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Study on Spatial-Temporal Evolution of Townships Traffic Accessibility in Inner Mongolia

Zhishuang Li[1], Xiuqing Zhao[1]*, Chaoge Jihuleng[2]
[1]College of Geographical Sciences, Inner Mongolia Normal University, Hohhot, Inner Mongolia, China
[2]College of Mathematics and Natural Sciences, Mongolian State University of Education, Mongolia
*Corresponding Author.

Abstract:

The change of regional transportation accessibility is the basis for the evolution of its spatial pattern. This paper takes the townships in Inner Mongolia as the research object, based on the ArcGIS Network analysis model, the changes and spatial evolution characteristics of traffic accessibility in five time sections from 2001 to 2019 are quantitatively analyzed. The results shows: from 2001 to 2019, the road network construction in Inner Mongolia ushered in rapid development, with road mileage continuously increased, the network structure continuously optimized, and the road level continuously improved; the average accessibility of townships decreased year by year, with township accessibility increased significantly, respectively, with difference in accessibility gradually narrowed; The spatial pattern of township accessibility extends and spreads in an irregular ring to the surrounding areas from the northern part of Chifeng, the northern part of the Zhenglan Banner of Xilin Gol League, Zhengxiangbai Banner, the central part of Ulanqab, and the central part of Hohhot, with accessibility gradually decreased,the northern part of Chifeng, the southern part of Xilingol League, and the central part of Ulanqab have always been in high-level accessibility areas in five time sections,the townships with low level of accessibility are concentrated in the western and northern parts of Hulunbuir and the western region of Alxa League.

Keywords*: Accessibility, Spatial -Temporal Evolution, Townships, Inner Mongolia*

I. INTRODUCTION

Transportation network plays a vital role in regional development [1]. Township represents an open system [2], the interaction between townships and between townships and regions is a result of connection of the transportation network [3]. Transportation network serves as the material premise of urban development, which plays an extremely important role in urban spatial structure and system composition. An important indicator to measure the transportation network development status is accessibility [4-6]. Accessibility reflects the status and role of each township in the transportation network to a certain extent, as well as the future development potential and competitiveness of the township, which is also one effective factor in evaluating the development opportunities and market control capability of a region [7-9].

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Township transportation accessibility has become a recent research hotspot of experts and scholars, and abundant research results have been reached. Seen from the research scope of existing studies, there are not only macro-scale studies across countries and regions [10, 11], but also meso-scale studies at the national, provincial, and urban circles [12, 13], as well as micro-scale studies within cities and regions [14]. However, the research objects are basically concentrated at the city and county levels, and there is no research on township accessibility. Moreover, the selected regions are mainly concentrated in the developed regions in the eastern and central regions, and relatively little attention is paid to the underdeveloped western regions, especially the vast Inner Mongolia [15].

The "rural revitalization strategy" is the general starting point of the "three rural" work in the new era, and its implementation effect determines whether China can build a moderately prosperous society in an all-round way [16]. Urban-rural integrated development is the fundamental solution to rural revitalization strategy. Townships serve as a pivotal link connecting urban and rural areas, which is an important bridge for the integrated development of urban and rural areas, the main carrier to solve the "three rural" problems, and an effective starting point for the implementation of the rural revitalization strategy [17]. It is necessary to vigorously promote the high-quality development of townships, continuously improve the comprehensive competitiveness of townships, so that they become an important platform for improving the level of rural public services, an important carrier for undertaking urban functions and rural migrant population, and an important engine for accelerating rural economic development, thereby driving "rural revitalization" through “township revitalization”.

Inner Mongolia Autonomous Region is an important window open to the north and an important ecological security barrier. It has special geographical location and complex geographical environment elements. Compared with coastal and developed areas, Inner Mongolia has uneven distribution of towns, low density, small scale, underdeveloped economy, and inconvenient transportation, also with sharp differences between townships and villages in farming area, pastoral area, farming-pastoral areas. Convenient transportation is the material prerequisite and guarantee for the high-quality development of townships and the continuous improvement of comprehensive competitiveness, also the starting point for rural revitalization [18, 19]. In view of this, based on the road and railway traffic data of five time sections in Inner Mongolia Autonomous Region, this paper analyzes the traffic accessibility and spatial evolution characteristics of Inner Mongolia townships in different periods to judge the future competitiveness of each township in Inner Mongolia and also provide decision-making basis for the development of new urbanization and rural revitalization in Inner Mongolia.

