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Analyzing the Structure of Residence–Leisure Network in Shenyang City

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Abstract: Leisure is an important part of the daily activities of urban residents. A relatively dense flow of people will be generated between residential areas and supermarkets, as well as between residential areas and highly popular park facilities. These flows of people can reflect the characteristics of residents' leisure activities and the spatial characteristics of urban residence–leisure functions, as opposed to static leisure facilities and places; it is a new perspective for the study of urban spatial structure. Network studies on the relationship between residential and leisure functions within cities are rarely seen. In this study, from the flow space perspective, based on the questionnaire data, points of interest data, and mobile phone signaling data, the actual leisure travel flows of residents with different travel purposes can be identified, including residence–shopping leisure flows and residence–park leisure flows, and the corresponding urban networks can be constructed from them. With the help of complex network analysis, this paper discusses different types of residence–leisure network structures and their influencing factors in terms of network characteristics, node strength, and QAP analysis. It deepens the understanding of the urban spatial structure and provides the theoretical basis and technical support for urban structure analysis, urban layout optimization, and urban planning and management. The results show that: ① Both residence–shopping leisure and residence–park leisure networks have the small-world characteristics and scale-free properties of complex networks. ② The characteristics of the nodes of the residence–leisure network for different leisure travel purposes indicate that residents go more to Taiyuan Street and the New North Station business circle for shopping activities, and the parks that attract residents to go out for walks are concentrated in the central part of the city. ③ Different types of network structures have a strong correlation with the number of residential functions and leisure facilities but have a weak correlation with the difference in the number of inhabitants and leisure travel distance. This study enriches the research cases of the urban residence–leisure network structure to a certain extent. Shenyang City has the same background of rapid expansion as other large cities in China, and this study has an important role in planning and inspiration for solving urban diseases and achieving the orderly and rational development of large cities.

Keywords: residence–shopping leisure; residence–park leisure; network structure; complex network; influencing factors

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1. Introduction

Leisure is an essential function of the city. "Basic Leisure Studies" defines the essential characteristics of leisure: leisure is a free activity free from any compulsion. The leisure activity is an end in itself; what a person considers a leisure activity worth pursuing and acts on is driven by an inner instinct—purely for the sake of leisure itself, purely to obtain inner satisfaction [1]. Residents' demand for leisure and recreation is increasing day by day, and leisure activities became an important part of their daily lives. Leisure is a measure of urban social civilization and residents' quality of life, and urban progress is accompanied by the development of leisure [2]. The urban leisure space in this study is a physical place for urban residents to perform various leisure activities, such as entertainment and shopping in their leisure time, and is composed of different types of leisure facilities, which are the support and carrier of residents' leisure activities and are closely related to their leisure quality level and life satisfaction [3]. Western scholars studied the forms of urban leisure space from the aspects of qualitative theoretical development and quantitative performance measurement. They analyzed leisure space and quality of life from three aspects: physical and mental health benefits, environmental benefits, and social identity. They also studied the social production of leisure spaces from the levels of tourism and the needs of the residents [4]. In China, scholars conducted research on leisure spaces from the perspective of different disciplines [5]. Research was conducted on the temporal aspects of geography based on an activity log survey in order to study the travel motivation and spatiotemporal structure of urban residents on rest days [6]. Tourism geography studied the structure of urban leisure space using field surveys, questionnaires, and statistical methods [7]. From the perspective of humanism, research was also conducted on the spatial layout of leisure places within cities of commercial entertainment places and other micro-locations [8]. Urban geography, urban planning, and related disciplines used spatial analysis methods to study the layout of urban leisure functions [9].

Mobile phone signaling data are the record of information exchanged between mobile phones and base stations when the mobile phone users are active in the mobile communication network, which can reflect the spatial location of the mobile phone users at a certain time in real-time [10]. Mobile phone signaling data provides the possibility to describe the spatiotemporal dynamics of urban residents' living, recreation, and other activities, and provides a new perspective and path for urban space research. In 2005, Ahas and Mark first proposed the use of mobile location data of mobile phones for urban spatial research to monitor the total population and movement trajectories, as well as to predict and prevent the occurrence of crowds, and thus fundamentally changed public life and management in the information era by using the social positioning method [11]. In 2006, Ratti et al. presented the research results of using mobile phone data to analyze the spatiotemporal changes of urban activities in the form of hot spot maps. The changes in people flow activities in the metropolitan area of Milan, Italy at different periods, such as day/night, working days, weekends, major event days, etc. [12], which were noted in the research results, were enlightening. Subsequent research included descriptions of spatial phenomena, such as using mobile phone call data to characterize changes in urban people flow density [13], using mobile phone call duration data of 398 base stations in Rome to study the regularity of daily activities [14], using mobile phone data to analyze long-distance travel demand [15], to understand the mobility characteristics of urban residents, and to explore and analyze urban transportation patterns, commuting paths [16], and combining spatial use characteristics to identify functional areas and urban boundaries [17,18]. Chinese scholars mainly used mobile phone signaling data to study the urban system hierarchy [19], urban spatial structure [20], occupational–residential relationship [10], segregation of commercial centers and business circles [21,22], etc. Mobile phone-based research can effectively grasp the action mechanisms and operational status of urban and rural residents' behavioral activities, urban space utilization, traffic operations, and public facilities service levels [23]. Both residential and leisure functions are important urban functions. The residence–leisure functional relationship refers to the interaction of residents in the residential space and the leisure space, which is directional. The spatial relationship between residences and leisure is an important part of the urban internal structure that has an important impact on the operational efficiency of the city. However, big data-based research on quantitatively exploring this spatial relationship is scarce.

