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The research on the spider network model of passenger flow corridor recognition in urban rail transportation planning

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ABSTRACT

Passenger flow corridor recognition is one of the important research content of network framework phase in urban rail transportation planning. Because of the rail transportation planning aimed at long term forward, not completely follow the existing road network, but exist the interactive relationship with future trip distribution. In this article, the spider network model has been proposed based on the working process of rail transportation network framework to identify the Passenger flow corridor, by applying the traffic planning method, the distribution-assignment combination model, the basic geometric relationships, and TransCAD planning software technology. Firstly, the article discussed the theoretical basis and the calculation method of Spider Network Model in urban rail transportation network planning. And finally, the article carried out the applied research by using the method in big xi 'an passenger flow corridor analysis for example. The results shows that using the spider network model to recognition the spatial distributions of urban rail transportation passenger flow corridors is simple and effective.

KEYWORDS

Transportation planning; Urban rail transportation; Passenger flow corridor recognition; Spider network model.

INTRODUCTION

Passenger corridor is the axis of the urban passenger traffic demand, is also the place of large capacity public transportation line, its scale and length are important basis of the transit system selection, and the network layout **Error! Reference source not found.**. For small and medium-sized cities, passenger flow relationship relatively simple, and the planners could distinguished the passenger corridors by using intuitive judgment [2]. But for big city and megalopolis, intuitive judgment is very difficult, need to use quantitative method.

At present, there are some quantitative researches about the recognition of urban passenger flow corridor. For example, SUN Xing-tang etc. (2014) used a virtual network distribution method to study the distribution of passenger corridor of ZHEN-jiang city [3].Wang Chi-yu (2008) proposed a method Based on the fuzzy clustering analysis of OD to identify traffic corridor[4]; LI Xia-miao et. al. (2009) using the travel attraction weight, depicted the dynamic mutual feedback mechanism and transit oriented development strategy between the urban spatial structure and the traffic system, on the basis of this theory the inter-city rail transportation passenger flow corridor prediction method is given [5]; KONG Zhe et. al. (2010) put forward the passenger flow corridor problem divided into two phase like direction judgment and support road identification, using the dynamic clustering method and the Logit model to discuss the bus passenger flow corridor which being limited to Road network [6]; DI Di and YANG Dong-yuan (2014) established passenger route choice model on the basis of the theory of stochastic user equilibrium assignment, and draw relative fast and relative slow line combination operation impact on the operational efficiency of rail transportation passenger flow corridor [7]. Zhi-Chun Li et. al. (2011) presented A heuristic solution algorithm to solve the design problem of a rail transit line located in a linear urban transportation corridor, by using the service variables combined with rail line length, number and locations of stations, headway and fare [8]. Ashish Verma et. al. (2011) presented an integrated approach to identify and schedule a rail transit corridor in a city which has a potential demand for a new rail based mass transit system besides the street transit system and existing rail-based system (if any)., which consists of three stages: public transport demand forecasting, creation of corridor link set, and optimization of rail corridor using Geographical Information System (GIS) [9]. Vimal Gahlot et. al. (2012) proposed an two step model to solve the problem on the user oriented selection of bus rapid transit (BRT) corridor for Jaipur city in GIS environment [10].Yang Sun et. al. (2013) presented a method to optimal either rail transit network design or bus network design in same time, by using a multi-objective model to integrated rail transit and bus network to maximize rail ridership and minimize total passenger travel time[11].

In the urban rail transportation network design phase, the planners need the method of general to recognizing rail network structure without route information. So this article proposes the Spider network model to solve the problem. Spider network model is to simulate the structure characteristics of the spider web, a practical approach for the analysis of passenger corridor dynamically. Based on the systematic analysis of passenger flow forming mechanism, this article studied the theory basis and the calculation method of spider network model, by using the methods of graph theory and geometry. This research has certain reference value for urban rail transportation network planning and design.

THOUGHT OF SPIDER NETWORK MODEI

In urban rail transportation network planning of network architecture study, it is need to using the urban space development strategy, urban land use planning to judge urban forward passenger flow corridor structure. In practical work, this step is often relying on the experience of planners, with larger subjectivity. The spider network model is bringing forward to relative objectively the formation mechanism of passenger flow corridor and put forward a relatively objective analysis method

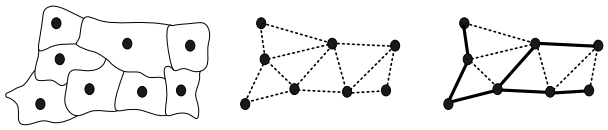

Figure 1 The analysis process of the spider network

The basic idea is as follows: first it constructs a network which contains multiple possible passenger flow direction. By using distribution-assignment combined model and making the passenger flow competition on the network line, it getting a composite traffic network. Then to hierarchical processing of the traffic network, it can inspire the traffic network planning.

