Urban Traffic Planning and Traffic Flow Prediction based on ulchis gravity model and Dijkstra algorithm

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Abstract. Traffic flow forecast is the basic content of urban traffic planning, its planning will play an important role in the development of small towns. Therefore, this paper takes Nanliang town as an example, analyzes the topography of Nanliang Town, and then makes planning on the functional zoning and spatial structure, the layout of various types of land and road network, based on this, the "four stage" demand forecasting method is used to study the development of Nanliang town's traffic demand. The original unit method and ulchis gravity model are used to predict the trip generation, the trip attraction and the distribution of traffic volume. The Dijkstra algorithm is used to calculate the shortest path. After that, the all-or-nothing assignment method and the improved multi-path Logit method were respectively adopted to allocate the space OD amount of various travel modes to the specific road network, and the traffic flow distribution results under the two allocation methods are obtained respectively. According to the distribution result chart, it can show that the improved multi-path Logit method is closer to the reality, it can provide theoretical support for the study of urban traffic demand.

1. INTRODUCTION

Over the past 40 years of reform and opening up, China's economy has made rapid development, the process of urbanization is accelerating, more and more cities will emerge, and whether the town planning is reasonable or not will greatly affect people's quality of life. Scholars all over the world have studied road traffic planning and traffic flow prediction. Akram (2020)[1] et al. put forward an adapted form of the Dijkstra algorithm that works out a picture fuzzy shortest path problem, a comparative analysis of our proposed method with the fuzzy Dijkstra algorithm is presented to support its cogency. Rachmawati (2020) [5] et al. compared Dijkstra with A* algorithm. Yefim Dinitz (2017) [9] et al. proposed the hybrid algorithm of Bellman-Ford-Dijkstra algorithm, which improved the running time limit of Bellman-Ford algorithm on the sparse distribution map of negative cost edges. Bozyigit(2017) [11] et al. modified Dexter algorithm by implementing the punishment system, tested the improved algorithm on the real traffic network of Izmir, and compared the results with Dijkstra algorithm. From the point of view of transfer times, suggested route distance and walking distance, the improved algorithm proposed by the author is quite effective for route planning in public transportation network. Broumi (2017)[13] et al. propose an extended version of Dijkstra’ algorithm for finding the shortest path on a network where the edge weights are characterized by an interval valued neutrosophic numbers. Finally, a numerical example is given to explain the proposed algorithm. Qing(2017) [10] et al. proposed an improved Dijkstra algorithm aiming at the path planning problem in the rectangular environment, which could find the
shortest path with all equidistances and get the optimal path with the shortest distance and time by adding running time into the path planning evaluation. Adnan (2020) [2], Dilip (2018) [3], Thomas (2017) [12], Xiaohui Wang(2020) [18] and others also proposed algorithms for finding the shortest path. Train (2016) [4], Xilei Zhao (2020) [6], Zeng (2019) [7], Aggarwal (2019) [8], Delle Site (2019) [14], Sepehr Ghader (2019) [15], Ma Kun (2020) [17] have carried out some research based on Logit model. Qing Li (2020) [16], Mengxue Ge [19], Jie Ye (2017) [20] all carried out research on traffic flow prediction.

In recent years, most studies in China are based on large cities, and there are few road network planning and traffic demand prediction for towns. Therefore, this paper takes Nanliang Town as an example to analyze the traffic planning and traffic flow prediction of small towns. In this paper, The first section analyzes and plans the functional zoning and spatial structure of Nanliang Town, the layout of various types of land use and road network according to the Standard for Planning of Town and Village(GB50188-2007). The second section uses the “four stages” demand forecasting method to forecast the traffic demand of Nanliang Town, so as to establish a reasonable land use layout and a clear traffic system.

2. Overall Planning of Nanliang Town
The overall terrain of Nanliang town is gentle, with a distance of 2500 meters from east to west and 1250 meters from north to south, with a total planning area of 310 hectares. The average annual growth rate of regional travel is 4%, and the peak hour factor of traffic volume is 24%. Based on the above general situation and the social and economic development status of the town, according to the Standard for Planning of Town and Village(GB50188-2007), a central town with reasonable land layout, reasonable road network planning, convenient and safe traffic, and various complete facilities has been built. The transportation plan is a medium and long term plan with a 10-year planning period. The base year of the plan is 2020, and the planning period is from 2021 to 2030.

