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User perspectives in public transport timetable optimisation

Jens Parbo *, Otto Anker Nielsen, Carlo Giacomo Prato

Technical University of Denmark, Department of Transport, Bygningstorvet 116B, 2800 Kgs. Lyngby, Denmark

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ABSTRACT

The present paper deals with timetable optimisation from the perspective of minimising the waiting time experienced by passengers when transferring either to or from a bus. Due to its inherent complexity, this bi-level minimisation problem is extremely difficult to solve mathematically, since timetable optimisation is a non-linear non-convex mixed integer problem, with passenger flows defined by the route choice model, whereas the route choice model is a non-linear non-continuous mapping of the timetable. Therefore, a heuristic solution approach is developed in this paper, based on the idea of varying and optimising the offset of the bus lines. Varying the offset for a bus line impacts the waiting time passengers experience at any transfer stop on the bus line.

In the bi-level timetable optimisation problem, the lower level is a transit assignment calculation yielding passengers' route choice. This is used as weight when minimising waiting time by applying a Tabu Search algorithm to adapt the offset values for bus lines. The updated timetable then serves as input in the following transit assignment calculation. The process continues until convergence.

The heuristic solution approach was applied on the large-scale public transport network in Denmark. The timetable optimisation approach yielded a yearly reduction in weighted waiting time equivalent to approximately 45 million Danish kroner (9 million USD).

1. Introduction

In a report from the Capital Region of Denmark (RH, 2009), it was estimated that 11.5 billion Danish kroner (DKK) will be lost due to travellers being delayed because of congestion in the Copenhagen Region in 2015. Furthermore, it was stated in the report that, to avoid the outlined scenario, people ought to start travelling by public transport rather than by car. The question is how this change in the market share between private and public transport is actually realised?

The present paper deals with timetable optimisation from the perspective of minimising the waiting time experienced when transferring either to or from a bus.

1.1. Literature review

Designing an attractive transit network is an important and strategic task, in the literature often referred to as the Transit Route Network Design Problem (TRNDP). Based on an existing bus network, Bielli et al. (2002) aimed at improving the performance and reducing the need for rolling stock by adapting lines and their frequency. Lee and Vuchic (2005) tried to design an optimal transit network as a compromise between minimal travel time, transit operator's profit maximisation and

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* Corresponding author. Tel.: +45 45256532.
E-mail addresses: jepar@transport.dtu.dk (J. Parbo), oan@transport.dtu.dk (O.A. Nielsen), cgp@transport.dtu.dk (C.G. Prato).

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minimisation of social costs. Elaborating mainly on the travel time description, Fan and Machemehl (2006) considered the transit route network design problem but separated travel time into four components (walking time, waiting time, in-vehicle time and transfer cost). The TRNDP has received much attention in the literature, and its significant contribution was notably summarised in two reviews by Kepaptsoglou and Karlaftis (2009), focusing on design objectives, operating environments, and solution approaches, and Guihaire and Hao (2008), focusing on unifying the area. Regarding future developments within this area, Kepaptsoglou and Karlaftis (2009) recommended that the focus should be on transfer policies and passenger transfer related items as waiting and walking distances, while Guihaire and Hao (2008) suggested that the focus should be on privatisation and deregulation, as well as integration and intermodality among transit networks by focusing on improving transfers globally instead of looking at within-mode transfers.

