Research Article

Comparison of Intercity Travel Network Structure during Daily Time and Holiday in China

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Intercity travel by residents promotes the regathering and dissemination of social and economic factors. Based on big data from Tencent's location-based service, 346 cities above the prefecture level in China were chosen as study objects, with 2018 as the study time node. To construct the intercity residents' travel network, complex network analysis and GIS spatial analysis methods were used. Furthermore, when analyzing the structural characteristics and spatial differences of Chinese residents' intercity travel from different time perspectives (the whole year, daily, Spring Festival travel rush, and special holidays), Gephi network analysis tools and ArcGIS spatial analysis software were used. The following are the major findings: daily and the whole year intercity travel by Chinese residents, as well as intercity travel during special holidays and the Spring Festival, all exhibit the "diamond" structure, with Beijing, Shanghai, Guangzhou-Shenzhen, and Chengdu-Chongqing at the core. The distribution of lines in and around the "diamond" is large and concentrated from the perspective of the hierarchical nature of the residents' intercity travel network. Significant increases in high-intensity population flow lines within the "diamond" can be seen during Spring Festival travel and holidays. The number of cities involved in the inflow line is significantly greater than that involved in the outflow line, as demonstrated by the number of residents in the first point of travel, indicating that there is a difference between the central cities flowing into and out of the network. The first flow of the central city is the most visible during the Spring Festival travel period. Most cities in the resident intercity travel network have relatively low degrees of centrality, closeness centrality, and betweenness centrality, and the number of cities with large values of the three is small, and they are concentrated in the apex and interior of the "diamond" structure.

1. Introduction

Travel migration and population flow are regarded as activities in which production factors are reallocated in space, thereby promoting the regathering and diffusion of social and economic factors [1]. Population travel embodies the interaction between their production and life styles and other production and life spaces; it reflects individuals' ability to participate in social and economic activities. The acceleration of globalization and regional integration has strengthened global ties even further. Regional communication and collaborative development are facilitated by an efficient, comprehensive transportation system, convenient communication services, and urban development modes. The current situation and prospects of urban development,

as the output and receiving place of population migration, determine the scale of population inflow and outflow. Residents' travel characteristics include travel purpose, travel time, and travel mode, which are useful for studying residents' behavior and alleviating urban traffic problems. The study of residents' travel can serve as a reference for the rational formulation of policies and has far-reaching implications for guiding the healthy development of urban transportation in the future [2, 3].

Population flow has evolved into a spatial representation of social and economic development in China. The scale of population movement influences the level of social and economic development. In the process of globalization, information technology, and regional integration, the connection between different regions in China is becoming

increasingly close, the trend of population flow is clear, the total amount of population travel is increasing year by year, and the travel purposes are becoming more diverse, such as studying, working, traveling, visiting relatives, and so on. Based on this, an in-depth study of the characteristics of China's residents' travel network, mastery of residents' travel rules, and comprehension of urban development differences reflected in residents' flow can provide a scientific theoretical foundation for the formulation of regional development planning.

"Flow space" was first proposed by Castells, an American sociologist, and detailed in his book *The Rise of Network Society* [4, 5]. He believes that "flow space" is the use of a specific medium across geographical distances in space to achieve the exchange of time and space elements. It depicts the transformation of traditional economies, societies, and cultures brought about by the advancement of information technology [4, 6]. Flows, in general, include information technology, people, things, transportation, and capital flow, and space is the material support for these flows. The rapid development of information technology allows cities to connect across physical distances, and the flow affects all aspects of residents' lives in various ways [7]. From the standpoint of geography, "flow space" is a new spatial logic established against the backdrop of the information age, supported by transportation infrastructure, and characterized by the continuous movement of people flow, logistics, traffic flow, information flow, technology flow, and capital flow [8]. The main components of "flow space" are various entity flows and virtual flows, and "flow's" high-speed characteristics make the circulation of various elements in space more convenient and efficient. "Flow" not only shortens the distance between cities but also serves as a carrier for residents' activities, cities, and regions while also promoting the development of urban spatial networks and reshaping geographical space. Because all kinds of elements flow at breakneck speed in today's information society, "flow space" is critical to the formation and development of urban and regional networks [8, 9]. "Flow space" data can now be accurately measured thanks to the rapid advancement of information technology and the efficient application of information data. Using various "flow" elements, residents' travel networks can be explored more dynamically, scientifically, and intuitively, and the essence of spatial relationships can be better approached.