Nanliang town is a central town with complete functions and facilities. According to the Standard for Planning of Town and Village(GB 50188-2007), the land for villages and towns is divided into residential land, public facilities land, production facilities land, external traffic land, road and squares land, engineering facilities land, green land and other land according to the main nature of land use. After analysis and calculation, the land use balance table of various land use properties is shown in Table 1.

This paper adopts the grid road network structure, which is also the most common layout form of urban road network in China. This layout not only makes the road system simpler, but also is conducive to the layout of buildings on both sides of the road. Nanliang town has three different levels of roads: trunk road, secondary trunk road and branch road. All roads coordinate and cooperate with each other to undertake the traffic volume of Nanliang town. The planning road network can clearly reflect the arrangement and layout of the town road network. The planning road network of Nanliang town is shown in Figure 1.

3. Traffic Demand Forecast
Traffic demand forecasting is one of the core contents of traffic planning. It uses the results of traffic investigation and analysis, data collection and analysis to establish various forecasting models, and use this model to predict the traffic demand of the planning area in the future, this can provide the basis for the planning evaluation of the transportation system.
In order to connect the generation and attraction of traffic demand with the social and economic indicators of a certain area, the spatial flow of traffic demand is shown by the traffic distribution map between traffic districts. Before the prediction of traffic occurrence and attraction, it is necessary to divide the urban traffic into small areas, so as to simulate the traffic flow on the road network with the traffic assignment theory. Nanliang town is divided into eight traffic districts according to the traffic division principle. The division plan of each district is shown in Figure 2.

![Figure 1 Road network planning of Nanliang town](image1)

![Figure 2 Traffic district division plan of Nanliang town](image2)

3.1. Prediction of Traffic Occurrence and Attraction

Trip generation and trip attraction is calculated by studying the traffic volume of each traffic district, that is, the trip production. Under the constraint of trip production, the trip generation and trip attraction of each traffic district are calculated.

In this paper, the original unit method is used to predict the trip generation and trip attraction, which is expressed by formula 1 and 2, that is, the area of various land-use properties and the corresponding occurrence and attraction rate are multiplied to obtain the occurrence and attraction traffic volume of different land-use properties, and then the occurrence and attraction traffic volume of various land-use properties in the same community are summarized.

\[ O_i = BX_i \quad \text{formula (1)} \]
\[ D_j = CX_j \quad \text{formula (2)} \]

\( i, j \) is traffic district, \( X \) is attribute variables such as resident population, employed population. \( B \) is unit trip times of a travel purpose. \( C \) is unit trip attraction times of a travel purpose. \( O_i \) is traffic volume of area \( i \). \( D_j \) is traffic volume of district \( j \).

Adjustment calculation, in the generation stage of travel, it is required to meet the requirement that the total amount of travel occurred in all communities should be equal to the total amount of travel attraction.

When the above conditions are not met, it is generally considered that the total amount of travel \((O=\sum_{i=1}^{n} O_i)\) of all residential areas is more reliable. Thus, the total amount of attraction can be multiplied by an adjustment coefficient \( F \), which can ensure that the total amount of travel attraction equals to the total amount of travel occurrence. The coefficient \( f \) can be calculated according to formula 3. The calculation results are shown in table 2.
The average annual travel growth rate of Nanliang town is 4%, and the planning year is 10 years. The traffic volume of each district in the planning year is obtained by multiplying the data shown in table 2 by the travel growth rate of each year. The calculation results are shown in table 3.
### Table 2 Current OD table of each community after adjustment unit: times / day

|   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | O  |
|---|----|----|----|----|----|----|----|----|----|
| 1 |    |    |    |    |    |    |    |    | 10822 |
| 2 |    |    |    |    |    |    |    |    | 6047  |
| 3 |    |    |    |    |    |    |    |    | 14462 |
| 4 |    |    |    |    |    |    |    |    | 7036  |
| 5 |    |    |    |    |    |    |    |    | 7999  |
| 6 |    |    |    |    |    |    |    |    | 13406 |
| 7 |    |    |    |    |    |    |    |    | 8364  |
| 8 |    |    |    |    |    |    |    |    | 7060  |
| D | 10405 | 5832 | 14670 | 6802 | 7944 | 14558 | 8128 | 6856 | 75196 |

