IOP Conf. Series: Materials Science and Engineering **392** (2018) 062165 doi:10.1088/1757-899X/392/6/062165

Research on Accessibility of Compound Traffic Network in Urban Agglomeration

Lei WEI[1], Jing HAN[2], Yin LUO[3], Cheng Bing LI[3]

[1]School of Transportation Science and Engineering, BUAA, Beijing, 100083, China

[2]School of Transportation and Mechanical engineering, Ordos Institute of Technology, Ordos, 017000

[3]School of Transportation, Inner Mongolia University, Hohhot, Inner Mongolia, 010070，China

Email:739875282@qq.com

Abstract: In order to improve the accessibility of urban agglomerations traffic network, the accessibility of urban agglomeration compound traffic network was empirically studied from a new view. A quantitative description of the accessibility of urban agglomeration was put forward by weighted travel time, weighted economic potential, and interaction force. Firstly, four single mode of transport sub-networks was built, including highway sub-network, rail sub-network, aviation sub-network and waterway sub-network so that urban agglomeration compound traffic network was formed by the superposition based on complex network theory. Secondly, the effective average travel time, city economic coefficient was chosen as quantitative measure index of accessibility. Finally, the model of Hohhot-Baotou-Ordos urban agglomeration compound traffic network was built to be empirically studied. The results show that it formed a structure of concentric circle with the center of Baotou and the accessibility intensity gradually decreases outward. The effective superposition of highway sub-network and rail sub-network can increase the accessibility of any point.

1. Introduction

With the rapid development of society and economy, the phenomenon of urban agglomeration is becoming more and more obvious. Traffic demand continues to rise in urban agglomerations. In the process of traffic network construction, the interaction between different modes of transportation causes bad competition and the accessibility of traffic network of urban agglomerations is restricted.

If the change of network accessibility measure index can be compared and the interaction between different transportation modes can be analyzed, it can effectively improve the cohesion of various transportation mode in urban agglomerations, realize the advantage complementation so as to avoid the bad competition between different transportation modes.

At present, scholars at home and abroad have made some achievements in the research of traffic network accessibility. The concept of accessibility was first proposed and the development opportunity of urban agglomeration can be evaluated through measuring traffic network structure by accessibility index[1]. Linneker B, etc. studied the impact on Londen's economy of changes in its Highway Network accessibility[3]. Jin F J, etc. investigated the accessibility of China's railway passenger transport network[4]. The influence of the development of high speed railway on the spatial pattern of urban agglomerations was demonstrated, and the corresponding spatial evolution trend was revealed[5-7]. The accessibility and evolution of the main nodes in the highway network of the Yangtze River Delta were studied by comparing the time interval and the weighted travel time[8].

In conclusion, for the study of accessibility, scholars at home and abhighway are mostly limited to the single mode of transportation network. There is little research on the accessibility of urban agglomerations. However, Connecting different modes of transportation efficiently will improve the overall performance of the transportation network and reduce transportation costs. Based on this, a model of urban agglomeration compound traffic network will be built with the object of urban agglomeration. Different traffic modes will be used to compare and analyze the accessibility between single traffic sub-network and compound network. It is beneficial to make scientific management strategy and can provide theory evidence for the convenient and reliable of urban agglomeration and management strategies.

2. Construction of urban agglomeration compound traffic network model

2.1. Construction of urban agglomeration highway sub-network model

There are two methods to build urban highway traffic network: one is Primal approach[9-12], the other is Dual approach[9-12]. Primal approach takes signal intersections on actual road as nodes, the routes between two intersections as edges of network model. Dual approach takes the actual exiting roads as nodes, and the intersections as edges of the network. In this paper, towns in agglomerations are taken as nodes, and roads among towns are taken as edges, so the urban agglomeration highway sub-network model is constructed.

2.2 Construction of urban agglomeration rail sub-network model

There are two methods to build rail transit network: one is Space L, the other is Space P. Space L takes rail stations in urban agglomerations as nodes, the routes between two interlinked sites. Space P takes train number as the node and the orbital site is defined as the edge. This paper will use the method of Space L, rail stations are defined as nodes, connections between nodes are defined as edges, so the urban agglomeration rail sub-network model is constructed.

2.3 Construction of urban agglomeration aviation sub-network model

At present, there are two kinds of modeling methods for aviation network,: take the airport in the city as the node or take the city where the airport is as the node. If there is flight between two airports or cities, there is an edge between the two nodes. Take the city where the airport is located as a node. If there is a flight between the nodes, the two nodes are connected by one side. Thus, the model of urban agglomeration aviation sub-network is constructed.