New information and communication technologies, such as the internet and mobile phones, play an important role in shaping and adjusting the spatial structure of cities. With the development of information technology, the quantification of the functional relationship between residential and leisure nodes within a city can be realized; that is, mobile phone signaling data can be used to obtain accurate information about the flow of people, identify the connections among the residential, occupational, and leisure places within the city, and obtain urban functional links, which cannot be obtained from or measured by traditional data sources [23]. It provides a new data source and new technology for urban planning [24], which helps to study the functional relationships within a city. Numerous real-world problems can be abstracted into networks composed of many nodes and edges expressing node relationships, such as knowledge interaction networks, social networks, technology networks, biological networks [25], and urban spatial interaction networks. The residence–leisure functional relationship can be abstracted as a residence–leisure network to be studied. The residence–leisure network in this study is a directed network constructed by residential nodes, leisure nodes, and the connecting edges between residential nodes and leisure nodes, in which the residential function is taken as the network origin point and the leisure function is taken as the network destination point, and the connecting edges of residential nodes and leisure nodes can reflect the interaction and connection between the two functions. The study of complex networks emerged at the end of the 20th century and was applied to fields such as mathematics, life sciences, and engineering disciplines [26]. The essence is to explore the structures (nodes) and connections between the structures [27]. Complex networks have the properties of small-world and scale-free. Small-world property refers to the phenomenon that the connection between any two nodes in a network can be achieved through a shorter path, even if the network scale is large [28]. Scale-free property means that, in a network, nodes that have a large number of connections with other nodes tend to be a minority; most nodes have fewer connections, that is, the degree distribution of nodes satisfies the power law distribution [29]. For different networks, complex networks explore the evolutionary laws of networks in terms of network formation, geometric properties, and structural stability to study the spatial characteristics of urban functions and the internal spatial structure of cities. The use of mobile phone signaling data can obtain accurate information on the movement of people, identify the connections between places of residence, work, and leisure within cities, and measure the functional connections within cities, providing a new data source and technical idea for urban planning [30] and contributing to the study of functional relationships within cities. China's urban development went through a rapid expansion phase, and Shenyang, as the largest regional center city in Northeast China, is in line with the background rapid expansion of other large cities. This study selects Shenyang as a case city, which has implications for the study of the spatial structure of residential and leisure relationships and the structure of functional relationships within cities in other large cities. The combined use of social location data and mobile phone signaling data can be utilized to help to understand the activity patterns of urban residents [24,31]. Therefore, this paper uses multiple sources of data, such as questionnaires, points of interest, and mobile phone signaling, to obtain residence–leisure functional links for different travel purposes in Shenyang, and thus constructs a directed weighted network of different types of residence–leisure OD relationships.

The study's next parts are the following: the second part introduces the study area, research data, and research methods; the third part analyzes the structural characteristics of urban residence–leisure networks for different travel purposes and their influencing factors; the fourth part discusses the results of the study; and the fifth part is the conclusion of the study and the optimization strategy for the urban spatial layout.

2. Materials and Methods

2.1. Case City

Shenyang, located in the south of Northeast China and central Liaoning Province, is an important city (9.118 million permanent residents) that is the capital and subprovince-level division of Liaoning Province. Before the 1990s, due to technical levels and other reasons, Hun River became a natural barrier for the southward expansion of Shenyang, which led to the long-term lag of the urban development in the Hunnan District. However, the development of damming-related techniques and technology and the formal establishment of the Hunnan New District in 2001 led the city to adopt the strategy of "Big Hunnan, New Shenyang", which sees expansion across the river as an essential step in the city's development. This strategy focuses on constructing the Hunnan New District and creating an urban spatial structure that can be characterized as "one city, two districts". In the process of urban development, Shenyang gradually realized the transformation of the Tiexi Industrial Zone, the expansion of the Dadong Industrial Zone, construction of the Beiling and Shenhai Industrial Zones, and the establishment of Huishan agricultural high-tech, economic technology, Zhang shi, Daoyi, Hushitai, Hunnan New District, and many other development zones. The development of the Hunnan New District and the successful transformation of the Tiexi Industrial Zone played decisive roles in reshaping new patterns of axial expansion in Shenyang.

In this paper, the research selects the central urban area determined in the "Shenyang Urban Master Plan (2011–2020)" as the research scope, mainly including the Shenhe District, Heping District, Huanggu District, Dadong District, Tiexi District, Hunnan District, Yuhong District, Shenbei New District, and Sujiatun District of nine administrative subdivisions (Figure 1), with an area of 1254.88 km^2 and a population of 6.202 million in 2020.

