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Discrete Optimization

The mixed capacitated arc routing problem with non-overlapping routes

Miguel Constantino[a,d], Luís Gouveia[a,d], Maria Cândida Mourão[b,d], Ana Catarina Nunes[c,d,*]

[a] Faculdade de Ciências, ULisboa, 1749-016 Lisboa, Portugal
[b] Instituto Superior de Economia e Gestão, ULisboa, Rua do Quelhas 6, 1200-781 Lisboa, Portugal
[c] ISCTE-IUL – Instituto Universitário de Lisboa, Av. das Forças Armadas, 1649-026 Lisboa, Portugal
[d] Centro de Investigação Operacional, ULisboa, 1749-016 Lisboa, Portugal

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ABSTRACT

Real world applications for vehicle collection or delivery along streets usually lead to arc routing problems, with additional and complicating constraints. In this paper we focus on arc routing with an additional constraint to identify vehicle service routes with a limited number of shared nodes, i.e. vehicle service routes with a limited number of intersections. This constraint leads to solutions that are better shaped for real application purposes. We propose a new problem, the bounded overlapping MCARP (BCARP), which is defined as the mixed capacitated arc routing problem (MCARP) with an additional constraint imposing an upper bound on the number of nodes that are common to different routes. The best feasible upper bound is obtained from a modified MCARP in which the minimization criteria is given by the overlapping of the routes. We show how to compute this bound by solving a simpler problem. To obtain feasible solutions for the bigger instances of the BCARP heuristics are also proposed. Computational results taken from two well known instance sets show that, with only a small increase in total time traveled, the model BCARP produces solutions that are more attractive to implement in practice than those produced by the MCARP model.
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1. Introduction

Capacitated arc routing mathematical models are often used to formulate delivering or collecting problems where the demands are associated with the links of the underlying network.

There are many variants of these problems. In the typical capacitated arc routing problem (CARP) the objective is to identify minimum cost (or time) routes to be traversed by the vehicles of a given fleet to perform the service in the streets of a network, starting and ending at a depot. The street segments demanding for service are called *tasks*, and have a given demand to be satisfied by one of the vehicles. The fleet is homogeneous, and the vehicles capacity must be respected.

The CARP was introduced by Golden and Wong (1981), and originally defined on undirected graphs. Since then, several CARP variations and generalizations have been reported in the literature, many of them motivated by real life applications, like waste collection, postal distribution or winter gritting. Dror (2000), Wøhlk (2008), and Corberán and Prins (2010) survey the research on the CARP and its variations, as well as their applications.

The Mixed CARP (MCARP) generalizes the CARP for mixed graphs, that is, graphs with arcs and edges. The MCARP is more suited to situations where the direction of the traversals has to be taken into account. This is the case of household waste collection (see e.g. Bautista, Fernández, & Pereira, 2008; Belenguer, Benavent, Lacomme, & Prins, 2006; Ghiani, Guerriero, Improta, & Musmanno, 2005; Gouveia, Mourão, & Pinto, 2010; Mourão & Amado, 2005; Mourão, Nunes, & Prins, 2009), or road network maintenance (see e.g. Amaya, Langevin, & Trépanier, 2007). The MCARP is NP-hard, since it generalizes the CARP, which is known to be NP-hard (Golden & Wong, 1981).

Since this work is motivated by a refuse collection problem, henceforward the task demands represent the amounts of refuse to collect.

Real world applications often require other constraints that must be added to the basic MCARP model. In some cases, it is not even easy to decide how to measure the additional specifications. Examples of such situations arise when workloads need to be equitably distributed among the vehicles, or different vehicle routes have to be constrained to separated geographical regions. On the recent paper of Ghiani, Laganà, Manni, Musmanno, and Vigo (2014) strategic and tactical issues involving these type of constraints are surveyed for solid waste management systems.

Also, too many intersections of the service areas of different vehicles can complicate the activities to be held in a region (see

* Corresponding author. Tel.: +351 217903000; fax: +351 217964710.
E-mail addresses: mfconstantino@fc.ul.pt (M. Constantino), legouveia@fc.ul.pt (L. Gouveia), cmourao@iseg.ulisboa.pt (M. C. Mourão), catarina.nunes@iscte.pt (A. C. Nunes).

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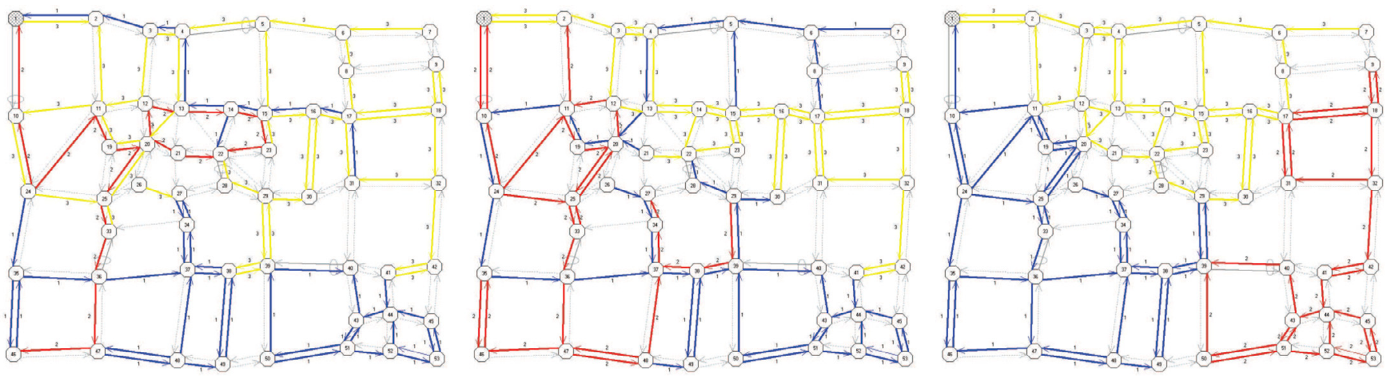