THE METHOD OF MAKING THE SPIDER NETWORK

Orientation division

For the relatively small size cities, the manual connection traffic zone cancroids form a spider network well to accept. But the city plans to build urban rail transportation tend to be larger scale, it is laborious and prone to errors such manual connection. For this we need to find a programmatic way. The real problem is that every node of the surrounding

have a lot of a neighbouring node, if connect one by one, on the one hand, the attachment is too much to easy analysis, on the other hand is not easy to highlight the passenger flow direction because of the interaction of different direction attachment. Considering the practical analysis process, needs to divide the passenger flow direction, but not too carefully, in order to avoid too multifarious calculation process. So might as well to any passenger flow points as object, with this point as origin to establish the right angle coordinate system as origin, and divide into eight quadrants, shown in figure 2.

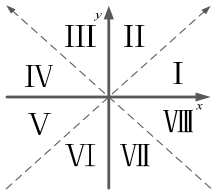

Figure 2 8 quadrants Based on the origin object point

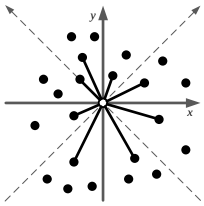

Figure 3 8 quadrant of the correlative node selection

Defining the point that most close to the object point in each quadrant is neighbouring nodes, namely when make spider network needs to connect the nodes. Then the next question is how to look for in a large number of nodes those eight critical nodes. Considering the general GIS software uses the latitude and longitude coordinates to confirm the only one node, then assume that object node of latitude and longitude coordinates are (x_0,y_0), adjacent nodes Wait for a judgment are (x,y).Introduce two distance vector $\vec{l}_x = x - x_0$ and $\vec{l}_y = y - y_0$, On the basis of the relationship between two vectors you can judge the node belong to which a quadrant, see table 1.

TABLE1 Quadrant division of adjacent nodes

quadrant	orientation	relationship	quadrant	orientation	relationship
	east by north	$\vec{l}_x > 0, \vec{l}_y \geq 0, \lvert\vec{l}_y\rvert < \lvert\vec{l}_x\rvert$		west by south	$\vec{l}_x < 0, \vec{l}_y \leq 0, \lvert\vec{l}_y\rvert < \lvert\vec{l}_x\rvert$
	north by east	$\vec{l}_x > 0, \vec{l}_y > 0, \lvert\vec{l}_y\rvert \geq \lvert\vec{l}_x\rvert$		south by west	$\vec{l}_x < 0, \vec{l}_y < 0, \lvert\vec{l}_y\rvert \geq \lvert\vec{l}_x\rvert$
	north by west	$\vec{l}_x \leq 0, \vec{l}_y > 0, \lvert\vec{l}_y\rvert > \lvert\vec{l}_x\rvert$		south by east	$\vec{l}_x \geq 0, \vec{l}_y < 0, \lvert\vec{l}_y\rvert > \lvert\vec{l}_x\rvert$
	west by north	$\vec{l}_x < 0, \vec{l}_y > 0, \lvert\vec{l}_y\rvert \leq \lvert\vec{l}_x\rvert$		east by south	$\vec{l}_x > 0, \vec{l}_y < 0, \lvert\vec{l}_y\rvert \leq \lvert\vec{l}_x\rvert$

It should be noted that the points on the axis classify his right domain according to the principle of right to merge into the right side. Any point of this plane can be classified in the 8 sets. And then, choose a point closest to the origin in each eight sets, as the link point of the direction. This means that any point on the plane p_i determines it's belong to which quadrant firstly. Might as well do not break general assumptions p_i belongs to quadrant Q, so:

$$p_Q = \max\{p_i | p_i \in Q\} \quad (1)$$

After all quadrants screening, get the neighbouring nodes in each quadrant, shown in figure 3.

Assignment flow strategy analysis

Traffic assignment model

There is a lot of different traffic assignment algorithm in urban traffic planning. For certain network, using different algorithm can get different results those have significant differences. So for the spider network, because the ultimate goal is to highlight the relationship of flow direction of passenger flow in space, so might as well use AON distribution, namely:

$$\min_x Z(x) = \sum_a x_a t_a \quad (2)$$

s.t.

$$\sum_k f_k^{rs} = q_{rs}, \forall r, s \quad (3)$$

$$\sum_k f_k^{rs} \delta_{ka}^{rs} = x_a, \forall r, s, a \quad (4)$$

$$f_k^{rs} \geq 0, q_{rs} \geq 0 \quad (5)$$

It can load q_{rs} (the flow between the OD points) into the shortest path.

