Integrating timetabling and vehicle scheduling in public bus transportation

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Abstract

The planning process for public bus transportation roughly consists of four steps: network route design, timetable generation, the generation of vehicle schedules and the generation of crew schedules. A lot of research has been done on optimizing the individual steps, but the integration of multiple steps has received less attention. However, this may lead to a more efficient planning. In this paper we present multiple integer linear programming models to integrate the timetable generation process and the vehicle scheduling process. The models are based on a time-space network with preprocessing steps. For the generation of arrival and departure times, these models are combined with local search.

The models were implemented and tested on real life data sets from the Dutch bus company Connexxion. The results indicate that a significant reduction of the operational costs can be achieved by optimization of the type and number of vehicles performing a service trip and by splitting service trips. Using local search to change the departure and arrival times in the current timetable can save even more.
1 Introduction

In recent years many public transportation companies have been privatized and public transport in an area is then tendered for by the public transportation companies. Because of this competition, more time and effort is spent on reducing operational costs.

A lot of research has been done on several aspects of planning in public bus transportation companies. The operational planning process can roughly be divided into four steps, route network design, timetable generation, vehicle scheduling and crew planning. Before we can generate a timetable the connections or lines have to be determined. This is also known as the network route design. In the timetabling problem the frequency of the lines and the departure and arrival times of the trips are determined. When multiple vehicle types are available, the vehicle type will often also be determined in the timetabling process. A part of the total timetable could be: “Line 128 will depart 2 times an hour; at -.12 and -.42”. In the vehicle scheduling process each trip will be assigned to a vehicle. The outcome of this process is a vehicle schedule containing which vehicle will service which trips. Finally, the crew is assigned to the vehicles and trips. In this paper we will investigate the integration of two steps in the planning process: the generation of timetables and vehicle schedules. Examples of questions concerning this topic are: ‘In a rural area would it be efficient to use in the morning peak 4 small buses per hour instead of two large buses, especially if you are also using small buses during the day?’ Or ‘Can you save a number of buses by shifting the departure times in the timetable?’ According to the Dutch situation, we assume that the timetable is clock face. In the Netherlands a timetable that is not clock face is only allowed for lines with a high frequency e.g. within large cities.

In many bus companies including Connexxion timetables are generated manually and software is only used to support the process by means of e.g. graphical presentation. However, a considerable amount of research has been performed on automatic timetable generation. For example, Ceder (Ceder, 2001) proposes to change the timetable with a procedure to evenly spread the amount of passengers amongst the buses. This will, however, not produce a clock face timetable and can therefore not be used by a Dutch bus company such as Connexxion. The Dutch railway company (NS) has done a lot of research on the automatic generation of periodic timetables for trains. (Peeters and Kroon, 2001) have shown an interesting way to automatically generate a cyclic timetable given the lines and frequencies. An hourly pattern is constructed using an Integer Linear Program which is adjusted for rush hours and periods with low demands on the capacity by manually adding or removing service trips. They use a transformed formulation of the Cyclic Railway Timetabling Problem (CRTP) and the – more general – Periodic Event Scheduling Problem (PESP) which was introduced by (Nachtigall,
Moreover a lot of research has been on multi-depot vehicle scheduling. An example of a survey is (Bussieck et al., 1997). A column generation technique was used by Ribeiro et al. (Ribeiro and Soumis, 1994) to solve the problem to optimality for sizes up to 300 trips and 6 depots. (Löbel, 1999) solves an ILP formulation derived from a multicommodity flow formulation by column generation and is able to handle large real-life instances. A recent approach from (Kliewer et al., 2006) extended in (Gintner et al., 2005) shows good results. The problem is represented as a time-space network with covering constraints. The use of time-space networks was first suggested by (Hane et al., 1995) for solving routing problems in airline scheduling. Kliewer et al. have adapted them for application in bus scheduling by greatly reducing the number of deadhead edges. The reason this works well is because the values of the variables in the solution of the LP relaxation are mostly integer since the formulation resembles the LP formulation for a minimum cost flow problem.

The integration of vehicle scheduling and crew scheduling has also been investigated. (Huisman et al., 2005) propose two algorithms for integrated vehicle and crew scheduling in the multiple depot case. Both algorithms are based on a combination of column generation and Lagrangean relaxation. In (Huisman and Wagelmans, 2006) a solution approach for the dynamic version vehicle and crew scheduling is proposed. Vehicle and crew scheduling is also investigated by (Rodrigues et al., 2006), whose techniques are based on integer linear programming coupled with heuristics.

In (Kliewer and Bunte, 2007) vehicle scheduling is combined with the possibility to make small changes to the timetable, i.e. by shifting the departure times of trips that have been identified as critical within a limited time window. This is achieved by extending the time-space network. Their computational results are encouraging.

The contribution of this paper is the development of models for vehicle scheduling which include the optimization of the type and/or number of vehicles for each trip and a local search algorithm for combining the computation of timetables times with vehicle scheduling. We developed integer linear programming models for vehicle scheduling where multiple vehicle types are allowed for each service trip, i.e., trip defined in the timetable. These models use a so-called Time-Space Network and extend the models presented in (Kliewer et al., 2006). One of our models has full flexibity in the assignment of bus types to a service trip as long as there is enough capacity to transport the expected number of passengers, e.g. if the expected number of passengers is 60 one standard bus with capacity 50 and one small bus with capacity 10 can be used. Another model chooses one vehicle type per service trip and then assigns the required number of buses to it. If there are more buses of the selected type required for the trip, the trip is splitted into multiple trips and these trip are divided evenly over time. For
example, if initially there are two trips per hour and one trip is executed by two buses these buses will run with an interval of 15 minutes. To include the optimization of the timetable we introduce an hierarchical approach. Recall that we assume that a timetable has to be clockface. We apply a local search algorithm where in each iteration the timetable is changed and for a fixed timetable and fixed vehicle types the cost are computed by solving a minimum cost flow problem. To the best of our knowledge this the first algorithm for integration of timetabling and vehicle scheduling allowing all possible departure and arrival times in the timetable under the condition that the timetable remains clock face. We implemented the algorithms and performed experiments with real-life data from bus company Connexxion.

The remainder of the paper is organized as follows. In Section ??, we present the integer linear programming models for vehicle scheduling and the local search algorithms. After that, in Section ?? we present our computational results. Finally, in Section ?? we conclude by discussing the applicability of the results and further research.

References