### Table 3 OD table of each community in 2030 unit: times / day

|   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | O  |
|---|----|----|----|----|----|----|----|----|----|
| 1 |    |    |    |    |    |    |    |    | 16019 |
| 2 |    |    |    |    |    |    |    |    | 8951  |
| 3 |    |    |    |    |    |    |    |    | 21407 |
| 4 |    |    |    |    |    |    |    |    | 10415 |
| 5 |    |    |    |    |    |    |    |    | 11841 |
| 6 |    |    |    |    |    |    |    |    | 19845 |
| 7 |    |    |    |    |    |    |    |    | 12381 |
| 8 |    |    |    |    |    |    |    |    | 10451 |
| D | 15402 | 8633 | 21716 | 10068 | 11758 | 21550 | 12032 | 10149 | 111308 |

#### 3.2. Traffic Distribution Forecast

Traffic distribution prediction is the second step of the four stage traffic demand forecasting model, which transforms the occurrence and attraction of traffic volume or the predicted occurrence and attraction traffic volume of each district into the spatial OD table between the districts, namely OD matrix.

##### 3.2.1. Calculation of Minimum Right of Way and Shortest Path

Dijkstra algorithm is a typical shortest path algorithm, which is used to calculate the shortest path from one node to all other nodes. The main feature is that it extends to the outer layer around the starting point until it reaches the end point. Dijkstra algorithm can get the optimal solution of the shortest path, based on this, this paper uses Dijkstra algorithm.

Dijkstra algorithm is as follows: first, starting from starting point O, give each node a label, which is T and P label two categories. T label is a temporary label, which represents the upper limit of the shortest path weight from the starting point to the point, P label represents the fixed label, and represents the shortest path weight from the starting point O to the point. In the process of labeling, the t-label is always changing, while the P-Label is not changing. All points not marked with p-mark are marked with T-Mark. In each step of the algorithm, the t-label of a point is changed into a P-Label until all the t-labels are changed into p-labels, that is, the shortest path weight from the starting point O to other points is obtained, and the labeling process is finished.

##### 3.2.2. Traffic Distribution Forecast

In this paper, ulchis gravity model is used for calculation. The calculation formula is shown in formula 4, and the calculation results are shown in table 4.
\[ Q_{ij} = \frac{O_i \times D_j \times f(C_{ij})}{\sum D_j \times f(C_{ij})} \]  

formula (4)

\( O_i, D_j \) is the occurrence and attraction of traffic volume in the future, \( f(C_{ij}) \) is traffic impedance coefficient. Its common form is \( f(C_{ij}) = C_{ij}^{-r} \), \( r \) is undetermined coefficient, this paper takes 1. \( C_{ij} \) is the minimum right of way between the centroid of a district, This paper uses Dijkstra algorithm to determine.

The adjustment calculation is carried out by using the Detroit method. The calculation idea is as follows: firstly, the occurrence growth coefficient \( F_{Oij} = U/O \) and the attractive growth coefficient \( F_{Dj} = V/D \) are calculated. Then calculate the reciprocal of the traffic growth coefficient \( G = T/X \), and calculate the adjusted traffic volume according to the formula \( Q_{ij}^1 = Q_{ij} \times F_{Oij} \times F_{Dj} \times G \). After iterative calculation, the OD table of traffic volume among the districts is shown in table 5.

3.2.3. OD Expectation Line

The OD expectation line is a straight line connecting the centroid of each community. Its width represents the number of trips between each community, which can reflect the shortest distance expected by people. Figure 3 is the OD expectation line of Nanliang Town. In the figure, the straight lines between 0-1000, 1000-2000 and >2000 are respectively represented by different line widths, so as to reflect the traffic volume between each cell. The capital numbers one, two and three are each cell. The number above the line of different cells is the traffic volume between each cell.

| 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | O  |
|----|----|----|----|----|----|----|----|----|
| 1  | 2089 | 2022 | 2886 | 1012 | 2178 | 3370 | 1344 | 1117 | 16017 |
| 2  | 1555 | 630 | 1983 | 659 | 911 | 1976 | 644 | 592 | 8951 |
| 3  | 1663 | 1485 | 3782 | 2013 | 1814 | 6246 | 2022 | 2382 | 21407 |
| 4  | 877 | 743 | 3027 | 842 | 787 | 2034 | 894 | 1212 | 10415 |
| 5  | 1518 | 825 | 2193 | 633 | 1127 | 3125 | 1568 | 852 | 11841 |
| 6  | 1716 | 1308 | 5522 | 1196 | 2285 | 3475 | 2561 | 1780 | 19845 |
| 7  | 918 | 572 | 2397 | 705 | 1537 | 3434 | 1123 | 1694 | 12381 |
| 8  | 694 | 478 | 3170 | 869 | 759 | 2170 | 1540 | 772 | 10451 |

