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Solving the mobile mapping van problem: A hybrid metaheuristic for capacitated arc routing with soft time windows

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A B S T R A C T

Creating digital maps often requires driving around the streets in a so-called “mapping van”. Tele Atlas, the world leading supplier of maps and map data, uses a fleet of such vehicles to take pictures of streets and road signs. Minimising the number of days that a vehicle needs to traverse all streets in a given region gives rise to a capacitated arc routing problem. A specific characteristic of this problem, however, is the fact that taking pictures in the direction of the sun should be avoided as much as possible. This requirement adds soft time windows to the problem.

In this paper we solve the mobile mapping van problem by transforming it into a vehicle routing problem with soft time windows. We then apply a hybrid metaheuristic, consisting of a local search phase to decrease the number of days and an iterated local search phase to minimise the time window violations. An exact linear programming solver is embedded to calculate the ideal starting time of the vehicle in each street.

Our method is tested on academic and real-life problem instances and shown to be effective.

1. Introduction

Tele Atlas is the world leading supplier of geographical data. To update and improve its data, “mobile mapping vans” (see Fig. 1) drive around to take pictures of streets and road signs. Afterwards, these pictures are analysed and the information collected is used to update the map database. In order to save costs, Tele Atlas aims to minimise the number of days required to travel through all the streets in a certain region, using a single van. Determining the order in which to drive through each street in a certain region is the objective of this paper.

Tele Atlas distinguishes three different street types, that have to be traversed in different ways. In a one way street, pictures can only be taken while driving in the driving direction. In a relatively narrow two way street, pictures can be taken in both directions at the same time. To cover a broad two way street—in which the two driving directions are separated by a berm for example—the van has to drive through the street in both directions. Such broad two way streets can be modelled as two one way streets.

The problem to minimise the total time required to travel through all streets can be modelled as a mixed capacitated arc routing problem (MCARP), in which the roads in the network can either be undirected edges (narrow two way streets) or directed arcs (one way streets or broad two way streets that have been modelled as two one way streets).

Besides minimising the number of days, Tele Atlas wants to minimise the number of pictures taken towards the sun, since many of these pictures are useless. As a result, many streets can only be successfully traversed during a certain time of the day. This extra objective can be modelled with soft time windows, based on the orientation of the streets. Taking pictures towards the sun, i.e. violating the time window, will be penalised in the objective function. Note that Tele Atlas does not require vans to completely avoid driving towards the sun. If that was the case, this problem should be modelled with hard time windows.

In order to solve the MCARP with soft time windows efficiently, the problem is first converted to a vehicle routing problem with soft time windows (VRPSTW). This technique is based on a technique, described in the literature [1,2,13,17], to convert an undirected CARP into a VRP, and which has proven to work well before.

The remainder of this paper is organised as follows. In the next section, a short literature review is presented. In Section 3, the problem formulation and the transformation to a VRPSTW is discussed.

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Fig. 1. A Tele Atlas "mapping van".

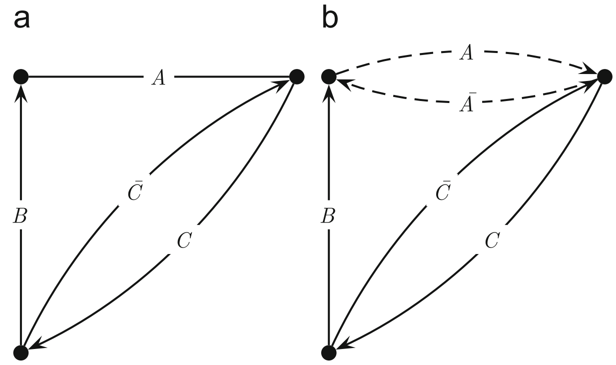

Fig. 2. An edge (A) is transformed into two arcs (A and $\bar{A}$), of which only one needs to be traversed. (a) Example road network with undirected edges and directed arcs. (b) Example road network with edges replaced by arcs.

Section 4 describes the solution procedure and in Section 5 experimental results are discussed. Section 6 concludes this paper and adds suggestions for further research.