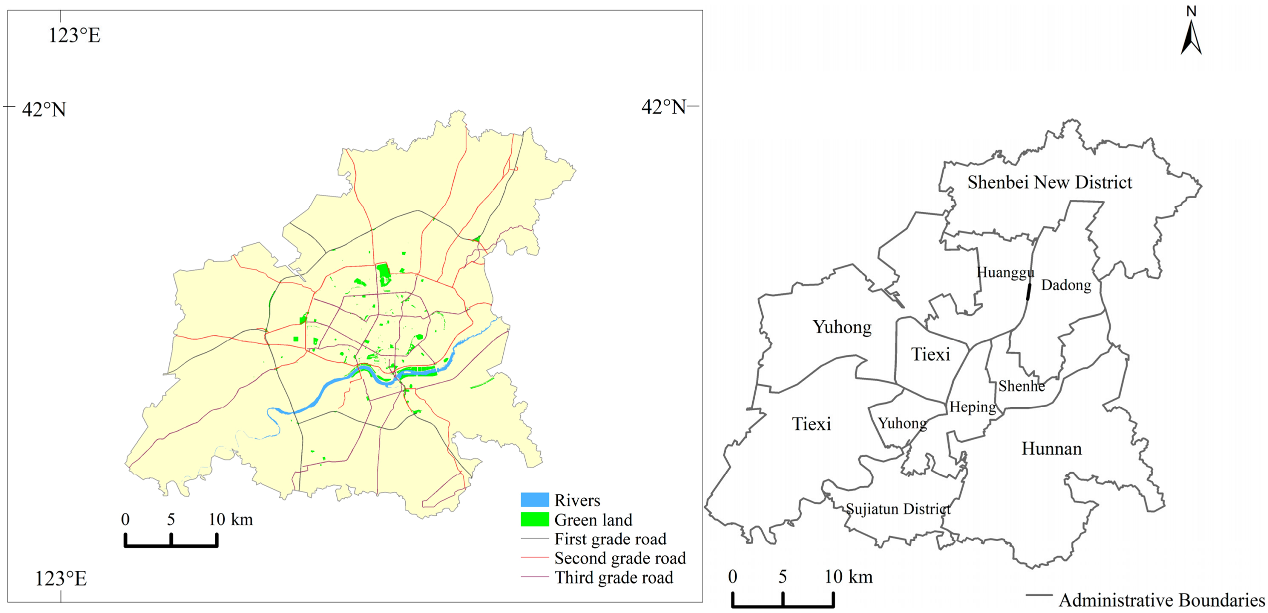

Figure 1. Shenyang downtown area: source from https://www.tianditu.gov.cn (accessed on 20 May 2020).

2.2. Data Sources

2.2.1. Questionnaire

The questionnaire on "Shenyang Residents' Leisure Activities" was distributed through "Questionnaire Star" (https://www.wjx.cn/) from 15 September to 27 September 2020. The questionnaire mainly includes 6 questions related to basic personal information and 16 questions about leisure mode, leisure place, and leisure travel mode at different times (weekdays, weekends, and holidays). Since the survey population is Shenyang residents and the IP address of the recovered questionnaires is Shenyang, it can be judged as a valid questionnaire. The final number of completed questionnaires collected was 746, with 521 valid questionnaires from IP addresses in Shenyang.

2.2.2. Point of Interest

The point of interest data originated from the 2018 Shenyang AutoNavi map. WGS 84 projection was performed on the point of interest data, with 1903 shopping leisure facilities and 232 park green space facilities.

2.2.3. Mobile Phone Signaling Data

The research data were derived from the mobile phone signaling data of Unicom users in Shenyang for the month of May 2018. Mobile phone signaling data have a large amount of user privacy. In order to avoid the leakage of user privacy, the data needs to be desensitized before use, also known as de-privatization. After desensitization, the data did not involve any privacy issues. Considering factors such as the configuration of base stations in Chinese cities and the measurement accuracy, the authors created a grid (scaled to 500 m $\times$ 500 m) of the city—a total of 5374 grid squares—to aid the research. The acquired data includes the grid number, the number of people within the grid, the longitude and latitude of the grid, and so on. During the study period, the average daily low temperature in Shenyang was 12 °C and the average daily high was 24 °C, the daily average temperature was 18 °C, and 90% of days saw sunny and cloudy weather; in other words, the study period had suitable weather for mobile phone users to engage in outdoor activities. Because mobile phone signaling data cannot directly clarify the purpose of mobile phone users' activities, we created the following rules to identify residential and leisure-related spaces and activities.

To measure the resident population, we adopted the following rules: First, we identified the residential observation period as lasting between 21:00 and 8:00 the next day (that is, when users were in one place for this period they were assumed to be at home). Second, we summed up users' total amount of time spent in given locations between these hours on a monthly basis and assumed that the location with the highest amount of time spent was their place of residence. Third, the number of days in a month exceeds two weeks (that is, where it was considered to be inhabited by residents).

To measure and conceptualize places of leisure, we observed users' positions when they stayed more than one hour in non-residential and non-working grids on weekends and holidays.

Multi-source data fusion is used throughout this study. Through the mobile phone signaling data, we can first identify the leisure travel activity trajectory of Shenyang residents, obtain the main places of leisure activities of Shenyang residents based on the questionnaire, and further identify the shopping leisure activity trajectory and park leisure activity trajectory by combining point of interest data with location attribute information. The combination of the three types of data helps to validate each other's data and improve the accuracy of the actual use of the data.

