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Setting services in public transit lines in short time periods under time-varying demand

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Abstract

This paper focuses on a mathematical programming based model for setting the schedule of a given number of services on a public transportation network. The structure of the model is that of a time-expanded or diachronic network, where origin to destination flows vary dynamically over a short time horizon (several hours) and are assumed to be known deterministically. The model basically aims to minimize the total travel time of passengers during the time horizon by properly setting the lag times between services on the lines and thereby accommodating conveniently the schedules of the services on different lines in order to enhance transfers. Two different types of diachronic networks are considered, in which three basic algorithmic alternatives have been tested: a heuristic method based on the classical projected gradient, Benders decomposition, and a combination of both. Among other applications, the model can potentially be applied in operational aspects for disruption recovery in Rail-Rapid Transit and Suburban Railway systems by using bus shuttles or auxiliary bus lines. The computational viability of the model, in terms of adequate response time, is shown using test networks of auxiliary bus lines. Its computational performance in readjusting schedules for larger suburban rail systems is also evaluated.

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Keywords: Public transportation; Dynamic service scheduling; Time-varying demand;

1. Introduction

Systems for disruption recovery on the public transportation networks of metro and suburban trains require proper planning and specific tools in order to be effective. One of the most used methods in cases where the regular system suffers line blockage is to use bus-bridging (Pender et al. (2013)). The design of these systems has been addressed from strategic aspects such as the location of bus depots, economic viability, the required decision support systems (Kepaptsoglou and Karlaftis (2008)), the design and dimensioning of bridging lines under a static approach (Codina et al. (2013), Van der Hurk, E. et al. (2016)) and the effects of high demands that need to be satisfied (Codina et al. (2013)). Design models of these recovery systems generally rely on those used for strategic and operational planning for public transportation systems. However, they must meet demanding requirements in terms of computational response, and they all have the limitation of being static and are unable to face situations with dynamic demand or that are markedly irregular, pulsed or with strong peaks. These issues were recently addressed in Codina and Montero (2014), Codina et al. (2014) and in Jin et al. (2015), all of which introduce a necessary time-varying component in the solutions to recovery problems.

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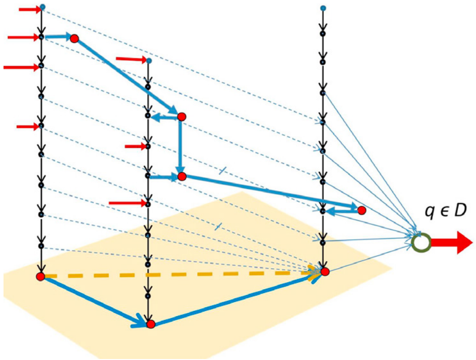

Figure 1. Discrete diachronic network.

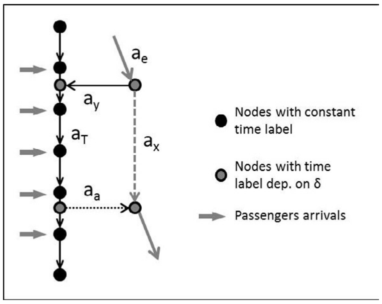

Figure 2. Details of a partially continuous diachronic network.

The model presented in this paper focuses on the problem of scheduling a set of services for a given set of lines within a short time horizon (few hours), such that the total travel time of the trips in a dynamic origin-destination matrix is minimized. The contribution of this paper consists of the formulation of dynamic models for this problem and the development of efficient heuristic methods based on Benders decomposition and projected gradients, with response times of minute fractions. Because the model is oriented (although not limited) to recovery problems in transit networks using bus-bridging systems, another distinctive characteristic of our approach is the explicit consideration of dwell times and the avoidance of units overlapping at stops. Taking into account these aspects is very relevant, as the alleviating capacity and degree of effectiveness of the bus-bridging system needs to be faithfully reflected by the model. Up to the authors' knowledge, no other work has explicitly considered these aspects of the problem. The approach is very different from time-table setting models such as those in Schöbel (2006), and the synchronization of schedules in our model is simply obtained as a by-product. Instead of using a sophisticated dynamic transit assignment model such as in Papola et al. (2009) and in Haupt et al. (2009), passengers within the time horizon are assumed to be assigned to the lines by means of a simple capacitated multi-destination network flow model with a diachronic structure, which is very close to the networks in Nuzzolo and Russo (1994) and is also very similar to the ones in Codina et al. (2014) and in Jin et al. (2015).

The outline of the paper is as follows: two different types of diachronic networks are considered and are described in section 2, as well as the main assumptions adopted by the model. On the one hand, discretized diachronic networks in which arrivals-departures of transport units and passenger o-d trip flow demands adjust to a pre-specified time granularity and on the other hand, networks on which arrival-departure of transport units are set in continuous time, although dynamic demands adjust to the time granularity. On these two types of networks three basic algorithmic alternatives have been tested: projected gradient, Benders decomposition and a combination of both which are described in section 3. In section 4 computational results are presented on small and medium size networks modeling bus-bridging systems during periods of few hours and for a larger network modeling a corridor of suburban railways during a period of twelve hours.

2. Conceptual model and network structure

The assumptions of the model are the following ones: a) the layout of the set of lines L of a public transportation system are known; b) the dwell time at stops, $x(\ell)$, $\ell \in L$, and the travel time at line segments are constant and known, c) the total number of services n_ℓ operating for each line ℓ is also known, d) there are no queues of transport units at stops and e) all the transportation units operating on line $\ell \in L$ have equal capacity $b(\ell)$. f) a dynamic OD trip matrix is known over a fixed time horizon H. Then, the model basically aims to minimize the total travel time of the OD trips by setting the lag time $\delta_{\ell,s}$ between consecutive services $s, s+1$ of each line $\ell \in L$ so that units do not overlap at stops. A model under these assumptions can be useful in the context of adjusting time lags in a system of auxiliary bus lines operating within a limited time period of disruption.