(a) MCARP (b) Connectivity model (c) BCARP

Fig. 1. lpra2 instance – optimal solutions for three vehicles.

e.g., Mourgaya & Vanderbeck, 2007; Muyldermans, Cattrysse, Van Oudheusden, & Lotan, 2002). According to Kim, Kim, and Sahoo (2006) and Poot, Kant, and Wagelmans (2002) for instance, solutions with an excessive number of vehicle crossovers tend to be rejected by the practitioners. Kim et al. (2006) also remark that the overlapping of service areas is strongly related to the intersection of the vehicle routes. The number of intersections may decrease if each vehicle service area is concentrated in a geographical region.

An adequate definition of these “nice” regions (sets of arcs and edges) is not easy to state since besides needing to be separated and workload balanced, their shape should have other “nice” characteristics. These, apart from being subjective, also allow practitioners to accept or reject a solution after a single viewing. A survey on measures used in the literature for the classification of the regions is provided later in Section 2.

Two of these “attractive” characteristics for the service areas are: (i) *connectivity* and (ii) *compactness*. While connectivity can be clearly defined as the possibility of traveling between any two points of a region without leaving it, there are different measures of the compactness of a region (MacEachren, 1985). In general, these measures compare the region against an “ideal compact shape”, such as a circle or a square, or they are based on the distances between points in the region – higher distances mean, in general, less compact regions.

Typical solutions for MCARP models are usually very unsatisfactory in terms of the above criteria. Fig. 1a depicts the optimal MCARP solution for instance lpra2 (see Section 6.1 for a description of the data set), where we can see the overlap of several different vehicle routes (identified by a different color) and very irregular (thus, not “nice”) regions served by each route. Furthermore, we even observe disconnected sequences of tasks within each vehicle service. Thus, solutions resulting from solving the “pure” MCARP can be very inadequate to implement in practice.

The disconnected components observed in the MCARP solutions has motivated our first attempt to improve the shape characteristics of the routes. In this approach, we have imposed constraints guaranteeing that the set of tasks within each route are connected. We omit from this paper the details of how we have modeled and implemented this approach. However, we refer the reader to Fig. 1b, which illustrates the solution for the instance lpra2 obtained after adding such “connectivity” constraints to the model. It is quite clear that this solution, despite having connected sets of tasks, still exhibits several undesirable situations such as vehicle routes that overlap and spread (being non compact) in the collection zone.

This attempt to model the “nice” features of the routes by adding connectivity constraints illustrates what we have mentioned before, namely that it may not be straightforward to measure and describe the “attractiveness” specification of the routes, in a mathematical way.

Motivated by this unsuccessful experiment, in this paper we propose, study and test a new model that uses a constraint simpler to formulate and that is based on a different way to measure the non-overlapping of the vehicle routes. We call this new problem the bounded overlapping MCARP (BCARP). The overlapping is measured in terms of the number of nodes that are common to the tasks of different routes.

One motivation for considering this measure is as follows. We may interpret the set of these common (shared) nodes as representing the boundaries between the regions served by each route, and their number as the length of the corresponding boundaries. Thus, one way to promote “nice” (disjoint and compact) regions is by limiting the length of their boundaries.

Fig. 1c depicts the optimal BCARP solution for instance *lpra2*, where we have included the new constraint on non-overlapping routes. It is interesting to compare the three solutions in the figure in order to see the advantage of the latest approach, in terms of compactness and separation of the regions served by each route. Moreover, although connectivity was not enforced in the BCARP model, the resulting solution has connected sets of tasks in each route.

In this work we consider three main measures to evaluate the “nice” characteristics of solutions. While the first one measures the connectivity, the other two try to measure the compactness, as detailed in Section 5.

This paper is organized as follows. After the review literature (Section 2), the relevant notation is presented in Section 3.1. Next, in Section 3.2 we review a model for the MCARP from Gouveia et al. (2010) which will be used as a backbone to model the more restrictive version of the MCARP here studied. In Section 3.3 we describe a variant where we want to minimize the number of shared nodes, named as the non overlapping MCARP (NOMCARP). The value of the NOMCARP objective function is then used to define the upper bound for the number of overlapping nodes in the MCARP. In Section 3.4 we propose a model for the BCARP that is obtained from combining the MCARP model with constraints from the NOMCARP, and a constraint guaranteeing the referred bounded overlapping. Section 4 is devoted to the methodology employed to find feasible solutions for the BCARP. Solutions for small sized instances are obtained by solving the models in sequence as described above. Heuristics are developed and used to obtain solutions for the larger sized instances. The measures introduced to evaluate the solutions (Section 5) precede the computational results. These involve two sets of well known benchmark instances and are presented and analyzed in Section 6, before the conclusions, in Section 7.

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