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Optimization of Rolling Stock Distribution and Routing Problem for the First Train of Urban Rail Transit

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Abstract: Reasonable distribution of the first train of urban rail transit is significant for reducing operation costs and improving service quality. In order to reduce disparities of departure time between the first trains of different stations along a line of urban rail transit, an optimization of rolling stock distribution and route problem for the first train with multiple depots and multi type rolling stocks is studied to determine origin depots and corresponding deadhead routes for rolling stocks. Operation lines of urban rail transit are abstracted into a directed graph, and a 0-1 integer programming model is developed. The model takes the minimum total deadhead distance of rolling stocks as target, considering constraints of depot maintenance and storage capacity, re-entry ability of the switchback station, line capacity, and supply-demand balance. It is accurately solved by ILOG CPLEX software. Compared with traditional distribution models, the model can simultaneously obtain both matching scheme and travel path of rolling stocks. Taking a line of urban rail transit in a city as a case study, feasibility and effectiveness of the model are verified. The results show that compared with manual scheme, the model can reduce total deadhead distance of rolling stocks by 28.691 km, its reduction rate is up to 6.1%.In addition, by analyzing occupancy of depot and re-entry stations, it shows that departure ability is a bottleneck. Turn-back capacity and depot capacity nearly have no effects on routes of rolling stocks.

1. Introduction

Improving the service quality of the first bus of urban rail transit plays an important role in meeting passengers' early travel demand and improving passenger travel satisfaction. In the practice of urban rail transit operations at home and abroad, the departure mode of the first bus mainly includes the mode of the passengers operating and operating before the start of the vehicle, and the vehicle is concentrated to the first station. The latter can avoid the situation where the departure time of the first bus of the uplink and downlink stations on the long-distance line is too large, thus improving the service level of urban rail transit. In this mode, for the multi-vehicle and multi-return station lines, the bottom of the vehicle that is responsible for the first bus operation needs to depart from a certain vehicle yard, and travel to the first bus station to carry passengers through the direct route or the path that is returned via the return station. In a rail transit, a group of cars and trailers that are linked together with a unique number of vehicles is called the bottom of the vehicle. Different vehicle exit paths may result in different distances and energy consumption. The main task of the first bus bottom plan and route plan is to assign the car bottom in the yard (vehicle section and parking lot) to the first train of the map and determine the exit path of the car. The quality of the preparation and the operating cost and service level are directly Related. Reasonable urban rail transit first bus distribution plan and path plan can reduce the operating costs of enterprises and improve the quality of urban rail transit services [1].

At present, researches at home and abroad have focused on train operation maps and vehicle floor planning in the operation period. There are few studies on the deployment and route optimization of the first bus of urban rail transit. Zhong Qingwei aims at the minimum total air travel distance. Based on the uniqueness of the path, the feasibility of the route and the capability of the yard and the re-entry station, the first train of the urban rail line is deployed and the path of the outbound route is optimized. In this document, the model is only applicable to the case of a single line. With the development of urban rail transit, networked operation has gradually become a trend. It is necessary to study the first-city distribution and path optimization of urban rail under the conditions of networked operation. Cadarso studied the robustness of urban rail transit. Jiang Zhibin optimized the use of the vehicle under multiple traffic conditions. He Bisheng et al. proposed a vehicle bottom planning optimization model and solved it with a combined generation algorithm. Zheng Li et al. considered the constraints of the vehicle bottom operation mode, the yard capacity and the connection between the vehicle sub-nodes, and constructed an optimal model for urban rail transit vehicle use under collinear or network conditions. However, most of the above-mentioned documents are aimed at the problem of vehicle bottom operation during the operation period of urban rail transit, to determine the task of the vehicle under the vehicle, and not to consider the distribution and exit path of the first bus before the start of operation [2].

In summary, there are few concerns and researches on the first-car deployment and route optimization of urban rail transit at home and abroad. At present, in the actual operation, the first-city vehicle distribution plan and route plan for urban rail transit are mostly based on manual experience. Inefficiency, and it is difficult to ensure the quality of the program, it will be difficult to meet the job requirements in the case of more vehicle bottom demand. In this paper, considering the constraints of the yard, the re-entry station and the line capacity constraints and the balance between supply and demand, the vehicle's first bus distribution and path optimization model of the urban rail transit is constructed with the minimum total air travel distance as the target. The ILOG CPLEX mathematical optimization software is used to solve the problem. The model is analyzed and the feasibility and effectiveness of the model are verified by an example [3].

