Research on Optimization of Customized Feeder Bus for High-speed Railway Connection with Consideration of Travel Time Uncertainty

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Abstract. In order to cope with the inconvenience for passengers who need to take high-speed railway (HSR) due to the HSR stations in China being far away from the city center, this paper proposes a customized feeder bus (CFB) service for HSR connection. The research aims to optimize the comprehensive interests of the government, operators, and passengers, and constructs a mixed integer nonlinear optimization model that integrates customized bus line planning and timetable optimization with consideration of travel time uncertainty, and also considers the passenger assignment problem during the timetable optimization. In addition, the research also designs a heuristic decomposition algorithm to improve computation efficiency for solving large-scale cases. Finally, the results of test example and practical example show that the proposed model has better performance in reducing costs, passenger travel time deviations, government subsidies and energy consumption. Besides, it can provide more reliable services to passengers.

Keywords: Customized Bus, Feeder Service, Timetable Optimization, Passenger Assignment

1 Background

China high-speed railway (HSR) has developed rapidly in the past thirty years. However, in contrast to the efficiency and convenience of HSR, people generally spend a significant amount of time reaching and leaving an HSR station, which is primarily because most HSR stations in China have been built in suburban areas on the edge of cities (Wu and Han, 2022, Xu et al., 2023). Therefore, HSR feeder services have been brought into sharp focus to address the first and the last mile problem.

Customized bus (CB) service, as a superior feeder mode, integrates the characteristics of regular bus service with its low price and large capacity, along with the flexibility of taxi service. CB serves passengers with shared travel patterns fit for ride-sharing (Huang et al., 2020), which suits HSR passengers who typically plan trips in advance, ensuring that they reach stations on time. CB provides timely responses to passengers' needs with its flexibility and a fixed itinerary upon launch, ensuring punctual arrivals at HSR stations for travelers.

Research on CB as the HSR feeder mode is limited, highlighting two issues. First, supply-side models often unrealistically disregard vehicle empty runs, travel time uncertainty, and vehicle heterogeneity, affecting resource efficiency and service reliability. Second, passenger behavior models are oversimplified, neglecting how passengers' travel preferences influence optimization outcomes.

Based on this, this study formulates an integrated optimization model for Customized Feeder Bus (CFB) services that plans routes and schedules together, considering vehicle capacity and balancing the interests of operators, the government, and passengers for enhancing profitability, minimizing subsidies, and increasing satisfaction. It considers travel time uncertainty to enhance the robustness of CFB services. Moreover, passenger assignment model is included to refine timetable quality. To address the dispersion of HSR station passenger flows, this study advocates for hub stations to attract demand, improve transfer efficiency and boost operational profits.

2 Model and solution algorithm

Our CFB service consists of a set of candidate stops S, a set of routes P that contains all possible stop combinations and limited available services V provided by vehicles with a specific capacity. Each operational service will be assigned to a route, and all vehicles of operational services departing from an HSR station, passing through several stops on a particular route and final return to the HSR station. Vehicles will stop at intermediate points for passengers to board and disembark. Because varying traffic conditions on different routes during different time periods lead to travel time uncertainty, we have set different additional travel times for each time period based on the expected trip duration within each interval. That is to say, the actual travel time of the vehicle on the route will vary according to the different time periods in which it travels. The proposed model optimizes route design and timetable with consideration of passenger reaction, because passengers can choose to accept or reject services based on the deviation between the service timetable and their ideal time. A small example containing an HSR station, a hub station, five stops and two routes is illustrated in Fig.1.

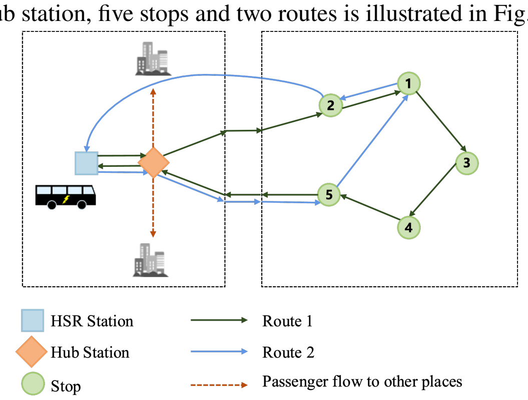

Fig. 1. An example of CFB service.