2.4 Construction of urban agglomeration waterway sub-network model

The method of constructing waterway network model is similar to the model of rail transit network, and is divided into Space, L and Space P. The urban agglomeration waterway sub-network model can be modeled by analogy. The city in which the port is located is taken as a node. If there is a same route between the ports, there is an edge between the nodes. Thus, the urban agglomeration waterway sub-network model is constructed.

2.5 Construction of compound traffic network model

There are two main ways to construct the traffic network, the road mapping method and the site mapping method". With regard to urban agglomeration, because of the large number of nodes and uneven distribution of the network, the complexity of the network is high and the error is great. If the road mapping method is used, the traffic network characteristics can not be accurately reflected. Therefore, the "site mapping method" is adopted in this paper". The urban agglomerations are abstracted into undirected and weighted networks. Take the city and important township among the urban agglomeration as the node, if there is a line between the two nodes, there is an edge. If two nodes are adjacent, they can be regarded as a point, the edge is in like manner.

3. Accessibility index of urban agglomeration compound traffic network

3.1 Urban agglomeration compound weighted average travel time

In a urban agglomeration compound traffic network, compound weighted average travel time is the effective time from one node to another. The smaller the index value is, the higher the accessibility of the node is, namely, the economic development of the node is rapid. It can be obtained by formula (1).

$$A_i = \sum_{x=1}^{4} A_{ix} \times \omega_x \qquad (1)$$

Where, A_i represents the weighted average travel time of node i within the urban agglomeration; A_{ix} represents weighed average travel time of mode x j (including roads, railways, aviation and water transport mode) of node i; ω_x represents the weight of mode x (the value of x is 1, 2, 3 and 4. They are roads, railways, aviation and water transport mode respectively) in urban agglomeration; ω_x is affected by many factors and can be determined by entropy method.

For A_{ix}, it can be obtained by formula (2).

$$A_{ix} = \frac{\sum_{j=1}^{n} T_{ijx} \times M_j}{\sum_{j=1}^{n} M_j} \qquad (2)$$

where, A_{ix} is the weighted average travel time of mode x of node i in urban agglomeration; n is the nodal degree of node i in a traffic sub-network; T_{ijx} is the shortest distance(measured by time) from node i to node j by mode x (the value of x is 1, 2, 3 and 4. They are roads, railways, aviation and water transport mode respectively); M_j is the economic strength of node i or the radiation force and attraction to the surrounding area. It can be obtained by formula (3).

$$M_j = \sqrt{P * GDP} \qquad (3)$$

Where, P is the total population of node j ,GDP is the total output value of node j .

3.2 City economic non strength coefficient of urban agglomeration

The interaction network between cities is the interrelation intensity between city and city. The intensity of economic relations between cities can be measured by Newton's gravity model, the formula (4) is as follows.

$$F_{oj} = \frac{\sqrt{P_o G_o}\sqrt{P_j G_j}}{D_{oj}^{\ 2}} \qquad (4)$$

Where, F_{oj} is the economic non strength coefficient between city o and city j ; P_j 、 P_o 、 G_j G_o respectively indicate the population and GDP of city o and city j ; Time distance can be calculated by formula (5) (6).

$$D_{oj} = \frac{fs_o}{T_{oj}} \quad (5)$$

$$fs_o = \sqrt[n]{a_1 a_2 \cdots a_n} \quad (6)$$

Where, D_{oj} is the size of city O's influence on the city J; fs_o is the economic development level index of city O; T_{oj} is the reachability time between city O and city J; a_n is a single index of urban economic strength(n takes 1,2,3; respectively indicate GDP, Gross industrial output value, fixed assets investment). The data is from the Inner Mongolia Autonomous Region statistical yearbook. The driving speed is determined according to the technical standard of highway engineering and the national railway regulations, the highway is 80 kilometers per hour, and the railway is 100.

3.3 Weighted economic potential of urban agglomeration compound network

Economic potential is an index that reflects the accessibility from economic costs. The greater the score is, the greater the economic potential of node i is, and vice versa.

$$P_i = \sum_{x=1}^{4} P_{ix} \times \omega_x \quad (7)$$

Where, P_i is the economic potential of node i; P_{ix} is the economic potential of using some kind of transit (x takes 1,2,3 and 4; respectively indicate roads, railways, aviation and water transport mode). It can be calculated by formula(8).

$$P_i = \sum_{j=1}^{\gamma} \frac{M_j}{D_{ij}^{\alpha}} \quad (8)$$

M_j is the economic strength of node j or the radiation force and attraction to the surrounding area; D_{ij} is the traffic cost(time cost) of using a traffic mode from node i to node j. α is distance friction coefficient, usually taken as 1[9]. α is the number of cities that have been measured.