II. MATERIALS AND METHODS

2.1 Data Sources

The traffic network data and township point data in Inner Mongolia come from the Bigmap open source database and the "Inner Mongolia Autonomous Region Atlas", "Administrative Division Brief Book of Inner Mongolia Autonomous Region", "Inner Mongolia Autonomous Region Map (1:2600,000)" in

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2001, 2006, 2011, 2016, 2019, and "Inner Mongolia Statistical Yearbook" in 2002, 2007, 2012, 2017, 2020. The number of townships (including Sumu) in Inner Mongolia was 1,555 in 2001 and 1,226 in 2006. After excessive township merging from 2007 to 2011, the number of townships was 636 in 2011, increased to 769 in 2016, and 778 in 2019.

In view of the differences in speed between different road grades and different travel modes, the road speed is assigned value with reference to relevant literature [20, 21]. The specific assignment table for different roads is shown in Tab. I.

TABLE I. Speed assignments on roads and railways (km/h)

road					**railway**		
Expressway	national road	provincial road	County (township) road		High-speed rail	bullet train	Ordinary railway
120	100	80	40		250	160	100

2.2 Research Methods

In this paper, a comprehensive transportation network model of Inner Mongolia is built. Based on the ArcGIS network analysis method, with the help of ArcGIS 10.6 software, data of transportation network and all township nodes are extracted after vectorization, projection conversion, rectification of Bigmap open source database and the scanning map of the "Inner Mongolia Autonomous Region Map" of 5 time sections. A land transportation network database of basic geographic data in Inner Mongolia is hereby established. In the accessibility calculation, the accessibility analysis method based on minimum impedance proposed by Allen is adopted. This method uses the average minimum impedance from the center point to all destination points as the accessibility evaluation index of the center point, as shown in Equation 1 and Equation 2 [22, 23].

$$Ai = \frac{1}{n-1}\sum_{\substack{j=1 \\ j\neq i}}^{n}(d_{ij}) \tag{1}$$

$$A = \frac{1}{n}\sum_{i=1}^{n}(A_i) \tag{2}$$

In the formula, d_{ij} represents the minimum impedance between nodes *i* and *j*, which can be distance, time or cost, etc.; *Ai* represents the reachability of node *i* on the network, which is the average value of the minimum impedance from this node to all other nodes on the network. The minimum impedance can be the shortest distance, the shortest time, the least cost, etc.; *A* is the reachability of the entire network and the average reachability of each node.

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The minimum impedance average value selected herein is time, that is, the minimum time cost between two townships; the accessibility of a township is measured by the average value of the minimum time cost to reach all other townships from a certain township.

III. CONCLUSION

3.1 Development and Changes of Road Network

Since the national implementation of western development, the road network construction in Inner Mongolia has developed rapidly. Tab. II is a statistical table of changes in road mileage in Inner Mongolia from 2001 to 2019. As can be seen from Tab. II, by the end of 2019, the road mileage in Inner Mongolia reaches 206,089km, which is 2.9 times that of 2001, with an average annual growth rate of 3.4%. Where, expressway is 6,633km, with an average annual growth rate of 5.2%; the first-class road is 8,843km, with an annual average growth rate of 5.1%; the second-class road is 18,779km, with an annual average growth rate of 3.9%; the third and fourth-class roads are 172,141km, with an average annual growth rate of 3.6%; substandard roads are 6,726km, with an average annual decrease of 2.7%. The railway mileage reaches 13,284km, which is 2.1 times that of 2001, with an average annual growth rate of 2.8%. Where, the mileage of ordinary railways is 12,675km, with an average annual growth rate of 2.7%; the mileage of bullet trains is increased by 323 kilometers, and the mileage of high-speed railways reaches 286km. Fig. 1 is an analysis diagram of the road network development and evolution in Inner Mongolia. It can be seen from the figure that expressways, national roads, provincial roads and railways are relatively dense in prefecture-level cities and surrounding areas, the road grades are high, all above the second grade. The vast areas located in banner counties and townships are dominated by county and township roads of basically third and fourth grade, which is relatively low.

