Integrated Optimization of School Starting Times and Public Bus Services

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Abstract. In many rural areas, the public bus service is demand-oriented: By far the biggest group of customers are pupils who are transported to their schools within certain strict time limits. Usually, all schools start around the same time, which causes a morning peak in the number of deployed buses. However, schools are allowed to change their starting times within some interval. The question is, how to simultanenously rectify the starting times for all schools and bus trips in a certain county so that the number of scheduled buses is minimal. This problem can be formulated as a vehicle routing problem with coupled time windows (VRP-CTW), which is an extension of the vehicle routing problem with time windows (VRP-TW), where additional coupling constraints on the time windows are introduced. We give a mixed-integer programming formulation for VRP-CTW, and present solutions and lower bounds for randomly generated and real-world instances.

1 Introduction

In rural areas pupils on their ways to school and back home are usually the biggest group of customers for public means of transportation. In Germany it has become custom that schools start in a small time interval around 8:00. On the transportation side, this leads to a high number of deployed vehicles (i.e., buses) that have to transport the pupils in time, with a peak from 7:00 to 8:00. After having served the morning rush hour, most of the buses are sent back to the depot, for there is nearly no further demand. The afternoon peak at the end of school is usually much lower, for schools do not release all pupils at the same time. Hence the main focus for the optimization, i.e., a reduction of the total number of deployed buses, is the morning peak. Responsible for the transportation of pupils to their schools and back are the respective county administrations. Since they are funding bus companies with public money, they are interested in a cost-efficient organisation.

Changing the starting time of all schools in some county generally creates a strong opposition from the people affected by the change. To give an example, if some school doesn't start at, say, 7:50, but at 8:30, then all its pupils leave home more than half an hour later, which might cause troubles for working parents. In the afternoon, the children return later, and therefore might no longer be able to attend a sports club. Here the consulting company *BPI-Consult*, a subsidiary of the Finnish *Jaakko Pöyry*, enters the

stage. Appointed from the county administration, BPI suggests new school starting times, accordingly adjusts the trip time tables, and plans new bus schedules using fewer buses than before. Then, BPI accompanies the whole process of embedding their solution into real-life, which includes negotiations with all participants (schools, bus companies, parents, county government officials) and potentially re-optimization, when new constraints appear that make previous solutions infeasible. Up to now, BPI successfully consulted four counties and one city, where the number of buses was reduced by 15 – 20%, which yields a yearly cost saving of 10 – 15%, see [7] for details. In each of these cases, the solutions were generated manually, which in the past turned out to be a tedious task for a human planner.

A wide range of transportation problems involving public bus transit, pupils and/or schools were already studied before, see [2–4], to name just a few. However, none of the presented models completely fits to our problem, mainly for some or all of the following reasons: In all previous modelling approaches, the time windows of school starting times are fixed and cannot be changed to save buses. Pupils are always transported directly to school, and changing the bus is not allowed. Some models focus on scheduling drivers, which is not an issue for us: Since our time horizon is small (mainly from 5:00 till 9:00), no breaks are needed, thus the drivers do not change the bus. Relocating bus stops, designing routes (trips) and assigning pupils to routes is sometimes part of the optimization, but for us these are input figures. BPI-Consult is not touching these issues, even if the number of deployed buses could be lowered in theory. From a mathematical point of view, this of course reduces the combinatorial complexity of the problem significantly. From BPI's point of view it is mainly a political decision: Changing only the starting times of trips and schools already creates enough opposition. The mathematical model we present in this article reflects these restrictions. It was designed to become part of a software tool supporting the planners at BPI.

2 A Mixed-Integer Programming Model

In general, our problem belongs to the class of vehicle routing problems with time windows (VRP-TW), see [5], for instance. In a generic formulation of this problem, a fleet of vehicles starting at a depot is sent to customers, picks up some commodities up to a maximum load and drives back to the depot. Each customer has a time window, in which the arrival time of the vehicle must be. In case of an earlier arrival of the vehicle, waiting is permitted. The lexicographic bi-criterial objective is: 1) minimize the number of deployed vehicles, and 2) minimize the total driving time (or distance) of the entire fleet. The model we developed to solve BPI's integrated planning problem is a modification of VRP-TW. We start with a detailed description of the sets and parameters needed as input figures.