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New integer programming formulation for multiple traveling repairmen problem

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Abstract

The multiple traveling repairman problem (kTRP) is a generalization of the traveling repairman problem which is also known as the minimum latency problem and the deliveryman problem. In these problems, waiting time or latency of a customer is defined as the time passed from the beginning of the travel until this customer's service completed. The objective is to find a Hamiltonian Tour or a Hamiltonian Path that minimizes the total waiting time of customers so that each customer is visited by one of the repairmen. In this paper, we propose a new mixed integer linear programming formulation for the multiple traveling repairman problem where each repairman starts from the depot and finishes the journey at a given node. In order to see the performance of the proposed formulation against existing formulations, we conduct computational analysis by solving benchmark instances appeared in the literature. Computational results show that proposed model is extremely effective than the others in terms of CPU times.

Keywords: *Traveling repairmen; traveling salesman; minimum latency; routing; modeling*

1. Introduction

The Traveling Salesman Problem (TSP) is the basis of the routing problems. The Traveling Repairman Problem (TRP) which is also named as the minimum latency problem, the cumulative traveling salesman problem or the traveling deliveryman problem (Silva et al., 2012) is a special type of routing problem. In these problems, waiting

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time or latency of a customer is defined as the time passed from the beginning of the travel until this customer's service completed is. The Multiple Traveling Repairman Problem (kTRP) is a generalization of the TRP hence the Minimum Latency Problem finds *k* tours or paths, each starting at the depot and covering all the nodes while minimizing total waiting time (latency). Applications of this problem can be found in home delivery of pizzas, emergency aid logistics, routing automated guided vehicles in a flexible manufacturing system, school bus routing and minimizing average flow time for jobs of scheduling machines (Fischetti et al., 1993). It has been shown kTRP is NP-hard (Tsitsiklis, 1992; Archer and Williamson, 2003). Thus, solution strategies for kTRP are concentrated on the exact solution procedures by Picard and Queyranne (1978), Lucena (1990), Simchl-Levi and Berman (1991), Bianco et al. (1993), Fischetti et al. (1993), Eijl (1995), Wu et al. (2004) and/or heuristics by Blum et al. (1994), Goemans and Kleinberg (1998), Ausiello et al. (2000), Arora and Karakostas (2003), Chaudhuri et al. (2003), Nagarajan and Ravi (2008), Salehipour et al. (2011), Ngueveu et al. (2010) and Dewilde et al. (2010).

There exist a few formulations for finding the optimal solution of the problem directly in the literature. Sarubbi et al. (2008) applied for the minimum latency problem the model proposed by Picard and Queyranne (1978) for the time-dependent the traveling salesman problem. Kara et al. (2008) developed a mixed integer linear programming formulation for the minimum latency problem. Mendez-Diaz et al. (2008) suggested an integer programming formulation for the traveling deliveryman problem. Angel-Bello et al. (2013) developed two integer programming formulations for TRP. They reviewed existing formulations and conducted a comparative computational analysis of the formulations. They conclude that one of the new formulations named as model A is superior to the others. The emerging developments in the information technology allow us to find optimal solution of some routing problems directly by using a suitable software and user friendly formulations. Recently, Kara and Derya (2015) found the shortest tour time of 400-node traveling salesman problem with time windows within seconds using CPLEX 12.5. Those developments motivate us to develop new mathematical models for the k-traveling repairman problem.

In this paper, we adapt model A of Angel-Bello et al. formulation to the k-traveling repairman problem and we compute the performance of this formulation against the existing k-traveling repairman formulations. The main contribution of this paper is to present a new polynomial size integer programming formulation for the k-traveling repairman problem that can be used to find optimal solutions of the real life problems.

In Section 2, we present the definition and application of the k-traveling repairman problem and we investigate the existing formulations of the k-traveling repairman problem in the literature. We propose a new mathematical model for the k-traveling repairman problem in Section 3. We conduct computational analysis of the proposed model against existing models and summarize the results in Section 4. Concluding remarks are outlined in Section 5.

2. Problem identification and existing formulations

Given a network G = (V, A) where V= {1, 2… n} is the node set of the customers, {0} is the depot and {n} is the terminal node. A = {(i, j): i, j $\in$ V, i $\neq$ j} is the set of arcs. d_{ij} is the time of the travel from the node *i* to the node *j*. *k* is the number of identical travelers. x_{ij} is the decision variable. x_{ij} = 1 if the arc (i, j) is on the repairman, and zero otherwise.

With those given above, we define k-TRP as:

- Each node (customer) is served exactly by one traveler,
- Each route starts from the depot and ends at the terminal node,
- The objective is to find a set of k traveler routes of minimum total time passed until the all customers served.

The mathematical models of the k-repairmen problem in the literature are explained in this Section. Kara et al. (2008), by defining additional arc based decision variables y_{ij} as;

y_{ij} = if the arc (i,j) is on the path then this variable shows the sequence of node j from the end, and zero otherwise. Their formulation has O(n^2) binary variables and O(n^2) constraints. We named this formulation as M1 and used in computational analysis.

Luo et al. (2014), defined node based decision variables u_{ik} as the arriving time of vehicle k to node i and then presented an integer programming formulation. This model has exponential number of constraints, thus it is insufficient for direct use with an optimizer.