Traffic distribution model

Assumption that the travel distribution within the zone subject to gravity model, then the traffic exchange capacity q_{rs} between partition r and s can be expressed as[12]:

$$q_{rs} = K_r K_s' O_r D_s e^{-\alpha c_{rs}}, \forall r, s \quad (6)$$

$$K_r = \left(\sum_s K'_s D_s e^{-\theta c_{rs}} \right)^{-1}, \forall r, s \quad (7)$$

$$K'_s = \left(\sum_r K_r O_r e^{-\theta c_{rs}} \right)^{-1}, \forall r, s \quad (8)$$

This is known as the double constraints gravity model in traffic planning. According to the relevant theoretical research can know that formula (6) to formula (8) and the following mathematical programming are equivalent [12].

$$\max_x H(x) = -\sum_{rs} q_{rs} (\ln q_{rs} - \ln Q) \quad (9)$$

s.t.

$$\sum_s q_{rs} = O_r, \forall r \quad (10)$$

$$\sum_r q_{rs} = D_s, \forall s \quad (11)$$

$$\sum_{rs} q_{rs} c_{rs} = Q\bar{c} = C \quad (12)$$

$$q_{rs} \geq 0, c_{rs} \geq 0 \quad (13)$$

Due to the detailed analysis of the traffic demand forecast work often is in parallel with the network framework study in rail transportation network planning in general, so forward traffic distribution is not clear. So you can imagine the above two analysis work together.

Traffic distribution–assignment combination model

In this paper, the problem we study based on the related theory in the traffic planning, is known the above the combination of the two phase model as shown below:

$$\min_x Z(x, q) = \sum_a x_a t_a - \frac{1}{\xi} \sum_{rs} q_{rs} (\ln q_{rs} - \ln Q) \quad (14)$$

s.t.

$$\sum_k f_k^{rs} = q_{rs}, \forall r, s \quad (15)$$

$$\sum_k f_k^{rs} \delta_{ka}^{rs} = x_a, \forall r, s, a \quad (16)$$

$$\sum_s q_{rs} = O_r, \forall r \quad (17)$$

$$\sum_r q_{rs} = D_s, \forall s \quad (18)$$

$$\sum_{rs} q_{rs} c_{rs} = Q\bar{c} = C \quad (19)$$

$$f_k^{rs} \geq 0, q_{rs} \geq 0, c_{rs} \geq 0 \quad (20)$$

Solution of the mathematical programming can get the passenger flow on the side of the spider network. Then the next question is how to implement the above analysis by computer software technology.

Based on the analysis of TransCAD process implementation scheme

Spider network method is a very flexible method, can be used for a variety of different situations. one of the most direct application is rail transportation passenger flow corridor recognition, as well as the new city road network architecture research. From a theoretical perspective, spider network method is not the four stage method can directly design network. Considering the need of practical engineering application, combining with TransCAD planning software, analysis steps are as follows:

Step.1 Using the TransCAD characteristics of rapid calculation straight-line distance between each point in space generates all connected network between any two nodes with [Distance Matrix] order.

Step.2 Set up the menu:[origin number], [terminal number], [origin *X* coordinate], [origin *Y* coordinate], [terminal *X* coordinate], [terminal *Y* coordinate], [spatial distance], [quadrant].And according to [origin number], [quadrant], [spatial distance] to order lowest to sort, and export to Excel.

Step.3 In Excel, executing judgment if belong to the same origin point and the same quadrant point, take the first record; or delete.

Step.4 Use the order import the above sheet into the TransCAD as matrix, draw the desire line.

Step.5 Bring up the background data, form new type[Time0]、[Speed0]、[Capacity0], and according to characteristics of transportation systems of the analysis object assignment.

Step.6 Implement the combination model assignment, using traffic distribution-assignment combination model (formula (14) to (20)) finish assignment flow of road network.

Then this will get the traffic flow path selection results in accordance with the principle of shortest path. In other words, that is, get the distribution of passenger flow channel in space.