In terms of objective function, we consider minimizing the number of unserved passengers, the passenger travel time deviation, the government subsidy and the total electricity consumption and taking their weighted sum to transform into a single objective function. Therefore, the model can make reasonable decisions to balance passenger demand and economic feasibility, and save energy as well. In order to ensure that the model result meets the practical condition, we include CFB routing uniqueness constraint, planning horizon constraint, vehicle headway constraint, minimum boarding rate constraint, time deviation constraint, and UE condition considering vehicle capacity constraint.

The introduction of the UE condition leads to the nonlinearity of the model, which means that it is difficult to calculate by traditional methods in large-scale examples. Therefore, a decomposition algorithm (DA) is suggested to solve it and the algorithm flowchart is shown in Fig. 2. We split the original problem into two sub-problems, the timetable optimization problem and the passenger assignment problem, then solve them through an iterative process until the deviation of two successive iterations reaches the lower limit or the number of iterations reaches the upper limit. Specifically, in solving the passenger assignment problem, the timetable is given, while in solving the timetable optimization problem, the passenger service choices are given.

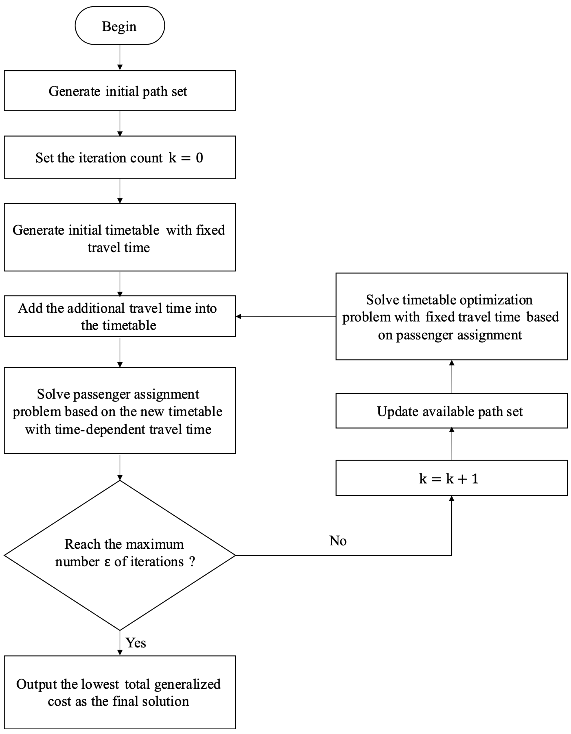

Fig.2. Algorithm flowchart

In addition, considering that a set of routes P could get too large for big instances, in the large-scale algorithm, we gradually generate a set of paths by adding new routes for passengers who have not boarded the bus, which means that we do not have to generate all possible paths at the beginning.

3 Numerical examples

We conducted tests on two examples. In the small-scale example, we have demonstrated that compared to the benchmark result which used all-stopping services with the uniform vehicle type, the proposed model with consideration of differentiated capacities and skip-stop patterns could improve the passenger boarding rate by approximately 8.16%, reduce the travel time deviation by 30%, decrease the government subsidy by about 1.93%, and lower energy consumption by roughly 60.09%, as shown in Table 1.

Table 1. Comparison result.

Group	α	β	γ	δ	Obj
Control	62	42	5276	131.7	10134.5
Experimental	58	60	5380	330	13430
Results deviation	6.90%	-30.00%	-1.93%	-60.09%	-24.54%

(α: Number of boarding passengers, β: Travel time deviation, γ: Government subsidies, δ: Energy consumption)

Furthermore, considering travel time uncertainty can enhance service reliability and punctuality, preventing passengers from missing trains.

In the Guangzhounan Railway Station-Guangzhou Higher Education Mega Center calculation example, the CFB operation plan calculated by our model could reduce travel time per person, compared with the existing plan.

4 Conclusion

In pursuit of augmenting the convenience and comfort of feeder services for HSR commuters while improving service reliability with consideration of vehicle travel time uncertainty, this paper proposes a mathematical model to optimize CFB service. In order to improve the solution efficiency, we have designed a decomposition algorithm to iteratively solve the passenger assignment problem and the timetable optimization problem. The results of numerical examples demonstrate that the proposed model can effectively reduce costs, better match passenger flow demands, and provide passengers with more punctual and reliable services.

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