In general, Inner Mongolia has continuously improved road level and continuously optimized network structure. Expressways, first-class roads and second-class roads account for a relatively small proportion in overall, but with relatively fast average annual growth rate; substandard roads have decreasing proportion year by year. By the end of 2019, there are 21 expressways out of the area, and the number of expressways in banner counties and urban areas reach 64; all banner counties are connected with Class I and above roads, ports are connected with Class II and above roads, and key ports are connected with Class I roads. According to the "China Statistical Yearbook (2020)", railway network in Inner Mongolia ranks the first in the country in total scale. However, due to the vast territory of Inner Mongolia, the railway density network is relatively small. The total mileage of bullet trains has reached 323 kilometers, thus building the one-hour economic circle connecting "Hohhot, Baotou, Ordos, Ulanqab". The high-speed rail from Hohhot to Beijing was opened to traffic, with 286km high-speed rail in Inner Mongolia, thus ending the history of no high-speed rail in Inner Mongolia.

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TABLE II. Statistical table of road Mileage changes in Inner Mongolia from 2001 to 2019

year	Road mileage (km)							Railway mileage (km)			
	total road mileage	Classified highway	high way	first class road	Second class road	Third, fourth class road	Substand ard road	Tota l rail way mile age	High-speed rail	Bullet train	Ordinary railway
2001	70408	60234	0	195	4825	55214	10174	6127	0	0	6127
2006	128762	83831	1255	2424	9107	71045	44931	6525	0	0	6525
2011	160095	147946	2874	3710	13689	127673	13049	7986	0	0	7986
2016	196061	188340	5153	6682	16913	159592	7721	12845	0	323	12164
2019	206089	199763	6633	8843	18779	165508	6726	13284	286	323	12675

