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Research on Public Transport Network Optimization and Station Layout based on K Shortest Path Algorithm

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Abstract

In recent years, my country is facing serious traffic congestion problems. Considering from the aspects of alleviating traffic pressure and developing green transportation, vigorously developing public transportation is the best way to solve urban transportation problems, and the most basic measure for developing public transportation is design and optimization. Bus network. This article is mainly to establish a bus network optimization model, with the ultimate goal of minimizing the number of bus stops, and obtain feasible bus routes from a certain station, bus routes and their departures through the improved K-shortest path algorithm, restrictions and screening conditions. The site composition is based on the K-shortest path tree of the site. Through the optimal combination of K-shortest path tree to meet the coverage and directness requirements of the bus network, the optimal bus line set and bus station layout of the bus network can be obtained. This can increase the coverage of bus lines and reduce the number of bus trip conversions, thereby improving the efficiency of public bus travel for residents.

Keywords

Public transportation; Public transport network optimization model; K shortest path algorithm; Bus station layout.

1. Introduction

In recent years, the rapid growth of car ownership has led to a rapid increase in demand for urban road infrastructure. Under this situation, major cities are facing traffic problems such as traffic congestion, increased accidents, and serious exhaust pollution, which have brought serious consequences, not only causing inconvenience to residents' daily life and travel, but even affecting the city. economic development.

Throughout the experience of solving similar traffic problems at home and abroad, the development of public transportation is the main means to alleviate traffic problems. Public transportation has the characteristics of large transportation volume, small space occupation, and energy saving. However, the rapid development of my country's economy currently does not match the development of the backward urban public transportation. The shortcomings of public transportation vehicles, such as slow speed, in punctuality, low coverage, and low direct rate, greatly reduce the attractiveness of public transportation for residents' travel, making public transportation at a disadvantage in the process of transportation structure transformation.

This thesis rationally optimizes the design of urban public transportation network, which can generate future public transportation routes and network, and adjust and optimize the existing public transportation network and network. Based on the internal mechanism of the public transportation network, the urban public transportation network is generated through a certain algorithm, which ensures the accessibility of urban public transportation, reasonable station settings, and low number of trips, thereby improving the efficiency of residents' public transportation.

2. Literature Review at Home and Abroad

For the design and optimization of public transportation network, domestic and foreign scholars mainly establish mathematical models to obtain the optimal set of public transportation routes that meet the conditions. Domestic scholar Wu Jiahao and others mainly consider the public transportation demander's point of view, and propose to take the minimum total travel time of passengers as the objective function, and establish a single-objective optimization model to study the design and optimization of public transportation network [1]. Hobeika et al. divided the bus stations into various districts, established an optimization model, took minimizing the total distance traveled by bus vehicles as the objective function, and applied heuristic algorithms to obtain bus routes [2]. Avishai et al. summarized the most commonly used objective functions in the bus network optimization model, namely, minimizing operating costs from the perspective of operators and maximizing consumer surplus from the perspective of consumers [3]. Scholars such as Van proposed a new type of objective function, with the goal of minimizing the number of transfers to design the bus line and the frequency of the bus system [4].

The algorithm for solving public transportation network design problems mainly includes simulated annealing algorithm, genetic algorithm and ant colony algorithm. Yu Lijun et al. proposed a new optimization model based on the drawbacks of transfer and station duplication in line network optimization and solved it with an improved simulated annealing algorithm. Scholars such as Ngamchai improved the genetic algorithm from the perspective of operators, and realized the simultaneous design and optimization of bus lines [5]. Petrelli also pointed out that genetic algorithm has the characteristics of "good calculation effect, high efficiency, and more reasonable line network" [6]. Zhao et al. used a hybrid algorithm combining simulated annealing algorithm and genetic algorithm to solve the optimal solution of the public transport network [7]. Yu et al. applied the ant colony algorithm to the design of public transportation network, and at the same time determined the optimal station and route [8].

Scholars at home and abroad have conducted research on the layout of public transit stations. Scholars such as Wang Wei researched the optimal station spacing, mainly optimizing the optimal distribution of intermediate stations, and also studied the location of public transport hub stations [9]. However, these studies basically only focus on the depot itself, and there is a lack of research on the coordination of depots and bus lines. Previous studies on the optimization of public transportation networks were all aimed at optimizing the public transportation network, solving the optimal set of public transportation routes, and did not pay attention to the role played by the bus depots in the process of solving the bus routes, and the bus depots after obtaining the optimal bus routes How to make a reasonable layout. The layout of the bus depots and the generation of the bus line set interact with each other. In the optimization process, the overall optimization of the bus network from the line, the line network to the depots should be considered.

