Computers and Electrical Engineering 000 (2018) 1–15

Contents lists available at ScienceDirect

Computers and Electrical Engineering

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

An improved ant colony optimization for the multi-trip Capacitated Arc Routing Problem☆

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ARTICLE INFO

Article history:
Received 21 September 2017
Revised 27 January 2018
Accepted 29 January 2018
Available online xxx

Keywords:
Urban waste collection
Disposal facility
Multi-trip Capacitated Arc Routing Problem
Improved Max-Min Ant System
Taguchi design method

ABSTRACT

The urban waste collection problem and its disposal activities are among the most important municipal services involving many operational issues. In this paper, a mixed-integer linear programming (MILP) model was developed for the multi-trip Capacitated Arc Routing Problem (CARP) in order to minimize total cost. In the proposed model, depots and disposal facilities were located in different places. In order to validate the proposed model, several small-sized instances were solved by the CPLEX solver of GAMS software. Then, a hybrid algorithm using the Taguchi parameter design method was developed based on an improved Max-Min Ant System (IMMAS) to solve well-known test problems and large-sized instances. Computational results show high efficiency for the proposed algorithm.

1. Introduction

Nowadays, a variety of Municipal Solid Waste (MSW) is produced, and the outbreak of its pertaining social, economic and environmental incompatibilities has encountered municipal services management with many problems in the fields of collection, transportation, processing and disposing of such waste. Since 75 to 80 percent of solid waste management system costs concern collection and transportation of wastes [1], evaluation and optimization of this system play a significant role in reducing these costs. Waste must be collected, transferred and disposed in accordance with hygiene considerations in the fastest possible way. The most common way is to collect waste from residential houses and transport them directly to disposal facilities. Accordingly, the importance of optimizing waste management systems becomes more notable. Therefore, choosing the optimal policy of waste collection has an important effect on reduction in costs. In the routing problems defined for urban waste collection, two categories of problems are defined [2]. In the first category which is called Vehicle Routing Problem (VRP), a series of predetermined nodes are defined, the objective of which is to find the optimal routes that traverse all the nodes. In the second category which is called Arc Routing Problem (ARP), a number of edges are defined in the network, and the objective is to find the optimal routes that traverse all those edges. The urban waste collection is

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. G. Ramirez Gonzalez.
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https://doi.org/10.1016/j.compeleceng.2018.01.040
0045-7906/

organized as the latter category in real world applications. Waste is located along the edges (edges are streets or alleys that are sources of waste or demand). In ARP, capacities of vehicles are limited and will decrease when they move from one edge (alley/street) to another.

In this paper, a Capacitated Arc Routing Problem (CARP) is studied in urban waste collection under demand uncertainty. CARP is a classical combinatorial optimization problem that determines an optimal set of routes for vehicles to visit a subset of edges and/or arcs in a given network with respect to some specific constraints, where each edge typically denotes an alley/street in the real world [2]. As mentioned before, transportation costs are extremely high in urban waste collection, so decreasing transportation costs and the numbers of required vehicles is very important and constitutes the main objective of this paper. Despite the applicability of this subject and its importance in finding an effective solution for the proposed problem, few studies exist in the literature.

Beltrami and Bodin [3] presented one of the first routing problems related to urban waste collection. They applied the classic Vehicle Routing Problem (VRP) to waste collection in New York and Washington municipalities with considering different types of vehicles (i.e. trucks, trolley boats, tug ships, and mechanical vacuum). They were able to improve the Clarke and Wright algorithm in line with optimal route determination. The results were implemented in municipalities and yielded high benefits for both cities. Although VRP has been studied widely in the literature with various applications [4–6], CARP has more appropriate applications in studying waste collection and its routing problems.

Filippi and Pia [7] considered a new version of CARP with two different types of vehicles in which only one of them (first type vehicle) moves to the disposal facility. The second type vehicle would fill up the first type vehicle with waste. In this situation, the decisions needed to be made are the appointing of the meeting times for the vehicles at some places for unloading, as well as determining their optimal routes.

Polacek, Doerner, Hartl, and Maniezzo [8] considered a CARP with Intermediate Facilities (CARP-IF) and tour length restrictions to load up or unload the service vehicle. The objective is to find an optimal route for each vehicle, such that the total demand serviced by a vehicle between the depot and the first intermediate facility or between two intermediate facilities does not exceed the capacity of the vehicle. Ghiani, Laganà, Laporte, and Mari [9] solved a CARP-IF considering capacity and tour length constraints using a new Ant Colony Optimization (ACO) and an auxiliary graph. Experimental results indicated that their proposed algorithm was able to make significant improvements to the best-known heuristics. Grandinetti, Guerriero, Laganà and Pisacane [10] solved a CARP by a heuristic algorithm considering three minimization objectives of the transportation cost, the longest route and the number of used vehicles. Lacomme, Prins, and Tanguy [11] developed the first competitive version of the ACO algorithm for solving the CARP, which generates initial solutions using three heuristic algorithms and then, improves them by a local search approach. They managed to obtain appropriate results in terms of run times. Santos, Coutinho-Rodrigues and Current [12] proposed an improved ACO for solving the CARP. They made some modifications in the initial population generation, decision rules, and local search procedures. They implemented the algorithm for solving seven test problems in the literature and obtained good results.

Chen, Hà, Langevin, and Gendreau [13] presented a CARP to formulate a routing problem for evaluating the maintenance activities of a road network. They considered travel and service time to be stochastic. They developed the model using a chance constraint programming concept and solved it by applying a branch and bound algorithm.

Recently, Babaee Tirkolaee, Alinaghian, Bakhshi Sasi and Seyyed Esfahani [14] developed a robust CARP for a waste collection application using a Hybrid Simulated Annealing Algorithm (HSA). They showed that the performance of the proposed hybrid metaheuristic is acceptable. Tang, Wang, Li and Yao [15] proposed an efficient and scalable approach for CARP with the application to a waste collection problem. The mechanism of their approach is to hierarchically decompose the tasks involved in a CARP into subgroups and solve the induced sub-problems recursively by implementing local search.

In this research, a CARP with multi-trip vehicles was studied. Some of the main contributions of this paper are as follows:

(1) Presenting a novel mathematical model in which the locations of the vehicle depot and the disposal are separated, and the possibility of allocating multiple trips to a vehicle according to maximum available time is considered.
(2) Developing an efficient hybrid solution method based on an ACO algorithm and a heuristic algorithm to solve different-sized problems.
(3) Determining the optimal value for the parameters of the algorithm using the Taguchi design method.

The remainder of the paper is organized as follows: Problem definition and the mathematical model will be presented in Section 2. In Section 3 and 4, the proposed solution method to the problem and experimental results will be described respectively. Finally, Section 5 summarizes the results obtained in the research.

2. Problem definition

Based on public health and environmental aspects, waste should be disposed as soon as possible since it is a major source of contamination, otherwise, disease transmission, bad smells, and leachates leakage would cause severe pollution to the environment. These factors lead to endangering human health. So, in waste collection systems, waste disposal facilities are located outside of the urban area according to these environmental reasons and depots of waste collection vehicles are located in suburban areas.

Given an undirected graph $G = (V, E)$, where V is a set of nodes and E is a set of edges. Node number 1 denotes the depot, and node number n denotes the disposal facility. Moreover, there are K identical vehicles with a capacity of W_k. For each