2.3. Research Methods

2.3.1. Small-World Property

Small-world properties can be measured by average path length and clustering coefficient (Table 1).

(1) The average path length is the average value of the shortest path length between the connecting nodes.

(2) The clustering coefficient is used to reflect whether other nodes connected to a given node are connected to one another (which in turn reflects the local attributes of network connections).

Table 1. Indicators for determining the small-world characteristics of complex networks.

Indicators	Calculation Formula	Formula Meaning
Average path length	$L = \frac{2}{n(n-1)} \sum_{i \geq 1} d_{ij}$	n is the number of nodes in the network; d_{ij} is the shortest path length between nodes i and j.
Clustering coefficient	$C_i = \frac{E_i}{\frac{1}{2}k(k-1)} = \frac{2E_i}{k(k-1)}$	E_i represents the number of triangular connections containing node i. k is the degree of node i, which is the number of nodes connected to i.
Determination of small-world characteristics	$L >> L_{random}$ and $C >> C_{random}$	L_{random} and C_{random} are the average path length and clustering coefficient of a random network of the same size, respectively.

A network in which the connections between nodes are randomly generated can be called a random network. The classical random network model (ER) was proposed by Erdos and Renyi in 1960 [32], and it was found that random networks have small mean path lengths and small clustering coefficients. If a network has both a small average path length and a large clustering coefficient, such a network has the small-world property.

2.3.2. Scale-Free Property

The degree of a network node reflects the possibility that a node is directly connected to other nodes in the network, where the average of the degrees of all nodes in the network is called the average degree of the network. The distribution of node degrees in a network is described by the probability distribution function $p(k)$ [29], which can reflect the type of network, where the probability distribution of node degrees in complex networks is characterized by the power law distribution. When the $p(k)$ of the node degree is a power function, its network structure has a scale-free property and belongs to the complex network. The probability of node k is:

$$p(k) = {}^{n_k}/_{N}$$

In the formula, the degree of node i refers to the number of connecting edges of node i: that is, k_i, $\{k_i = k; i = 1, 2, \cdots, l\}$ represents the set of nodes with degree k, n_k is the number of nodes in the set, and N is the number of nodes in the network.

2.3.3. Node Strength

The node strength in a weighted network indicates the strength of the interaction between nodes, also known as the weighted degree, which can characterize the strength of the connection between residential and recreational sites in the network. The node strength of the directed weighted network can be divided into two types of node entry and exit degrees depending on the pointing of the connected edges, which reflect the attractiveness and control of the network nodes, respectively, from which the node net flow ratio [33] is derived to measure the relationship between node entry and exit degrees. The calculation formula is as follows:

$$NFR = \frac{S_{in}(v_i) - S_{out}(v_i)}{S_{in}(v_i) + S_{out}(v_i)}$$

In the formula, S_{in} (v_i) is the in-degree strength, and S_{out} (v_i) is the out-degree strength. NFR is the net flow ratio. When the net flow ratio is greater than 0, the in-degree strength of the node is greater than the out-degree strength, indicating that the heat degree of the area is increasing; otherwise, the heat degree is decreasing.

2.3.4. QAP Analysis Method

Since the problem of "multicollinearity" in relational data affects the regression analysis, traditional statistical methods cannot be used. The use of matrix regression analysis of social networks, i.e., quadratic assignment procedure (QAP for short), can be used to explore the correlation of spatial relational data. The hypothesis test of the dyadic correlation in social network analysis is used, which is divided into matrix correlation analysis and regression analysis of the matrix. QAP is a method to compare the similarity of two square matrices based on random permutations of matrix data. The method gives the correlation coefficients of the two matrices by comparing the individual lattice values corresponding to the two square matrices, and the coefficients are tested nonparametrically. QAP regression analysis is used to analyze the regression relationship between multiple matrices and one matrix [34,35].

$$R = f(X_1, X_2, \ldots, X_n)$$

In the formula, R is the spatial network relationship matrix of different types of residence–leisure functions, which can be interpreted as the explanatory variables of the regression, and x_i (i = 1,2,...,n) is the matrix of influencing factors, which can be interpreted as the explanatory variables of the regression.

3. Results

3.1. Complex Network Characteristics

3.1.1. Construction of Residence–Leisure Functional Relationship Network with Different Travel Purposes

The number and trajectory of leisure trips of Shenyang residents in May 2018 can be identified by using mobile phone signaling data. With the help of ArcGIS software, the 500 m $\times$ 500 m grid is used as the basic unit for the residence–leisure functional relationship data processing. In the process of residence–leisure functional relationship identification, records with the number of residents from residence to leisure in the central city of Shenyang greater than two were selected to exclude errors caused by the accidental travel of the residents. Descriptive statistical analysis was conducted in SPSS, and it was found that the number of residents of five is the median, so the study extracted a total of 179,225 records from the central city from the residence to the leisure place with the number of residents greater than four to reflect the general pattern of leisure activities of urban residents, making the results more realistic and reliable.