A network is a carrier made up of abstract nodes and connecting node edges that can describe the complex and intertwined objective world [2]. Network or networked research perspectives have been introduced into geography research with the development of research theories and methods [8]. In urban geography, it is assumed that cities are not isolated in regional space but rather have complex interactions with one another, forming the urban network. This type of network has a distinct spatial structure as well as a functional organization [10]. The interaction and complementary advantages between and within cities are strengthened through the exchange of population, materials, information, finance, and other elements. As a result, complex networks of various scales and levels, such as

transportation networks, population flow networks, and information networks, have evolved [11]. At the end of the twentieth century, complex network theory based on mathematical graph theory and statistical physics provided a theoretical foundation for the study of network system complexity [12, 13]. Following that, scholars from various fields attempt to use complex network theory to explore the real world by abstracting various complex relations in the objective world and then excavating and describing the complexity characteristics and structural relations of the complex world [14, 15]. Scholars have discovered that the real world network is a small world or scale-free complex network, rather than a regular network connected according to certain rules or a random network connected in a random way [14, 16]. Complex network theory and methods are becoming the primary research tools as network complexity increases [14, 16]. As a result, based on the theory of "flow space" and the network perspective, it is critical to study intercity residents' travel in order to master the law of residents' spatial movement and the dynamic characteristics of intercity spatial correlation on a regional scale [17].

Human activities, such as mobile trajectory, mobile signaling, location request, and so on, will generate a large amount of spatiotemporal information data. It contains rich semantic features and spatiotemporal dimension dynamic association information, which must be exploited and applied in a reasonable, efficient, and comprehensive manner [18]. With the rapid development and popularization of sensor networks, wireless communication, mobile positioning, and Internet technology in the Big Data era, it is now possible to research and obtain high-precision and massive individual movement trajectory data [16, 19]. Big data with geographic positioning information has numerous benefits, including broad coverage, high time precision, multiple attributes, and so on. Simultaneously, spatial big data mining exploration, computer science, geography, and other methods intersect to provide strong support for population flow and another possibility for quantitative research on the spatial characteristics of population flow. Furthermore, statistical analysis of massive data is very useful in discovering the implicit and robust laws of data, which greatly reduces the uncertainty caused by sample randomness [20]. Big data records a large number of people flow, logistics, and information flow data, which not only assists us in conducting fine research [21, 22] but also contributes significantly to improving the accuracy and comprehensiveness of the research. The use of geographic big data to perceive human social activities is currently a hot topic in academic research. The travel big data reflects the displacement and time-space trajectory of human activities, which provides data support for scholars to study deeply and carefully on a microscale [23]. Moreover, the observation and development of the continuity of multiperspectives and large scale bring new ideas and new technologies to geography [23–25].

People do not pay much attention to the intercity residents' travel network at the moment. Mastering the structure and rules of intercity residents' travel networks and reasonably planning the routes and flows of residents' travel

has become one of the most effective ways to promote the long-term development of cities and regions. As a result, beginning with different travel time periods (the entire year, daily, special holidays, and the Spring Festival travel rush), this paper conducts a comprehensive evaluation of the structural characteristics and contact pattern of residents' travel networks in 346 Chinese cities, which has both theoretical and practical significance. On the one hand, it can help us understand and grasp the national residents' travel rules and status; on the other hand, it can provide scientific references for regional development planning.

The significance of this paper lies in the following aspects: First of all, the study of residents' intercity travel can provide scientific reference to guide the rational flow of population and the planning of regional town systems; second, we use the "flow space" research method instead of the traditional static local space; and third, we use big data of location instead of traditional static statistics to ensure the timeliness of the data. Fourth, we compare the similarities and differences in Chinese residents' intercity travel network structures over time.

2. Related Work

With the advancement of information processing technology and the popularity of smart phones, a number of businesses began to collect population positioning and travel data, which are widely used in scientific research. Scholars analyze the problem of residents' travel using a variety of data sources. Jiang investigated the primary reasons for residents to travel by taxi using Swedish urban taxi trajectory data [26]. Murakami obtained travel information from residents via telephone interview, recorded travel information from private cars combined with GPS, and then conducted a comparative analysis on resident behavior characteristics [21]. Limtanakool et al. discovered differences in behavior characteristics and network structure heterogeneity using data from a European long-distance interregional travel survey [27]. De Montis et al. built an intercity travel network based on intercity commuting data from Italy and studied the structural characteristics of the intercity travel system [28]. Western scholars frequently use Twitter data to examine the temporal and spatial distribution characteristics of population flow [23]. Chinese scholars have frequently used data from Sina Weibo [29, 30], Baidu migration data [31], and Tencent population migration data [32, 33] in recent years. For example, Li et al. [9] used Baidu migration data to examine the characteristics of population migration during the Spring Festival in China. Pan and Lai [34] collected Tencent's population migration data during the Mid Autumn Festival and National Day holidays, divided the holiday into travel, journey, and return periods, and analyzed the population migration in each period. These studies used big data to analyze individual and group behavior and reflect spatial behavior, spatial cognition, and connection mode. Such data can be used to reflect individual and group decision-making in terms of spatiotemporal behavior, and it is becoming a hot research frontier for studying travel and population flow.

3. Methods and Data Sources

Chinese residents travel at different times of the year [35], such as during the Spring Festival, Mid Autumn Festival, and National Day. To begin, we examine the proximity effect of a travel network using intercity correlation potential. Second, we investigate the urban hierarchy as reflected by the travel network using transition centrality and transition control.