2. Literature review

The problem discussed in this paper is a capacitated arc routing problem with soft time windows. Arc routing has recently received a large amount of research interest, but arc routing with time windows is still a relatively underexplored subject, although some metaheuristic optimisation approaches exist. Aminu and Eglese [1] tackle the Chinese postman problem with time windows using a constraint programming approach. They develop two approaches, one of which tackles the problem directly, whereas the other transforms the problem into a node routing problem. Brandão and Eglese [4] develop a tabu search heuristic for the capacitated arc routing problem. Labadi et al. [12] develop a GRASP method with path relinking for the capacitated arc routing problem with time windows. In Belenguer et al. [3], a memetic algorithm is designed to tackle the MCARP and this is currently the only published metaheuristic for the MCARP.

Contrary to arc routing, time windows have been an important object of study in the area of vehicle routing. Undoubtedly the best-studied problem in this area is the vehicle routing problem with (hard) time windows (VRPTW), for which a large number of efficient heuristic methods exists [5,6]. The literature on vehicle routing with soft time windows, on the other hand, in which it is allowed to arrive early or late at a customer's location thereby incurring a penalty cost, is much more limited. An early approach to model and solve a multi-objective VRPSTW can be found in Min [15], who uses this problem to model the case of a public library distribution system. More recent approaches can be found in Taillard et al. [21], who develop a tabu search heuristic and Ioannou et al. [11], who develop a heuristic based on a nearest-neighbour approach. In Calvete et al. [7] a goal programming method is developed. Min [15] developed a multi-objective method to solve a public library distribution system problem. One possible way to solve an arc routing problem, also used in this paper, is to transform it into an equivalent node routing problem. The first transformation appeared in Pearn et al. [17], a more recent and more efficient one can be found in Longo et al. [13].

3. Problem formulation and transformation

We are given a single mapping van with a fixed maximum travel time per day. The mapping van starts at the same node (corresponding to a hotel) each day and has to return to this hotel at the end of the day, before exceeding its maximum travel time for that day. Every (directed) arc or (undirected) edge in the graph has a given, fixed, travel time, as well as a soft time window, i.e. an earliest time at which traversal of this arc or edge should begin and a latest time traversal should end if no penalty cost is to be incurred.

The penalty cost for not (entirely) traversing an arc during its time window is based on the time window violation. A time window violation is defined as the time difference between the start of the visit and the opening of the time window or between the closing of the time window and the end of the visit, divided by the width of the corresponding time window.

The total travel time in any given day is the sum of the travel times of all streets traversed that day. On the one hand, the travel time per day is constrained by a fixed maximum, on the other hand, the objective is to reduce the travel time per day in order to make it possible to reduce the required number of days. In general, some streets will have to be traversed several times in order to completely traverse the map. Of course, pictures have to be taken only once in any given street. When traversing a street several times, the best time (i.e. the one that incurs the lowest penalty) can be chosen to take pictures.

The objective of this capacitated arc routing problem with (soft) time windows is to determine the order in which to visit all streets, i.e. travel all arcs and edges of the map, in such a way that the weighted sum of (a) the number of days and (b) the total time window violation, is minimised.

As mentioned, our mixed capacitated arc routing problem with soft time windows is first transformed to a vehicle routing problem with soft time windows. This conversion is done in two steps. In a first step, all (undirected) edges are replaced with two (directed) arcs of identical length, of which only one needs to be traversed (see Fig. 2 for an example). In a second step the arc routing problem is transformed into a vehicle routing problem by replacing each arc with a node (customer) to visit. This is shown in Fig. 3, in which the road network of Fig. 2 is transformed. The distance between each pair of nodes is determined as the shortest distance between the end node of the arc corresponding to the first customer and the starting node of the arc corresponding to the second customer, resulting in an asymmetric VRPSTW. This shortest distance is defined as the shortest path between the two nodes and can be calculated by any algorithm for the shortest path.

In the remainder of this paper, we will only use the transformed VRPSTW formulation of the mobile mapping problem and use the term "node" to refer to "the traversing of a street by a mobile mapping van".