Expert Systems With Applications 53 (2016) 160–171

Contents lists available at ScienceDirect

Expert Systems With Applications

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

A hybrid metaheuristic algorithm for heterogeneous vehicle routing problem with simultaneous pickup and delivery

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ARTICLE INFO

Keywords:
Vehicle routing
Heterogeneous fleet
Local search
Reverse logistics

ABSTRACT

The Vehicle Routing Problem with Simultaneous Pickup and Delivery (VRPSPD) is a variant of the classical Vehicle Routing Problem (VRP) where the vehicles serve a set of customers demanding pickup and delivery services at the same time. The VRPSPD can arise in many transportation systems involving both distribution and collection operations. Originally, the VRPSPD assumes a homogeneous fleet of vehicles to serve the customers. However, in many practical situations, there are different types of vehicles available to perform the pickup and delivery operations. In this study, the original version of the VRPSPD is extended by assuming the fleet of vehicles to be heterogeneous. The Heterogeneous Vehicle Routing Problem with Simultaneous Pickup and Delivery (HVRPSPD) is considered to be an NP-hard problem because it generalizes the classical VRP. For its solution, we develop a hybrid local search algorithm in which a non-monotone threshold adjusting strategy is integrated with tabu search. The threshold function used in the algorithm has an adaptive nature which makes it self-tuning. Additionally, its implementation is very simple as it requires no parameter tuning except for the tabu list length. The proposed algorithm is applied to a set of randomly generated problem instances. The results indicate that the developed approach can produce efficient and effective solutions.

1. Introduction

The Vehicle Routing Problem with Simultaneous Pickup and Delivery (VRPSPD) has attracted research interest due to its applicability in numerous reverse logistic systems involving bi-directional flow of goods. Originally, the VRPSPD assumes a homogeneous fleet of vehicles to serve a set of customers requiring delivery and pickup services simultaneously. However, in many practical situations, companies employ heterogeneous fleet of vehicles to satisfy customer demands. Therefore, this paper extends the original version of the VRPSPD by assuming the fleet of vehicles to be heterogeneous. This version of the problem can arise in many practical applications of reverse logistics, and constructing an effective solution strategy to the problem is one of the most critical issues for operating the transportation system efficiently. In the bottled drinks industry, for example, full bottles are delivered and empty ones which are used for recycling are collected simultaneously from the customers. Other practical applications can be seen in the collection of used materials such as car parts, industrial equipments and computers for remanufacturing or dissembling operations (Zachariadis, Tarantilis, & Kiranoudis, 2009). Moreover, the problem can be seen at grocery stores in which pallets or boxes are collected and reused for transportation (Dethloff, 2001).

The Heterogeneous Vehicle Routing Problem with Simultaneous Pickup and Delivery (HVRPSPD) can be described with graph theory terms as follows: Let G = (N, A) be a complete graph, where $N=\{n_0, n_1,\dots, n_n\}$ is the set of nodes in which n_0 represents the central depot and the remaining ones the customers. $A=\{(n_i,n_j):n_i, n_j \in N, i\neq j\}$ is the set of arcs that represent the linkages between the customers and c_{ij} shows the distance between customers i and j. Each customer $\{n_1, n_2,\dots, n_n\}$ requires a nonnegative delivery quantity d_i and a nonnegative pickup quantity p_i. The fleet of vehicles involves M different vehicle types each of which has a vehicle capacity Q_m, a fixed cost F_m and a unit variable cost v_m ($m = 1,\dots, M$). Two different cases of the HVRPSPD can occur depending on the availability of the vehicles. In the first case, the number of available vehicles for each type is unlimited and the vehicle fleet mix problem should also be solved, which corresponds to our problem. In the second case, the availability of each type of vehicle is known beforehand. Thus, our objective for the HVRPSPD in our case is to determine the best fleet composition as well as the set of vehicle routes minimizing the total cost and satisfying the following constraints: (i) every route initiates and finishes

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http://dx.doi.org/10.1016/j.eswa.2016.01.038
0957-4174/

at the central depot; (ii) each customer must be serviced once by one vehicle; (iii) all delivered goods must be originated from the depot and all pickup goods must be transported back to the depot; (iv) the transported amount of goods cannot exceed the capacity of a vehicle. From the theoretical point of view, the HVRPSPD is an NP-hard combinatorial optimization problem because it is a variant of the standard version of the VRP.

In this study, we develop a simple hybrid local search algorithm based on an adaptive Threshold Accepting (TA) strategy and Tabu Search (TS) for the HVRPSPD with an unlimited number of vehicles. The developed algorithm, HLS, uses a non-monotone threshold function with a tabu list. One of the most important features of the algorithm is that the applied threshold function does not need any parameter tuning which makes the algorithm self-tuning. That is, it self-adaptively adjusts the threshold value in order to provide necessary diversification and intensification in the search process. Moreover, the employed tabu list further improves the diversification of the search process by preventing the algorithm from cycling. The effectiveness of the proposed algorithm is tested on randomly generated instances. The results show that the proposed approach gives good solutions in reasonable computation times.

The rest of this paper is organized as follows: In Section 2, related literature of the problem is given. In Section 3, a mathematical formulation developed for the HVRPSPD is introduced. In Section 4, detailed information about our solution methodology is presented. An illustrative example is given in Section 5. The computational results are presented in Section 6. Finally, concluding remarks and future research are given in Section 7.