3.1. Complex Network Analysis. Network analysis is a critical component of GIS spatial analysis. Network analysis is founded on graph theory, which encompasses graph theory analysis, optimization analysis, and dynamic analysis [36]. Erdos and Renyi, mathematicians, established a random graph [36] in 1960, which provided a new method for constructing networks. Then, after conducting extensive actual data research, scientists discovered that the majority of actual networks are not regular or random networks. It heralds the arrival of the stage of complex network research. The term "complex network" refers to a network that is somewhere between a completely regular network and a completely random network. It is a small world with a network that is not scaled [37]. This feature is common in population travel networks [38]. Degree and its distribution characteristics, agglomeration degree and its distribution characteristics, betweenness and its distribution characteristics, and so on are the fundamental measures of complex network research [39, 40]. In this paper, the following indicators are used.

3.1.1. Degree Centrality. Degree reflects the interaction of a node with other nodes and is an important expression of city interconnection. The higher a node's degree, the greater its degree centrality and the more important its position in the network [41]:

$$C_D(i) = \frac{K_i}{N-1}. \quad (1)$$

$C_D(i)$ is the degree centrality of node i , K_i is the degree of node i , and N is the number of nodes in the network [41].

3.1.2. Closeness Centrality. Closeness centrality measures the proximity of a node to other nodes in the network by using the shortest path distance. The closer a node is to its centrality, the more important it is in the network [42, 43].

$$C_C(i) = \frac{1}{\sum_j D_{ij}}. \quad (2)$$

$C_C(i)$ is the closeness centrality of node i ; D_{ij} is the shortest path distance between node i and node j [42].

3.1.3. Betweenness Centrality. The proportion of nodes passing through all of the network's shortest paths is described by betweenness centrality. If the shortest path between many nodes passes through a specific node, the node has high betweenness centrality; the larger the value, the

greater the node's transfer and connection ability in the network [41]:

$$C_B(m) = \sum_{i \neq j} \frac{\sigma_{ij}(m)}{\sigma_{ij}}. \quad (3)$$

$C_B(m)$ is the betweenness centrality of node m , σ_{ij} is the number of all shortest paths from node i to node j , and $\sigma_{ij}(m)$ is the number of all shortest paths from node i to node j through node m [41].

3.1.4. Measurement of Intercity Correlation. The proportion of the connection strength of a specific line in the network to the total connection strength [44] is referred to as the intercity correlation potential measure, and it represents the importance of a specific intercity connection edge in the network. The following is the precise formula:

$$RSI_{ij} = \frac{t_{ij}}{\sum_{i=1}^I \sum_{j=1}^J t_{ij}}. \quad (4)$$

t_{ij} is the travel population size between city i and city j , RSI_{ij} is the intercity correlation superiority degree, and $0 \leq RSI_{ij} \leq 1$. If the value is closer to 1, it means that the greater the proportion of lines connecting cities j and i , the higher the degree of dominance [22, 45].

3.1.5. Alter-Based Centrality and Alter-Based Power. In the study of world city networks, Zachary proposed the concept of recursive centrality and recursive control, which he later changed to Alter-based centrality (AC) and Alter-based power (AP) [46, 47]. He believes that centrality refers to resource concentration and diffusion. The aggregation of resource elements (labor, capital, information, and so on) to world cities, as well as the outward diffusion of resource elements from world cities, is both manifestations of centrality [48]. The control power represents a city's influence and dominance in the resource circulation process. The location of the network and the role it plays determine the size of a city's control power [48].

3.2. Data. The data used in this paper is from the "Tencent location big data" platform's population migration data (heat.qq.com/qianxi.php), and the time node is from January 1, 2018, to December 31, 2018, a total of 365 days of more than 600,000 population migration data. The data attributes include the origin and destination cities' longitude and latitude coordinates, the total amount of migration, and the migration ratio of three different modes of transportation (plane, train, and car). The migration volume is determined by the migration ratio, and the population migration volume is used to determine the strength of the network connection between cities. We compiled data to determine the intensity of population flow between cities in 2018 and used it to build the residents' travel network.

Given the study's comprehensiveness and representativeness, we chose Tencent migration data from the entire year (2018) as the basic data and conducted in-depth analysis

from various travel periods. In terms of the time period, four representative periods were chosen for the study: daily, Spring Festival travel rush, special holidays, and the entire year. (Daily time: 2018.11.01–2018.12.10, Spring Festival travel rush: 2018.02.01–2018.03.12, Special holidays: Other statutory holidays except for Spring Festival) In order to fully cover the trip, the data includes daily data for two days before and after the holiday. Figure 1 depicts the locations of major cities in China.

