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Integrated Public Transport Timetable Synchronization and Vehicle Scheduling with Demand Assignment: A Bi-objective Bi-level Model Using Deficit Function Approach

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Abstract

In the operations planning process of public transport (PT), timetable synchronization is a useful strategy utilized to reduce transfer waiting time and improve service connectivity. However, most of the studies on PT timetable synchronization design have treated the problem independently of other operations planning activities, and have focused only on minimizing transfer waiting time. In addition, the impact of schedule changes on PT users' route/trip choice behavior has not been well investigated yet. This work develops a new bi-objective, bi-level integer programming model, taking into account the interests of PT users and operators in attaining optimization of PT timetable synchronization integrated with vehicle scheduling and considering user demand assignment. Based on the special structure characteristics of the model, a novel deficit function (DF)-based sequential search method combined with network flow and shifting vehicle departure time techniques is proposed to achieve a set of Pareto-efficient solutions. The graphical features of the DF can facilitate a decision-making process for PT schedulers for finding a desirable solution. Two numerical examples are illustrated to demonstrate the methodology developed.

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Keywords: public transport, timetable synchronization, vehicle scheduling, demand assignment, bi-objective bi-level model, deficit function

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1. Introduction

1.1. Background and motivation

One of the most challenging problems in transportation planning is how to shift a significant number of private car users to public transport (PT) in a sustainable manner. The problem of improving PT patronage and its compatibility with user needs is multifaceted. However, one may rather intuitively assume that improving PT service reliability, from the user perspective, and reducing operations costs, from the operator perspective, will lead to an increase in ridership and competiveness compared with private car use. For most PT systems, inter-route transfer connections are important factors affecting service reliability. Timetable synchronization is a useful strategy used to reduce transfer waiting time, provide a well-connected service and improve PT service reliability (Ceder, 2001; Ceder, 2016).

Most previous studies (e.g., Daganzo, 1990; Bookbinder and Desilets, 1992; and Ceder et al., 2001) on the PT timetable synchronization problem have treated the problem separately, rather than coupled with, or isolated from, other operation planning activities, such as vehicle scheduling, transit assignment and network design. However, as pointed out by Ceder (2001, 2016), it is preferable that all operation planning activities can be planned simultaneously in order to exploit the system's capability to the greatest extent, and thereby, maximize its productivity and efficiency. Some researchers (e.g. Ceder and Stern, 1984; Van den Heuvel et al., 2008; Ibarra-Rojas et al., 2014; Liu and Ceder, 2016a; and Liu et al., 2016) have focused on integrating the PT timetable synchronization problem (TSP) with the vehicle scheduling problem (VSP) in order to analyze the trade-off between level of service and operations costs.

To date, there are two main decision-making problems that have not yet been addressed regarding an integrated approach to simultaneously analyze timetable synchronization and vehicle scheduling tasks. First, almost all previous studies focused on optimizing operation parameters only, such as trip offset times, route headways and vehicle trip chains. However, the effect of the changes of these operation parameters on PT users' trip choice behavior which have a heavy impact on other planning activities, is not taken into consideration in the timetable optimization process. Second, there is a lack of effective and efficient solution methods for finding a set of Pareto-efficient solutions so as to help for the purpose of assisting in multi-criteria decision analysis from the perspectives of both PT users and operators. To bridge these gaps, this study addresses the integrated PT timetable synchronization and vehicle scheduling problem with transit assignment (ITSVS-TA) for tactical and operational planning purposes.

1.2. Literature review

The problem of identifying the optimal synchronized PT timetable is essentially the problem of deciding on the best dispatching policy for transit vehicles on fixed routes. This has been dealt with quite extensively in the literature. Several approaches and computer-aided software packages have been developed. According to the different features, the approaches developed can be categorized into four groups: (i) interactive graphical optimization approach, (ii) analytical modelling approach, (iii) mathematical programming approach, and (iv) control theory approach.

In the first group, interactive graphical optimization techniques, which is recognized as the earliest approach actually applied in practice, have been proposed by a few researchers (e.g., Rapp and Gehner, 1976; Désilets and Rousseau, 1992; Fleurent et al., 2004; and Vuchic, 2005). Other earlier theoretical investigations of the PT timetable synchronization problem (PT-TSP) are mainly focused on how to set route headways and offset times. Salzborn (1980) studied a special inter-town route connected by a string of feeder routes. Daganzo (1990) examined the single transfer node case, and provided some intuitive rules for setting the headways of the inbound and outbound routes.

The second approach to solve the PT-TSP employs analytical formulations for idealized PT systems. Wirasinghe et al. (1977) and Wirasinghe (1980) developed approximate analytical models for investigating the optimal design parameters of a coordinated rail and bus transit system atop rectangular grid or ring-radial networks. A series of follow-up studies (e.g., Lee and Schonfeld, 1991; Chien and Schonfeld, 1998; Chowdhury and Chien, 2002; Ting and Schonfeld, 2005; Sivakumaran et al., 2012; and Kim and Schonfeld, 2014) have been conducted. Knoppers and Muller (1995) investigated the impact of fluctuations in passenger arrival times on the possibilities and limitations of synchronized transfers. As pointed out by Liu and Ceder (2016b), one limitation of the analytical modelling approach is that it fails to accurately calculate the measures of the cost components of the objective functions considered.

The third approach widely found in the literature adopts mathematical programming models. Klemt and Stemme