2. Problem Description

A city rail transit line is equipped with multiple parking lots. Before the start of the daily operation, a certain number of vehicle bottoms are departed from these yards, and are rushed to the first bus stop stations either directly or at the return station. Solving the problem of multi-vehicle and multi-vehicle urban rail transit first-floor deployment and route optimization is to determine the departure of each vehicle under the premise of meeting the restrictions on the departure capacity of the yard, the demand of the first bus at the station, and the passing capacity of the road. The vehicle yard and reasonable arrangement of the bottom of the vehicle path, so that the total air distance is the smallest. It is worth noting that in this process, it is also necessary to meet the requirements of the type of vehicle bottom at each first bus station (such as 4 car bottom, 6 car bottom, 8 car bottom, etc.).

This problem is illustrated by an urban rail transit line with 9 stations, 2 depots and 3 reentry stations, as shown in Figure 1. The line is a two-directional single-line urban rail transit line, and the stations are sequentially numbered S 1 ~S 9 in the upward direction, wherein the S 1 station and the S 9 station are respectively the starting and ending stations of the line. O 1 and O 2 are the two yards of the line, which are connected to the S 3 station and the S 8 station respectively. The S 1 , S 6 and S 9 stations are the return stations for the bottom of the vehicle. The downstream direction of the S 5 station is required. The bottom of the car serves as the first train, as shown by the black triangle in the picture. There are three types of vehicle layout and empty exit route plan: 1 Depart from the O 2 of the yard, go straight to the S 5 station to act as the first bus, as indicated by the solid arrow in the picture; 2 From the yard O 1 to go up, reach S 3 stations and return to the down direction via S 6 station, drive to S 5 station, as indicated by the dotted line arrow in the figure; 3 start from the yard O 2, go to the S 8 station and turn back to the down direction via the S 9 station. To the S 5 station, as indicated by the dashed arrow in Figure 1.

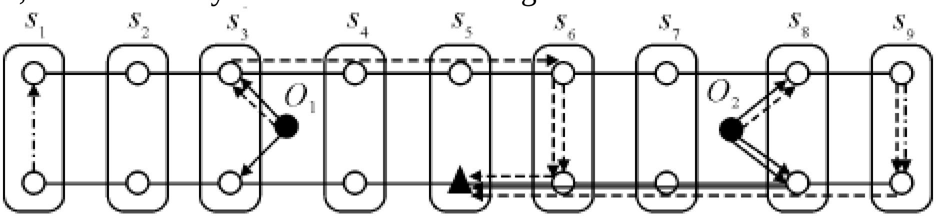

Figure 1: Schematic diagram of the first bus distribution of urban rail transit

3. Model construction

3.1. Model hypothesis

In order to facilitate the description and simplify the problem, the first model of urban rail transit vehicle distribution and path optimization model constructed in this paper makes the following assumptions:

Hypothesis 1: The train operation map and the vehicle bottom road plan have been completed during the line operation period. The vehicle bottom demand station and the first train collection in the two directions have been determined, and the preparation of the vehicle bottom exit line is not considered.

Hypothesis 2: The bottom of the car is concentrated from the yard, and it is quickly escaping to the starting station, and the arrival time is not later than the start of the line operation.

Hypothesis 3: Both the yard and the re-entry station can only return to the bottom of the vehicle within a given period of time, that is, the vehicle has a capacity limit, and the return station has a re-entry capacity limit.

Hypothesis 4: Each yard is only connected to one station, and each re-entry station has only one-way re-entry capability. However, it should be noted that the model proposed in this paper can also be easily extended to describe the complex approach of the yard and the re-entry station with two-way re-entry capability, just adjust the wire network structure.

