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SpeedRoute: Fast, efficient solutions for school bus routing problems

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ABSTRACT

School bus planning problem (SBPP) has drawn much research attention due to the huge costs of school transportation. In the literature, the SBPP is usually decomposed into the routing and scheduling subproblems due to its complexity. Because of the nature of the decomposition, even if all the subproblems are solved to optimality, the final solution may not be as good as the solution from the integrated model. In this paper, we present a new approach that incorporates the scheduling information (namely the trip compatibility) into the routing stage such that the interrelationship between the subproblems is still considered even in the decomposed problems. A novel two-step heuristic adopting the trip compatibility idea is presented to solve the school bus routing problem under single-load assumptions. The first step finds an initial solution using an iterative minimum cost matching-based insertion heuristic. Then, the initial trips are improved using a Simulated Annealing and Tabu Search hybrid method. Experiments were conducted on randomly generated problems and benchmark problems in the literature. The result shows that our two-step heuristic improves existing solutions of single-load problems by up to 25% on benchmark problems.

1. Introduction

According to the National Center for Education Statistics, the *U.S. spent over $23 billion on public student transportation in 2012–2013*. This is about $914 per student (National Center for Education Statistics, 2016). Due to the vast amounts of funds being invested in school transportation, improving operational efficiency, even a little, could result in huge savings. While there are various objectives that school transportation authorities have, we focus on the more monetary and quantitative measures. In this study, we assume that the primary objective of designing a school bus transportation system, from the operator's perspective, is safely transporting all students with minimum cost while satisfying constraints such as maximum ride time, vehicle capacity, and time window. This problem is formulated as a school bus planning problem (SBPP).

A school transportation plan consists of a routing plan and a scheduling plan. The routing plan is a collection of *trips* where each trip can be represented as a sequence of stops. A morning trip, for a given school, usually starts by picking up the first group of students from a student location stop and sequentially visits a set of other student stops that are exclusive to that school and finally arrives at the stop corresponding to the location of the school. The scheduling plan is made of a

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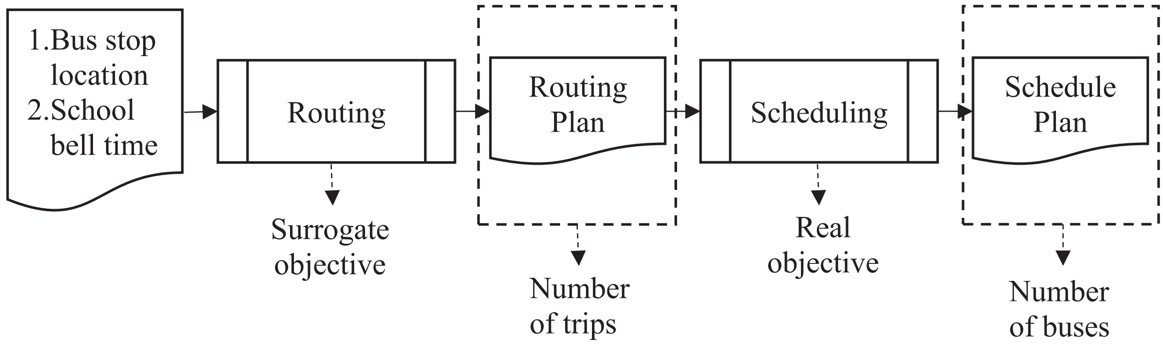

Fig. 1. Flowchart of routing and scheduling.

set of *routes* where each route starts from the depot and sequentially serves a set of compatible trips. An ordered trip pair is called *compatible* if the deadhead time between the last stop of the preceding trip and the first stop of the successive trip is less than or equal to the available time window between the two trips. The cost of a school transportation plan mainly includes the acquisition cost of a bus, bus driver employment cost, and operations cost (like gas, maintenance, etc.). The first two costs are fully determined by the number of buses (i.e., the number of routes in the scheduling plan), and the last one highly depends on the total travel time/distance. Therefore, the objective of the SBPP is to minimize the weighted sum of the number of buses and the total travel time/distance. The former is of higher priority than the latter because the acquisition cost of a bus and bus driver employment can easily overwhelm the marginal mileage costs.

It is worth noting that in this study, we are focusing on more monetary related parameters of the problem. Apart from minimizing the total cost, improving the level of service is another possible objective. Bowerman et al. (1995), Li and Fu (2002) and de Souza Lima et al. (2017) tried to balance between trips including the load and the ride time. Corberán et al. (2002) and Pacheco and Martí (2006) minimized the maximum ride time for students. Yan et al. (2015) separated the vehicle flow and passenger flow to accommodate the transfer. They specifically minimized the passenger time lost, which consists of the delay time (additional travel time if using the transfer as compared to traveling without transfer) and the waiting time (school start time minus the bus arrival time).

In this study, we focus on the single-load variant of the school bus routing problem. The single-load variant is more restrictive than the mixed-load alternative in the sense that it assumes that students from different schools cannot sit on the same bus trip. While from an operational perspective, the single-load case is more restrictive and results in more costs, from a practical point of view, it is still an important problem as many school districts do not allow mixed-load due to parent concerns or other socio-political concerns. We develop a two-step heuristic algorithm for solving the single-load school bus routing problem with the consideration of trip compatibility. Our solution approach is general and can be used for solving other variants of vehicle routing problems that include routing and scheduling such as dial-a-ride and pickup and drop-off and delivery problem with time windows. We show the effectiveness of our proposed methodology on benchmark problems from the literature.

The rest of the paper is structured as follows: In Section 2, we review some of the literature regarding solution methods for solving the school bus routing problem and related variants of vehicle routing problems, and we summarize our contributions. In Section 3, we present our solution algorithm. Section 4 analyzes the results and illustrates the performance of our proposed solution algorithm on randomly generated problems and benchmark problems. Finally, Section 5 concludes the paper.

2. Literature review

As pointed by (Park and Kim, 2010), the majority of the school bus planning research decompose the SBPP into subproblems and only focus on one of the subproblems. While a few recent studies such as (Park et al., 2012) and (Bögl et al., 2015) formulated integrated mathematical models for the SBPP, due to the complexity of the models, they decomposed those models into sub-problems during the solution process. A conceptual flowchart of the SBPP that includes routing and scheduling is shown in Fig. 1. Here, bus stop selection and school bell times are assumed to be predetermined.

As discussed above, the primary objective of the SBPP is to minimize the number of buses used. However, due to the precedence of the routing step, this objective cannot be accounted for in the process of routing. As a consequence, a surrogate objective is required to solve the routing problem. Different surrogate objectives will lead to different routing plans, which will further result in different scheduling plans. Traditionally, the surrogate objective for routing is to: 1) minimize the number of trips; or 2) minimize the total travel distance or the travel time (Schittekat et al., 2013; Faraj et al., 2014; Kinable et al., 2014); or 3) a mixture of 1 and 2 (Díaz-Parra et al., 2012; Caceres et al., 2017). Those surrogate objectives also serve as the evaluation criteria in many heuristics like the insertion cost estimation in trip construction algorithms and the exchange move goodness estimation in local search algorithms.