Transportation Research Part B 67 (2014) 18–34

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

Scheduled paratransit transport systems

G. Dikas, I. Minis *

Department of Financial and Management Engineering, University of the Aegean, 41 Kountouriotou Str., Chios 82 100, Greece

ARTICLE INFO

Article history:
Received 22 July 2013
Received in revised form 1 May 2014
Accepted 2 May 2014

Keywords:
Demand responsive transit systems
Paratransit systems
Branch and Price for MILP
Door-to-door bus services

ABSTRACT

In this paper we focus on ways to provide individualized services to people with mobility challenges using existing modes of public transport. We study the design of an interesting case, in which a bus operating in a public transport route may diverge from its nominal path to pick-up passengers with limited mobility and drop them off at their destination. We have modeled the design problem by a mixed integer-linear program, and we developed an exact Branch and Price approach to solve it to optimality. The proposed approach includes a labeling algorithm in which we introduced appropriate dominance rules, which do not compromise optimality. We have compared the efficiency of our approach with that of related algorithms from the literature. Furthermore, we have used the proposed approach to study key aspects of the system design problem, such as the effect of various constraints on the service level, and the tuning of the system's parameters to address different transport environments.

1. Introduction to demand responsive transport services

In this paper we focus on flexible public transport services that address the needs of the elderly, as well as those of people with a disability. Of interest are ways to provide individualized bus services to people with mobility challenges using existing modes of public transport. Such services promote equality between client groups, while, at the same time, offer high quality transport to people with a disability, and limit public transport expenditures.

Our work is motivated from the need to serve the first and last leg of any public transport trip; that is the legs between the origin (e.g. home) and the departure bus stop, as well as the arrival bus stop and the destination (e.g. place of work, hospital). Often such distances are considerable, especially in suburban or rural areas. In order to eliminate these trip legs, some municipalities have introduced semi-flexible bus routes (Flipper Project, 2011). The latter include a reference (nominal) route that serves fixed regular bus stops; however, when there are requests from clients with limited mobility, one or more of the vehicles serving the route may diverge from this nominal path, pick up the clients from their origin and eventually drop them to a regular bus stop or to a special destination. Obviously diversions are possible within a certain distance from the nominal path.

The concept of Demand Responsive Transit (DRT) services has attracted attention in the last decade. Mageean and Nelson (2003) evaluated the application of DRT using telematics in five cities across Europe; their results indicated that DRT services may provide efficient public transportation, as well as an excellent level of service. Similar studies have been carried out by Brake et al. (2007) and Nelson et al. (2010). Their results indicated that the application of flexible transportation services or DRT services involve changes in business models, citizen behavior, and technology support. Recently, Nourbakhsh and

* Corresponding author. Tel.: +30 2271035450.
E-mail addresses: gdikas2@aegean.gr (G. Dikas), i.minis@fme.aegean.gr (I. Minis).

http://dx.doi.org/10.1016/j.trb.2014.05.001
0191-2615/

Ouyang (2012) proposed a structured flexible route transit system, which eliminates the walking time to and from bus stops. This system allows buses to pick-up or drop-off passengers within predefined service areas, called bus tubes. The authors' quantitative analysis indicated that system operational costs are lower than those of an equivalent system that combines fixed-transit routes and taxi services, the latter to serve the first and last trip legs.

Diana et al. (2007) studied ways to organize a public transport service in order to reduce environmental impact. They concluded that emissions may be reduced by DRT services in low demand scenarios; they also suggested that smaller vehicles could be more suitable for this kind of service. Criteria for assessing flexible transport have been developed by Ferreira et al. (2007). Zografos et al. (2008) presented a methodology for developing Flexible Transport Systems (FTS), and described a related application in the City of Helsinki. Mulley and Nelson (2009) considered bus-based flexible public transport services, concluding that such services may revitalize bus public transport. Broome et al. (2012) evaluated the efficiency of providing FTS bus transport to the elderly. They concluded that demand may be doubled, while overall satisfaction may increase significantly. Finally, Nguyen-Hoang and Yeung (2010) assessed a flexible demand-responsive form of public transportation, they called paratransit. They concluded that the benefits of paratransit exceed the related costs.

