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A matheuristic for transfer synchronization through integrated timetabling and vehicle scheduling

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ABSTRACT

Long transfer times often add unnecessary inconvenience to journeys in public transport systems. Synchronizing relevant arrival and departure times through small timetable modifications could reduce excess transfer times, but may also directly affect the operational costs, as the timetable defines the set of feasible vehicle schedules. Therefore better results in terms of passenger service, operational costs, or both, could be obtained by solving these problems simultaneously.

This paper addresses the tactical level of the integrated timetabling and vehicle scheduling problem as a bi-objective mixed integer programming problem that minimizes transfer costs and operational costs. Given an initial non-cyclical timetable, and time-dependent service times and passenger demand, the weighted sum of transfer time cost and operational costs is minimized by allowing modifications to the timetable that respect a set of headway constraints. Timetable modifications consist of shifts in departure time and addition of dwell time at intermediate stops with transfer opportunities.

A matheuristic is proposed that iteratively solves the mathematical formulation of the integrated timetabling and vehicle scheduling problem allowing timetable modifications for a subset of timetabled trips only, while solving the full vehicle scheduling problem. We compare different selection strategies for defining the sub-problems. Results for a realistic case study of the Greater Copenhagen area indicate that the matheuristic is able to find better feasible solutions faster than a commercial solver and that allowing the addition of dwell time creates a larger potential for reducing transfer costs.

1. Introduction

Transfers add substantial amounts of travel time to journeys in large public transport systems. Reduced transfer times resulting from a better synchronization of trips in timetables could increase ridership of public transport and thereby potentially diminish congestion (Ibarra-Rojas and Rios-Solis, 2012). A higher mode share for public transportation furthermore aids to reduce rising pollution levels. Therefore, the integration of timetabling and vehicle scheduling is important because it improves passenger service at limited operating costs (Guihaire and Hao, 2010). This paper addresses this issue in the context of tactical timetable and vehicle schedule design.

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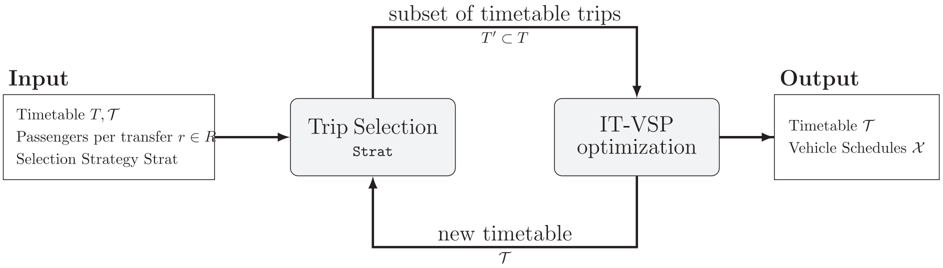

Fig. 1. Flow diagram of the matheuristic approach.

Timetables and vehicle schedules are closely related problems, but are traditionally solved sequentially (Desaulniers and Hickman, 2007). Indeed, a small change in the timetable could render an initial vehicle schedule infeasible, *or* could create options for less costly vehicle schedules. Sequentially optimizing these plans can therefore result in suboptimal solutions. That there is a benefit in integrating timetabling and vehicle scheduling was already demonstrated by e.g. Ceder (2001); Van den Heuvel et al. (2008); Petersen et al. (2013); Ibarra-Rojas et al. (2014) and Laporte et al. (2017), who report savings of up to 20% in transfer waiting times while keeping operational costs at a similar level.

This paper addresses the tactical level of the *integrated timetabling and vehicle scheduling problem* (IT-VSP) as a bi-objective mixed integer programming problem that minimizes transfer costs and operational costs. Given an initial non-cyclical timetable, and time-dependent service times and fixed passenger demand per transfer, the weighted sum of transfer time cost and operational costs is minimized by allowing modifications to the timetable that respect a set of headway constraints. Timetable modifications consist of shifts in departure time and addition of dwell time at intermediate stops with transfer opportunities. Novelty of the current work lies in the far wider set of allowed timetable modifications in the IT-VSP, the detailed representation of vehicle schedules, and the new matheuristic that for the first time allows to compare results to a lower bound on the problem.

The contributions of this paper are threefold: (i) We present a mathematical formulation for the IT-VSP that allows for a far wider set of timetable modifications by allowing both a change in departure time as well as increases in dwell time under headway constraints; (ii) we propose a matheuristic approach that generates good quality solutions for real size instances faster than a general purpose commercial solver; and (iii) we apply our methodology to a real case study for the express bus network in the Greater Copenhagen area. Results of the case study indicate that the integrated planning of timetables and vehicle schedules can reduce both excess transfer times for passengers and the operational costs. The solutions of the matheuristic in one hour of computation time are substantially better than the solutions of a general purpose solver after seven days of computation time.

The matheuristic, depicted in Fig. 1, selects and solves a sub-problem of the IT-VSP in each iteration. The input consists of the set of timetabled trips, an initial timetable, a fixed passenger demand per transfer opportunity, and a selection strategy for defining the subproblem. We propose and compare four selection strategies. The matheuristic consists of the two blocks in Fig. 1, executed iteratively. First a subset of timetable trips is selected according to the selection strategy. Next the IT-VSP mixed integer programming formulation is solved, rescheduling timetables for selected trips only while simultaneously optimizing the vehicle schedules. Specific features of the model are the dynamic assignment of transferring passengers to transfer-to trips, the allowance of non-cyclic timetables, pre-defined changes in on- and off-peak travel times of vehicles, and the creation of detailed vehicle schedules for the planning horizon (e.g. 24 h). The output defines the new, best known timetable, as well as vehicle schedules that cover that timetable. The iterations stop when either a maximum time or a maximum number of iterations have been reached.

The remainder of this paper consists of a problem description (Section 2), a literature review (Section 3), a formal problem definition including the MIP formulation (Section 4), the matheuristic (Section 5), and a case study and discussion of results (Sections 6 and 7), as well as conclusions and suggestions for future research (Section 8).

2. The integration of timetabling and vehicle scheduling

Given a set of bus lines and desired frequencies, the *Transit Network Timetabling* (TNT) problem defines the departure and arrival times for each stop visited by each trip. The general TNT problem aims at maximizing passenger service, and may consider schedule synchronization and transfer times. The *Multiple Depot Vehicle Scheduling Problem* (MDVSP) has the goal of operating a set of timetabled trips using vehicles from a set of depots at a minimum cost. When only one depot is available, the problem is referred to as the *Single Depot Vehicle Scheduling Problem* (SDVSP), which is solvable in polynomial time. Inputs to the problem are the number of vehicles available at each depot, a set of timetabled trips to be serviced (which is the output of the TNT), and a distance matrix between all terminal stops and depots. Vehicles must start and end at the same depot.

The IT-VSP applies modifications to a provided timetable to minimize a weighted sum of passenger costs and operational costs resulting from the vehicle schedules. Passenger demand is known and fixed, and defined as a number of passengers