4. Empirical research on accessibility of Hohhot-Baotou-Ordos urban agglomeration compound traffic network

4.1 Construction of Hohhot-Baotou-Ordos urban agglomeration compound network model

Hohhot-Baotou-Ordos urban agglomeration, in Inner Mongolia Autonomous Region, is selected as the research object. Cities and important countries are taken as the node. If the nodes are opened to traffic, there is an edge between two nodes. Hohhot-Baotou-Ordos urban agglomeration is located inland, there is no waterway, and the air route is single. So the compound traffic network of urban agglomeration is mainly considered from highway and railway. The highway sub-network and rail sub-network are superimposed to form a compound traffic network.

4.2 Weighted travel time analysis

When the node contains two modes of traffic, namely highway and rail, entropy method is used to determine that highway transit weight is 0.833, rail transit weight is 0.167. According to formula (1), the index values of nodes in compound traffic network are as shown in Table 1.

Table 1 An important indicator of city groups in all counties in the district

nodes	Highway travel time	Rail travel time	Compound weighted travel time	Total population at the end of the year(people)	City quality	GDP	Gross industrial output value(million yuan)	fixed assets investment (millionyuan)	city economic development level index (fs_0)
Huhhot New City District	2.11	1.99	2.08996	355366	2142575.444	3339527	374654	1360800	5575288.129
Huhhot Sai-han District	2.33	2.45	2.35004	401686	1269341.228	2679503	1331214	1451200	4300222.661
Batou Kun-dulun District	2.15	1.4	2.02475	643600	1037457.875	7132737	8818694	2755126	1729855.385
Baotou Donghe District	1.98	1.33	1.88314	506600	1089382.555	2952615	1839506	2129700	1194088.579
Tumd Right Banner	2.12	1.37	1.99976	308200	654064.523	1388061	670635	1240000	1048991.939
Bayan Obo	4.5	4.98	3.9823	25500	688359.3528	189132	28330	190963	851009.3902
Dongsheng District	2.38	2.32	2.21634	253127	333498.2783	5073976	3179800	4005333	608640.7963
Dalad Banner	2.08	1.55	1.96644	359528	149091.7141	2800259	3106783	1520133	523814.4293

"——" means non-existent in Table.

According to the formula (2) (6), the weighted average travel time value of each city is calculated. Here Huhhot New City District Huhhot Sai-han District, Batou Kun-dulun District, Baotou Donghe District, Tumd Right Banner, Bayan Obo, Dongsheng District, Dalad Banner are listed. When these eight cities can only be transported by highway, their travel time are 2.11, 2.15, 2.38, 2.33, 1.98, 2.12, 4.5 2.08 respectively. Compound weighted travel time are 2.08997, 2.02475, 2.21634, 2.35004, 1.88314, 1.99976, 3.9823, 1.96644 respectively. It can be seen that Hohhot-Baotou-Ordos urban agglomeration compound traffic network's weighted travel time is close to that of highway sub-network, but slightly lower. The superposition of highway sub-network and rail sub-network has not brought about great changes of accessibility. Compared with the single highway sub-network, the change rate of the compound network is not large, which shows that the highway transit is still the main mode of passenger and freight transport, the railway accounts for less.

In route of Donghe District (1.88314) - Baotou Kun-dulun (2.02475) - Baiyunebo (3.9823), the compound weighted travel times are increased, which indicate a gradual decline of accessibility. So as the route of Baotou Donghe District（1.88314）- Dalad Banner（1.96644）- Dongsheng District(2.21634）. In addition, Other counties Township are all in the 8 site coverage area, which can be approximately equal to the site. By this token, the closer to Baotou, the lower the city index score is and the higher the accessibility is. Conversely, reachability decreases.

4.3Non strength coefficients analysis

According to the formula (4) (5) (6), the non strength coefficients between the cities can be calculated. The population size and GDP value of urban areas in Inner Mongolia in 2014 is adopted. Huhhot New City District has influence on the economic non strength coefficient of seven other cities. The order from high to low is Bayan Obo(97.84), Dongsheng(26.77), Kun-dulun District(24.31), Dalad Banner(20.97), Tumd Right Banner(16.53), Donghe District(2.47), Sai-han District(0.4). The non strength coefficients of Dongsheng to the other 7 cities arranges from high to low as Huhhot New City District(90,03), Bayan Obo(92.96), Saihan District (54.62), Tumd Right Banner(24.26), Kun-dulun District(14.52), Donghe District(10.11), Dalad Banner(4.88). The non strength coefficients of Baotou to the other 7 cities arranges from high to low as Huhhot New City District (113), Bayan Obo(73.4), Saihan District(67.94), Dongsheng(20.17), Tumd Right Banner(11.03), Dalad Banner (2.09), Donghe District(0.78). Concentric circles trend has been formed of Baotou, Hohhot, Ordos area, Baotou is is the center and diverge outwards, The farther away from Baotou, the higher economic coefficient is and the lower the accessibility is. And Baotou is more closely connected with the surrounding cities than Hohhot and Ordos.

