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Public transport vehicle scheduling featuring multiple vehicle types

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ABSTRACT

Vehicle scheduling is a crucial step of the public transport planning process because it results in the number of vehicles required, thus it is directly related to fixed cost and labor cost. It is desirable, therefore, to minimize the number of vehicles used and operational cost. This paper proposes a new methodology for the multiple vehicle types vehicle scheduling problem (*MVT-VSP*). The methodology is based on a minimum-cost network flow model utilizing sets of Pareto-optimal timetables for individual bus lines. Given a fixed fleet size the suggested methodology also allows a selection of the optimal timetable. The method developed enables to stipulate the use of a particular vehicle type for a trip or to allow for a substitution either by a larger vehicle or a combination of smaller vehicles with the same or higher total capacity. Moreover, a variation of the method portrayed makes it possible to construct sub-optimal timetables given a reduction of the vehicle-scheduling cost. It is demonstrated that a substitution of vehicles is beneficial and can lead to significant cost reductions in the range of more than 27%. The suggested methodology is applied to a real-life case study in Auckland, New Zealand, and the results show improvements of greater than 15% in terms of the cost of fleet compared with vehicle schedules that are provided by standard models.

1. Introduction

1.1. Background

There is no doubt that increased usage of public transport service can be a remedy to reduce urban traffic congestion and air-pollution level. This can be attained by making the public transport service more attractive; that is, more reliable, no crowding, and enabling competition with the cars in terms of travel time and cost. It is to note (Ceder, 2007) that the assumption that passengers will adjust themselves to a given timetable instead of adjusting the timetable to passenger demand constitutes a major source of unreliable service. When passenger demand is not met, public transport vehicles slow down, traveling behind schedule and entering the inevitable process of further slowing down. This situation will eventually lead to the known bunching phenomenon with the vehicles that follow. In contrast, a situation of overestimating demand may result in vehicles running ahead of time. Two recent studies by Hassold and Ceder (2012) and Ceder et al. (2013) show how to use multiple vehicle sizes to improve the matching between departure times (timetable) and passenger demand so as

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to improve public transport reliability. However, these two studies were performed at the route level and it was not clear whether or not the introduction of different vehicle sizes/types will not result in an increased operational cost especially from the fleet-size (of various sizes) perspective. This work is a continuation of these two timetabling-related studies with the consideration of vehicle-scheduling cost.

A further description of the two studies is as follows. Hassold and Ceder (2012) demonstrate how to make public-transit services more attractive by using two simultaneous objectives: minimizing the average estimated passenger waiting time and minimizing the discrepancy from a desired occupancy level on the vehicles. The first objective will improve the service and attract more users, and the second objective will assure economical operation. A network-based procedure is used to create timetables with multiple vehicle types to solve this bi-objective problem. Ceder et al. (2013) describes a methodology to approach even-headway and even-load timetables by utilizing different available bus sizes. The composition and size of the fleet of buses can be either given or with a flexibility of introducing new sizes. Two objectives were set. First, minimize the deviation of the determined headways from a desired even headway. Second, minimize the deviation of the observed passenger loads from a desired even-load level of the buses at the maximum-load point. The first objective will reduce the expected waiting time of randomly arriving passengers and thus will increase the attractiveness of the public-transport service. The second objective will improve the reliability of operation for fluctuating demand, and will improve the utilization of the buses from the operator perspective.

1.2. Vehicle scheduling related issues

Vehicle scheduling is an important step within the public transport planning and describes the process of assigning vehicles to the trips of a timetable. Given a desired timetable, the quality of vehicle schedules is often measured by the minimum number of vehicles required to cover all trips (Ceder, 2007). It does not only have a significant impact on the capital cost for acquiring the vehicles, but also on the fixed cost of maintenance, etc. More importantly, the need for a large number of vehicles implies more manpower. Depending on the region and other factors, the cost for drivers can account for a noteworthy share of the total cost; e.g., the share of driver cost shown in the case study of Shaw-Er et al. (2005) is as high as ~% of the total cost. There are several variations of the vehicle scheduling problem (*VSP*) which require different solution approaches. The variations are based on given characteristics of the problem, such as the number of depots or the number of vehicle types. Daduna and Paixão (1995) describe several of these variations and discuss solution approaches and their complexity. Haghani et al. (2003) provide a comparative analysis of bus transit vehicle schedules using a large real world example. They show that, under certain conditions, a single depot vehicle scheduling model performs better than the corresponding multiple depot model.

Bunte and Kliewer (2009) provide a detailed literature review and discuss the modeling approaches for different kinds of vehicle scheduling problems. This work describes the case of a multiple vehicle types vehicle scheduling problem (*MVT-VSP*). The vehicle types have different capacities and might have different fixed and variable cost. According to Lenstra and Kan (1981) the problem is $\mathcal{NP}$-hard for the single depot case. There have been numerous approaches published (e.g., Smith and Wren, 1981; El-Azm, 1985), all of which consider multiple vehicle types. A common approach published by Bodin et al. (1983) and also used in Costa et al. (1995), includes the use of a multigraph with a sub-network for each vehicle type. However, if there are further restrictions such as certain trips requiring a certain vehicle type, the model has to be further extended. This was considered by Forbes et al. (1994) and Löbel (1997). It was also included in a time–space network approach by Kliewer et al. (2006). In particular, this research focuses on a single depot vehicle scheduling problem with multiple vehicle types (*SD-MVT-VSP*). There are further constraints added which require the trips in the network to be covered by a particular vehicle type. In general this type of a problem can be solved by dividing the vehicle scheduling problem into sub-problems – one for each vehicle type – and solve those to optimality independently. However, in this case the main difference between the vehicle types is their capacity. Therefore, determining the optimal solutions for the separate cases does not necessarily lead to the best global solution. This is shown by an example depicted (with notations) in Fig. 1, in which trips between Stations *A* and *B* re to be covered.

The number of required vehicles can be reduced by allowing interaction between the sub-problems, while still satisfying the capacity constraints for the expected passenger demand. This substitution of one vehicle type by another vehicle can help reducing the fleet size required.

Ceder (2011) proposed a methodology to schedule vehicles of different types, where vehicle types can be substituted by others according to a predefined cost for each type to cover a trip. The approach uses the so called deficit-function method allowing deadheading trip insertion and shifting of departure time within given tolerances to reduce the fleet size required.

Haase et al. (2001) suggest a simultaneous vehicle and crew scheduling approach for a homogeneous fleet and one single vehicle. The crew scheduling is solved using a column generation approach. The corresponding vehicle schedule can be derived in a polynomial time. Kéri and Haase (2007) suggest a similar approach to solve the vehicle and crew scheduling simultaneously allowing shifting of departure times. A multicommodity network flow model and column generation is used to solve the problem optimally, where the objective function minimizes the number of buses and then the crew cost. The model is restricted to a homogenous fleet, but can be extended to include a heterogeneous fleet.

Kliewer et al. (2012) consider a multiple depot case for the simultaneous vehicle and crew scheduling with time windows. A time–space network formulation is used and shifting of trips is explicitly modeled using additional arcs in the network. It is shown that allowing the shifting of trips can significantly improve both vehicle and crew schedules by cost reduction. Because of the increased complexity of the problem heuristics are employed to reduce the computational time required.