3. Related Theories about Optimization Design Of Public Transportation Network

3.1. Representation of the Bus Network

3.1.1 Overview of Graph Theory

Through graph theory, the real path problem is simplified into a two-dimensional graph problem composed of points and edges. In graph theory, the graph is transformed into a mathematical description. The figure is represented as$G = (V, E)$, which $V = \{v_1, v_2, v_3, \dots, v_n\}$ represents the set of points in the graph and $E = \{e_1, e_{2,} \dots, e_m\}$ represents the set of connected edges between nodes in the graph G, and splits the graph into a combination of points and edges. The existence of graph theory can solve graph problems through mathematical methods and simplify real problems.

3.1.2 Application of Graph Theory in Transportation Network

Graph theory is widely used in transportation networks and is often used to solve the problem of optimization of transportation network design. When using graph theory to solve traffic network problems, the points in the graph can represent road intersections, bus stops, etc.; edges represent roads or bus routes, etc. In the transportation network, the specific meaning of weight is generally the meaning of location and the meaning of "length". Find the location of the bus stop in the city road network map, use the bus stop as a point in the city bus network map, simplify the road sections connected between the stops into edges, and transform the city road network into an urban bus network through such a Space L method. Obtain a concise and clear bus network diagram.

A bus network represented by graph theory. Circles represent stations. The number and relative location characteristics of the stations are clear at a glance; the line segments connected between the circles represent the connected road sections between the two stations, and the presence of edges between the two circles indicates the two bus stations There are connected road sections between, and the number on the road section indicates the "length" of the connecting road section between the two stations (that is, the edge weight). This "length" can represent the distance between two stations, or the average running time of public transport vehicles between two stations at a certain speed, and other data that represent the meaning of road segment weights.

4. Optimization Model of Public Transportation Network

This chapter mainly introduces the parameters and conditions of the bus network optimization model, establishes the corresponding objective function and constraint conditions, establishes the mathematical model and gives the solution algorithm of the model so that the optimal set of bus routes and reasonable bus stops are obtained under the corresponding constraints .

4.1. Related Concepts and Assumptions in the Model

4.1.1 Related concepts in the model

(1) K shortest path algorithm and improved K shortest path algorithm

K shortest path refers to the K shortest paths that exist between two nodes in a non-decreasing order of length in a given graph. The K shortest path algorithm can obtain multiple feasible paths between two points in increasing order of length. The improved K-shortest path algorithm is: first find the shortest path between two stations and obtain the shortest path length, and determine the maximum path length between the two stations by the maximum increase coefficient K. Then use the K shortest path algorithm to sequentially calculate the paths that meet the length condition.

(2) K-shortest path tree and its combination tree

The shortest path in the K range from a node to all other nodes is called the shortest path in the K range based on a certain node. These shortest paths in the K range based on a certain node or the paths selected according to certain requirements form the basis K-shortest path tree for this node. The combination of K-shortest path tree increases the number of departure nodes, the number of road sections, the number of paths, etc. on the basis of a single K-shortest path tree. In the specific meaning of the public transportation network, the combination of K-shortest path tree is the mutual cooperation and optimization of bus depots and bus lines.

(3) K-shortest path tree's direct access to stations and passengers

Direct access to stations: In the K-shortest path tree based on one station, if two stations are located on the same bus line, the two stations can be reached directly.

Passenger direct access: If the OD amount of bus travel is allocated between the bus line stations, the passengers between the two stations with direct station access will also have direct access.

(4) Bus lines

The bus lines in the K-shortest path tree based on a certain station do not completely include all the shortest paths within the K range in the K-shortest path tree that constitute a station. In reality, the bus line will be affected by the length of the line and the number of stops. Because the number of shortest paths within K range from one station to all other stations is too large, the repeatability of the road sections is too high, which is not in line with reality. Therefore, the shortest path in the range of K must be deduplicated to obtain the bus line set.

(5) Bus station

From the perspective of the K-shortest path tree, if one or more of the K-shortest path trees contain bus lines, the bus line set in the bus network can cover the widest and the directness of stations and passengers can meet the required requirements , The departure station on which these K-shortest path trees are based is the bus station.