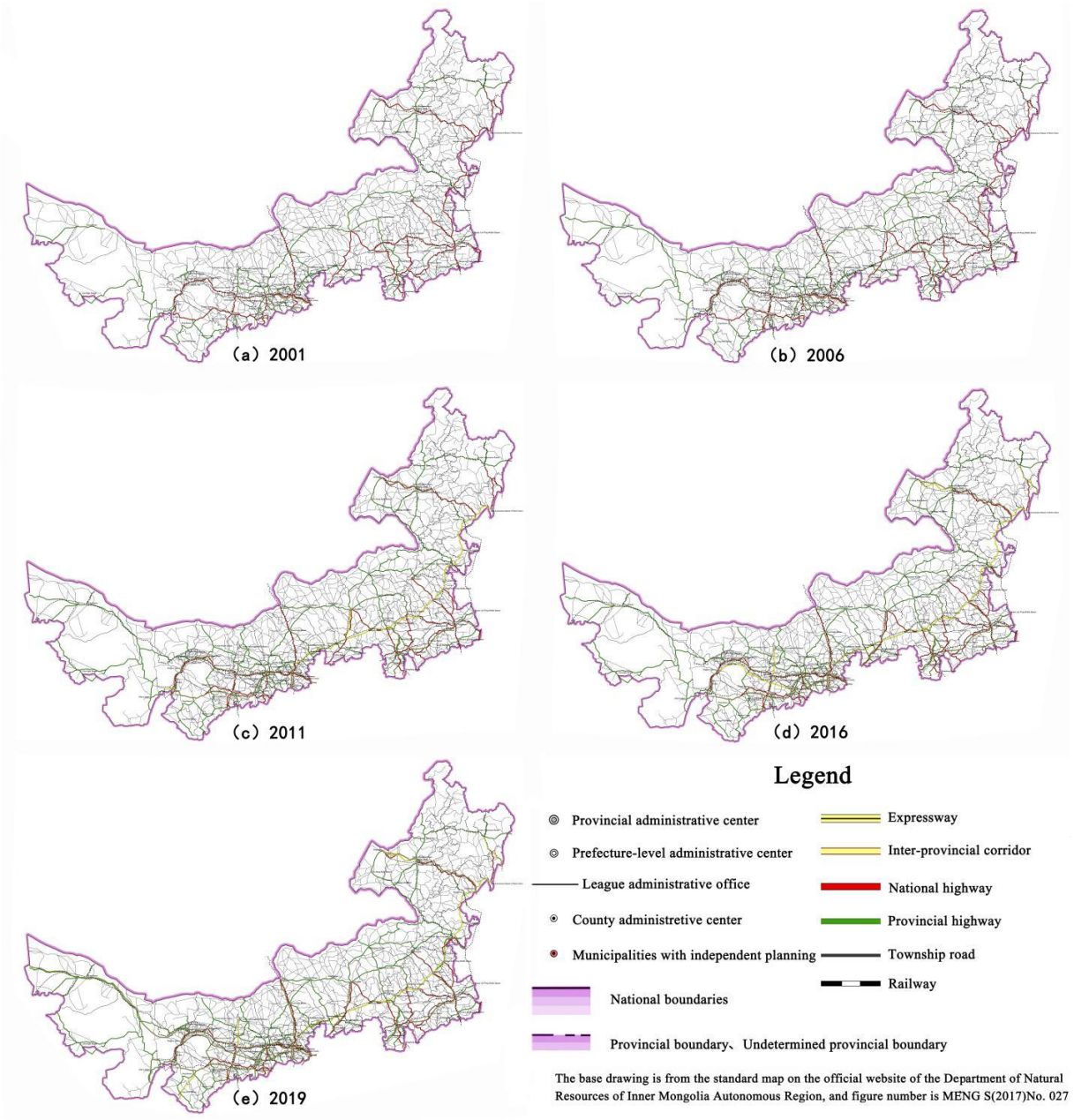

Fig 1: development and evolution of highway and railway in Inner Mongolia

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3.2 Changes in Township Traffic Accessibility over Time

In this paper, the average value of the minimum time cost in travel between townships is used as the accessibility index of townships, so less time means better accessibility. In the five time sections, the changes in the maximum, minimum and average values of the township accessibility in Inner Mongolia are shown in Tab. III. It can be seen from Tab. III that the average value of the minimum time cost in township accessibility decreases year by year. From 2001 to 2019, the average value of accessibility decreases by 3.76h. From the 4 time sections of 2001 to 2006, 2006 to 2011, 2011 to 2016, and 2016 to 2019, the average accessibility of townships decreases by 1.52h, 2.34h, -0.32h and 0.22, respectively. It can be seen that with the gradual improvement of the transportation network system in Inner Mongolia, the township accessibility is significantly improved, showing obvious stages. Where, years from 2006 to 2011 have the most significant increase in accessibility, mainly due to the fact that during this period, the inter-provincial channel S105 was connected to the east-west line of Inner Mongolia. S105 is a first-class road with fast and convenient connection with the townships along the line, which significantly increases the overall regional accessibility. At the same time, due to the massive township merging from 2007 to 2011, the number of townships is reduced from 1226 in 2006 to 636 in 2011, which reduces the number of nodes in the calculation, so that the average accessibility gradually decreases in overall. The average township accessibility increases by 0.32 hours between 2011 and 2016, and the road network does not change much during this period, mainly due to the increase in the number of townships from 636 to 769. Judging from the extreme values of accessibility in Tab. 3, the extreme values of accessibility in the five time periods are 21.88h, 19.03h, 15.81h, 16.15h, and 16.11h, respectively. According to Tab. 3, the extreme values of accessibility are 21.88h, 19.03h, 15.81h, 16.15h and 16.11h, respectively in the 5 time periods, so township accessibility is increased significantly, with the difference in accessibility between townships decreased gradually

TABLE III. Average and extreme value of accessibility in Inner Mongolia from 2001 to 2019

year	max	min	average
2001	29.45	7.57	18.51
2006	26.50	7.47	16.99
2011	22.55	6.74	14.65
2016	23.04	6.89	14.97
2019	22.80	6.69	14.75

