem variants.

This paper is organized as follows. Section 2 gives a detailed literature survey on the VRP with a heterogeneous fleet. In Section 3, the VRPHETW is described and formulated as a mathematical programming model. Subsequently in Section 4, a tabu-search algorithm is proposed to solve the VRPHETW. In Section 5, available sets of standard test cases are introduced and specially generated test cases are also proposed. Then in Section 6, experiments are conducted and the results are compared with the best-known published solutions for each problem variant. Finally, this paper concludes in Section 7 with a summary and possibilities for future research work.

2. Literature review

In the literature, several problem variants of the VRP consider a heterogeneous fleet, where vehicles have various capacities, fixed costs, variable costs, number of vehicles for each vehicle type, or latest returning times for vehicles to return to the depot. The fleet size and mix vehicle routing problem (FSMVRP) is one of the earlier problem variants with a heterogeneous fleet. In the FSMVRP, vehicles have differing vehicle capacities for different vehicle types, and the number of vehicles is not limited. The solution to the FSMVRP is to find a fleet composition and a corresponding routing plan that minimizes the total cost. The FSMVRP arises in strategic decisions, such as when a company wants to acquire a vehicle fleet and needs to determine the size and composition of the fleet.

The FSMVRP with fixed cost (FSMVRP-F) considers only fixed costs in the total cost and was first introduced by Golden, Assad, Levy, and Gheysens (1984). Taillard (1999) developed a heuristic column generation method based on a tabu search and constructed 8 test cases for the FSMVRP with variable cost (FSMVRP-V), which considers only variable costs in the total cost. Gendreau, Laporte, Musaraganyi, and Taillard (1999) and Wassan and Osman (2002) presented tabu-search heuristics and reported results for the FSMVRP-F and FSMVRP-V test cases. Renaud and Boctor (2002) analyzed constructive heuristics and improvement procedures for the FSMVRP-F. Choi and Tcha (2007) proposed a better bound based on column generation and used it in a branch-and-bound algorithm. They reported results for the FSMVRP-F and FSMVRP-V, and also solved the FSMVRP with fixed and variable costs (FSMVRP-FV).

The FSMVRP is a special case of the VRP with a heterogeneous fleet (VRPHE) by setting an unlimited number of vehicles. The VRPHE is much harder to solve than the FSMVRP but it is able to represent the operational decisions in determining the vehicles that should be deployed among available vehicles. Taillard (1999) introduced the VRPHE and constructed 8 VRPHE test cases. Tarantilis, Kiranoudis, and Vassiliadis (2003) designed a threshold accepting algorithm and an improved version of the algorithm is proposed in Tarantilis, Kiranoudis, and Vassiliadis (2004). Li, Golden, and Wasil (2007) presented a deterministic algorithm variant of simulated annealing, called a record-to-record travel algorithm, which outperformed the threshold accepting method of Tarantilis et al. (2004) on the VRPHE test cases. Prins (2009) presented genetic algorithms hybridized with a local search to solve the FSMVRP and VRPHE. Brandão (2011) designed a tabu-search algorithm and introduced some new test cases.

The FSMVRP with time windows (FSMVRPTW) was first introduced by Liu and Shen (1999). They developed a savings-based construction heuristic and an improvement heuristic inspired by the work of Golden et al. (1984). Subsequently, Dullaert, Janssens, Sorensen, and Vernimmen (2002) proposed new heuristics and reported better results than the previous heuristic approaches for solving the problem. Belfiore and Favero (2007) presented a scatter search approach to solve the FSMVRPTW. Dell'Amico et al. (2007) proposed a robust and efficient solution algorithm based on a parallel insertion procedure. Paraskevopoulos, Repoussis, Tarantilis, Ioannou, and Prastacos (2008) introduced a two-phase solution framework based on a hybridized tabu search with a new reactive variable neighborhood search metaheuristic. Bräysy, Dullaert, Hasle, Mester, and Gendreau (2008) presented an effective multi-restart deterministic annealing metaheuristic and reported results for a new problem variant, for which the distance replaced the en route time as variable cost. Bräysy, Porkka, Dullaert, Repoussis, and Tarantilis (2009) combined threshold accepting and local search metaheuristics to guide four local search procedures, and reported results on solving large-scale problem instances. Kritikos and Ioannou (2013) allowed overloads to achieve cost reductions with minimal and controlled violations in the capacity of vehicles. However, their costs without violation are not as good as that of Liu and Shen (1999).

For the VRPHE with time windows (VRPHETW), there are fewer papers in the literature than the FSMVRPTW. Semet and Taillard (1993) developed a tabu-search algorithm for the VRPTW with a heterogeneous fleet, vehicle-dependent utilization costs, accessibility and other restrictions. Rochat and Semet (1994) proposed a tabu-search approach for that VRPTW that considers drivers' breaks and accessibility restrictions. Brandão and Mercer (1997) developed a tabu-search procedure in which weight and volume capacity restrictions were considered with the number of trips per day, restricted access for some vehicles, and maximum driving times. Yepes (2002) used a threshold-accepting algorithm, and Yepes and Medina (2006) presented a three-step local search algorithm based on a probabilistic variable neighborhood. Besides being less studied than other problem variants, most of the papers on the VRPHETW focus on the real applications and so the test cases and results are not comparable.

Throughout the literature survey, it is found that numerous problem variants exist, and that the notations used are not consistent. Thus, we summarize the various problem variants in Table 1, together with the corresponding references. Table 1 also shows the constraints and costs considered for each problem variant.

Table 1
Problem variants of heterogeneous fleet routing problem in the literature.

Problem variants	References	Fixed cost	Variable cost	Limited no. of vehicles	Time windows	Latest returning times
FSMVRP-FV	Choi and Tcha (2007), Prins (2009)	√	√			
FSMVRP-V	Taillard (1999), Gendreau et al. (1999), Wassan and Osman (2002), Choi and Tcha (2007), Prins (2009)		√			
FSMVRP-F	Golden et al. (1984), Taillard (1999), Liu and Shen (1999), Gendreau et al. (1999), Wassan and Osman (2002), Renaud and Boctor (2002), Dullaert et al. (2002), Dell'Amico et al. (2007), Choi and Tcha (2007), Prins (2009)	√				
VRPHE	Taillard (1999), Tarantilis et al. (2003, 2004), Li et al. (2007), Prins (2009), Brandão (2011)		√	√		
FSMVRPTW	Liu and Shen (1999), Dullaert et al. (2002), Belfiore and Favero (2007), Dell'Amico et al. (2007), Paraskevopoulos et al. (2008), Bräysy et al. (2008, 2009), Kritikos and Ioannou (2013)	√			√	