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A dynamic capacitated arc routing problem with time-dependent service costs

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ABSTRACT

This paper describes a dynamic capacitated arc routing problem motivated from winter gritting applications. In this problem, the service cost on each arc is a piecewise linear function of the time of beginning of service. This function also exhibits an optimal time interval where the service cost is minimal. Since the timing of an intervention is crucial, the dynamic aspect considered in this work stems from changes to these optimal service time intervals due to weather report updates. A variable neighborhood descent heuristic, initially developed for the static version of the problem, where all service cost functions are known in advance and do not change thereafter, is adapted to this dynamic variant.

1. Introduction

In the capacitated arc routing problem (CARP), a set of required arcs, each with an associated demand, is served at minimum cost with a fleet of vehicles of finite capacity based at a given depot. The CARP occurs in real-world applications when street segments are served, like winter gritting and street sweeping, or when the demand is aggregated over a number of locations along a street segment, like postman problems. In the classical version of the problem, there is a fixed cost associated with each arc for traveling on this arc or for serving it. In the time-dependent variant of the problem, the service cost on a required arc is also a function of the time of beginning of service.

It is worth noting that a number of transformations of CARPs into node routing problems are reported in the literature (e.g., Longo et al., 2006; Pearn et al., 1987; Tagmouti et al., 2007), because node routing has been much more studied than arc routing. Accordingly, a large and diverse set of problem-solving methods for node routing problems is readily available and can be applied to CARPs after the transformation. On the other hand, it is much easier to exploit the characteristics of a problem by working on its original formulation, as empirically demonstrated in Tagmouti et al. (2008).

Winter gritting was first modeled as a CARP in Eglese and Li (1992). The authors discuss routing efficiency issues based on different network characteristics. For example, the presence of *T*-junctions in rural networks and one-way streets and highways in urban networks are shown to significantly impact routing efficiency measures. In Eglese (1994), a winter gritting problem is reported where a number of salt depots are located on the network for vehicle replenishment. The problem is solved with simulated annealing, using a savings-based heuristic to generate the starting solution (Clarke and Wright,

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1964). In Li and Eglese (1996), the authors propose a two-phase construction heuristic. After selecting an arc to initialize a route, new arcs are inserted in the first phase by going backward from the node at one end of the selected arc back to the depot. In the second phase, arcs are inserted by going forward from the node at the other end of the selected arc to the depot. In Muyldermans et al. (2002), the authors first divide the service area into districts that are served from the same depot. Then, routes are constructed in each district with the Augment-Insert heuristic (Pearn, 1991). In Lotan et al. (1996), a combined depot location-arc routing problem is reported.

Apart from winter gritting, other real-life problems modeled as CARP are:

- *Street sweeping*: This problem was first studied in Bodin and Kursh (1978, 1979). In this work, each arc has to be serviced within a given time window.
- *Electric meter reading*: The "capacity" constraint here comes from the fact that each employee has a work time limit, see Stern and Dror (1979).
- *Refuse collection*: This problem, first considered in Bodin et al. (1989), is a CARP with two-dimensional capacity constraints due to a true capacity constraint for each vehicle and a work time limit for each driver.
- *Snow removal*: This problem was addressed in a rural context in Haslam and Wright (1991). In this work, the authors both consider the minimization of operating costs and the maximization of road safety while the snow is being removed.

These real-life problems have all been studied in a static context, where it is assumed that all data about the problem are known in advance. However, this is not necessarily the case in real-word applications, where some information might not be readily available when the vehicles start their routes. When new information is unveiled as the routes are executed, the problem becomes dynamic. Although there is a fair number of papers on dynamic node routing problems, particularly with regard to the integration of new customer requests into vehicle routes (Ghiani et al., 2003; Ichoua et al., 2000; Psaraftis, 1995), dynamic CARPs have not attracted yet the attention of the research community. There is, however, a few work on the CARP with stochastic demands, where the demands are described by random variables, see Fleury et al. (2004, 2005), Christiansen et al. (2009). In this case, an expected cost can be optimized if an appropriate recourse strategy is defined to handle route failures (i.e., when the actual accumulated demand happens to exceed vehicle capacity).

In the dynamic CARP addressed here, weather report updates lead to modifications to the optimal time of beginning of service on each required arc and thus, to dynamic modifications to the current routes. The service cost function considered on each required arc is a piecewise linear function of the time of beginning of service. This function also exhibits an optimal time interval where the service cost is minimal (Tagmouti et al., 2007).

The paper is organized as follows: In Section 2, the static version of the problem is formally introduced and the variable neighborhood descent (VND) heuristic proposed in Tagmouti et al. (2008) to solve it is briefly described. In Section 3, the dynamic variant is introduced, followed by a description of the corresponding adaptation of the VND. In Section 4, the problem generator to run the tests is detailed and numerical results are reported.

2. The static problem

2.1. Problem definition

Let $G = (V, A)$ be a directed graph, where V is the vertex set and A is the arc set, which is partitioned into a subset of required arcs A_1, and a subset of non required arcs A_2. With each required arc $e \in A_1$ is associated a demand d_e, a length l_e, a travel time tt_e, a service time st_e, a travel cost tc_e and a time-dependent piecewise linear service cost function $sc_e(T_e)$, where T_e is the time of beginning of service on arc e. The arcs in A_2 have a length, a travel time and a travel cost only. A set of K identical vehicles, each with capacity Q, is available to serve the required arcs. The service is performed along a route without any waiting time from one required arc to the next (as typically observed in winter gritting applications).

The objective is to serve all required arcs in the graph with least-cost feasible routes, where the cost is the sum of service costs and travel costs. More precisely, let r_k be the route traveled by vehicle k, which is made of required arcs $(e_1, \ldots, e_l)$ and deadhead arcs $(e_{l+1}, \ldots, e_{l+p})$. The route cost is then:

$$C(r_k) = \sum_{i=1}^{l} sc_{e_i}(T_{e_i}) + \sum_{i=l+1}^{l+p} tc_{e_i}. \quad (1)$$

Fig. 1 shows two typical piecewise linear service cost functions. The type illustrated in Fig. 1b, where the flat portion corresponds to the optimal service time interval, is the one used in our computational experiments.

2.2. Problem-solving methodology

The problem-solving methodology for solving the static version of the problem is a Variable Neighborhood Descent (VND) heuristic (Tagmouti et al., 2008). We briefly restate it here for the sake of completeness.