Seen from the number of townships with different time costs in accessibility (Tab IV), from 2001 to 2019, the proportion of townships with accessibility within 10 h increases from 50.07% to 68.67%, and the proportion of townships with accessibility at 10-20h and above 20h decreases by 17.52% and 1.10% respectively. The time period from 2006 to 2011 has the rapidest increase in township accessibility, and the proportion of townships with accessibility within 10 h increases by 15.22%; the proportion of townships with accessibility at 10-20 h and above 20 h decreases by 13.01% and 0.12%, respectively. From 2006 to 2011, the overall accessibility of the region increases by leaps and bounds. By 2019, only

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0.26% townships have accessibility above 20 h, indicating significantly reduced travel time of most townships in Inner Mongolia.

TABLE IV. Proportion of towns in average time cost of different reachability from 2001 to 2019

Year / Time	2001	2006	2011	2016	2019
Within 10h	50.07%	52.20%	67.42%	64.35%	68.67%
10h-20h	48.59%	46.5%	33.49%	35.13%	31.07%
Over 20h	1.36%	1.03%	0.91%	0.52%	0.26%

3.3 Spatial Evolution of Township Traffic Accessibility

Fig. 2 shows the spatial distribution of township accessibility changes in Inner Mongolia from 2001 to 2019. As can be seen from Fig. 2, in 2001, among the townships in Chifeng area with accessibility within 8 hours, there are 4 in Bahrain Left Banner, 6 in Bahrain Right Banner, 5 in Linxi County, and 2 in Hexigten Banner; in Xilin Gol League, there are 2 in Zhenglan Banner and 2 in Zhengxiangbai Banner; in Ulanqab Region, there are 10 in Huade County, 6 in Shangdu County, 6 in Qahar Right-wing Rear Banner, 3 in Qahar Right-wing Front Banner, 1 in Jining District and 2 in Zhuozi County. Among the townships in Hulunbuir Region with accessibility above 22h, there are 2 in Erguna City, 4 in New Barag Right Banner; in Alxa League Region, there are 7 in Ejina Banner and 5 in Alxa Right Banner. The accessibility of other townships takes townships within 8h accessibility as the center, and spreads outward in an irregular ring, with accessibility gradually decreased.

