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Location arc routing problem with inventory constraints

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ABSTRACT

Dust suppression of hauling roads in open pit mines is done by periodically spraying water from a water truck. The objective of this paper is to present and compare two methods for locating water depots along the road network so that penalty costs for the lack of humidity in roads and routing costs are minimized. Because the demands are located on the arcs of the network and the arcs require service more than once in a time horizon, this problem belongs to the periodic capacitated arc routing domain. We compare two methods for finding the initial depot location. We then use an exchange algorithm to modify the initial location and an adaptive large neighborhood search algorithm to modify the initial routing of vehicles. This method is the first one used for depot location in periodic arc routing problems.

1. Introduction

1.1. Location arc routing problems

Arc routing problems deal with operational decisions on how to find the routes that satisfy a set of customers located on the arcs of a network while minimizing the routing cost associated with it. When the objective is to determine the best location of a set of depots so that routing costs are minimized, the problem becomes a location arc routing problem (LARP). Both decisions, locating depots and finding routes to serve customers, are done simultaneously [13].

A classification of location routing problems can be found in [15]. Although many examples refer to location problems in the context of node routing problems, i.e. the demands are located on the nodes of a network, some applications can be found in the arc routing domain. A review of the methods used in location arc routing problems can be found in [16].

The first LARP application was presented by Levy and Bodin [13] in 1989 to find the best location for postal carriers to park their vehicles so that they can perform a tour to deliver mail. The authors introduced a location, allocation and routing (LAR) approach in which locations for the depots are selected, then the edges to be served are assigned to each depot and finally a route is built to serve those edges. Ghiani and Laporte [7] approached the Location Rural Postman Problem (LRPP) by transforming it to a Rural Postman Problem (RPP) when there are no bounds on the number of depots and by using a branch and cut method to solve it. Ghiani and Laporte [8] reviewed the common applications of LARP, such as mail delivery, garbage collection and street maintenance. The review covered common heuristics used to solve LARP problems that include the above mentioned LAR as well as the ARL, in which customers are first assigned to a vehicle route, then the route is formed and finally, depot locations are determined.

Other applications where location decisions are made in the arc routing domain include garbage collection using mobile depots [6]. Small capacity trucks move along the streets, collecting garbage and delivering their contents into the larger trucks used as temporary depots. The authors use a variable neighborhood descent to schedule meetings of both types of vehicles so that the small trucks reduce the number of returns to the main depot. A similar application was presented in [1], where one type of vehicles is used to paint street lines while a second type is used to refill at specific points in the network.

For this work, we consider an arc routing problem in which a fleet of identical vehicles with limited capacity provide service to the edges of the network. The edges need to be visited more than

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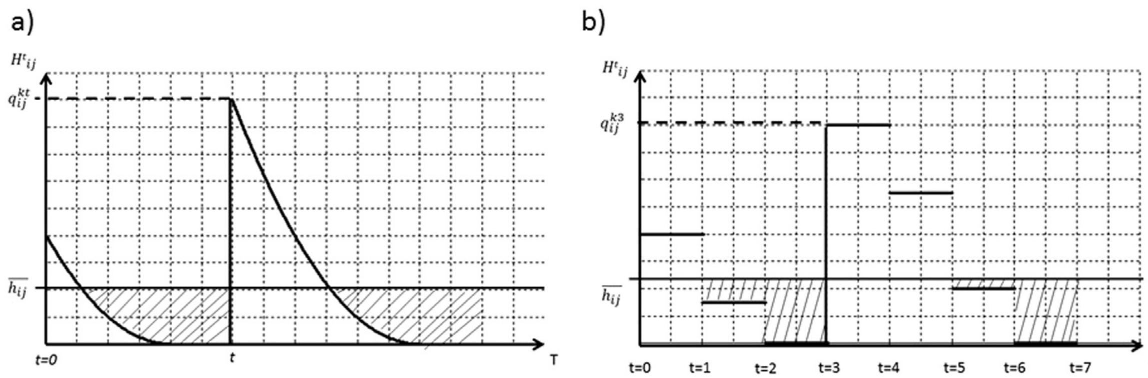

Fig. 1. Humidity level of edge (i,j).

once in a time horizon. Because several visits are scheduled, the vehicles need to go back to the depot in order to refill and start a new route. This problem is called periodic capacitated arc routing problem (PCARP). The objective is to locate a number of depots along the network so that the refill process can be improved.