3.2. Symbol Description

The urban rail transit operation line can be represented by a directed network G=(N , A). Where: N is the set of nodes, N = {i|i =1, 2,..., n }, including the parking lot (vehicle section and parking lot) node and the line up and down station node; A is the arc segment set, A = {(i , j)|i , j ∈N , and i ≠

j }, consisting of the departure line of the yard, the return line of the return station and the connecting line between the adjacent station nodes; T is the set of the vehicle type, m $\in T$;V is the collection of the bottom of the first bus for urban rail transit, k $\in V$.
Define parameters. Cij is the cost of the arc passing through the arc (i, j), expressed by the distance of the road segment (i, j); bij is the passing ability of the arc segment (i, j), including the passage capacity and the exit line of the yard. Capacity and return line re-entry ability can be calculated according to departure time, departure interval, turn-around station turn-back time and turn-back interval; tk is the type of vehicle bottom k, tk $\in T$; pm is the grouping of vehicle bottom type m The number of vehicles; S mi is the longest grouped vehicle bottom type that node i can repair; D mi is the demand for m types of vehicle bases of node i.

3.3. Mathematical model

Optimize the target. Since the bottom of the vehicle is not carried during the journey from the yard to the starting station, the optimization goal of the model is to minimize the total distance of the vehicle: $\min F=-\sum_{t=1}^{T}\sum_{i=1}^{B}\pi_i^T\left(w_i^T-w_i^{T-1}\right)+\alpha\sum_{t=1}^{T}\sum_{i=1}^{B}\sum_{j=1}^{B}d_{ij}G_{ij}^t+\beta\sum_{i=1}^{B}\sum_{j=1}^{B}d_{ij}Z_{ij}^T$.

Restrictions. Node traffic balancing constraints. In this paper, the road network is abstracted into a directed network graph, so each node needs to ensure the flow balance, that is, the bottom of a certain node must exit the node, namely: $LD_1=\max_{\{\mu_1\}}\{L_1\}$. The typical vehicle type of urban rail transit has 4 car bottoms, 6 car bottoms and 8 car bottoms. The car bottom needs to be repaired after each operation or mileage. Due to the limitation of the design of the parking lot and the maintenance warehouse, each yard has only limited daily maintenance capability for each type of vehicle bottom. It should be pointed out that the short-bottomed vehicle bottom can be overhauled in the parking lot at the bottom of the vehicle. And storage, so the number of vehicles of the type used for the first bus dispatch (including the number of short-numbered car bases of this type of group length and below) cannot exceed the parking capacity of the vehicle for the type of vehicle, ie: $LD_2=\max_{\{\omega_t\}}\{L_2\}$. The number of vehicle bottoms and the type of vehicle bottom required for each starting station at the beginning of the operation period are determined. Therefore, the total number of vehicle types arriving at each starting station should meet the demand for the type of vehicle bottom at the starting station, namely: $LD_3=\max_{\{\lambda_t,\mu_t\}}\{L_3\}$. In summary, the model of the first bus distribution and path optimization of urban rail transit is (1)~(10). The model is a 0-1 linear programming model, and the ILOG CPLEX mathematical optimization software can be used to quickly solve the optimal solution. Therefore, this paper uses ILOG CPLEX mathematics optimization software to solve the proposed first bus bottom optimization and path optimization model.

4. Conclusions

The first round of urban rail transit deployment and path optimization is a key issue in the management of urban rail transit operations, but the issue has not received widespread attention. This paper firstly analyzes the optimization problem of the first bus distribution of urban rail transit in multi-vehicle and multi-vehicle models. Then, it constructs the 0-1 linear programming model of the first train of urban rail transit, and uses ILOG CPLEX mathematical optimization software to solve the problem model. Finally, the validity of the model is verified by an example. The results of the example analysis show that based on the model established in this paper, the ILOG CPLEX mathematical optimization software can be used to solve the accurate optimal solution of large-scale problems in a short time. The solution of the first bus bottoming plan obtained by the solution can reduce the total air travel distance of the vehicle by 28.691 km, and the annual total air travel distance can be reduced by more than 10 000 km, which reduces operating costs and has better quality. By analyzing the capacity occupancy rate of the vehicle's bottom appearance, it can be known that the vehicle's ability to exit is the bottleneck capability that limits the deployment of the vehicle bottom and the exit path. In addition, by analyzing the sensitivity of the exit interval, it can be seen that shortening the exit interval can improve the vehicle's ability to exit, thereby shortening the total empty distance of the first bus.

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