After the questionnaire survey, it is found that residents in Shenyang mainly go out to shopping malls and supermarkets, parks, and other leisure places for leisure activities on weekends and holidays, besides home leisure activities such as reading books, watching TV, and surfing the internet, and the proportion of residents going to shopping malls, supermarkets and walking in parks is relatively close. According to the different travel purposes of Shenyang residents, leisure activities can be divided into two types: shopping leisure activities and park walking activities. With the help of mobile phone signaling data and point of interest data of shopping facilities and parks, the residence–shopping leisure function relationship and the residence–park leisure function relationship can be identified from the residence–leisure functional relationship. The number of connections between the residential function and shopping leisure function is 127,375, and the number of residents engaged in shopping activities is 773,711; the number of connections between the residential function and park leisure function is 25,072, and the number of residents engaged in park leisure activities is 104,709. A network is composed of many nodes and some edges connecting two nodes. The residence–leisure network based on residents' travel activities is constructed as a residence–leisure functional relationship network with residents' place of residence as the origin, different types of leisure places (shopping facilities or parks) as the destination, the travel between residence and different types of leisure places as edges, and the directed weighted matrix with the number of residents' leisure activities as the weight to build the residence–leisure functional relationship network, respectively. The residence–shopping leisure network consists of a directional weighted matrix with nodes of 2267 $\times$ 666, edges of 127,375, and weights of the number of residents from the place of residence to the shopping place. The residence–park leisure network consists of a directional weighted matrix with 1768 $\times$ 133 nodes, 25,072 edges, and a weight of the number of residents from the residential area to the park area.

3.1.2. Small-World Characteristics of Residence–Leisure Networks for Different Travel Purposes

The average path length of the residence–shopping leisure network is 2.331, and the residents pass through 2.331 edges on average from the residential node to the shopping leisure node, and the network has a high transmission efficiency. The clustering coefficient of the residence–shopping leisure network is 0.523, and there is a network local connection feature with a large proportion of links between the nodes connected to each node, and the shopping leisure activities have a local agglomeration. The average path length of the residence–park leisure network is 2.333, and the residents pass through 2.333 edges on average from the residential node to the park leisure node, which indicates the high transmission efficiency of the network. The clustering coefficient of the residence–park leisure network is 0.465, and there is a network local connection feature with a large proportion of links between the nodes connected to each node, and park recreation activities have local clustering. The clustering coefficient of the residence–shopping leisure network is larger, the shopping leisure facilities where residents often conduct leisure activities have strong spatial clustering distribution characteristics, and the clustering of the park's spatial layout is slightly weaker. The average path length of the network is small and the clustering coefficient is high. On a whole, residential nodes and leisure nodes in the network can be connected through shorter paths, and a larger proportion of connections exist between nodes connected to each other. The average path lengths of random networks of the same size as the residence–shopping leisure network and the residence–park leisure network were 1.92 and 2.825, respectively, and the clustering coefficients were 0.025 and 0.008, respectively. The average path length of the residence–park leisure network is slightly smaller than its random network and the clustering coefficient is larger than its random network. Additionally, the average path length and clustering coefficient of the residence–shopping leisure network is larger than their random network counterparts, which can be combined to determine that the networks all have the small-world characteristics of complex networks.

3.1.3. Scale-Free Characteristics of Residence–Leisure Networks for Different Travel Purposes

The average degree of the residence–shopping leisure network is 56.014, each node is connected to 56.014 other nodes on average, and the probability of nodes with a below-average degree is 64.07%. The average degree of the residence–park leisure network is 14.133, and each node is connected to an average of 14.133 other nodes, with a probability of 60.43% for nodes below the average degree. The number of nodes that are well connected to other nodes in different types of residence–leisure networks is limited, and nodes with higher-than-average degrees generally have hub characteristics in the network. The probability distribution of node degrees in different travel purpose residence–leisure networks also shows a power law distribution pattern (Figure 2). Most of the nodes in the network have only a few connections, a few nodes have a large number of connections, and nodes with hub characteristics are few in the network. Both residence–leisure networks with different travel purposes have the scale-free characteristics of complex networks.

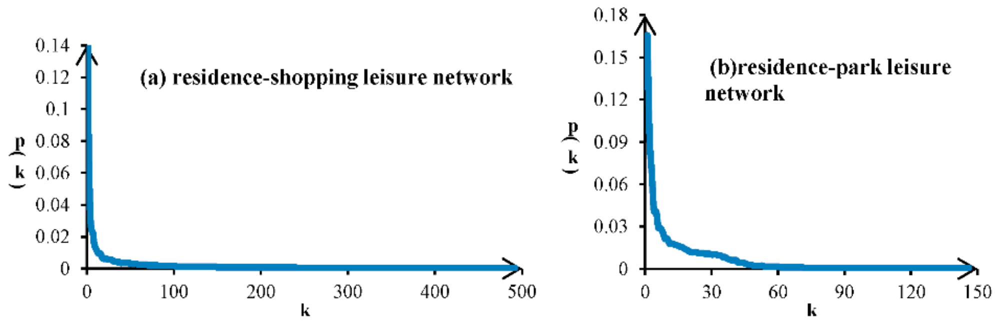

Figure 2. Probability distribution characteristics of the node degree of residence–leisure network for different travel purposes.