4. Results

4.1. Hierarchical Characteristics of Residents' Intercity Travel. Based on the natural fracture method, we use ArcGIS to classify Chinese residents' intercity travel routes and intensity (Figure 2). Across the four time periods, it is discovered that population travel routes are denser in the east than in the west. In all four time periods, population travel routes are denser in the east than in the west and denser in the south than in the north. The population of high-intensity travelers is concentrated in the east and south. The "Hu Huanyong Line" divides travel routes and the number of Chinese residents into two distinct parts, with more parts in the east and fewer parts in the west, forming a "diamond" structure with Beijing, Shanghai, Guangzhou-Shenzhen, and Chengdu-Chongqing as the core. There are obvious differences in residents' travel patterns across time periods, primarily as follows: According to the entire year residents travel routes and intensity map (Figure 2(a)), Beijing, Shanghai, Dongguan, Shenzhen, Chongqing, Chengdu, and Changsha are the major cities with more than 31.8 million residents; 3081–31.8 million lines are diffused and filled along the "diamond" structure. The line space between 12.68 million and 30.81 million people is mostly filled with "diamond" structures, and there is also a trend of northeast and southwest expansions. The number of visitors ranges between 5.16 and 12.68 million. There are numerous routes, the majority of which connect provincial capitals in the northwest, southwest, and northeast. Short routes connecting provincial capital cities and other prefecture-level cities characterize the travel routes of 1.34 to 5.16 million people. In order to more clearly show the difference in population travel routes and intensity during the three time periods of daily (Figure 2(b)), special holidays (Figure 2(c)), and Spring Festival (Figure 2(d)), we categorize them according to the standard of the daily time period, it shows that the number of lines with the high-intensity population during the three periods of daily, holidays, and Spring Festival transportation has increased significantly, and the carrying pressure on each line has generally increased. In the first level (population travel intensity >2.59 million), there are 25 lines in a daily time period, 52 in holidays, and 69 in Spring Festival travel. The number of daily, special holiday, and Spring Festival travel rush travel routes among the 1.11–2.59 million people is 97, 232, and 289, respectively. There are 440, 673, and 1022 population travel routes in the third level (450–1.11 million people). The number of lines at the fourth level (between 120,000 and 450,000 people) is 1517, 2018, and 2815, respectively. The number of routes at

FIGURE 1: Locations of major cities in China.

each level has increased from daily-special holiday-Spring Festival transportation, with the number of routes at the third and fourth levels increasing the most. This demonstrates that the increased routes are primarily concentrated in the “diamond” interior and the northeast and northwest regions. The number of people traveling increased significantly during the Spring Festival and special holidays. The purpose of travel during the Spring Festival transportation is complex (return home, study, tourism, etc.), which mostly involves medium and long-distance travel, including many cities in China. Travel on special holidays, on the other hand, is generally limited by time, so it tends to travel nearby.

According to the statistical table of residents’ travel network scale in different periods (Table 1), the number of intercity trips of Chinese residents reached 14,947.96 million in 2018, with the Spring Festival travel rush accounting for 15.72 percent of the total trips. Special holiday trips accounted for 11.57 percent of total trips, while daily trips accounted for 7.35 percent. During the Spring Festival and special holidays, residents’ trips are more concentrated, and the number of trips is greater. The average number of trips per day has surpassed 50 million. Spring Festival, China’s most important traditional festival, holds a special place in the hearts of the Chinese people. Spring Festival is a day for family reunions, and most wanderers return home for the occasion. This unique sense of belonging to one’s hometown increases the likelihood of traveling. During special holidays, many people choose to travel or engage in other activities to enrich their leisure time. Throughout the year, the contact line has the highest value, followed by the Spring Festival and daily periods, and the number of sides is the smallest during special holidays. The density shows that the whole year > Spring Festival travel rush > special holidays > daily. In 2018, the links between each node city in the residents’ travel network are closer than during daily and special holidays,

and the links during the Spring Festival travel rush have increased, but there is still a gap when compared to the whole year.

We chose to characterize the dominant relationship in the network, i.e., the first flow, in order to more clearly and concisely demonstrate the travel of residents in each city in China. It is a method of revealing the important spatial structural characteristics of the entire network by reducing the amount of data, thereby reflecting the network status of cities on a macroscopic scale [49]. In the population mobility network, the first flow is the line of a city with the highest flow. The first flow consists of the first inflow and first outflow. The route with the most inbound traffic in a city is referred to as the first inflow, while the route with the most outbound traffic is referred to as the first outflow. Figure 3 depicts the first outflow and first inflow lines for each city (the lines with inflow and outflow degree values of 1 are hidden in the figure to facilitate a clear and intuitive display of the flow effect). And overall, in each of the four time periods, the number of cities involved in inflow lines is significantly greater than the number of cities involved in outflow lines, and there are differences in the cities with the highest number of inflow and outflow lines in the same time period:

- (1) During the Spring Festival period, Chengdu has the highest first inflow, followed by Beijing, Wuhan, Urumqi, and Zhengzhou, among others. Each inflow center city is primarily the provincial capital city and receives inflow from surrounding cities, primarily prefecture-level cities in the province. Chengdu receives visitors not only from neighboring prefecture-level cities but also from provincial capital cities such as Nanjing, Jinan, and Lhasa. Beijing accepts inflows from cities such as Lanzhou, Changsha, Wuhan, Harbin, and Nanchang, encompassing a diverse range of cities with a high level of connectivity. Two cities flowed out of each other from the first outflow, such as Taiyuan-Jinzhong, Guangzhou-Foshan, Yuncheng-Linfen, and so on. During the Spring Festival, Chongqing has the most outflow routes, followed by Chengdu and Beijing. Lai conducted the same study [49]. Chongqing was found to be a net outflow city during the Spring Festival, while Shenzhen, Kunming, and Shanghai experienced greater outflows of residents, with outflow grades improving. During the Spring Festival, the first outflow routes are staggered and highly interconnected, whereas the first inflow has a gyratory distribution in the center.
- (2) There is a clear trend of staggered links between the first inflow cities during special holiday periods, with some cities avoiding provincial capital cities and linking with other prefecture-level cities. Chengdu maintains first place, Wuhan has increased the number of contact lines and has surpassed Beijing, the number of cities with the first mutual inflow of the two cities has increased, and Chengdu has more contacts with Xi’an and Nanjing during this period.

