Optimization Analysis of Urban Rail Transit Train Operation Scheme under Through-operation Conditions

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Abstract

Urban rail transit train through operation can be realized across multiple lines to complete the train operation plan, with a certain systematic, can reduce the frequency of passenger transfer activities, and shorten the travel time. By integrating the resource advantages of interchange stations, it can ease the traffic pressure and improve the economic benefits. This paper describes the connotation characteristics of through operation as an over-track transportation mode, and the advantages of urban rail transit development under the conditions of through operation, analyzes the necessity and feasibility conditions of through operation from the aspects of passenger flow conditions, equipment and facilities conditions, and further analyzes the general method of preparing through operation opening program, thus puts forward the influencing factors of the opening program of through operation to cope with the passenger flow, line capacity, return station capacity, train conveying capacity and other aspects of the urban rail transit train through the operation of the impact of the program.

Keywords

Through-operation, Urban rail transit, Train operation scheme, Optimization analysis

1. Introduction

Through-train operation is the inevitable choice of urban rail transit network operation, which can effectively meet the demand for direct travel of cross-line passenger flow, relieve the pressure of passenger flow organization at interchange stations and shorten passenger travel time. Compared with the single-line independent operation, through operation pays more attention to coordination and connection between lines, and the service level of urban rail transit is improved. However, the train grouping scheme, stopping scheme, and interchange scheme under thorough operation also face more challenges. The train operation plan is the core basis of urban rail transit organization, which stipulates the train crossing plan of the line within the specified period and affects the operation effect and service level of urban rail transit.

There have been a lot of research results on running through the organization. Aoki M et al. [1] conducted a statistical analysis of the passenger flow data of Tokyo rail transit in Japan and calculated the travel time of passengers and operating cost of enterprises under two modes of operation, namely through and independent, to compare and analyze the benefits of through operation to passengers and enterprises. Dahl G [2] analyzed the organization mode of German light rail and French national railroad over-track operation and argued the social benefits of the over-track operation mode by comparing the passenger ticket revenue before and after operating over-track trains. Drechsler G [3] illustrated the organization mode of French railroads and German light railways implementing over-track operation and made a detailed analysis of the changes in operating costs before and after the over-track operation. Huang Zhengxin et al. [4] introduced the through-tracking scheme of two experimental tram lines in Wuhan and analyzed the actual operating effects...
of the lines to prove the superiority of the through-tracking scheme. Fourteen cities in China have organized the operation mode of small and large crossings [5], such as Guangzhou Metro Line 2. A total of 15 Y-shaped lines are in operation in Chinese cities [6], such as Shanghai Metro Line 11, where the operation is organized in a branch-line partial through-run add minor interchange mode.

2. Connotation and characteristics of through-train operation of urban rail transit

2.1 Concept of through-train operation

Through-train operation is a technical method of train operation organization in the networked operation organization of urban rail transit. In the urban rail transit network, there are signaling types of equipment of different standards, and trains run from the transport line to the connecting line through the main line or the ferry line at the over-track station or the over-track interval and share a section with the trains of the connecting line to realize the interconnection and intermodal transportation between the rail transit network. The essence of the through-rail operation is over-rail transportation, which is the method to achieve optimal global benefit. Under the background of urban rail transit network development, the lines in the urban rail transit network may be managed by different operating companies, and the through-train operation may occur between the lines managed by a certain company or between the lines managed by different companies.

2.2 Advantages of through-train operation

(1) Under through operation, passengers do not need to transfer, which greatly reduces the generation of transfer passenger flow, improves the directness of passenger flow, reduces the number of passenger transfers, saves passenger travel time, and improves the service level of urban rail transit. By providing different levels of transportation products, it compresses the broad cost of passenger travel, attracts a large number of passengers, and increases the operating income of urban rail operating companies. Compared with single-line independent operation where over-track transportation can only be completed by passenger transfer, through-track operation shortens the travel time of over-track passengers, improves the utilization of line network resources, and enhances the stability of the entire line.

(2) Through-train operation attracts part of the interchange passenger flow to direct passenger flow, reduces the passenger flow at interchange stations during peak hours, lowers the density of passenger flow at interchange stations, avoids safety hazards caused by overcrowded passages due to excessive passenger flow, eases the pressure of passenger flow at interchange stations and large passenger collection points, and improves the safety of interchange stations and the lines where they are located and even the entire network operation.

(3) Under thorough operation, sharing of vehicles, parking lots, vehicle sections, operation management, maintenance equipment, human resources, and other resources enables full utilization of capacity resources, better matching of capacity with passenger demand, saving enterprise costs, promoting balanced line full capacity, and improving the sustainability of urban rail transit development.