3.2. Node Characteristics of Residence–Leisure Networks

3.2.1. Node Characteristics of Residence–Shopping Leisure Network

The number of nodes in the residence–shopping leisure network is 2274, and the nodes are classified into high, medium, and low-weighted degree values by the natural break method (Figure 3). There are 45 nodes with a high-weighted degree, 298 nodes with a medium-weighted degree, and 1931 nodes with a low-weighted degree, and the number of nodes with a prominent position in the network is small. There are weighted degree high-value nodes of agglomeration distribution in Taiyuan Street, Middle Street, and New North Station Trade Center in the central part of the city, and there are also weighted degree high-value nodes in Xingong Trade Center in the central and western part, Wulihe Trade Center in the south, and Changjiang Trade Center in the north, reflecting the importance and influence of traditional trade centers in the network, while shopping leisure facilities in Xingong, Wulihe, and Changjiang Trade Center also have a construction foundation and are more important in the network. The nodes with a medium-weighted degree are distributed in the central part as well as in the peripheral Shenbei New District Dao Yi Street and Huxi Street of Sujiatun District, where the number of shopping leisure nodes with high importance within Dao Yi Street is higher. In addition to some nodes around the south bank of the Hun River, the high-value areas of weighted degree are concentrated on the north bank of the Hun River, and the number of shopping leisure facilities on the south bank of the Hun River that are attractive to residents is relatively low. The weighted degree of residence–shopping leisure network nodes shows a weakening trend of circles from the center outward, the importance and influence of nodes in peripheral areas are weaker, and shopping leisure facilities laid out in peripheral areas are less attractive to residents at a distance. The net flow ratio of the central nodes in the residence–shopping leisure network is mostly less than 0, while the net flow ratio of the peripheral nodes is greater than 0, which indicates that the central business center has a strong radiation and driving effect on the development of the surrounding areas. A small number of nodes with radiating effect exist in the peripheral areas of the city, and the basis for the development and construction of trade centers exists in the peripheral areas, which is important for the surrounding residents to obtain leisure functions and improve the construction of the secondary city.

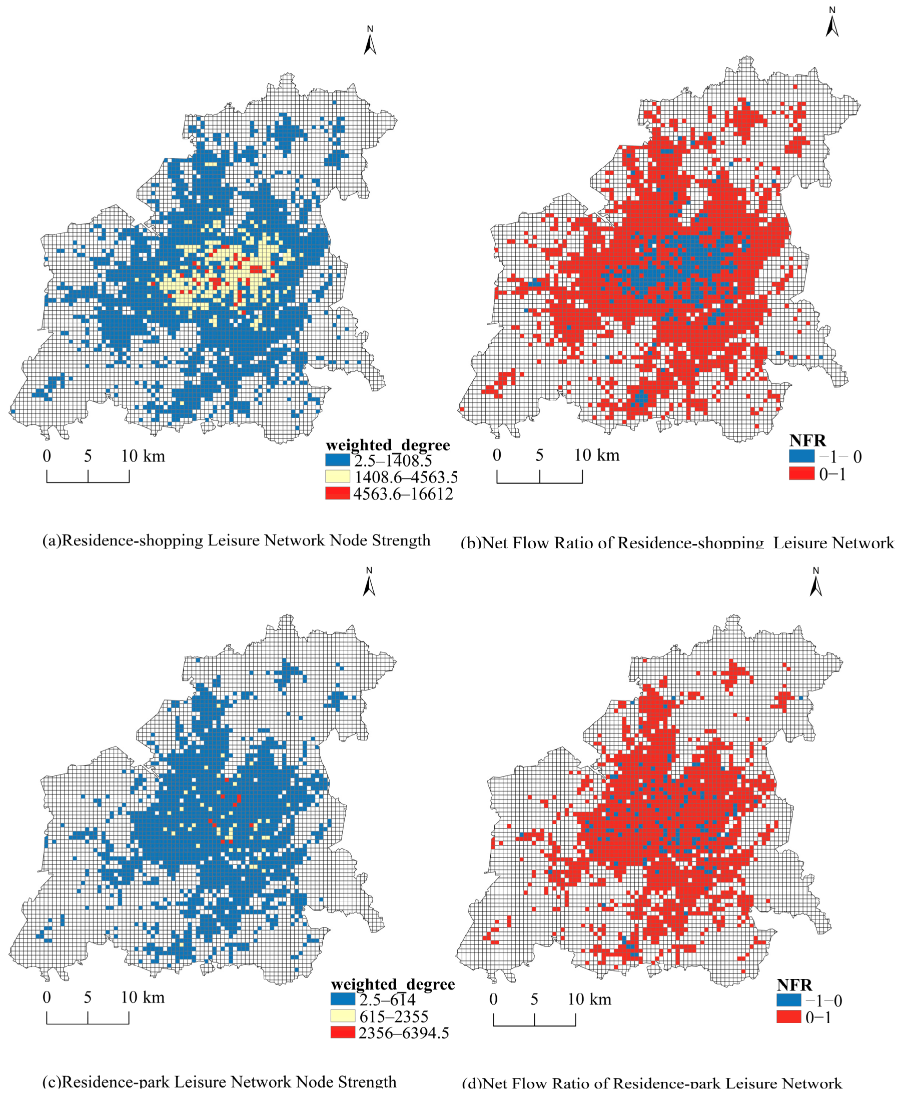

Figure 3. Spatial distribution of node degrees of residence–leisure networks for different travel purposes.