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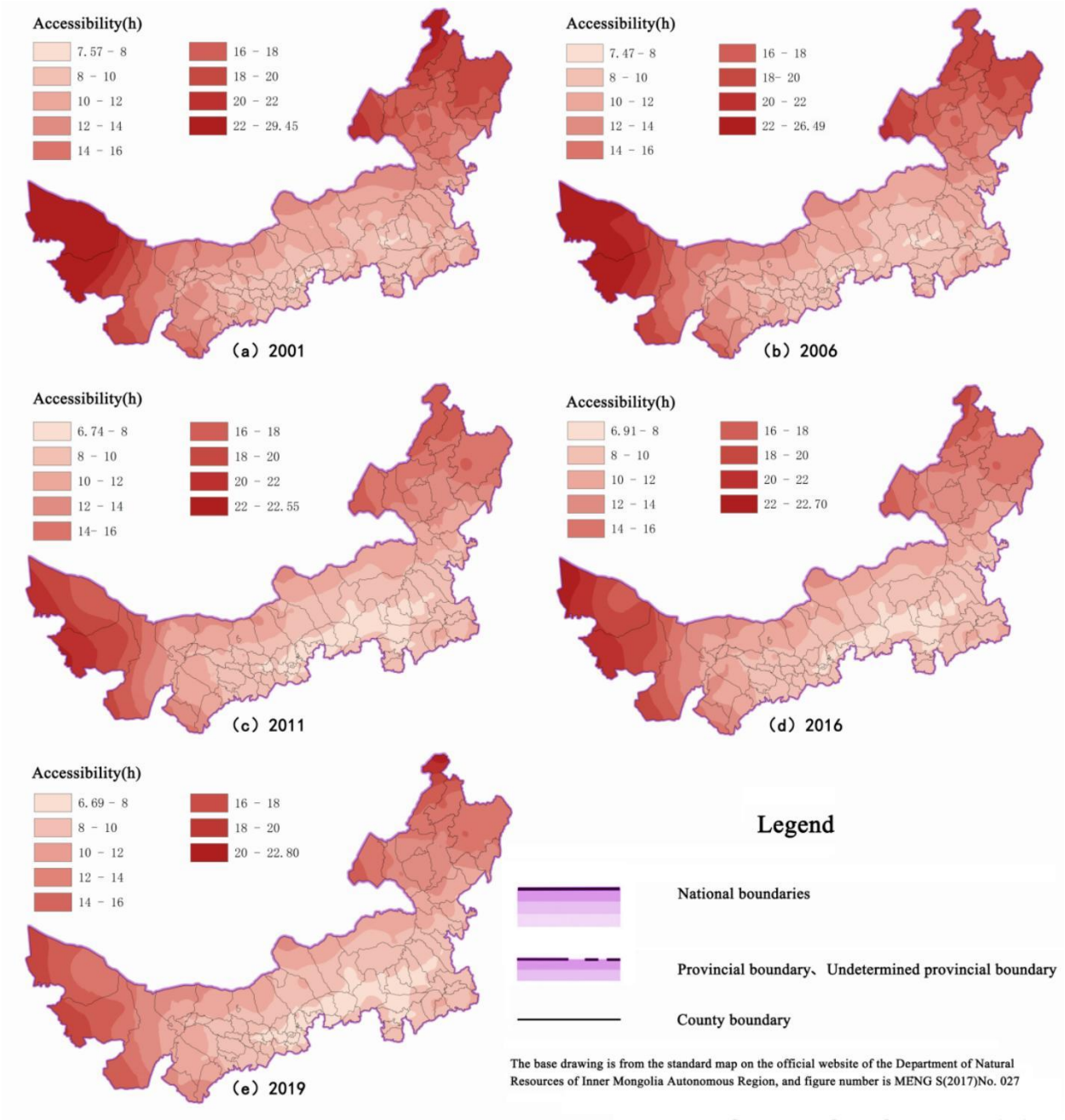

Fig 2: accessibility changes of villages and towns in Inner Mongolia from 2001 to 2019

In 2006, accessibility of 2 townships in Zhuozi County and 3 townships in Qahar Right Front Banner in Ulanqab Region changes from within 8 h to 8-10 h, and that of 1 township in New Barag Right Banner and 3 townships in Alxa League region of Hulunbuir Region changes from above 22h to 20-22h. Except this, accessibility of townships changes little in other areas. In 2011, the number of townships with accessibility within 8 h increases significantly, including 3 in Jarud Banner in Tongliao; 7 in Ar Horqin Banner, 5 in Bahrain Left Banner, 9 in Bahrain Right Banner, 6 in Linxi County, 9 in Hexigten Banner, 9 in Wengniute Banner, 12 in Chifeng City, 1 in Harqin Banner, 3 in Aohan Banner in Chifeng Area; 2 in

