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A robust periodic capacitated arc routing problem for urban waste collection considering drivers and crew's working time

Erfan Babaee Tirkolaee [a,*], Iraj Mahdavi [a], Mir Mehdi Seyyed Esfahani [b]

[a] Department of Industrial Engineering, Mazandaran University of Science & Technology, Babol, Iran
[b] Department of Industrial Engineering, Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

In this paper, a novel mathematical model is developed for robust periodic capacitated arc routing problem (PCARP) considering multiple trips and drivers and crew's working time to study the uncertain nature of demand parameter. The objective function of the proposed model aims to minimize total traversed distance and total usage cost of vehicles over a planning period. To solve the problem, an improved hybrid simulated annealing algorithm (SA) is developed based on a heuristic algorithm and an efficient cooling equation. It has been proved that the performance of the proposed algorithm is acceptable in comparison with the exact solution method. Finally, the results have shown the effects of different uncertainty level of the demand parameter on the problem to be considered as a managerial overview in decision making process under uncertainty.

1. Introduction

Nowadays, generating different types of solid wastes and manifestation of their associated social, economic and environmental inconsistencies create numerous complications for urban service management in regard to the collection, transportation, processing and disposal of such wastes. An optimal planning in collecting, management, and disposal of urban waste are one of the most important strategies that can yield multiple improvements in both total cost and health.

Due to the fact that 60–80 percent of costs of solid wastes management are related to collecting and transporting them (Lifset, 1992), the evaluation of underlying collection and transportation system plays a significant role in reducing and solving the problems of urban service management (Golden et al., 2002). The wastes should be collected, transported and disposed in the least time, through the best method, and directly from household areas to disposal sites. Based on the above discussions, the significance of an optimal system of waste collection becomes more highlighted. Therefore, selection of optimal policy of waste collection has a significant impact on reducing costs.

In routing problems related to the urban wastes collection, two categories of problems are defined (Golden et al., 2002). In the first category, there is a predefined node series with positive demand and the objective is to find the best tours which cover all nodes-Capacitated Vehicle Routing Problem (CVRP). In the second category, a series of predefined edges is existed with positive or zero demand and the objective is to find the best tours covering all required edges (edges with positive demand)-Capacitated Arc Routing Problem (CARP).

Although VRP has been studied widely in the literature with numerous applications (Tirkolaee et al., 2017; Mirmohammadi et al., 2017; Alinaghian et al., 2014), the CARP has more appropriate application in studying waste collection and its routing problems (Babaee Tirkolaee et al., 2016). So, the second category is the problem being studied in this research. In this problem, wastes are along the edges (i.e. streets or alleys with demands). In addition, the capacity of vehicles is limited and when vehicles traverse the required edges, their remained capacities decrease. Drivers and crew's working time is another important parameter which has a great impact on determining the number of required vehicles besides the capacity constraints. The objective is defined to determine the optimal routes of serving the required edges based on a daily planning in a week.

In the following, important research in the literature of CARP for urban waste collection has been reviewed and described.

Chu et al. (2005) introduced a periodic capacitated arc routing problem (PCARP) in order to provide a weekly planning horizon. They proposed a mathematical model based on a mixed integer linear programming (MILP) and solved the problem through two innovative methods. The objective was to assign a set of service

* Corresponding author.
E-mail address: e.babaee@in.iut.ac.ir (E.B. Tirkolaee).

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days to each edge in a defined network and solving the resulting routing problem for each period to minimize the size of the required fleet of vehicles and total traversing cost during the predefined time horizon.

Lacomme et al. (2005) developed a periodic capacitated arc routing problem (PCARP) for practical applications such as collecting waste. They describe few models of PCARP with a simple categorization scheme. For instance, they defined that the demand of each arc might be dependent upon the planning period or the last date of service. They used an evolutionary algorithm (EA) based on a complex intersection operator to simultaneous modify and apply operational and tactical decision makings such as service days and day trips. Pia and Filippi (2006) introduced a version of capacitated arch routing for two types of vehicles in which the first type of vehicle could unload at the base while the second type unloads its wastes into the vehicles of the first type. In their developed problem, determination of optimal routes is accompanied by optimal decision-making for two types of vehicles. They solved this problem by developing a variable neighborhood descent algorithm (VND).