3.2.2. Node Characteristics of Residence–Park Leisure Network

The number of nodes in the residence–park leisure network was 1774, and the nodes are classified into high, medium, and low-weighted degree values by the natural break method (Figure 3). There are 10 nodes with a high-weighted degree, 45 nodes with a medium-weighted degree, and 1719 nodes with a low-weighted degree; the number of nodes with a prominent position in the network is small. The weighted degree high-value nodes are mainly distributed in the central part of the city within the second ring, Taishan Park, Bitang Park, Huigong Square, Shenyang North Station Square, Shenyang Station Square, Democracy Square, and South Lake Park, and are all within the range of high-value nodes. These areas have a strong attraction to residents, and urban park squares with a strong attraction to city residents on weekends and holidays are scattered in the central part of the city. The medium-weighted nodes are mainly located in the central part, and one medium-weighted node exists in both Daoyi Street in the northern part of Shenbei New District and Huxi Street in the southern part of Sujiatun District in the periphery. The nodes with low-weighted degrees are mainly distributed in the periphery, which reflects the weak influence of the region in the network and its weak attraction to urban residents. The residence–park leisure network has a higher number of nodes with a net flow ratio greater than 0 and a higher number of nodes with strong clustering effects in the network. The number of nodes with a net flow ratio less than 0 is small, and they are mostly located in urban parks and squares, which are more attractive to the residents of the surrounding and peripheral areas, and show their strong radiation ability in the network.

3.3. Analysis of Influencing Factors of Residence–Leisure Network Structure

To avoid multicollinearity, traditional multiple regression statistical tests require the independence of independent variables [36], which does not apply to the relational data of the network. Quadratic Assignment Procedure analysis is mainly for relational data and the method avoids the problem of multicollinearity [37]. With the help of UCINET software, QAP analysis can be performed on the travel flow construction matrix to realize the analysis of influencing factors of the spatial structure of the residence–leisure functional relationship. The different influencing factors of the spatial structure of the residential–leisure functional relationship for different travel purposes in Shenyang mainly include the differences in the number of residential functions, the differences in the number of leisure facilities, the differences in the number of inhabitants, the differences in the number of bus stops, and the distance of leisure travel between residential nodes and leisure nodes (Table 2).

Table 2. Description of the variable matrix of the residence–leisure network structure.

Variables		Description	Data Source
Types	**Name**		
Dependent variable	Residence–shopping leisure network R_1	The number of nodes is constructed as a 2267 × 666 matrix based on the number of residents of the city for shopping leisure trips, with 0 as the threshold for binary conversion.	May 2018 Mobile Signaling Data
Dependent variable	Residence–park leisure network R_2	The number of nodes is 1768 × 133 matrix is constructed based on the number of residents who travel for leisure in urban parks, and the binary conversion is performed with 0 as the threshold.	May 2018 Mobile Signaling Data
Independent variable	Differences in the number of residential functions X_1	The difference between the number of residential functions in the residence–leisure grid as a percentage, with 0 as the threshold for binary conversion, constructs the difference network in different grids, with the difference greater than the row mean set to 1, otherwise 0.	POI data of Shenyang Gaode Map in 2018

Table 2. *Cont.*

Variables		Description	Data Source
Types	Name		
Independent variable	Differences in the number of leisure facilities X_2	The difference of the ratio of the number of leisure facilities in the residence–leisure grid, with 0 as the threshold for binary conversion, constructs the difference network in different grids, with the difference greater than the row mean set to 1, otherwise 0.	POI data of Shenyang Gaode Map in 2018
Independent variable	Differences in the number of inhabitants X_3	The difference between the number of population in the residence-leisure grid, with 0 as the threshold for binary conversion, constructs the difference network in different grids, with the difference greater than the row mean set to 1, otherwise to 0.	May 2018 Mobile Signaling Data
Independent variable	Difference in the number of bus stops X_4	The difference of the number of bus stops in the residence–leisure grid, with 0 as the threshold for binary conversion, constructs the difference network in different grids, the difference is greater than the row mean set to 1, otherwise 0.	POI data of Shenyang Gaode Map in 2018
Independent variable	Leisure travel distance X_5	The travel distance from the residential function to the leisure function is classified, and the travel is assigned a value of 1–5 points with the thresholds of ≤5000, 5000–10,000, 10,000–20,000, 20,000–30,000 and >30,000, and the parallel mean value is the threshold for binary conversion.	May 2018 Mobile Signaling Data

According to the QAP regression analysis based on the number of residents' leisure activities and the influencing factors (Table 3), the correlation coefficients were all greater than 0, the p values were all less than 0.05, the regression analysis was statistically significant, and the dependent variable network spatial structure was correlated with all five independent variables. The spatial structure of different networks has a strong correlation with the number of residential functions and leisure facilities, indicating that the more residential functions within the grid, the more residents have diversified demands for leisure activities. It is difficult for the leisure function within the grid to meet the demand of residents in the region, and more residents go out of this grid cell to other grid cells to obtain leisure functions, thus affecting the spatial structure of different types of networks. The differences in the number of leisure facilities between different grids contribute to a significant supply and demand relationship between grids for leisure functions, with residents in grid cells with a low number of leisure facilities going out more often to grid cells with a high number of leisure facilities for leisure functions. The greater the differences in the number of leisure facilities between different grids, the greater the number of residents who travel for leisure. Grids with a high number of leisure facilities are more attractive to residents for leisure activities, affecting the spatial structure of different types of networks. Due to the limited number of parks, the greater the differences in the number of inhabitants between the residential function and park leisure function grids, the greater the number of residents engaging in the park leisure activities. Both have a strong correlation, and the difference in the number of inhabitants will significantly affect the spatial structure of the residence–park network.

