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On the Collaboration Uncapacitated Arc Routing Problem

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A R T I C L E I N F O

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A B S T R A C T

This paper introduces a new arc routing problem for the optimization of a collaboration scheme among carriers. This yields to the study of a profitable uncapacitated arc routing problem with multiple depots, where carriers collaborate to improve the profit gained. In the first model the goal is the maximization of the total profit of the coalition of carriers, independently of the individual profit of each carrier. Then, a lower bound on the individual profit of each carrier is included. This lower bound may represent the profit of the carrier in the case no collaboration is implemented. The models are formulated as integer linear programs and solved through a branch-and-cut algorithm. Theoretical results, concerning the computational complexity, the impact of collaboration on profit and a game theoretical perspective, are provided. The models are tested on a set of 971 instances generated from 118 benchmark instances for the Privatized Rural Postman Problem, with up to 102 vertices. All the 971 instances are solved to optimality within few seconds.

1. Introduction

Collaboration among carriers becomes more and more valuable because of surging pressures to improve profitability and to reduce costs. Nowadays, collaborative transportation is regarded as one of the major trends in transportation research. Indeed, increasing carrier insurance and fuel costs combined with a more intense market competition lead carriers to look for new and more efficient solutions. Primarily, carriers focus on reducing costs looking for efficient route planning and scheduling. These costs are strongly correlated with the location of customers. Whereas a carrier would benefit from having its customers concentrated in the same area, for a number of reasons they may end up being geographically dispersed. This forces the carrier to create long routes for its vehicles, with associated high cost in terms of vehicles usage and drivers time. It is often the case that customers that are inconveniently located for a carrier are conveniently located for a different carrier. Thus, a collaborating set of carriers can redistribute the customers, opening up, through collaboration, cost saving opportunities otherwise non-achievable.

In general, there are different types of carriers: general, regional or functional. The general carrier is non-specialized and has the assets and the logistics to serve all its customers taking care of all kinds of item distributions. Instead, a regional carrier is more bound to a defined geographical service area whereas a functional carrier serves a specific market or specific goods that require a specialization in transportation. Hence, for instance, a regional carrier can rely on a general one to serve customers outside its service area, or a general carrier can choose to handle particular goods (such as furniture, frozen foods) through a functional carrier.

Logistic collaboration can be pushed further considering that it allows carriers to increase the average load of the vehicles. In fact, also in the case the customers are located in the same area, the load to be delivered in a trip by a carrier may be substantially lower than the vehicle capacity and make the individual trip non-profitable. A carrier that has to deliver a certain amount of goods that fills only part of the capacity of its smallest vehicle may borrow a vehicle of the right size from another carrier or transfer the load on a vehicle of another carrier traveling to the same area at the same time.

Increasing attention to the environmental impact of emissions in cities represents an additional strong motivation to study collaboration among carriers, since local authorities increasingly push carriers to find new policies and new technological and logistical solutions that improve city logistics. In [31] challenges and pressures faced by carriers to cooperate to make urban freight transport more efficient are pointed out, and best practices actually brought into practice in The Netherlands are presented.

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Recently, collaboration has been enhanced by advances in information and communication technology that have enabled information sharing among carriers. Information can be shared in two alternative ways. In a centralized collaboration scheme, a central decision maker redistributes customers and/or logistic assets among carriers. This decision maker may be a third party who acts in a non-partisan way or may be a large carrier that resorts to other carriers to manage all its orders and customers. In a decentralized collaboration scheme, carriers exchange their orders individually or in clusters. In this case, carriers cooperate at the same level trusting each other for the information shared. All the above considerations and approaches apply to both truckload or less-than-truckload carriers.

In this paper, we focus on situations where collaboration is managed in a centralized way. We consider a set of carriers cooperating under the guidance of a central station that acts in a non-partisan way. Each carrier has a depot and a set of customers. Each customer is represented with an arc and its service generates a revenue. Each carrier identifies a subset of customers that it wants or needs to serve. These customers may be the most easily served, the most profitable or the most strategic ones. The remaining customers are defined as shared customers, that is customers that may be served by other carriers. A shared customer may end up being served by the carrier that decided to share it, when combined with customers shared by other carriers. Part of the revenue of a shared customer goes to the carrier that decided to share the customer and part goes to the carrier that actually serves it. We allow a shared customer not to be served by any carrier of the coalition. In this case the revenue is not collected by any carrier. This corresponds to the situation where the customer is not profitable for any carrier of the collaborating group and in a further phase a different and interested carrier will be searched. We assume that each carrier has one vehicle and that vehicle capacity is not relevant, that is the vehicles are uncapacitated.