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Xilinhot City, 6 in Zhenglan Banner, 3 in Zhengxiangbai Banner, 4 in Taibusi Banner, 1 in Xianghuang Banner in Xilin Gol League Area; 5 in Huade County, 9 in Shangdu County, 5 in Qahar Right Wing Rear Banner, 2 in Qahar Right Wing Middle Banner, 5 in Qahar Right Wing Front Banner, 2 in Xinghe County, 2 in Jining District, 4 in Zhuozi County, and 4 in Fengzhen City in Ulanqab; 9 in the urban area of Hohhot and 4 in Tumd Left Banner in the Hohhot area. Chifeng area and Ulanqab area rank the first in the number of townships within 8h accessibility. The townships with accessibility of more than 22 h only include 2 townships in Ejina Banner and 1 township in Alxa Right Banner. Accessibility of other townships still takes townships within 8 h accessibility as the center and spreads outward in an irregular ring, with accessibility gradually decreased. At the same time, the number of townships with 8-10h accessibility increases significantly. The reason is that S105 passes through Ordos, Baotou, Hohhot, Ulanqab, Chifeng, Tongliao, Hinggan League, and Hulunbuir as a major transportation artery connecting the east and west of Inner Mongolia, which significantly increases the accessibility of townships along the line. Compared with 2011, the number of townships within 8 h accessibility decreases in 2016. The number of townships within 8 h accessibility in Chifeng, Xilingol League, and Ulanqab areas tends to shrink on the north and south sides in space. Fengzhen City in Ulanqab and all townships in Hohhot exit from the ranks within 8 h accessibility. No change is shown in the number of townships with accessibility above 22 h. On the basis of 2011, the number of townships with 8-10 h accessibility continues to increase, spreading towards south and north in space. Compared with 2016, the number of townships within 8 h accessibility in 2019 changes little in Tongliao area, Chifeng area, Xilin Gol League area; Huade County, Shangdu County, Qahar Right Wing Rear Banner, Qahar Right Wing Mid Banner of Ulanqab area. All townships in Jining District of Ulanqab Region, all townships in Qahar Right Front Banner, 8 townships in Xinghe County, 7 townships in Fengzhen City, 3 townships in Liangcheng County, 7 townships in Zhuozi County, 6 townships in Hohhot City, Hohhot Region, 1 township in Horinger County, 1 township in Wuchuan County, 4 townships in Tumd Left Banner, and 1 township in Tuoketuo County enter the rank of townships within 8h accessibility, which are connected into one in space. The number of townships with 8-10 h accessibility has increased significantly; there is only one town in the north of Ergun City with accessibility above 22 h. Most townships in Tongliao, Chifeng, Xilingol League, Ulanqab, Hohhot, Baotou, and Ordos have accessibility within 10 h; only one township in the northernmost part of Ergun City has accessibility above 20 h. The opening of the intercity train connecting "Hohhot, Baotou, Ordos, Ulanqab" and the Hohhot-Beijing high-speed railway significantly improves the accessibility of the townships along the line.

In overall, the spatial pattern of township accessibility in Inner Mongolia extends and spreads in an irregular ring to the surrounding areas from the northern part of Chifeng, the northern part of the Zhenglan Banner of Xilin Gol League, Zhengxiangbai Banner, the central part of Ulanqab, and the central part of Hohhot, with accessibility gradually decreased. The northern part of Chifeng, the southern part of Xilingol League, and the central part of Ulanqab have always been in high-level accessibility areas in five time sections, benefiting from the superior geographical location and convenient transportation of these three areas. The townships with low level of accessibility are concentrated in the western and northern parts of Hulunbuir and the western region of Alxa League. Located in the fringes of Inner Mongolia, these two areas have low road network grade and density and low traffic accessibility. Transportation is the material prerequisite and guarantee for high-quality development of townships and continuous improvement of

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comprehensive competitiveness. The townships in the northern part of Chifeng, the northern part of Zhenglan Banner of Xilin Gol League, the northern part of Zhengxiangbai Banner, the central part of Ulanqab, and the central part of Hohhot are located at areas with high-level accessibility, enjoying significantly greater potential for future development than other townships.

The following conclusions can be drawn from the foregoing analysis.

(1) From 2001 to 2019, the road network construction in Inner Mongolia ushered in rapid development, with road mileage continuously increased, the network continuously optimized, and the level continuously improved. Expressways, first-class roads and second-class roads account for a relatively small proportion in overall, but with relatively fast average annual growth rate; substandard roads account for a decreasing proportion year by year.

(2) From 2001 to 2019, the average accessibility of townships decreased by 3.76h, with township accessibility increased significantly. The extreme value of accessibility was 21.88h, 19.03h, 15.81h, 16.15h, 16.11h, respectively, with difference in accessibility gradually narrowed. The proportion of townships with accessibility within 10 h increased from 50.07% to 68.67%, and in 2019, the number of townships with accessibility above 20 h accounted for only 0.26%, indicating that the vast majority of townships in Inner Mongolia have significantly shorter travel time.

