Computers & Industrial Engineering 90 (2015) 402–413

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

The vehicle routing problem with multiple prioritized time windows: A case study

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ARTICLE INFO

Article history:
Received 17 February 2015
Received in revised form 6 September 2015
Accepted 9 October 2015
Available online 22 October 2015

Keywords:
Multi-objective optimization
Vehicle routing problem with multiple prioritized time windows
Cooperative coevolutionary multi-objective quantum-genetic algorithm

ABSTRACT

This paper addresses Multi-objective Vehicle Routing Problem with Multiple Prioritized Time Windows (VRPMPTW) in which the distributer proposes a set of all non-overlapping time windows with equal or different lengths and the customers prioritize these delivery time windows. VRPMPTW aims to find a set of routes of minimal total traveling cost and maximal customer satisfaction (with regard to the prioritized time windows), starting and ending at the depot, in such a way that each customer is visited by one vehicle given the capacity of the vehicle to satisfy a specific demand. This problem is inspired from a real life application. The contribution of this paper lies in its addressing the VRPMPTW from a problem definition, modeling and methodological point of view. We developed a mathematical model for this problem. This model can simply be used for a wide range of applications where the customers have multiple flexible time windows and violation of time windows may drop the satisfaction levels of customers and lead to profit loss in the long term. A Cooperative Coevolutionary Multi-objective Quantum-Genetic Algorithm (CCMQGA) is also proposed to solve this problem. A new local search is designed and used in CCMQGA to reach an appropriate pareto front. Finally, the proposed approach is employed in a real case study and the results of the proposed CCMQGA are compared with the current solution obtained from managerial experience, the results of NSGA-II and the multi-objective quantum-inspired evolutionary algorithm.

1. Introduction

The Vehicle Routing Problem (VRP) is a well-known combinatorial optimization problem (COP) with a wide range of applications. It deals with the determination of minimum cost routes from a central depot to a set of geographically dispersed customers. The Vehicle Routing Problem with Time Window (VRPTW) is an extension of the VRP where another constraint is added, requiring the start of service at each customer within a time window. A Time Window (TW) is defined as the time interval within which a vehicle has to arrive at a node, and it is usually characterized by an early arrival time (EAT) and a late arrival time (LAT) (Deflorio, Perboli, & Tadei, 2010). If the time window constraints must be satisfied strictly, such a problem is called the Vehicle Routing Problem with Hard Time Window (abbreviated as VRPHTW). But, satisfying the appropriate delivery time is one of the most significant challenges in distribution management. It has a direct impact upon customers' satisfaction and business profit. Distributers try to satisfy customers' time windows, but they may not be able to handle this because of the constraints in resources or distribution costs and therefore, it leads to the reduction of customer's satisfaction. Therefore, they usually consider the soft time windows which can be violated by paying appropriate penalties. In some cases, however, the violation of time windows does not directly incur any penalty cost, although the satisfaction levels of customers (the service level of suppliers) may drop, leading to profit loss in the long term. Furthermore, in some cases, determination of penalty cost is difficult.

As a consequence, distributers, in addition to minimizing distribution costs, try to maximize customers' satisfaction or minimize the total penalty. In fact, on the one hand, distributers would like to maximize customers' satisfaction and on the other hand, the distribution cost may increase. But what aspects should be considered in the tradeoff between distribution cost and customers' satisfaction? Should it be similar to the service level for all customers? Are all customers equally important to us? Should the information obtained from previous service levels for each customer (customers' satisfaction from previous services) be considered to determine the current service level? The purpose of the present paper is thus designing and solving a new multi-objective vehicle routing problem with multiple time windows in order to arrive at an

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http://dx.doi.org/10.1016/j.cie.2015.10.005
0360-8352/

appropriate tradeoff between distribution cost and customer satisfaction. Some of the above aspects are considered as objectives and constraints of the model and others are considered in order to choose a preferred solution by Decision Maker (DM) after solving the model. The contribution of this paper, therefore, lies in its addressing the VRPMPTW from a problem definition, modeling and methodological point of view. We developed a mathematical model for this problem. We also proposed a Cooperative Coevolutionary Multi-objective Quantum-Genetic Algorithm (CCMQGA) to solve the problem. In the proposed algorithm, the problem is decomposed into two modules: one for meeting the sequence of customers (customer module) and the other for the number of customers in each vehicle (vehicle module). These species evolve separately with the only cooperation happening during fitness evaluation. In fact, the fitness of an individual in a species depends on the individual of a different species. For the evolution of customer and vehicle modules (species), we used quantum-inspired evolutionary algorithm with a binary representation and genetic algorithm with an integer representation, respectively. Thus, in the proposed algorithm a species is devoted to the evolution of vehicle module that leads to improvement of the efficiency of the algorithm. A new local search is also designed and used in CCMQGA to reach an appropriate pareto front. This research is motivated by a real problem the authors faced in a distribution company. The proposed approach was implemented in this real case and the results of the proposed CCMQGA were compared with current solution obtained from managerial experience, the results of NSGA-II and MQEA[1] algorithm.

