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Benefits of horizontal cooperation in dial-a-ride services

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ABSTRACT

Dial-a-ride services provide collective on-demand transportation, usually tailored to the needs of people with reduced mobility. This paper investigates the operational effects of horizontal cooperation among dial-a-ride providers. The current practice is that users choose a particular provider to submit their requests. Providers operating in the same area create their routing solutions independently of each other, given their own set of customers. In contrast, horizontal cooperation through joint route planning implies that customer requests can be exchanged among providers in order to minimize the overall routing cost. In addition to quantifying the operational benefits generated by such a horizontal cooperation, this paper identifies operational characteristics that influence the magnitude of the savings. A real-life case study reveals the reasons why providers benefit from certain request exchanges, as well as the extent to which these exchanges are predictable in advance. The solutions are obtained using a large neighborhood search algorithm that performs well on benchmark data.

1. Introduction

A dial-a-ride system is an application of demand-dependent, collective passenger transportation (Cordeau and Laporte, 2003). Each customer requests a trip between an origin and a destination of choice, to which a number of service level requirements are linked. The service provider attempts to develop efficient vehicle routes and time schedules, respecting these requirements and the technical constraints of a pickup and delivery problem (Parragh et al., 2008). A frequent objective is to minimize operational costs subject to full demand satisfaction and side constraints, but service level criteria may be optimized as well. Balancing the human and economic perspectives involved in solving such a dial-a-ride problem (DARP) is essential for organizing quality-oriented, yet efficient transportation of customers with special needs, such as elderly or disabled. In light of the ageing population, dial-a-ride systems are gaining importance to complement regular transportation modes. They fulfill a social role as well, preventing isolation of vulnerable groups in society.

When a certain area is served by multiple dial-a-ride providers with a comparable quality policy, most users living in that area will intuitively submit their requests to the provider located closest to their homes. The different providers create their vehicle routes and schedules independently of each other, based on the requests they receive. Whereas strategies to share information or resources have been cost-effective practices among logistic service providers for many years (Verdonck et al., 2013), they are completely unexplored in the domain of dial-a-ride services. Also the academic literature lacks insights into the effects of cooperation in the specific context of demand-responsive passenger transportation, e.g. due to tighter quality

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requirements. The present paper performs an analysis on *joint route planning* in dial-a-ride services. This particular form of horizontal cooperation assumes a centralized decision making, enabling service providers to exchange customer requests such that overall routing costs are minimized. The problem is solved using a large neighborhood search (LNS) metaheuristic whose performance is demonstrated using common benchmark data from the literature.

The contribution of this paper is threefold. First, the potential of horizontal cooperation through joint route planning among dial-a-ride providers is analyzed. Second, the operational characteristics that influence these benefits are identified using artificially constructed data in which the operational setting is varied. This analysis allows to draw general conclusions on a more strategic/tactical level regarding the benefits of cooperation. Third, a real-life case study is performed to discover the reasons why service providers benefit from exchanging certain requests. The predictability of these exchanges influences the extent to which information must be disclosed to enable a successful cooperation. Note that all analyses focus on the joint operational benefits incurred by the overall cooperation. To allocate these benefits among the providers, which falls outside the scope of this paper, gain sharing techniques from existing literature on horizontal cooperation (e.g. Shapley value, alternative cost avoided method, equal profit method) may be used (Verdonck et al., 2016).

The remainder of this paper is structured as follows. Section 2 introduces the standard DARP and provides a mathematical formulation of the variant used in this work. Section 3 summarizes related literature on horizontal cooperation in logistics and translates these principles to the domain of demand-responsive people transportation. Section 4 discusses the structure of the LNS metaheuristic. Section 5 presents the artificial and real-life data sets used for the computational tests and analyzes the results. Section 6 draws conclusions in view of a practical implementation of horizontal cooperation and suggests ideas for future research.

2. Problem statement

Cordeau and Laporte (2003) introduced a standard definition of the DARP. It consists of designing several minimum-cost vehicle routes in a complete graph of nodes and arcs. The nodes represent pickup and delivery locations of customers, as well as a single vehicle depot. The arcs between these nodes have an associated travel time and cost, which is incurred if the arc is traversed by a vehicle. Routes start and end at the depot within fixed time intervals and respect a maximum route duration. The service at each customer location starts within a hard time window. A maximum user ride time cannot be exceeded and a vehicle's load should respect the maximum capacity. To ensure a correct physical route construction, precedence and pairing of a customer's origin and destination must be ensured by visiting them in the right order, using the same vehicle. A service duration indicates the time that may be needed for loading and unloading customers.

The problem studied in this paper involves multiple service providers that may or may not cooperate. Since each participating provider disposes of at least one depot, a multi-depot variant of the DARP (Braekers et al., 2014) needs to be solved. In scenarios with horizontal cooperation among the providers, the principle of joint route planning implies that requests may be served by a vehicle originating from any given depot. In a scenario without cooperation, requests are preassigned to one specific provider, usually based on the customer's geographical situation. In addition, the real-life case study concluding Section 5 involves multiple customer types (Parragh, 2011) and configurable vehicle capacity (Qu and Bard, 2013). The former means that customers are categorized based on their mobility, i.e. whether they use a wheelchair or not. This heterogeneity is reflected in the fact that the vehicles offer a number of standard seats and wheelchair spaces. Their design is instantaneously configurable, meaning that the ratio between both resource types can be modified at any stop in the route according to a limited set of configurations.

A mathematical formulation for this rich problem variant can be composed by building upon the arc-based mixed-binary linear programs of Cordeau (2006), Røpke et al. (2007), Parragh (2011), Qu and Bard (2013) and Braekers et al. (2014). The resulting formulation is shown by Eqs. (1)–(15). Given an input of n user requests, each node i in the range $1, \ldots, n$ represents the pickup location of a specific user i, whereas node $n+i$ represents the corresponding delivery location. The four-index binary decision variable x_{ij}^{kf} indicates whether vehicle k traverses the arc between nodes i and j in configuration f, where the set of possible configurations F_k depends on the vehicle k. Each vehicle route is assumed to start at an origin depot and end at a destination depot (Eqs. (4) and (6)). One and the same vehicle should reach and leave corresponding pickup and delivery locations i and $n+i$ (Eqs. (2), (3), and (5)), which ensures flow conservation and pairing. However, without horizontal cooperation, only a limited set of vehicles (i.e. the vehicles from one specific provider) is eligible to serve a particular user (Eq. (7)). The use of an index k for parameters related to travel costs/times allows to account for vehicles originating from multiple depots at different physical locations, even though a single node is used to represent the start depot 0 and end depot $2n+1$. Decision variable L_i^k computes the ride time of user i (Eq. (10)) and cannot exceed the maximum user ride time L (Eq. (13)). Explicit precedence constraints become redundant if L_i^k is set at least equal to the associated direct ride time. Decision variable B_i^k tracks the service start in node i (Eq. (8)) and should respect the time window of this node (Eq. (12)). A vehicle may idle at any time and place, e.g. when it reaches a node before the start of the time window. Decision variable Q_i^{kr} registers the load of resource r upon leaving node i (Eq. (9)) and cannot exceed the capacity C_{kf}^r of vehicle k in configuration f for resource r (Eq. (14)), respectively. The vehicle's configuration can be changed at any node. The time span between the moment a vehicle leaves the origin depot and the moment it returns to the destination depot cannot exceed the maximum route duration T_k (Eq. (11)). A minimum-cost selection of arcs is made (Eq. (1)), subject to all constraints and full demand satisfaction. Finally, note that Eqs. (8) and (9) can be linearized as proposed by Cordeau (2006).