4.4Compound traffic time analysis

In Hohhot-Baotou-Ordos urban agglomeration, when the node contains two modes of traffic, namely highway and rail, entropy method is used to determine that highway transit weight is 0.833, rail transit weight is 0.167. According to formula (8), the index values of nodes in compound traffic network are as shown in Table 2.

Table 2 economic potential

nodes	Highway economic potential	Railway economic potential	Compound weighted economic potential
New City District	1951.02	854.12	1767.8377
Saihan District	2043.34	673.26	1814.53664
Kun-dulun District	1508.89	1326.56	1478.44089
Donghe District	2164.45	1517.78	2056.45611
Tumd Right Banner	1407.06	1257.66	1382.1102
Bayan Obo	587.28	235.38	528.5127
Dongsheng	1186.44	648.03	1096.52553
Dalad Banner	1346.51	1470.79	1367.26476

According to the formula (7) (8), the compound weighted economic potential of each city can be calculated. By comparison, the compound economic potential is higher , indicating that compound traffic can relieve the pressure of a single traffic mode. The economic potential index value of roads is higher than that of railway, because in the urban agglomeration, the highway transit is as the main mode. The total proportion of the compound weighted economic potential in the Donghe Distric was 17.89%, which indicated that the compound traffic network had the highest cost, the largest number of trips, and the best accessibility. The accessibility of these 8 cities decreases as the distance from the Donghe District decreases, and the weighted economic potential decreases gradually. The lowest was Bayan Obo (528.5127). The compound traffic network of Hohhot-Baotou-Ordos urban agglomeration takes Baotou as center, forms a divergent concentric circle structure.

5. Conclusion

An empirical research of accessibility has been made on Hohhot-Baotou-Ordos urban agglomeration. The data shows that Hohhot-Baotou-Ordos urban agglomeration compound network is with single structure, The superposition of rail transit does not make the network structure change greatly, but the rail traffic disperses the traffic pressure of the highway network to a certain extent, and increases the accessibility with the surrounding city. Cities with the comprehensive strength have better accessibility, closing to Baotou, Hohhot, Ordos and Dongsheng. By the comparison of nodes and edges, it is found that the accessibility of cities is not proportional to the comprehensive strength of cities. Therefore, in the future planning, the degree of node can not be single index of the accessibility of urban agglomerations.

References

[1] Hansen W G. How accessibility shapes land-use [J].Journal of the American Institute of planners.1959, 25:73-76.
[2] VACLAV D. Cities and highway networks in Europe [J].Journal of Transport Geography.1996,4(2)： 107-121.
[3] Linneker B, Spence N. Road transport infrastructure and regional economic development the regional development effects of the M 25 London orbital motorway [J]. Journal of Transport Geography, 1996, 4(2): 77-92.
[4] Jin F J, Wang J E. Expansion of China's railway network in twentieth Century and its spatial accessibility [J]. Journal of geography, 2004,02:293-302.
[5] Yang J H. The influence of high speed railway on the accessibility of urban agglomeration in Hunan [J]. Human geography, 2014,02:108-112.
[6] Zhao D, Zhang J X. The spatial pattern of the Yangtze River Delta urban agglomeration under the influence of high speed railway [J]. The resources and environment of the Yangtze River Basin, 2012,04:391-398.
[7] Jiang H B, Xu J G, Qi Y. Beijing-Shanghai high-speed railway to the regional central city of land accessibility of [J]. Journal of geography, 2010,10:1287-1298.
[8] Jin C, Lu Y L, Fan L L. Based on the highway network of Yangtze River Delta tourism attractions of up to character Bureau [J]. Journal of natural resources, 2010,02:258-269.
[9] Liu H, Shen Y M, Xue J. Study on the urban network concentration and spatial structure of Beijing, Tianjin and Hebei based on traffic accessibility [J]. Economic geography, 2013,08:37-45.
[10] Li C B, Hao Y C, Wang W Y. Research on City Agglomeration Compound Traffic Reliability [J]. Journal of System Simulation, 2017,03:29-3.
[11] Li C B, Wei L, Hao Y C. Research on Characteristics of City Agglomeration Compound Traffic Network [J]. Journal of System Simulation, 2016,12:28-12.
[12] Lin Q. Study on the vulnerability assessment of Beijing metro station operation based on entropy weight model [D]. Beijing Jiaotong University, 2015.]