The motivation for studying this problem comes from potential applications. In general, applications arise in private companies offering services which allow competition and collaboration, and where customers may be modeled as arcs of a network. As an example we mention home pick-up and delivery, including private mail and small packaging distribution, and taxi services. For example, the problem that we address can model a group of independent taxi drivers collaborating under the guidance of a central station.

We call the proposed problem, that may be seen as belonging to the class of arc routing problems with profits, Collaboration Uncapacitated Arc Routing Problem (CUARP). We study two different variants of the CUARP. In the first one the goal is the maximization of the total profit of the coalition of carriers, independently of the individual profit of each carrier. The second variant includes a lower bound on the individual profit of each carrier. This lower bound may represent the profit of the carrier in the case no collaboration is implemented. We formulate mixed integer programming models for the two variants of the problem and study their relations with well-known arc routing problems. We also look at the CUARP from a game theory perspective. As it is usual in arc routing problems, the proposed formulations have a number of connectivity constraints which is exponential in the number of customers. This leads us to study the separation problem for such constraints. We solve the formulations for the two proposed variants with a branch-and-cut algorithm and quantify the impact of collaboration. Starting from 118 benchmark instances for the Privatized Rural Postman Problem, we generate a total of 971 instances, with 2 or 3 carriers and varying characteristics, such as different locations of the depots and different thresholds for the profit. We solve all instances within few seconds. On each instance we compare the optimal solution obtained in the case where no collaboration is allowed with the case where collaboration is allowed, and show that the profit of the coalition increases up to twice or even three times the profit achieved without collaboration.

The rest of the paper is organized as follows. Section 2 introduces the relevant literature. The two variants of the CUARP are formally described and formulated in Section 3. Section 4 presents the theoretical results. In Section 5 we describe the separation procedure for the connectivity constraints that is used in the branch-and-cut algorithm. Data generation and computational experiments are described in Section 6. Finally, conclusions and future work are discussed in Section 7.

2. Literature review

The literature on collaboration in transportation can be divided in two streams, one on vertical and the other on horizontal collaboration. Vertical collaboration arises when shippers and customers collaborate to help each other optimize their objective, while horizontal collaboration takes place when shippers collaborate among them (and/or the same do customers) at the same logistic level. Ergun et al. [19] develop a collaboration model among shippers, involving only full truckload companies, to identify tours that minimize asset repositioning costs. The same authors discuss in [18] how to reduce truckload transportation cost through the identification of repeatable, dedicated continuous move tours using collaboration among carriers to reduce the need for repositioning and lowering costs. Mason et al. [28] focus on customer driven supply chain and freight management with the aim of studying if collaborative models for management transportation give optimized solutions.

Some authors addressed carrier collaboration from a perspective of costs and profits allocations, possibly within a game theory context. Figliozzi [20] proposes a setting in which a set of carriers, each with its own customers, has some incentive to submit all customers requests to a centralized collaborative decision making mechanism based on sequential second-price auction. Özener et al. [30] focus, instead, on reducing costs through collaboration. Given a set of lanes carriers have to serve, their aim is to set up a process to exchange lanes either sharing or not sharing information about customers and/or side payments. Agarwal and Ergun [1] study transportation networks that operate as an alliance among different carriers. They focus on formation of alliances and network design using both mathematical programming and game theory to investigate the mechanism that leads to an optimal collaborative strategy. In contrast to those studies, in our setting we deal with a network of carriers (regional or functional) that form a coalition to collaborate and we consider as a given fact that collaboration is better than competition, as pointed out in Agarwal et al. [2], Meyer et al. [29], and Fugate et al. [21].

Audy et al. [9] and Krajewska et al. [26] are case oriented papers. The former deals with the supply chain of the Canadian furniture industry, while the latter deals with more general coalitions among carriers. Both make use of game theory to allocate cost among companies, customers, carriers and coalitions. In particular, in [26] the authors also use the classic Shapley value to allocate costs among carriers and coalitions of carriers. In [23] various criteria are presented to allocate costs using classical game theory in a vehicle routing problem. Our perspective in this paper is quite different. While we do not focus on cost allocation among carriers, we study how to improve profits for the whole carriers network within the framework of a fixed collaboration agreement by stating our model as a prize-collecting arc routing problem with several carriers and depots.