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Innovative Applications of O.R.

The windy rural postman problem with a time-dependent zigzag option

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In this research, we focus on the windy rural postman problem with the additional option to zigzag street segments during certain times of the day. If a street is narrow or traffic is light, it is possible (and often desirable) to service both sides of the street in a single pass by zigzagging. However, if a street is wide or traffic is heavy, we must service the street by two single traversals. For some streets, we further impose the restriction that they may only be zigzagged at specific times of the day, e.g., in the early morning when there is virtually no traffic. Real-life applications arise, among others, in trash collection and newspaper delivery. This specific arc routing problem combines two classes of problems known from the literature, arc routing problems with zigzag options and arc routing problems with time dependencies. We present and discuss two (mixed) integer programming formulations for the problem at hand and suggest exact solution approaches. Furthermore, we analyze the effects of zigzag and time window options on the objective function value and test our solution approaches on real-world instances.

1. Introduction and Problem Description

There have been many papers published on arc routing topics over the last several decades; see Corberán and Laporte (2014) for a comprehensive treatment of this research area. In this paper, we focus on one important class of arc routing problems, called the windy rural postman problem (WRPP), with several practical extensions.

In the WRPP, some (not necessarily all) of the streets in a network must be serviced and the street distances are asymmetric. Furthermore, we consider the additional option to zigzag street segments during certain times of the day. If a street is narrow or traffic is light, it is possible (and often desirable) to service both sides of the street in a single pass by zigzagging. However, if a street is wide or traffic is heavy, we must service the street by two single traversals. For some streets, we further impose the restriction that they may only be zigzagged at specific times of the day, e.g., in the early morning when there is virtually no traffic. This variation was first suggested by Golden (2013). We point out that, in this paper, we consider time windows with upper bounds only (lower bounds are always 0). This reflects the real-world environment in which zigzagging could only happen in the early morning hours.

Real-life applications arise commonly in trash collection and newspaper delivery. This specific arc routing problem combines two classes of problems known from the literature, arc routing problems with zigzag options and arc routing problems with time dependencies. We present and discuss two (mixed) integer programming formulations for the problem at hand and suggest exact solution approaches. Furthermore, we analyze the effects of zigzag and time window options on the objective function value and test our solution approaches on real-world instances.

Based on our experiments and analysis, we make at least two key observations. The first is that this is a very computationally challenging problem, especially when there are numerous time windows and/or the time windows are narrow in width. The second is that the presence of zigzag options, both with and without time windows, can result in dramatic route changes and cost savings.

We now present an example in Fig. 1 to motivate the use of zigzags with and without time windows. In Fig. 1(a), we have an arc routing problem instance. There are five nodes. Node 0 is the