The Demand Adaptive System (DAS) of Daganzo (1984), Crainic et al. (2000, 2005) and Malucelli et al. (2001) is a special case of DRT and is related to the problem being addressed in this paper. In their case, optional bus stops are defined and are activated in order to provide improved service.

Another case closely related to the one addressed in this paper is the Mobility Allowance Shuttle Transit (MAST) services of Quadrifoglio et al. (2006, 2007, 2008) and Quadrifoglio and Dessouky (2008). In MAST, a vehicle moves repeatedly from an origin point to a destination point and serves additional intermediate bus stops (checkpoints), while it is allowed to deviate within a certain range of the main route to serve additional requests. A latest departure time is defined for each check point and cannot be violated. Chandra and Quadrifoglio (2013) also discuss the importance of first and last mile connectivity and propose an analytic queuing model for estimating a near optimal terminal-to-terminal cycle length for a demand responsive feeder service to maximize quality of passenger service.

In this paper we focus on a semi-flexible public transport system, much like the one described at the beginning of the introduction, which we call the Scheduled Paratransit Transport System (SPTS). The scope of SPTS is to serve paratransit requests by a scheduled public bus service. To address this scope we introduce a new routing problem, which we call the Demand Responsive Bus Routing Problem (DRBRP), for which we introduce a mathematical model that captures all aspects of SPTS. Furthermore, we propose an exact Branch and Price (BP) framework to solve to optimality problems of practical size. For the sub-problem of this framework we modify the labeling algorithm developed for the Elementary Shortest Path Problem to meet the special constraints of DRBRP. Moreover, we study the design of SPTS in three representative environments: urban, suburban, and rural. The design study focused on the tuning of the system parameters to suit the characteristics of each environment. Finally, we investigate the efficiency of the proposed exact method through extensive testing.

Note that DRBRP may be viewed as a combination of: (a) the Team Orienteering Problem (TOP), see Vansteenwegen et al. (2011) and to Savelsbergh and Sol (1995), and (b) the Pick-up and Delivery Problem (PDP) with additional constraints related to the sequence of nominal routes of bus services, see Desaulniers et al. (2002). The Dial-a-Ride Problem (DARP) is an interesting variant of the PDP, which is related to the paratransit case, see Cordeau and Laporte (2007), Karabuk (2009), Paquette et al. (2013) and Kirchler and Calvo (2013).

The structure of the rest of this paper is as follows. Section 2 describes the service delivered by SPTS and its unique aspects with respect to the literature. Section 3 presents a mixed integer linear programming model for the DRBRP. Section 4 describes the proposed solution approach. Section 5 presents the design study and the computational experiments, while Section 6 summarizes the conclusions of this study.

2. Description of SPTS

In SPTS, similarly to other dial-a-ride systems (see Paquette et al., 2009), a paratransit request is booked prior to the start of the service period. Typically reservations may be placed for multiple trips to be performed within a week, or for a trip with a departure time within the next few hours. Each paratransit request specifies the desired pick-up and delivery points and the latest time of arrival at the destination. These paratransit requests will be served by allowing buses of a scheduled bus service to deviate from their nominal routes.

The SPTS route includes several predefined regular bus stops, which in every bus trip are visited in a prescribed sequence. The route is served by multiple bus trips (offset in time), and the earliest and latest bus departure times from each regular bus stop are defined per bus trip. For each trip we consider that the earliest departure time from a regular bus stop is equal to the minimum travel time of the bus between the start of the route (first regular bus stop) and the bus stop under consideration. The latest departure time in effect limits the deviation of the bus trip from the nominal route and maintains an adequate service level for the passengers waiting at the regular bus stops.

Each bus in the system has a certain capacity for paratransit clients. The paratransit requests are flexible, i.e. they may or may not be served. Each request is considered to be known before the start of the trip and comprises a pick-up location, a drop-off location, and the latest time that the client may reach its destination (drop-off location). This latest drop-off time is defined by the client. The pick-up time is considered in our case indirectly in the objective function of the problem (see below).