In the literature, several solutions have been proposed to the timetable optimisation problem with various approaches to the consideration of transfers. One of the problems that have received much attention is the Timetable Synchronisation Problem (TTSP, e.g., Ceder, 2007; Liu et al., 2007; Ibarra-Rojas and Rios-Solis, 2012), which aims at maximising the number of simultaneous arrivals at transfer stations. Wong et al. (2008) developed a timetable optimisation model trying to minimise the total passenger transfer waiting times by changing the offset of the bus lines. This approach was also used, though with different objectives, by Bookbinder and Désilets (1992), Knoppers and Muller (1995), Cevallos and Zhao (2006), Hadas and Ceder (2010) and Petersen et al. (2012). Guihaire and Hao (2010) maximised the quality and quantity of transfer opportunities. While the quantity was self-explanatory, the quality was a twofold concept: firstly, it was based on the number of passengers; secondly, it was based on an ideal transfer time, i.e., a cost function was introduced to force the transfer time to be as close as possible to the ideal one. Niu and Zhou (2013) applied a timetable optimisation approach taking into account the passengers boarding at crowded stations. The objective was to minimise passengers' waiting time at stops and also reduce the waiting time passengers who were not able to board their desired service suffered because of congestions. They applied a genetic algorithm to solve the problem for each station in a double-track corridor. De Palma and Lindsey (2001) tried to minimise schedule delay (i.e., difference between preferred and actual departure time) by choosing the best timetable among a finite set of a priori created timetables. Taking a more holistic and strategic view of the transit network, Zhao and Ubaka (2004) applied two different algorithms to find the optimal set of transit routes to maximise route directness, minimise number of transfers and maximise service coverage. Another alternative perspective was used in the study by Yan et al. (2012), where the objective was to design a reliable bus schedule for fixed bus routes with a series of control points, and the punctuality of the busses was continuously controlled for and it was intended to improve it by letting the drivers recover the schedule by speeding up in order to reach the next control stop on time. Including the requirements for different types of rolling stock, Ceder (2011) developed an extended version of the deficit function to efficiently allocate different types of rolling stock where needed to accommodate the demand on each transit line based on an existing timetable.

In all of these studies, some prior information on users' travel behaviour was used, but passengers were assumed not to change their route choice when the timetable was changed. Normally, one would expect demand to change accordingly, when the supply is changed. In this context, the supply should be seen as the transit system, hence also the timetable, while the demand reflects the transport, namely the passengers' route choice. With this in mind, it seems appropriate to look at some of the timetable optimisation approaches which have considered the balance between supply and demand. Actually, this balance was noted as missing by Zhao and Ubaka (2004) and more recently by Ibarra-Rojas and Rios-Solis (2012). An early study formulated the timetable optimisation problem as a bi-level nonlinear non-convex mixed integer programming problem (Constantin and Florian, 1995). The objective of the upper level was to minimise the total expected travel time plus the waiting time. This was done by changing frequency settings in the timetable. The lower level problem was a transit assignment model with frequencies determined by the upper level. Wang and Lin (2010) developed a bi-level model to minimise operating cost related to the size of the fleet plus the total travel cost for passengers. Here the upper level referred to the determination of service routes and the associated headways. The lower level referred to the route choice behaviour, which was found by using a deterministic Frank–Wolfe loading approach. Ma (2011) applied a bi-level approach for the optimal line frequencies in a transit network, meaning the frequencies that minimise passengers travel time plus the operating cost. The lower level problem (route choice) was solved by using a Cross Entropy Learning algorithm, which was able to find the user equilibrium in transport networks. The upper level problem (optimising line frequencies) used the Hooke–Jeeves algorithm to find improvements in the current solution. Considering the same problem of finding the optimal frequency for a bus network, Yu et al. (2009) applied a bi-level programming model with the objective to reduce passengers' total travel time. In this approach, the upper level determined the bus frequencies by a genetic algorithm while the lower level assigned transit trips to the bus route network by use of a label-marking method. The two levels were solved sequentially until convergence.

One of the first studies to consider transfer time minimisation and also how passengers adjusted their travel patterns accordingly was Feil (2005), who applied a Steepest Descent approach to find the most promising offset changes and evaluated their actual impact with a public assignment model.

1.2. Objective and contribution

In the present paper, the objective was to minimise the weighted transfer waiting time. A weight reflecting the number of passengers transferring and their actual value of time was assigned to every transfer. The weight was based on the individual