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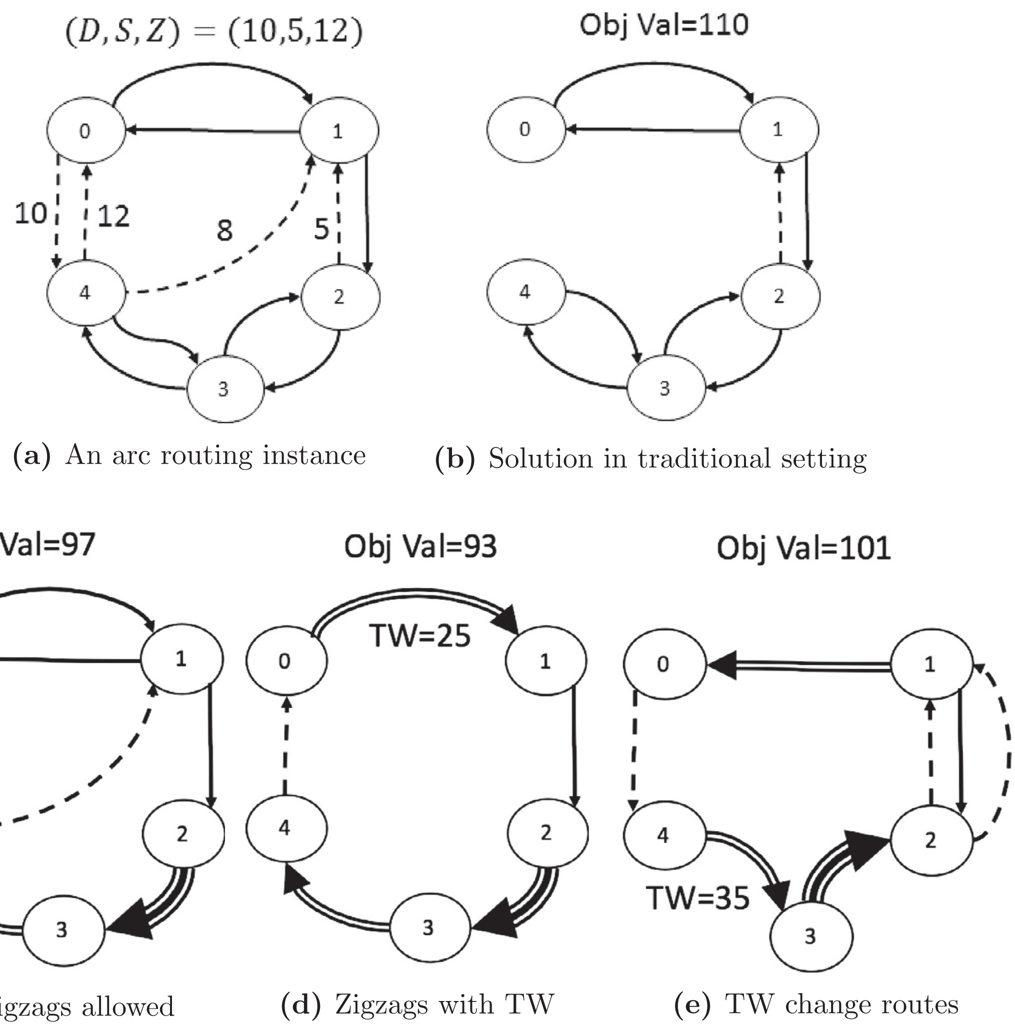

Fig. 1. A motivating example (TW: time windows).

depot. Solid lines represent arcs which require service. For simplicity, in this instance, all solid lines have travel time $D = 10$, normal service time $S = 5$, and service time in zigzag (zigzag time) $Z = 12$. Dashed lines are arcs over which one can travel. The number besides a dashed line is its travel time. For instance, for arc (0, 4), the travel time is 10. If we solve this instance as a traditional arc routing problem, the optimal route is shown in Fig. 1(b) and its objective value is 110. Notice that arcs (0, 4), (4, 0), (4, 1) are not used in this solution although they can be shortcuts to access node 0. Now, if we require zigzagging on segment {2, 3} (one segment $\{i, j\}$ consists of two arcs (i, j) and (j, i)) and allow segment {3, 4} to be zigzagged, the route in Fig. 1(c) is now optimal and the objective value is 97. Here, the double-line arc and the triple-line arc represent zigzagging an edge which is zigzag possible and zigzag required, respectively. Furthermore, if segment {0, 1} can be zigzagged before time 25, we can obtain an even better route (see Fig. 1(d)). The objective value is reduced to 93. Lastly, these zigzags with time windows can change a route dramatically. If we allow the same three segments to be zigzagged, but a time window is imposed on segment {3, 4}, instead of segment {0, 1}, then a very different result is obtained. For example, if we can zigzag on segment {3, 4} before time 35, then the optimal route is changed to be the one in Fig. 1(e) with objective value 101.

This is the first paper to present models and solution approaches for an arc routing problem that combines zigzag options and time-dependencies. Furthermore, we study the impact of zigzag options and zigzag time, based on real-world data. The plan for the remainder of this paper is as follows. A review of the literature is provided in Section 2. Mathematical formulations are presented in Section 3. Our computational study is presented in Section 4. In Section 5, we discuss our conclusions and mention some ideas for future research.

2. Literature review

The WRPPZTW (windy rural postman problem with zigzags and time windows) combines two variants of arc routing problems, arc routing problems with zigzag options and arc routing problems with time dependencies/constraints. In what follows, we will summarize the relevant literature of both variants; we present a literature overview in Fig. 2.

A limited amount of literature has been published on arc routing problems with time dependencies. These dependencies relate, e.g., to service and travel times or costs that change over time or to time windows that are imposed to denote when a service on a required arc has to start or end (see Fig. 2). Most of these arc routing problems are addressed from a node routing perspective. A common modeling approach in node routing problems with time constraints is to incorporate a time variable for each customer to capture the starting time of its service (e.g., see Toth & Vigo,