| D  | 11029 | 8063 | 24961 | 7929 | 11397 | 25830 | 11696 | 10401 | 111307 |

Table 4 OD table of distribution traffic volume unit: times / day

| 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | O  |
|----|----|----|----|----|----|----|----|----|
| 1  | 2089 | 2022 | 2886 | 1012 | 2178 | 3370 | 1344 | 1117 | 16017 |
| 2  | 1555 | 630 | 1983 | 659 | 911 | 1976 | 644 | 592 | 8951 |
| 3  | 1663 | 1485 | 3782 | 2013 | 1814 | 6246 | 2022 | 2382 | 21407 |
| 4  | 877 | 743 | 3027 | 842 | 787 | 2034 | 894 | 1212 | 10415 |
| 5  | 1518 | 825 | 2193 | 633 | 1127 | 3125 | 1568 | 852 | 11841 |
| 6  | 1716 | 1308 | 5522 | 1196 | 2285 | 3475 | 2561 | 1780 | 19845 |
| 7  | 918 | 572 | 2397 | 705 | 1537 | 3434 | 1123 | 1694 | 12381 |
| 8  | 694 | 478 | 3170 | 869 | 759 | 2170 | 1540 | 772 | 10451 |

| D  | 11029 | 8063 | 24961 | 7929 | 11397 | 25830 | 11696 | 10401 | 111307 |

Table 5 OD table of distribution traffic volume after adjustment unit: times / day

| 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | O  |
|----|----|----|----|----|----|----|----|----|
| 1  | 2848 | 2113 | 2451 | 1254 | 2194 | 2744 | 1350 | 1064 | 16019 |
| 2  | 2105 | 654 | 1672 | 811 | 910 | 1597 | 642 | 560 | 8951 |
| 3  | 2340 | 1602 | 3315 | 2576 | 1885 | 5251 | 2096 | 2342 | 21407 |
| 4  | 1234 | 801 | 2654 | 1078 | 818 | 1710 | 927 | 1192 | 10415 |
| 5  | 2104 | 877 | 1894 | 798 | 1154 | 2588 | 1601 | 825 | 11841 |
| 6  | 2409 | 1408 | 4828 | 1526 | 2369 | 2913 | 2648 | 1746 | 19845 |
| 7  | 1308 | 625 | 2128 | 914 | 1618 | 2924 | 1178 | 1686 | 12381 |
| 8  | 986 | 520 | 2806 | 1123 | 797 | 1842 | 1611 | 766 | 10451 |

| D  | 15332 | 8600 | 21748 | 10079 | 11745 | 21569 | 12054 | 10181 | 111308 |
3.3. Modal Split
Traffic mode division is the third stage of traffic demand forecasting, which is to allocate the total traffic volume to various traffic modes. According to the different basic units of traffic mode selection, the traffic mode is divided into the centralized model and the non-centralized model. The centralized model takes the traffic area as the unit, and makes statistics and unified treatment for the traffic mode selection of the traffic behavior participants. The disaggregation model takes the individual of traffic behavior participants as the unit, constructs the model to determine the selection probability of various traffic modes, and then calculates the traffic mode selection results to predict the division rate of traffic modes. Based on the relevant data of traffic distribution, according to the proportion of different modes of transportation when they travel, this paper calculates the traffic volume of various modes of transportation under different proportions. Then, the OD table shared by various modes of transportation is converted into the number table of vehicles, and then converted into the standard traffic volume. Finally, the traffic volume of the same mode of transportation is summarized. The calculation results are shown in table 6.