4.1.2 Model assumptions

In order to facilitate the optimization research of the public transportation network, when establishing the optimization model, it is necessary to make assumptions about some unrelated secondary factors in the model to simplify the model.

(1) The bus network is known and the location of the stop is determined;

(2) The departure station of the bus line is located at the bus station;

(3) The up and down lines of the bus are consistent;

(4) The entire bus line network is connected and does not include loops and loops;

(5) The travel OD matrix of bus passengers is known;

(6) Only consider the direct accessibility of stations and passengers in the bus network, without considering passenger flow distribution and departure frequency on the line.

4.2. Model Establishment

The bus network optimization model includes two parts. The first part is to obtain the optimized single K-shortest path tree in the bus network; the second part is to obtain the optimal combination of K-shortest path trees, that is, to minimize the number of stations. The ultimate goal is that with the least number of stops, the optimal bus line set can ensure the coverage of the bus line set, reduce bus blind spots, ensure the maximum proportion of direct passengers, and improve the efficiency of direct bus stops.

The first is to obtain the optimal single K-shortest path tree, that is, to obtain the optimal bus route from a certain stop, and the bus route is obtained from the shortest path within the K range.

(1) Maximum network coverage

$$\max A(m) = \frac{\sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}} \Delta_{ij} x_{ij}^{I_m}}{\sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} \Delta_{ij} x_{ij}} \quad i, j = 1,2,\cdots,n \tag{1}$$

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In the formula, A(m) represents the proportion of the number of road segments contained in the K-shortest path tree based on m stations to the total number of road segments in the bus network. I_m represents the bus line set contained in the K-shortest path tree based on m stations. Stations i, j the bus network station set V; n represents the total number of stations in the bus network.

$$\Delta_{ij}=\begin{cases}1, \textit{Station ij is an adjacent station in the bus network}\\0, \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{Other}\end{cases}$$

$$x_{ij}=\begin{cases}1, \qquad \textit{Stations i and j are in the bus network}\\0, \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{Other}\end{cases}$$

(2) The largest percentage of direct passengers

$$\max D_{od}(m)=\frac{\sum_{i=1}^{n}\sum_{\substack{j=1\\j\neq i}}^{n} p_{ij}x_{ij}^{I_m(k)}}{\sum_{i=1}^{n}\sum_{\substack{j=1\\j\neq i}}^{n} p_{ij}x_{ij}}\quad i,j=1,2,\cdots,n \tag{2}$$

In the formula: $D_{od}(m)$ represents the proportion of direct passengers based on the K-shortest path tree at station m; P_{ij} represents the number of passenger trips between stations and ij.

The largest proportion of direct stations

$$\max D(m)=\frac{\sum_{i=1}^{n}\sum_{\substack{j=1\\j\neq i}}^{n} x_{ij}^{I_m(k)}}{\sum_{i=1}^{n}\sum_{\substack{j=1\\j\neq i}}^{n} x_{ij}}\quad i,j=1,2,\cdots,n \tag{3}$$

The constraints are:

(a) Single path length constraint

$$l_{min}\leq \mathrm{l}\leq l_{max} \tag{4}$$

(b) Number of stations on a single line

$$n_{lmin}\leq n_l\leq n_{lmax} \tag{5}$$

(c) K value constraint

$$1\leq \mathrm{K}\leq 1.6 \tag{6}$$

The second optimization is to obtain the optimal combination of K-shortest path trees based on different stations, so that the combined bus line set meets the optimization requirements, and at the same time determines the most reasonable bus station layout. That is, the optimization goal is to minimize the number of bus stops, that is, the minimum K-shortest path tree combination.

$$\min Z = N_{stree} \tag{7}$$

In the formula: D_{stree} is the number of K-shortest path trees contained in stree, that is, the number of bus stops.

The constraints are:

(a) Passenger direct ratio constraint

$$D_{od}(stree) \geq c_1 \tag{8}$$

In the formula: $D_{od}(stree)$ is K-shortest path tree combination. The proportion of direct passengers that can be reached by the line set contained in stree; the proportion of direct passengers that can be achieved by optimization of the c_1 bus network.

(b) Station direct ratio constraint

$$\mathrm{D}(stree) \geq c_2 \tag{9}$$

In the formula: $\mathrm{D}(stree)$ is K-shortest path tree combination.

The proportion of direct stations that can be reached by the line set contained in stree; c_2 is the proportion of direct stations that are required for the optimization of the bus network.