2. Literature review

Over the last decade, the VRPSPD has attracted research interest due to its practicability on many logistic systems involving both distribution and collection operations. The VRPSPD is first introduced by Min (1989). In this study, a real life problem of book distribution and collection from a central library to 22 remote libraries is handled, and a cluster-first and route-second method is implemented to solve the problem. In this solution approach, once the customers are clustered, the Traveling Salesman Problem (TSP) is solved for each cluster in the routing phase. Dethloff (2001) suggested insertion-based heuristics in which four different insertion criteria, traveling distance, residual capacity, radial surcharge and combination, are employed. The author also presented a node-based mathematical formulation for the problem. Nagy and Salhi (2005) developed another heuristic solution approach for the VRP variants containing pickup and delivery operations. The developed method consists of several problem specific routines used for feasibility and improvement.

Dell'Amico, Righini, and Salani (2006) suggested a branch-and-price algorithm for the VRPSPD. In this study, the pricing problem is solved by employing two different methods, exact dynamic programming and state space relaxation. Additionally, suitable branching strategies are designed for both methods. Bianchessi and Righini (2007) proposed constructive and improvement algorithms containing variable neighborhood structures. Ai and Kachitvichyanukul (2009) developed a particle swarm optimization (PSO) algorithm, in which a random key-based encoding and decoding method is utilized, and 2-opt and a cheapest insertion based heuristic are implemented for improvement. Gajpal and Abad (2009) developed an ant colony optimization (ACO) algorithm for solving the VRPSPD. In this algorithm, the nearest neighbor heuristic is applied to create an initial solution and the trail intensities and parameters are initialized. Then the trail intensities are used to generate a solution for each ant. Subsequently, a local search procedure is implemented on each ant-solution, and elitist ants and trail intensities are updated. Another heuristic approach based on ACO is suggested by Çatay (2010). In this study, a new saving-based visibility function and a pheromone updating rule are developed. An initial solution is generated by using the nearest neighbor heuristic, and an improvement procedure consisting of four routines, namely intra-move, intra-swap, inter-move and inter-swap, are implemented to improve the solutions. Zachariadis, Tarantilis, and Kiranoudis (2010) proposed a two-stage heuristic algorithm based on adaptive memory programming. In the first stage of the algorithm, an initial solution is constructed by using a saving-based heuristic method. After that, the constructed solution is improved by using TS. This procedure is iteratively implemented until a predetermined number of routes which constructs a route pool are generated. In the second stage, new solutions are produced by using node sequences available in the route pool, and subsequently the TS-based improvement procedure is applied. After that, the route pool that establishes the adaptive memory is updated by using the obtained solutions from TS. A parallel algorithm is developed by Subramanian, Drummond, Bentes, Ochi, and Farias (2010). The algorithm is embedded with a multi-start heuristic in which Variable Neighborhood Descent (VND) is integrated with a perturbation mechanism. An insertion-based heuristic method is implemented to generate an initial solution. The proposed algorithm has the capability of tuning some parameters and exploring the high level of parallelism. Zachariadis and Kiranoudis (2011) presented a local search algorithm. In their study, neighborhood structures are explored by using an algorithmic concept which statically encodes tentative moves. For diversification, a variation of the aspiration criteria of tabu search (TS) has been implemented. Another exact solution approach has been suggested by Subramanian, Uchoa, Pessoa, and Ochi (2011). The authors developed a branch-and-cut algorithm for the VRPSPD. Goksal, Karaoglan, and Altiparmak (2013) presented another PSO based solution approach for the VRPSPD. In this solution methodology, PSO enables the algorithm to explore different search regions in the search space and VND is employed for intensification. In order to maintain the population diversity, an annealing-like strategy is applied. Avci and Topaloglu (2015) developed an adaptive local search algorithm for the VRPSPD. In the proposed approach, an adaptive threshold accepting methodology is integrated with VND.

Regarding the literature of the heterogeneous fleet vehicle routing problems, metaheuristic solution approaches have been widely suggested since its introduction by Golden, Assad, Levy, and Gheysens (1984). Some single solution based methods based on Tabu Search (TS) can be found in Gendreau, Laporte, Musaraganyi, and Taillard (1999)), Tailard (1999), Brandao (2009, Lee, Kim, Kang, and Kim (2008)), Li, Tian, and Aneja (2010) and Brandao (2011). Threshold accepting algorithms for the problem were developed by Tarantilis, Kiranoudis, and Vassiliadis (2003), Tarantilis, Kiranoudis, and Vassiliadis (2004) and Belmecheri et al. (2013), Li, Golden, and Wasil (2007). Prins (2009), Liu (2013), Liu et al. (2009) and Koç, Bektaş, Jabali, and Laporte (2015) proposed population-based heuristics for the problem.

Recently, the VRPSPD has been considered with different practical constraints by researchers. Minyong and Erbao (2010) suggested a Differential Evolution Algorithm (DEA) for the VRPSPD with time windows constraints. The algorithm creates an initial population by using a decimal coding procedure. An integer order criterion based on natural number coding is applied for the mutation operator and a penalty technique is implemented to prevent infeasible solutions. Wang and Chen (2012) presented an Evolutionary Algorithm (EA) in which GA is integrated with the cheapest insertion method for the VRPSPD with time windows. For the same problem, Wang, Mu, Zhao, and Sutherland (2015) suggested a parallel SA algorithm where residual capacity and radial surcharge based insertion heuristics are employed. The problem of home health care logistics which includes material pickup and delivery among