1.2. Periodic capacitated arc routing problem

The periodic capacitated arc routing problem, or PCARP, was introduced in [12] for a garbage collection problem in which the demands on the arcs were different from one period to the next one, and a solution was needed for the whole time horizon instead of for individual periods. This problem was shown to be NP-hard because it contains the capacitated arc routing problem (CARP) as a special case [12]. CARP was shown to be NP-hard in [9]. Some applications of the PCARP that have been studied in literature include the already mentioned garbage collection, road monitoring [17] and road maintenance and surveillance [19]. Due to the complexity of the problem, heuristic and metaheuristic algorithms have been used to solve large PCARP instances, including three heuristic algorithms proposed in [2], a memetic algorithm [11], a scatter search algorithm [3] and an ant colony optimization algorithm [10].

A special case combines the PCARP problem and inventory control (PCARP-IC). The arcs of a network act as customers that require certain quantity of material in stock. The inventory is replenished periodically by means of delivery vehicles with limited capacity. Vehicles return to a depot for refill and start a new delivery route. Applications include the dust suppression in open-pit mine roads [14] and [23] and plants watering in street medians and sidewalks. This problem was introduced as such in [23]. The authors propose a mathematical model which is capable of solving small instances. An adaptive large neighborhood search was proposed to solve larger instances of this problem in [24]. In order to accelerate the refill of vehicles, depots are strategically located along the network. To the best of our knowledge, location decisions have not been studied for a periodic capacitated arc routing problem. The only studies combining location and routing decisions for periodic applications are presented in [21] and [22]. Both refer to node routing problems.

The methodology presented in this paper is based on the mathematical model proposed in [23] and the heuristic algorithm developed in [24] for the problem presented in [23]. Both articles address the routing problem but not the depot-location problem. The contribution of this paper is a solution approach to the location problem in the periodic arc routing domain.

The paper is divided as follows: in Section 2, the definition of the problem of road watering in open-pit mines is presented as well as the mathematical model. The solution algorithm is presented in Section 3. Test results are shown in Section 4. Finally, concluding remarks are presented in Section 5.

2. Mathematical model

2.1. Road humidity and dust retention

In open-pit mines, when vehicles travel along the roads, dust clouds are formed. The most cost-effective method for suppressing dust in these temporary roads is to periodically spray water over them [20]. Due to evaporation and traffic volume, humidity is lost and needs to be replenished. The roads in the network can be traversed in any direction. They are classified according to their priority, where the roads with higher traffic volume have a higher priority. Consider a graph $G(N, E)$ where N is the set of nodes and E is the set of edges that represent the roads. A penalty cost is assigned for having a lower level of humidity than the required one to ensure dust particle retention. Fig. 1 shows the humidity level, H^t_{ij}, of edge $(i, j) \in E$. $\overline{h_{ij}}$ is the required level of humidity to ensure dust retention for edge $(i, j) \in E$. After a quantity of water, q^{kt}_{ij}, is delivered by vehicle k at time t, humidity is consumed until the next service. Fig. 1a shows the shortage of humidity that occurs when H^t_{ij} is less than $\overline{h_{ij}}$. Fig. 1b shows the same situation for a discretized time horizon divided in time periods of equal duration. H^t_{ij} is considered to be constant during a time period.

Because water trucks have a limited capacity, they reload at a depot before starting a new route. The objective is to find the location of water depots along the mine road network so that the penalty cost for lack of humidity and the routing cost are minimized. For this problem, we consider that the depots can handle any number of vehicles.

This problem combines strategic and operational decisions. The placement of depots is a long term decision, therefore, the performance of the vehicles is tested on different scenarios. A scenario is created when the values of some parameters are changed. For example, at the beginning of the time horizon the roads may have different levels of humidity. Each initial humidity level represents a scenario.

2.2. Mathematical model

The model presented in this section is based on the model presented in [24] that aims to minimize operational costs such as penalty and routing costs when one depot and a fleet of identical vehicles are considered. We include both of these costs tested under different scenarios in order to minimize long term costs such as vehicle and depot placement.

Consider a time horizon that corresponds to one working shift divided in T time periods. A time period is the amount of time it takes a water truck to cover a constant distance D at a constant