(3) The spatial pattern of township accessibility in Inner Mongolia extends and spreads in an irregular ring to the surrounding areas from the northern part of Chifeng, the northern part of the Zhenglan Banner of Xilin Gol League, Zhengxiangbai Banner, the central part of Ulanqab, and the central part of Hohhot, with accessibility gradually decreased. The northern part of Chifeng, the southern part of Xilingol League, and the central part of Ulanqab have always been in high-level accessibility areas in five time sections. The townships with low level of accessibility are concentrated in the western and northern parts of Hulunbuir and the western region of Alxa League.

(4) The townships in the northern part of Chifeng, the northern part of Zhenglan Banner of Xilin Gol League, the northern part of Zhengxiangbai Banner, the central part of Ulanqab, and the central part of Hohhot enjoy significantly greater potential for future development than other townships.

IV. DISCUSSION

In the process of new urbanization and rural revitalization, transportation accessibility has aroused wide concern from experts and scholars, but the research units are basically concentrated in cities and counties. Townships are the main battleground for new urbanization and rural revitalization, but so far, little attention has been paid to the research on township transportation accessibility. Since the implementation of the Western Development, the number of road traffic in Inner Mongolia keeps growing, the network structure is continuously optimized, and the road level is continuously improved.

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In overall, during the period 2001-2019, the overall traffic accessibility in Inner Mongolia townships has improved significantly, and the areas with better accessibility are located in Chifeng City, Xilingol League, Ulanqab City, Hohhot City, Baotou City, and Ordos City, which is consistent with Zhao Xiuqing's findings with counties as the research objects [15]. This paper evaluates the accessibility of townships in Inner Mongolia based on road and railway in Inner Mongolia. Where, Chifeng City, Xilingol League, and Ulanqab City have high-level township accessibility because these three areas are located on the edge of eastern and central parts of Inner Mongolia, boasting superior geographical position, developed transportation, and high accessibility level. The urban agglomeration of "Hohhot, Baotou, Ordos, Ulanqab" has the most developed transportation in Inner Mongolia. In particular, after the opening of the intercity train connecting "Hohhot, Baotou, Ordos, Ulanqab" and the "Zhangjiakou- Hohhot Speed Rail", the township accessibility is significantly improved.

From 2001 to 2019, the number of townships in Inner Mongolia changes greatly, from 1,555 in 2001, to 1,226 in 2006, to 636 in 2011, to 769 in 2016, and 778 in 2019. The change in the number of townships results in different number of nodes involved in the calculation in different years. It can be seen from Tab. 2 that compared with 2011, the road mileage and road grade have increased significantly in 2016. In theory, the maximum, minimum or average accessibility should be reduced to some extent, but Tab. 3 shows that the actual calculation results of the three values in 2016 are greater than the corresponding values in 2011, and the township accessibility level has decreased. At the same time, it can be seen from Fig. 2 that the number of townships within 8 h accessibility decreases in 2016, and the number of such townships in Chifeng, Xilin Gol League, and Ulanqab areas tends to shrink on both the north and south sides in space. All townships in the Hohhot area drop out of the rank within 8 h accessibility, indicating that changes in the number of townships will affect the calculation results of township accessibility, but will not affect the overall development trend and pattern of traffic accessibility.

In the development process of regional urbanization, cities and towns often rely on transportation infrastructure to change from connection with just one or two lines to the formation of transportation corridors and then to the development of complex transportation networks. The layout of transportation networks leads to spatial evolution in accessibility of regional cities and towns. Judging from the transportation network evolution in Inner Mongolia in the past 20 years, "Hohhot, Baotou, Ordos, Ulanqab" has formed a transportation corridor in Inner Mongolia, which is an area with better accessibility in the region, reducing the travel time between central and western Inner Mongolia. This paper only analyzes the traffic accessibility within the Inner Mongolia area. If external traffic conditions are considered, the accessibility of the boundary area in the study area will change, and the accessibility of each township in the area will also change. At the same time, the overall traffic accessibility value in the region will be increased, but the change trend and overall pattern will not change much.

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