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Vehicle and crew scheduling for urban bus lines

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Abstract

A solution to the urban transportation problem is given by vehicle and crew schedules. These schedules must meet the passenger demand and satisfy technical and contractual restrictions stemming from the daily operation of the lines, while optimizing some measure of operational cost. This work describes a computational tool developed to solve the urban transportation problem in the large metropolitan area of São Paulo, Brazil. The techniques used are based on integer programming models coupled with heuristics. The former produces good feasible solutions, and the latter improves the quality of the final solutions. While the operational and labor restrictions are specific to the city of São Paulo, the same ideas can inspire similar approaches for solving the urban transportation problem arising in other metropolitan areas.

Keywords: Scheduling; Crew; Vehicle; Transportation; Timetabling

1. Introduction

The urban transportation problem (UTP) has been the focus of several studies [34,8,32,17]. Most of its variations give rise to NP-hard problems [16,32,19]. Generally, the difficulties stem from a large set of complex and conflicting restrictions that must be satisfied by any solution. Most of these restrictions are reflected in a sizable number of operational conditions that involve specific characteristics of each bus line, among which are

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the number of vehicles, the number of passengers that must be transported, the varying duration of each trip along the day and the vehicle capacities. Also, a number of local labor and safety regulations, such as the maximum number of work hours in a day and mandatory rest periods, further restrict the construction of viable journeys. The solutions must also optimize some objective function, which includes precisely measured items, such as operational costs, but may also involve other items whose measures may not be completely clear, such as maintaining trip departure times well spaced along the day.

In one possible strategy for solving the UTP, short term vehicle and crew schedules can be obtained first. Next, the long term planning of crew rostering is addressed. Of course, this particular sequence of steps admits variations [2,5,35,36]. In this work, we will concentrate on the vehicle and crew scheduling subproblems for which, broadly speaking, there are two approaches.

First, we have the sequential approach where these subproblems are treated separately [13,14]. In vehicle scheduling, the problem is to construct blocks of consecutive trips. Each block must start and end at a depot, while satisfying appropriate operational restrictions. The set of blocks so constructed must also meet the passenger demand and minimize some objective criteria, such as the distance traveled or fuel consumed [8,18,19,22–24]. A number of computational tools have been developed to construct vehicle blocks [7,31,19,28]. For the crew scheduling problem, a set of work schedules is sought, a work schedule being a sequence of consecutive trips, maybe interspersed with rest time [14,13]. Besides covering all trips occurring in the vehicle blocks, work schedules must also satisfy a number of labor and operational restrictions. In general, the objective function tend to be more complex in crew scheduling, it being a combination of fixed cost items, such as wages, and variable cost items, such as extra duty time. As a result, crew scheduling is usually harder to solve than vehicle scheduling, and simple heuristics for this problem often run into poor local optima [32]. Earlier codings for crew scheduling have been based on heuristics [30,20]. More recent results are based on mathematical programming techniques [3,34,12], or have used a hybrid approach [35,36]. After both subproblems have been solved, the solutions are unified by mapping work schedules, possibly separated by relief periods, into vehicle blocks, while still preserving the quality of the solutions [17,21,35,4,34,26]. The sequential approach has been applied in a number of practical cases [33,11], and such experiences revealed that while it may work well in certain situations, it may not yield adequate results when exercised over slightly different scenarios. Also, often the solutions obtained must be manually adjusted before they can be enforced in practice.

When there are interdependent restrictions that involve crew and vehicles, solving both problems independently may not lead to operational solutions [14]. A second alternative for solving the UTP resorts to more integrated approaches, which tend to yield more adequate final solutions [13]. Since the set of restrictions that apply to crews is usually more stringent than those that apply to vehicles, some of the restrictions inherent to the former may be shifted to the latter, leaving the final crew scheduling for a second step [9,27]. Earlier attempts towards an integrated approach used heuristics [1] and graph pairing techniques [29,25,10]. More recently, linear programming partition models have been proposed [15], combined with column generation techniques. The results indicated that problems with up to 25 trips could be solved, while problems with 30 or more trips remained intractable. A combination of Lagrangian relaxation and column generation techniques have also been implemented to simultaneously solve vehicle and crew scheduling problems with multiple depots for real instances of the UTP, in Italy [6]. Since full integration between vehicle and crew scheduling usually results in a much more complex problem, this approach has received less attention [13,14]. In this work, a loosely integrated approach is developed into a computational tool that can be used to automatically solve the UTP for large urban areas in and around the city of São Paulo, in Brazil. Since, for a typical company operating in that area, about 50% of the operational costs comes from wages and related items, even small improvements in the schedules can produce sizable savings.