(4) The connectivity of lines between cities improves the accessibility of the areas covered by the urban rail transit line network, helps to improve the urban rail transit sharing rate, alleviates road traffic congestion, greatly promotes the group development of urban clusters composed of central cities and satellite cities, helps cities to decentralize the industrial functions of central cities to satellite cities, and guides the orderly development of metropolitan urban clusters.

3. Analysis of the conditions of through-train operation of urban rail transit

Although urban rail transit train operation has the above advantages, it also puts forward higher requirements on transportation organization technology and the complexity of transportation organization work.

The operation of a through train has certain requirements on the line, signal system, and other facilities and equipment of the rail transit system. Compared with the independent operation of a single line, the construction cost of the train transportation organization under thorough operation is higher. The operation will have a certain impact on the convenience of the line passengers, according to the principle of "according to the popular train", analyze the size of the passenger flow and passenger flow characteristics, and determine whether the line is suitable for through operation.

3.1 Passenger flow conditions

From the perspective of an optimization of operational efficiency, it is necessary to operate interline trains only when the ratio of interline passenger flow to total service passenger flow reaches a certain level. Therefore, it is necessary to take into full consideration that the through trains of different crossings serve passengers crossing the tracks in different interchange directions, and there are significant differences in the passenger flow characteristics of passengers crossing the tracks between different interchange directions of different crossing stations according to the line alignment and the
nature of the land along the line. Whether and how the through-operation trains should be operated should be analyzed according to the connection mode between the conveying line and the connecting line, and the passenger flow characteristics of over-track passengers at the over-track stations.

3.2 Equipment and Facilities Conditions

Through-operation trains should be consistent with the vehicle system, vehicle limits, and the power receiving methods running on the member lines, and the train lengths should be compatible to ensure that the vehicles of each line can be centrally serviced and to improve the equipment utilization rate. Through-operating trains should have the same design standards, taking into account the minimum curve radius, maximum limit slope, platform length, etc., and considering the compatibility of vehicles, equipment, and building boundaries. Through-operation lines should have a unified power supply, the same or compatible signal system, the same blocking method, the same design requirements for the train control system, the same or unified signal and vehicle interface, the division of consistent system structure and function, mutually compatible vehicle-ground information transmission system, etc. Establish a bureau-wide dispatching system through all lines, cross-route coordination and command, unified management, real-time monitoring of train operation of the whole network, planning schedule, implementation schedule, and emergency treatment in case of failure, etc.

4. Optimization of urban rail transit train operation plan

The urban rail transit train operation plan mainly covers the train crossing plan, grouping plan, and stopping plan, which is a comprehensive plan of urban rail transit operation and an essential part of urban rail transit train operation. A perfect urban rail transit train operation plan ensures the service quality of the urban rail transit system, meets the travel needs of different levels of passenger flow, reduces passenger travel costs, and saves enterprise operation costs.

4.1 General method of train operation plan preparation

The urban rail transit train through operation plan is based on the passenger volume, combined with the nature of passenger flow, matching the type, quantity, line and vehicle group of vehicles, etc., to prepare a comprehensive plan of urban rail transit train through operation based on the passenger volume. Generally speaking, the train operation plan is prepared according to the process of "passenger flow prediction, passenger flow analysis, plan generation, verification and optimization". The plan is continuously optimized based on the actual passenger flow or real-time passenger flow.

The train operation plan of urban rail transit includes the following contents: vehicle type and grouping mode: the common models of urban rail transit system are mainly A-type and B-type vehicles, and the two types of vehicles have different train crews and body lengths, and the corresponding grouping quantity is also different; train operation section: including train departure station, terminal station, and route; train operation pairs: the number of trains operated in the direction of operation or in the section to meet the passenger flow demand. The number of trains running: refers to the number of trains running in the direction or section to meet the passenger flow demand, generally considered to run in pairs in the upstream and downstream directions; train to stop scheme: when the line track and platform facilities meet the vehicle crossing conditions, the operating company develops fast and slow train running scheme and organizes cross-stop train transportation service according to the passenger flow demand and passenger flow characteristics.

4.2 General Method of optimization model establishment

Based on the current situation of urban rail transit operation, analyzing the successful cases of through operation, combining the experience of through operation train operation, comprehensively considering the through operation train operation between suburban line and central line, fast and slow train operation, focusing on the train crossing scheme and departure frequency, adopting the mode of fixed grouping and station stop, and effectively improving the operability of the model. In the general method of optimizing the model establishment:

(1) The necessity and feasibility conditions of using through-operation train operations are available between through-operation lines. The OD passenger flow between stations along the line is taken as a known parameter, and the arrival of passengers is considered to meet the uniform distribution law.