5. Actual Case Analysis

5.1. Study Area Selection

The area around Lixia District of Jinan City is selected to analyze the public transit network optimization model proposed in this paper. The area is shown in Figure 1.

Fig 1. Research area

Jinan Lixia District has a unique geographical location, densely populated, and there are universities, residential areas, commercial areas and scenic spots. Colleges and universities basically choose public transportation to travel, and residents also rely mainly on public transportation.

5.2. Example Solution

The public transit network optimization model based on the improved K-shortest path algorithm proposed in this paper is used to optimize the public transit network in the example area, and the optimized public transit line set and reasonable station layout are obtained.

First, divide the traffic area of the example area. A total of 8 traffic areas are divided into the area. Each traffic area has a bus stop. Assuming that the bus stops are set at the center of mass of the traffic area, the distance between each bus stop is based on the Calculation of connected road length.

The OD matrix of the residents' bus trips between each traffic district (without considering the internal trips of the traffic district) is as follows:

$$\begin{Bmatrix} 0 & 123 & 156 & 138 & 175 & 98 & 239 & 82 \\ 123 & 0 & 221 & 84 & 156 & 139 & 235 & 75 \\ 156 & 221 & 0 & 100 & 107 & 121 & 152 & 98 \\ 138 & 84 & 100 & 0 & 76 & 109 & 88 & 198 \\ 175 & 156 & 107 & 76 & 0 & 66 & 78 & 199 \\ 98 & 139 & 121 & 109 & 66 & 0 & 134 & 75 \\ 239 & 235 & 152 & 88 & 78 & 134 & 0 & 213 \\ 82 & 75 & 98 & 198 & 199 & 75 & 213 & 0 \end{Bmatrix}$$

The optimization of the bus network aims at minimizing the number of bus stops and increasing the direct ratio of passengers. Different values of K have different effects on the number of stops and the direct ratio of passengers. The area selected in this chapter is relatively small, so choose k=1.4. The passenger direct ratio is set to 0.95, the station direct ratio is set to 0.9, the number of stops in a single bus line is limited to 3 to 9, and the line length is limited to 3 to 9 times the average length of the network. The path selection criteria are: to reduce the number of repeated sections, reduce the number of routes, include as many sections as possible in the bus network, maximize the direct ratio of passengers and the direct ratio of stations, and make the path from one station to another station. There are two at most, and no overlapping sections are included. Solving the example area through MATLAB program to get the bus depot and bus route are shown in Table 1 and Table 2.

Table 1. Values solved in area of example

The internet	Depot	Passenger direct ratio	Station direct ratio	Number of lines	Repeat factor
8	2, 5, 8	95%	94%	7	1.6

Table 2. Bus lines in area of example

Label	Neighborhood				
1	3	5	4	1	
2	3	2	4	6	7
3	3	7	4	9	
4	5	2	6	8	
5	5	1	4		
6	8	4	5	7	
7	8	2	4	9	

It can be seen from Table 2 that the minimum number of bus depots that meet the conditions is 3, which are located in the No. 2, No. 5 and No. 8 transportation districts, corresponding to Daming Lake, Laodongmen Shopping Plaza and Shandong University Station. The population density in these three traffic communities is high, and the demand for public transportation is large. The direct ratio of bus passengers obtained by the model solution reached 95%, which met the direct bus travel demand of most passengers in the area. It can be seen that the number of bus depots solved in the optimization model of the bus network in this paper is not only small but also reasonably evenly distributed. The direct ratio of passengers obtained by the solution is very high, so residents and students will have high direct accessibility, fewer transfers, and high efficiency.

6. Conclusion

(1) This paper studies the optimization of the public transportation network. Based on the improved K shortest path algorithm, the optimization model of the public transportation network is constructed, the solution algorithm is given, and the solution process is realized through MATLAB to obtain the optimal solution of the public transportation network optimization model. The proposed bus network optimization model has a wide range of applicability, and the selection of K value is wider, based on the specific needs and costs when solving the network.
(2) The generation and selection of the shortest path in the K range in the bus network optimization model are set according to the detourable length and coverage requirements of the actual bus line, and the theoretical results are closer to reality. The optimal bus line set and number of stops are solved as far as possible to maximize the direct ratio of passengers to reduce passenger transfers. In the model, both the interests of passengers and the interests of the bus group are taken into consideration.

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