The remainder of the paper is organized as follows: Section 2 is devoted to the literature review. In Section 3, we introduce the problem and develop a mathematical model for it. Section 4 presents a cooperative coevolutionary multi-objective quantum-genetic algorithm to solve the model. In Section 5, a real case is studied and the computational results are discussed. Finally, the paper ends with the concluding remarks in Section 6.

2. Literature review

As mentioned earlier, time windows are either hard or soft. If the time window constraints must be satisfied strictly, such a problem is called the Vehicle Routing Problem with Hard Time Window (abbreviated as VRPHTW). The Vehicle Routing Problem with Soft Time Window (abbreviated as VRPSTW) is a relaxation of the VRPHTW. Time windows can be violated if a penalty is paid and this penalty is often assumed to be linear with the degree of violation (Figliozzi, 2010; Liberatore, Righini, & Salani, 2011; Xu, Wang, & Yang, 2012). The Vehicle Routing Problem with Multiple Time Windows (abbreviated as VRPMTW) has also been considered (Belhaiza, Hansen, & Laporte, 2013; Favaretto, Moretti, & Pellegrini, 2007). Some researchers studied the Vehicle Routing Problem with General Soft Time window constraints (Beheshti & Hejazi, 2014; Ibaraki et al., 2005).

In some cases, however, the violation of time windows does not directly incur any penalty cost, although the satisfaction levels of customers (the service level of suppliers) may drop and lead to profit loss in the long term. In these cases, researchers usually use fuzzy theory. This paper intends to study routing problem while considering customer satisfaction and without using any penalty for the violation of time windows; a brief review of relevant studies is thus presented below.

Tang, Pan, Fung, and Lau (2009) considered a vehicle routing problem with fuzzy time windows (VRPFTW). They applied trapezoid membership function to characterize the service level issues associated with time window violation and formulated VRPFTW as a multi-objective model with two goals: minimizing the travel distance and maximizing the sum of service levels of all customers. In order to find a Pareto solution, they developed a two-stage algorithm to decompose the original problem into two sub-problems, and sequentially followed these objectives to optimization (travel distance first, service levels second). Zhang and Li (2011) studied vehicle routing problem considering customer service preference. They described customers' preference for service in terms of the tolerable interval of service time, together with the desirable time for service. So they considered a fuzzy due time for each customer and solved the multi-objective problem with the following objectives: minimizing the fleet size of vehicles, minimizing the total traveling distance of the fleet, minimizing the average waiting time for vehicles and maximizing the average grade of satisfaction over customers. They proposed an insertion heuristic-based hybrid genetic algorithm in which the modified push-bump-throw procedure was employed to handle the fuzzy nature of the problem. Xu, Yan, and Li (2011) considered a multi-objective Vehicle Routing Problem with Soft Time Windows in a fuzzy random environment with the following objectives: minimizing the total travel cost and maximizing the average satisfaction level of all customers. They used the fuzzy random expected value concept to deal with the constraints and its equivalent crisp model was derived. They proposed the global–local–neighbor particle swarm optimization with exchangeable particles (GLNPSO-ep) to solve the equivalent crisp model. Zhang, Wang, Zhao, and Cattani (2012) proposed a self-adaptive grid multi-objective quantum evolutionary algorithm (MOQEA) for the Vehicle Routing Problem with Customers' Satisfaction. They represented the degree of customers' satisfaction by the membership function of the improved fuzzy due-time window, that is, an improved trapezoidal fuzzy number. In the MOQEA, the Challenge Cup rule was constructed for non-dominated solution set and a method for keeping the variety of the solution set was designed based on self-adaptive grid. Ghannadpour, Noori, and Tavakkoli-Moghaddam (2012) presented a multi-objective dynamic vehicle routing and scheduling problem with uncertainty in priority and request of customers. Their proposed model aimed at satisfying different customers according to their specific time windows as predefined by an expert as being very important, important, casual or unimportant. The total required number of vehicles, the total distance travelled and the waiting time imposed on vehicles were minimized, and the total customers' satisfaction for the service was maximized. They developed a solving strategy based on a GA. It consisted of three basic modules in which the state of the system, including the information of vehicles and customers at each time, was checked in the management module. The strategy module organized the information reported by the management module and constructed an efficient structure for solving in the subsequent module.

Some researchers have proposed methods other than the fuzzy set theory for the routing problems involving personal human feelings (customers' satisfaction). Wang and Li (2011) proposed a multi-objective VRP model with discrete variables in which two objective functions were run to minimize the total delivering path distance, while maximizing client satisfaction by fulfilling time-window requirements. In their model, the satisfaction levels of nodes to which goods were distributed were measured by comparing the arrival time of a vehicle with the time windows when delivery was requested. Moreover, the satisfaction level was higher in the case of early arrival time than in the case of late arrival given the same span beyond ready and due times. They developed a hybrid algorithm based on GA, incorporating some greedy algorithms to solve the problem. Fan (2011) proposed a tabu search algorithm for the vehicle routing problem with simultaneous pickup and delivery considering customer's satisfaction.

[1] Multi-Objective Quantum-inspired Evolutionary Algorithm.