FIGURE 2: Intercity travel routes and intensity of Chinese residents in different periods. (a) The whole year period. (b) Daily time. (c) Special holidays. (d) Spring festival travel rush.

TABLE 1: Statistics of residents' travel network scale in different periods.

Period	Total number of trips	Number of contact edges	Average daily trips	Proportion	Network density
The whole year	$1.49 * 10^{10}$	23759	$4.09 * 10^7$	1.000	0.199
Spring Festival travel rush	$2.34 * 10^9$	14063	$5.87 * 10^7$	15.719	0.118
Special holidays	$1.72 * 10^9$	11945	$5.08 * 10^7$	11.566	0.100
Daily time	$1.09 * 10^9$	12557	$2.74 * 10^7$	7.347	0.105

Beijing and Chengdu have the first outflow lines during the special holiday period, and tourist cities such as Urumqi, Jinan, and Kunming have risen in rank, with more travelers on special holidays and cities with more tourist resources more likely to attract tourists.

(3) Cities such as Chengdu, Beijing, Wuhan, and Zhengzhou continue to dominate the first inflows for the entire year, with significant interlocking links between cities and a more visible network intertwining phenomenon. Beijing is unquestionably the leader among the first outflows. Beijing, as China's

FIGURE 3: Continued.

FIGURE 3: The first flow (outflow and inflow) of urban residents at various times. (Note. The size of the circle indicates the number of connecting lines. The circle grows in size as the number of lines increases. The color of connecting lines matches that of nodes.) (a) First inflow during Spring Festival. (b) First outflow during Spring Festival. (c) First inflow during special holidays. (d) First outflow during special holidays. (e) First inflow during the whole year. (f) First outflow during the whole year. (g) First inflow during daily time. (h) First outflow during daily time.

capital, receives the first outflows from several provinces, which is the main concentration of the first outflows in northern China. Furthermore, the first outflow routes from Shanghai increase significantly throughout the year, particularly with cities such as Chengdu, Chongqing, Nanjing, and Hefei.

- (4) The first inflow and first outflow in daily periods are comparable to the total year period. For example, the number of contact lines in Chengdu is consistent with the entire year period, but there are minor variations. Line intertwining is most visible in the first inflow, with the number of first inflow lines decreasing in Beijing, Wuhan, and other provincial capital cities while increasing in some lower-ranked cities. The number of cities with degree values greater than one decreases significantly in the first outflow, and Chongqing has a higher status than Chengdu and is directly linked to Beijing, Nanjing, Lanzhou, Shenzhen, and Hohhot, among others. The figure contains the most ellipses, indicating that the number of interconnected cities is the greatest.

4.2. Centrality Characteristics. There are three indicators in this paper: degree centrality, closeness centrality, and betweenness centrality. They are chosen to calculate the nodes of the residential travel network at various time intervals. The degree centrality of a node city reflects its ability to interact with other nodes, and the higher its value, the more important and powerful its position in the network [41]. The closeness of the value of centrality reflects a node's position in the network, and the higher its value is, the closer it is to the network [50]. Betweenness centrality refers to a city's ability to act as a bridge node in order to communicate with other node cities, and the higher its value, the greater the node's transit and bridging ability in the network [41].

In this paper, we use Gephi software to calculate the three types of indicators, which we then aggregate and express using origin. Figure 4 depicts the results of the centrality of nodes in the travel network of Chinese residents over the course of a year. Most cities, in particular, have low betweenness centrality, degree centrality, and closeness centrality, with 298 cities meeting betweenness centrality <1000 , degree centrality <200 , and closeness centrality <0.8 at the same time, indicating a relatively obvious gap in Chinese city development. The proportion of cities that are highly developed is small, while the proportion of cities that are still developing is large. In 3D space, all three indicators form an ascending curve, with Shanghai having the highest value, having not only a large number of cities connected to it, but also playing the most obvious bridging role. Shanghai has the greatest ability to monitor and control the “node pairs” of other cities, as well as the most important position and status in the travel network of Chinese residents. Following them are the cities of Beijing, Chongqing, Guangzhou, Shenzhen, and Chengdu. These cities are at the far end of the “diamond” in the Chinese residents' travel network. They have a pivotal position in building the travel network of China, which has a strong economic base to support these cities to take on a larger travel population. Provincial capital cities such as Wuhan, Xi'an, Tianjin, Changsha, Lanzhou, and Jinan exist between the low and high values, as do noncapital regional centers such as Xianyang, Qingdao, and Foshan. Overall, the top ranked cities are primarily developed cities in the east, whereas western cities are more frequently located in low-value areas.