Table 6 OD table of traffic mode division

|     | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | total |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| 1   | 647 | 480 | 557 | 285 | 499 | 624 | 307 | 242 | 3642  |
| 2   | 478 | 149 | 380 | 184 | 207 | 363 | 146 | 127 | 2035  |
| 3   | 532 | 364 | 754 | 586 | 429 | 1194| 476 | 532 | 4866  |
| 4   | 280 | 182 | 603 | 245 | 186 | 389 | 211 | 271 | 2368  |
| 5   | 478 | 199 | 431 | 181 | 262 | 588 | 364 | 188 | 2692  |
| 6   | 548 | 320 | 1098| 347 | 538 | 662 | 602 | 397 | 4511  |
| 7   | 297 | 142 | 484 | 208 | 368 | 665 | 268 | 383 | 2815  |
| 8   | 224 | 118 | 638 | 255 | 181 | 419 | 366 | 174 | 2376  |
| total| 3485| 1955|4944|2291|2670|4903|2740|2314|25304 |

3.4. Traffic Assignment
Traffic flow assignment is the last stage of the “four stage” traffic demand forecasting. It is to allocate the OD matrix of various travel modes to each road in the traffic network according to certain route selection principles, and calculate the traffic flow and related traffic indicators on each road section, so as to analyze and evaluate the use of urban traffic network.

Traffic flow assignment methods can be divided into two categories: unbalanced assignment method and balanced assignment method. The method without Wardrop principle is called unbalanced assignment method, and the method using Wardrop principle is called balanced assignment method. In this paper, the all-or-nothing assignment method and the improved multi-path logit assignment method are used to allocate the traffic flow, and the results of the two distributions are analyzed and compared.

3.4.1. All-or-Nothing Assignment Method
All have all no assignment method is a static traffic assignment method. In this method, the path impedance is taken as a constant and the average speed of vehicles is assumed to be independent of
traffic load. Let all the OD volumes of the OD point pair are allocated on the shortest path connecting the OD point pair, and the traffic volume cannot be allocated on other paths. The advantage of this method is that the calculation is simple, but its disadvantage is that the traffic volume is all concentrated on the shortest path, which can cause uneven distribution of travel volume. This allocation method is the basis of other traffic allocation methods. The distribution results of this method in this paper are shown in Figure 4.

3.4.2. Improved Multi Path Logit Allocation Method

The improved multi-path assignment method reflects the rule that the probability of route selection decreases with the increase of the route length. The advantages of the improved multi-path assignment method are mainly reflected in two aspects: on the one hand, it can reflect the differences between travelers. When different travelers face the same origin-destination, they sometimes make different path choices due to individual differences. On the other hand, under the same conditions, this method can better reflect the randomness of traveler selection in actual travel. In actual travel, although most travelers may choose the shortest route, some travelers may choose other routes randomly due to various factors. The results of this method are shown in Figure 5.

In the improved multi-path assignment method, the probability of each route selected is calculated by logit model. Formula 5.

\[ P(r, s, k) = \frac{\exp \left[ -\sigma (t(k)/t_0) \right]}{\sum_{i=1}^{M} \exp \left[ -\sigma (t(i)/t_0) \right]} \]

Formula (5)

\( P(r, s, k) \) is distribution rate of OD T(r, s) on the k route; \( t(k) \) is right of way (travel time) of route K; \( t_0 \) is average right of way of each travel route; \( \sigma \) is allocation parameters; \( M \) is number of effective travel routes.

3.4.3. Comparative Analysis of the Results of the Two Allocation Methods

According to the results of the two distribution methods shown in Figure 4 and Figure 5, in the all-or-nothing distribution method, there is only traffic volume on a certain section. The traffic volume is relatively concentrated, and the traffic volume of each section is relatively unbalanced, which is easy to cause pressure on the road traffic. In the improved multi-path probability distribution method, the traffic volume of each section is relatively average, and most sections have traffic volume, which is more in line with people's actual travel choice.

Figure 4 Traffic volume of each section with all-or-nothing assignment method
4. Conclusion
This paper analyzes the basic conditions of Nanliang Town, such as topography, combined with the political and economic development trend of the town. The functional zoning and spatial structure of the town, the nature and layout of various types of land and road network are planned. On this basis, the original unit method and Ulchis gravity model are used to predict the occurrence and attraction of traffic volume and the distribution of traffic volume. Dijkstra algorithm is used to calculate the shortest path between each node. This paper uses Dijkstra algorithm to calculate the shortest path between each node, and allocates the spatial OD of various travel modes to the specific road network by using the all have all no allocation method and the improved multi-path logit method, and obtains the traffic flow distribution result chart. The analysis and comparison of the two allocation results show that the improved multi-path allocation method is more suitable for people's travel choice. This research method has a certain guiding significance for urban road network planning and infrastructure construction. This research provides theoretical support for the study of urban traffic development.

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