Fleury and Lacomme (2004, 2005) formulated a stochastic arc routing problem (SCARP) appropriate for urban waste collection in which some parameters such as demand, vehicles travel time are considered to be stochastic. They developed some EAs to solve the SCARP. After them, Laporte et al. (2010) presented a CARP problem considering stochastic demands. They solved the problem by a neighborhood search heuristic algorithm. They could prove the efficiency of their proposed algorithm.

Ramos et al. (2013) proposed a MILP formulation for a Multi-Depot Vehicle Routing Problem with Mixed Closed and Open Inter-Depot Routes where capacity and duration constraints are taken into account. They applied their model to a real case study and could create some savings in route planning. Son and Louati (2016) proposed a generalized vehicle routing model including multiple transfer stations, gather sites and inhomogeneous vehicles in time windows for Municipal Solid Waste (MSW) collection. They could show that their model reduces both total traveling distances and operational hours of vehicles in comparison with those of practical scenarios after applying a case study to the model.

Babaee Tirkolaee et al. (2016) developed a robust CARP for a waste collection application using a hybrid simulated annealing algorithm. They showed that the performance of the proposed hybrid metaheuristic is acceptable.

Akhtar et al. (2017) developed a Backtracking Search Algorithm (BSA) in CVRP models considering the smart bin concept to determine the best optimized waste collection routes. Their aims were to minimize the sum of the waste collection route distances. They create significant savings by solving their proposed model in comparison with a conventional condition. Recently, Tirkolaee et al. (2018) developed a MILP model for the multi-trip CARP in order to minimize total cost. They proposed a hybrid algorithm on an improved Max-Min Ant System (IMMAS) to solve well-known test problems and large-sized instances. They could demonstrate the high efficiency of their algorithm.

This paper is a development study for the previous research done by Babaee Tirkolaee et al. (2016) in order to cover its research gaps such as considering multiple trips and drivers and crews working time. The aim is to develop a novel mathematical model for the robust multi-trip PCARP regarding the waste collection problem in order to minimize the total cost (the usage cost of vehicles and traversing cost of the edges) considering the demand uncertainty of the required edges and working time of drivers and crew besides vehicles' capacity constraints in order to study the real world assumptions existed in the problem which has not been considered before. This proposed model constructs a general framework to be applied in each real case. The aim is to determine the optimal number and the optimal routes of the vehicles in each time period.

Since the proposed problem is a complicated version of the classic CARP, it would be an NP-hard problem (Golden and Wong 1981). Hence, a hybrid Simulated Annealing (SA) algorithm is developed using a constructive heuristic and an efficient cooling equation to solve the problem.

2. Model development

The problem is to determine the optimal number of vehicles the optimal tour for each vehicle including possible multiple trips with regard to the objective function which minimizes the usage cost of vehicles and the traversing cost of all traversed edges in all time periods of planning. In this problem, the vehicles are located in the depot, firstly. They begin their tour in order to service the required edges through collecting wastes and then, return to the depot after filling their capacity. The capacity constraint of vehicles and their maximum available times result in determining the number of required vehicles. In fact, drivers and crew's working time denotes the maximum available time considered for each vehicle. Moreover, since the demand parameter is considered to be uncertain, the robust model is presented based on the interval robust optimization approach introduced by Bertsimas and Sim (2004).

2.1. Problem assumptions

- The objective function, in addition to the minimization of traversing cost of the edges, is to minimize the number of required vehicles to meet the total demand.
- Each required edge is serviced only by one vehicle. Also, only one depot is considered in the problem.
- The vehicles are heterogeneous and the graph network is asymmetric. Each vehicle begins the tour from the depot and returns there finally.
- Each type of vehicle has a unique average speed and waste loading time on each edge.
- The traversing time and the waste loading time are different for each vehicle.
- Vehicle usage cost is the cost paying to the driver and related crew for each vehicle.
- Each vehicle has a maximum duration of service denoting the working time of its driver and crew.
- Each vehicle may have multiple trips.
- There is a time horizon for planning. The planning horizon is a week. Each required edge should be serviced every day. The collection planning of each vehicle is determined optimally for each week on a daily basis.
- Each required edge needs to be serviced in each period.
- The demand of required edges fluctuates in a given uncertainty interval.

2.2. Sets, parameters, and variables

In this section, the robust model of the proposed problem is presented. For this purpose, sets, parameters, and variables are defined firstly. Then, the theoretical basis of the robust optimization is described and finally, the robust model is presented.

Sets

V: Set of the nodes in the graph network
K: Set of the vehicles
E: Set of all the edges defined in the network