Figure 5 depicts the spatial representation of the centrality of the entire year period. There are six cities in the first tier (>0.723) of the spatial distribution of closeness centrality, namely Beijing, Shanghai, Chongqing, Guangzhou, Shenzhen, and Chengdu, indicating that these cities are the

FIGURE 4: Analysis of residents' travel network in the whole year.

FIGURE 5: Spatial distribution of centrality in the whole year.

most centrally located in the entire residential travel network. The second tier includes 15 cities that are secondary important nodes in the travel network, such as Hangzhou, Wuhan, Xi'an, Nanjing, and Dongguan. The third-tier cities are primarily provincial capital cities in the west and northeast and noncapital cities in the developed eastern region. The fourth and fifth tiers jointly guard the most remote and underdeveloped areas, which are also the nodes in the travel network of Chinese residents that cannot be abandoned. The degree centrality and betweenness centrality are normalized and presented as a bar chart in the graph, demonstrating that cities with high degree centrality also

have high betweenness centrality, indicating that they are consistent. The cities with a high degree of centrality are spatially distributed around the urban agglomerations of Beijing, Shanghai, Guangzhou, and Chongqing and the Beijing-Tianjin-Hebei, Pearl River Delta Chengdu-Chongqing, and Yangtze River's middle reaches. Furthermore, the capital cities of each province have significantly higher degree centrality values than neighboring cities, with an average degree centrality value of around 130 per city at the prefecture level and above, and there are more cases of multi-city connections. The betweenness centrality mainly demonstrates the transit and acceptance capacity of network

nodes, reflecting the gap between cities. Shanghai, for example, has the highest value (up to 5031), whereas Taizhou only has 12. Unlike degree centrality, betweenness centrality appears in each provincial capital city with larger values, either the provincial capital city or a more developed city, and some provincial capital cities in the east even have multiple high value points in one provincial capital. For example, Zhengzhou accepts nationwide travel exchange, disseminating it to neighboring cities, such as Luoyang and Kaifeng, which not only accept Zhengzhou's population flow but also connect cities with lower levels, and cities with larger betweenness centrality radiating and driving cities with smaller values around them.

Table 2 shows the number of cities with varying degrees of centrality indicators for three time periods: daily, special holidays, and spring festival. Cities in the lower tiers of the three centrality indicators account for a large proportion of the total. Degree centrality and betweenness centrality have the most cities in the fifth tier, while closeness centrality has the most cities in the fourth tier. Because the study cities are prefecture-level and above, few nodes belong to the end nodes in the battle for the central position of the travel network, and most nodes are more or less connected to each other. Cities in Northwest China and some remote cities have low closeness centrality due to topographical constraints, whereas cities with high participation in national residents' travel have high centrality. For daily, special holidays, and spring festival periods, the number of cities in the first and second levels of degree centrality is 17, 15, and 18, respectively, accounting for about 5% of the total number of cities, and the proportion of cities in the higher levels is small. In the fourth level, the number of cities during the spring festival is twice that of the other two periods, and students and workers return to their hometowns, and travel direction flows from big cities to small and medium cities, indirectly increasing the degree of centrality of third and fourth tier cities. It is worth noting that during special holidays, the number of high-quality cities is the lowest, owing to the fact that people are limited by time during this period, and they will mostly choose short-distance self-driving trips or close trips around, and do not generally go to big cities like Beijing and Shanghai. Betweenness centrality is always stable across the entire resident travel network, and the gap is also the smallest across all three time periods. During the Spring Festival, the number of cities varies the most between each tier, with the second tier experiencing the greatest growth and the third tier experiencing the smallest. The difference between the daily and Spring Festival periods is small in the closeness centrality. The number of cities in the third and fourth tiers clearly increases during the Spring Festival period, whereas the number of cities in the first to fourth tiers remains at its lowest during special holidays. When compared to the daily and Spring Festival periods, the number of cities in the fifth tier is the highest.

4.3. Spatial Proximity Effect. We compare the superiority of intercity connections over four time periods, and we take the period of each line's maximum intercity connection

superiority to obtain the superiority of different time periods. Figure 6 depicts each city's superiority relationship with other cities. A total of 7473 pairs of city connections are superior to other time periods during the Spring Festival, with the connections between cities in the south being spatially concentrated. The northern section consists primarily of a connection line centered on Beijing. During normal business hours, there are 4867 superior linkage lines, forming a diamond-shaped superior linkage structure with the cores of Guangzhou-Shenzhen, Beijing, Shanghai, and Chengdu-Chongqing. On special holidays, there are 4316 pairs of advantageous linkage lines that show a clear proximity effect in space, primarily connecting provincial capital cities with other secondary cities in the province. The proximity of superior linkage lines is the most important feature of special holidays, and residents will prefer to travel nearby during this period due to factors such as travel time, travel destination, and scale. Throughout the year, there are 7101 pairs of city connections that outperform other time periods, primarily in the form of core connection routes between Wuhan, Beijing, Chengdu, and Chongqing, such as Wuhan-Beijing, Chengdu-Lhasa, Wuhan-Kunming, and so on. Overall, the proximity effect is most visible in the four time periods for special holidays, which are primarily formed by connections between provincial capital cities and neighboring cities. The spring festival, daily life, and the entire year are based primarily on cross-regional connections with significant spatial differences.