EXAMPLES

According to the division of traffic zone in Xi'an, there are altogether 1448 traffic zones. The TransCAD generated traffic zone cancroids spatial distribution relations are shown in figure 4 below. The spider network of traffic zone spatial distribution in Xi'an is shown in figure 5 by calculation. From the perspective of the structure forms of the network is relatively complex, as well as the points degree distribution is analyzed. According to statistics, the node degree distribution of spider network is shown in the figure 6 and figure 7:

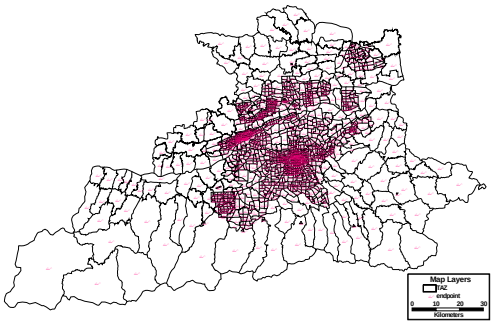

Figure 4 the relationship of traffic zones and centroids

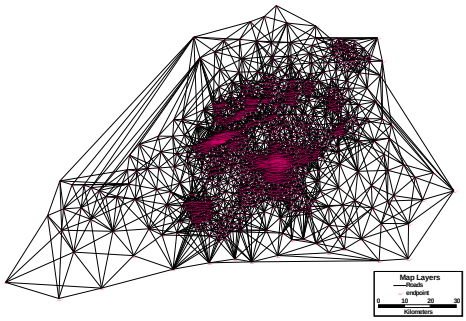

Figure 5 the spider network of traffic zone centroids

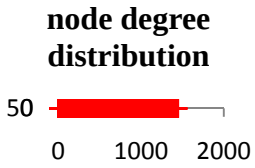

Figure 6 node degree distribution of spider network

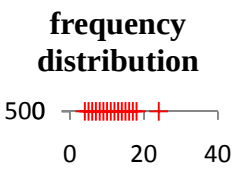

Figure 7 node degree frequency distribution of spider network

RESULT AND DISSCUSS

Among the various nodes, the degree distribution is between [4, 24], the highest frequencies are 9, 10, 43.1% and 68.8% respectively. Average node degree is 10.07, standard deviation is 1.83. From the perspective on the distribution of node degree, it shows that the spider network basically achieve the expected target of each node connection eight basic orientation, thus it can be used for analysis of spatial orientation distribution of passenger flow. From the result point of view, xi 'an passenger flow distribution on large scale presents east to west direction in future, the center of city presents northeast to southwest. This is consistent with the space development strategy of the urban planning. In order to further analyze passenger flow corridor structure relations, the layered method analysis result are shown in figure 8-12.

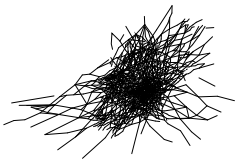

Figure 8 corridor of daily average more than 30000 persons per hour

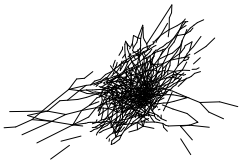

Figure 9 corridor of daily average more than 50000 persons per hour

Figure10 corridor of daily average more than 80000 persons per hour

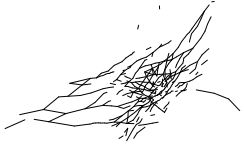

Figure 11 corridor of daily average more than 120000 persons per hour

Can be seen from the above analysis the following points:

(1)The structure of passenger flow within main urban area appears network structure.

(2)The main contact at the airport is more closely.

(3)Exist the half ring structure along the main urban area.

CONCLUSIONS

In this paper, through the study of the formation mechanism of the big city passenger flow corridor, the passenger flow distribution using the spider network are proposed to determine passenger flow corridor structure and its spatial location method. Through the rules for any node take the most near node in any division quadrant, and connect the two nodes. so the spider network can be made. Combined with the TransCAD planning software specific operation method is presented. The Gravity-AON combination model is formed in This article，and the corresponding algorithm is given. At last, by the example of xi 'an application can be analyzed. Through the study of this article, the several research conclusions:

(1) Spider network is a kind of effective method looking for passenger flow corridor and making basic traffic network structure.

(2) Spider network can be getting by connected the most near nodes of eight directions repeatedly.

(3) The spatial location of passenger flow corridor can be getting by doing distribution-assignment combination model for the spider network.

This article using the spider network method studied the problem of passenger flow corridor searching, and discussed the application in rail transportation network architecture. In fact different nature of the traffic flow in the process of formation of traffic corridor has a different mechanism. Further research on the mechanism of formation of the passenger flow corridor should be combined with different purposes, different modes of traffic flow, and discusses the possible application of spider network in that.

ACKNOWLEDGEMENT

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