(2) Under the fixed grouping mode, the stopping scheme adopts the station stopping mode, giving priority to the urban rail transit trains that can be matched by passengers to meet the demand for direct OD according to the passenger flow, and if there is no direct train available, the scheme that meets the shortest travel time requirement is matched.

(3) Matching all the OD passenger flow demands at each station along the through operation line to meet the travel demands proposed by each passenger along the line, ensuring the reasonableness of the total number of trains in the operation scheme, clarifying the running time of each intersection interval, and the independent use of each intersection
undercarriage turnover to realize the formation of synergistic operation between urban rail transit line networks.

4.3 Influencing factors of through-operation opening scheme

(1) Passenger flow index
The passenger flow index mainly refers to the analysis of total passenger flow, cross-sectional passenger flow, and cross-line passenger flow based on the through-operation line passenger flow data. The total passenger flow reflects the macro capacity of rail traffic demand; the cross-sectional passenger flow specifically reflects the spatial characteristics of passenger flow; the cross-line passenger flow is the passenger flow from one line to another line between two lines in through operation. Under operation, the cross-sectional passenger flow should consider the maximum peak cross-sectional passenger flow, and the total capacity of the actual trains should be not less than the maximum peak cross-sectional passenger flow. The larger the interline passenger flow, the higher the proportion of the entire line passenger flow, the higher the interline transfer pressure, and the higher the passenger demand for direct transportation after through operation.

(2) Passenger flow distribution characteristics
Passenger flow time distribution characteristics refer to the unevenness of the intensity of passenger flow at different times, the line passenger flow can be divided into flat-peak passenger flow, single-peak passenger flow, double-peak passenger flow, and multi-peak passenger flow. Flat-peak passenger flow is more evenly distributed throughout the day at various times, there is no obvious peak period of passenger flow, suitable for stopping station stopping program. Single-peak passenger flow is only one obvious peak passenger flow period in the whole day, and the passenger flow in other periods is low and evenly distributed, which is suitable for running unpaired trains. Double-peak passenger flow is one with two distinct peak periods throughout the day, which is suitable for reducing operating costs by adjusting the train interval. Multi-peak passenger flow is the formation of three or more peak hours during the whole day, which is rare under normal circumstances.

(3) Passing capacity of the line section
The passing capacity of the line section is the basis for making a through-operation train running plan, which limits the frequency of train running. The section passing capacity of urban rail transit through operation includes the passing capacity of the non-through section and through the section. The through section capacity is more constrained than the non-through section capacity, so it is a key factor to achieve through operation. By adjusting the train running speeds or using mobile automatic blocking, the tracking interval time can be shortened, thus increasing the line section capacity. In addition, the stopping time of trains and additional hours for trains to start and stop at each station also affect the section passing capacity.

(4) Return station capacity
The folding capacity of the folding station is the maximum number of trains that can be folded at the folding station per unit of time. When the train runs to the terminal of the crossing, it needs to carry out the turning operation and complete the cycle of undercarriage operation. Unlike the ordinary stations on the line, the train turning operation at the turning station takes longer, which affects the minimum train departure interval and therefore has a more obvious impact on the passing capacity of the whole line.

(5) Train Capacity
The train transport capacity refers to the maximum passenger capacity of the train, and its transport capacity size is determined by the train grouping and vehicle capacity. The larger the transport capacity of the trains running on the line, the fewer the number of pairs of trains needed to run. The train crew is the number of passengers designed to be carried in each vehicle, and after the vehicle selection is determined, the train crew is also determined. Therefore, the development of the operation plan is mainly related to the train grouping plan. Train grouping needs to be determined according to the line peak hour maximum cross-sectional passenger flow.

(6) Line operation management level
There are many different crossings under the through operation, and the through section runs many kinds of crossings at the same time, which makes operation management more difficult. The more pairs of trains run through the operation, the more frequent the coordination and cooperation between the operation organization and dispatching command of the two lines, and the higher the requirements for the operation management level. The train turnback operation also has higher requirements on the transport organization equipment and management level of the turnback station. All stations in the through section will have trains passing and stopping in different directions and different crossings, so each station should strengthen the guidance of passenger flow on the platform and do a good job in passenger organization and management to ensure the normal and orderly execution of the through operation train operation plan.

5. Conclusion
Through-train operation can realize the deep integration of the current urban rail transit train resources, so as to im-
prove the transportation service capacity and provide more convenient travel service to passengers. In view of the future
development trend, the frequency of through-train operation mode will be increased gradually in the context of the in-
creasing urban population, which is a high-quality solution to meet the needs of passengers’ travel and metro operation
efficiency. In this paper, we analyze the train operation scheme of through train operation and hope that the proposed
content can provide a reference for the relevant staff.

References

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