4.4. City Hierarchy. AC and AP jointly determine the status of cities in urban network analysis [51, 52]. In this paper, we use population travel data from the annual time period to calculate the AC and AP in order to investigate the city hierarchy formed under the resident travel network. The results were graded by natural break using ArcGIS, and they are shown in Figure 7. The city hierarchy presented by both AC and AP values has a pyramidal structure, which means that the higher the AC and AP values, the fewer cities there are. The AP and AC values in most cities are in the same gradation tier. For example, in Beijing, Shanghai, Chongqing, Chengdu, Shenzhen, and Dongguan, the AP and AC values are in the highest tier, but there are some cities that differ. Guangzhou, for example, has an AC value in the second tier and an AP value in the third tier. Overall, cities with high AC values outnumber those with high AP values. Cities' AC values have a positive correlation with their AP values, and cities with high AC values also have high AP values. Their ability to gather and distribute resources is strong, as is their ability to dominate resources, but there are differences in some cities. According to Zachary et al.'s method of measuring world city information networks, cities in travel networks are classified into four types based on AC and control scores: high centrality-high control, high centrality-low control, low centrality-high control, and low centrality-low control. Furthermore, city types classified according to centrality and control power can better identify the city status and attribute characteristics.

TABLE 2: Urban numbers of centrality at different levels.

Index	Period	First level	Second level	Third level	Fourth level	Fifth level
Degree centrality		>288	176–288	103–175	60–102	<59
	Daily time	7	10	27	80	222
	Special holidays	6	9	22	77	232
	Spring Festival travel rush	8	10	32	148	148
Betweenness centrality		>5559.4	1705.5–5559.4	670.7–1705.4	217.9–670.6	<217.8
	Daily time	6	7	17	23	293
	Special holidays	5	7	12	22	300
	Spring Festival travel rush	4	10	11	22	299
Closeness centrality		>0.636	0.568–0.636	0.532–0.567	0.506–0.532	<0.506
	Daily time	7	15	32	263	29
	Special holidays	6	9	31	225	75
	Spring Festival travel rush	7	13	49	239	38

FIGURE 6: Comparison of intercity travel network advantages of Chinese residents in different periods.

FIGURE 7: Classification of alter-based centrality and alter-based power in China.

In the residential travel network's city hierarchy (Figure 8), the ratio of the four city types: high centrality-high control, high centrality-low control, low centrality-high control, and low centrality-low control is 23 : 22 : 2 : 299. Low centrality-low control cities have the most people, low centrality-high control cities have the fewest, and high centrality-low control cities primarily serve as hubs. These cities have more opportunities for connection and convenient transportation and a suitable location provides more transit opportunities for small-scale cities to connect with large cities. Low centrality-high control cities serve as a gateway to neighboring cities, compressing opportunities and possibilities for regional residents to travel and demonstrating a monopoly on regional resource circulation [46]. As a result, a large number of small-scale cities (which can only exchange network resources through gateway cities) suffer from path dependence and lack of paths [46]. Cities with a high centrality-high control not only have a strong capacity to gather and spread resources, but they also have a strong dominance over resources and can be classified as typical cities.

5. Discussion

In terms of resident travel, we discover that there is a clear hierarchy. The first level is a "diamond" structure with nodes in Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu, Chongqing, and Wuhan; this structure supports China's entire transportation network and plays an important role in transportation lines. The second level is the network of contacts between provincial capitals. There are numerous travel routes and a large number of people between cities, which supplement and support the overall "diamond" structure. The third level transportation network is most visible as a link between prefecture-level cities and provincial

FIGURE 8: Hierarchical structure of Chinese cities.

capital cities. The fourth level network is primarily a contact network between cities at the prefecture level. Whether we look at the entire year, daily, special holidays, or the more special spring festival, we can see the existence of this hierarchy, which is consistent with the findings of Lai and Pan [27]. The existence of hierarchy also demonstrates the existence of a hierarchical structure between cities in China.

In terms of urban spatial connection, we discover that there are differences in urban spatial connection across four time periods. During the Spring Festival travel rush, the

space focuses on the connection between the southern cities, while the north primarily uses Beijing as the center of the connection line. In space, a rhombic dominant association structure with the cores of Guangzhou-Shenzhen, Beijing, Shanghai, and Chengdu-Chongqing forms in daily time. Special holidays exhibit an obvious proximity effect in space, with the majority of them focusing on the connection between provincial capital cities and other prefecture-level cities in the province. We discover that the proximity effect of special holidays is the most obvious when we compare the differences in urban spatial connection in four periods. The main benefit of special holidays is the short contact line distance. Residents in this period will choose to travel nearby based on travel time, destination, scale, and other factors. The Spring Festival travel rush, daily and year-round periods are primarily cross-regional connections with significant spatial differences.

We compute cities' AC and AP, as well as their hierarchical structure, which is characterized by a pyramid structure with a small top and a large bottom. Cities at the top include Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu, and Chongqing, among others. They have a strong sense of centrality and control, and they are the city with the best resident travel connections. These cities are the most appealing to residents; regardless of the time period, the intensity of residents' travel between cities is at the highest level. It demonstrates that population travel between these cities has become routine, unaffected by time. More cities have low centrality and control power. It demonstrates that these cities are at a relatively low level in the transportation network, and their appeal to residents and network control is not strong. There is a significant difference in travel time between the Spring Festival travel rush and holidays. Residents primarily return to their hometowns during the Spring Festival travel rush. People who work outside of the city will attend the reunion. As can be seen from the result chart of travel intensity, both the travel routes and the travel intensity of residents have improved, with long-distance travel performing best. Residents mostly take short trips and play during the holidays, which are limited by the length of the holiday. The number of short-distance trips increases sharply, as does the number of travel routes, as can be seen intuitively in the advantage correlation results. We believe that most existing studies on residents' travel are limited to a single time period, such as working days or holidays, and that there is a lack of research on residents' travel status throughout the year. As a result, this paper divides the entire year based on the travel habits of Chinese residents and finally determines the research period as follows: Spring Festival travel rush, daily time, special holidays, and the entire year. We improve the comparison of residents' travel differences across time periods in the time period selection, and we enrich the research on residents' travel directions. Simultaneously, the analysis of multiple periods can help decision makers better understand the travel rules and travel characteristics of residents over the course of a year, as well as serve as a point of reference for the formulation of relevant policies.

In comparison to previous statistical data, Tencent migration data is updated at a rapid rate and with high timeliness, breaking through the lag effect of traditional data. Tencent has a large user base and can provide a large amount of data with greater accuracy. Tencent had more users and higher accuracy when compared to other data. However, due to the nature of data generation and acquisition and the protection of personal privacy, it was impossible to obtain social attributes such as travelers' occupation, gender, age, and travel purposes. It was impossible to delve deeper into the population's willingness and the group effect. Furthermore, some travel paths may be disassembled, and the points of origin and destination cannot be studied as network nodes, resulting in errors in the research results. In the future, it will be necessary to integrate various data sources in order to analyze the characteristics of residents' travel and to provide new research ideas to global researchers.

The majority of existing studies examine the characteristics of residents' travel networks over a specific time period or in a specific region. There are few studies on a national scale and even fewer on different time periods in the country. This study has enriched the research by analyzing the structure characteristics of the Chinese residents of the intercity travel network over different travel time periods. Our research yielded the following new findings: (1) There is a clear hierarchy in the spatial structure of Chinese residents' intercity travel network, which is not monotonous but dynamic for different travel periods. (2) The main origins and destinations of Chinese residents change from time to time, as evidenced by the first flow. (3) The centrality and control power of Chinese cities are not the same in terms of transportation. Cities at different levels in the urban hierarchy of residents' travel networks play different roles and functions in the transportation network. This research can assist policymakers in proposing appropriate management measures for various travel time periods in order to improve the efficiency of residents' travel and optimize the residential travel network. It will also assist readers all over the world in better understanding the travel habits of Chinese residents and deepening their understanding of China.

6. Conclusions

This paper comprehensively evaluates the travel network structure characteristics and connection patterns of 346 Chinese cities based on different travel periods (the entire year period, daily time, special holidays, and Spring Festival travel rush). We arrived at the following conclusions:

- (1) In terms of routes and people, the travel network of Chinese residents along the "Hu Huanyong Line" showed an obvious trend of more in the east and less in the west during the four designated time periods.
- (2) From a hierarchical standpoint, the "diamond" frame structure centralized travel areas with Beijing, Shanghai, Guangzhou-Shenzhen, and Chengdu-Chongqing as nodes formed during these four periods, and the internal routes of the "diamond"

structure increased significantly during the Spring Festival travel rush and holidays.

- (3) Centrality depicts each city's position and status in the travel network, and the number of cities with low value is large. Centrality demonstrates that fewer cities have significant status, and they are primarily concentrated at the "diamond" structure's apex.
- (4) The spatial proximity effect demonstrates that during special holidays, residents' travel advantages are primarily related to proximity, as represented by the connection between provincial capitals and surrounding cities. During the Spring Festival travel rush, throughout the year, and on a daily basis, residents' travel advantages are primarily related to cross-region travel, and the spatial distribution varies.
- (5) The city level reflected by the travel network is primarily divided into four types: high centrality-high control, high centrality-low control, low centrality-high control, and low centrality-low control, with a city ratio of 23:22:2:299.

Data Availability

The population migration data of Tencent in 2018 are the core data of this paper, which can be obtained from the location big data released by Tencent. The data come from <https://heat.qq.com/qianxi.php>. In order to protect users' privacy, Tencent has closed the data acquisition interface, and the latest data can no longer be obtained. Therefore, it is inconvenient for us to disclose the obtained historical data. Some sample data can be sent via e-mail (qirunze_gis@163.com) to Qi Runze.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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