There are differences in the correlation between the spatial structure of different types of networks and the distance of leisure trips, and with the number of bus stops, all of which are weakly correlated with the distance of leisure trips. The correlation between residents' shopping leisure travel activities and leisure travel distance is 0.426, reflecting that the spatial structure of the residence–shopping leisure network is influenced slightly less by the leisure travel distance, and residents have diverse types of shopping leisure activities, and to meet diversified leisure needs and improve self-satisfaction, residents have more cross-regional access to high-quality shopping leisure functions. The correlation between residents' park leisure travel activities and leisure travel distance is low, at only 0.146. Residents' park leisure activities can be close to recreation, can experience the natural scenery and other diversified functions from a distance, and the influence of travel distance on the spatial structure of the residence–park leisure network is weak. The number of bus stops has a weak influence on residents' going out for shopping leisure activities in parks. Residents use multiple transportation modes on weekends and holidays to achieve the purpose of going out for shopping and leisure activities in parks.

Table 3. Correlation between dependent variables and influencing factors QAP analysis.

Variables	Residence–Shopping Leisure Network R_1		Residence–Park Leisure Network R_2	
	Correlation Coefficients	Significant Level	Correlation Coefficients	Significant Level
Differences in the number of residential functions X_1	0.734	0.000	0.721	0.000
Differences in the number of leisure facilities X_2	0.814	0.000	0.945	0.000
Differences in the number of inhabitants X_3	0.016	0.000	1	0.000
Difference in the number of bus stops X_4	0.008	0.022	0.408	0.000
Leisure travel distance X_5	0.426	0.000	0.146	0.000

4. Discussion

With the development of the social economy, leisure became an important lifestyle for residents, and a large number of residents choose to go out for leisure activities in their leisure time. The relationship between urban living and leisure functions can also reflect the characteristics of residents' daily activities, but there are relatively few existing research cases, and they focus a lot on residents' leisure travel behavior, urban living circle, and other areas. This paper studies the relationship between the two functional spaces of housing and leisure from a holistic perspective, which is somewhat different from previous studies. The construction of an urban residence–leisure network based on travel flow data can improve the accuracy, breadth, and depth of urban network research, and is also an important perspective to explore the urban spatial structure, providing a reference role for relevant applied research at the urban scale.

The central part of the city is the region with highly concentrated functions and the strongest degree of comprehensive development [38]. To ensure the healthy and orderly development of the city, the expansion of residential and leisure function space outward is a necessary path of development. The interesting finding obtained from this paper is that residents' shopping trips tend to ignore the impact of distance and that residents' cross-regional shopping activities are frequent. The study shows that there are great differences in the aggregation, scale, and quantity of the functions inside and outside the Third Ring Road in Shenyang; particularly, the allocation of leisure facilities in the southern area outside the Third Ring needs to be paid attention to. The central core area of Shenyang has a strong polarizing effect, with high inertia and path dependence of single-center development, and great difficulty in the development of the peripheral new towns. To achieve a balanced spatial layout of residential and leisure functions, leisure facilities of reasonable scale and type are allocated in different areas based on the number of people living in different residential functions, the age of residents, and other attributes [39], as well as through analysis of the population served by different levels of recreational facilities and the service radius. The above study found a distinct lack of large leisure facilities in the Hunnan district on the outskirts of the city, and it is recommended that leisure facilities of different levels should be allocated in suitable locations based on the leisure needs of Hunnan residents. As the residents of Hunnan District are far away from large commercial centers in the central part of the city, it is reasonable to build large commercial complexes to ensure the relative fairness of leisure activities and access to leisure functions for residents in all areas of the city and to improve the quality of their leisure activities. The well-established leisure facilities in the area help attract urban residents to live in the area, which in turn leads to the construction and development of Hunnan District. According to the relevant recommendations of different plannings, it can be chosen to invest in the construction of large leisure facilities of suitable service scale in the existing areas lacking leisure facility groups (such as Hunnan District), so that the area has a sufficient and high-quality leisure supply to ensure the accessibility of residents' leisure activities, which helps to realize the orderly construction of the new town and is expected to create the core of Hunnan.

Accessibility to residents for leisure travel is an important factor in securing leisure activities [40]. The spatial relationship of residential, leisure, and transportation functions in the city is particularly important, as it helps to alleviate the low accessibility of leisure activities caused by the mismatch between residential and leisure functions. The spatial development strategy of Shenyang is to expand southward and achieve balanced north–south development across the Hun River, but there are barriers to the south bank of the Hun River and the center, high transportation costs for travel, low convenience of life, and difficulty in ensuring the leisure needs and quality of life of residents. The construction of transportation hubs and complexes can be a way to realize the construction and development of new towns, meet the leisure needs of new town residents, improve the quality of life, and alleviate the problems of traffic congestion and big-city diseases within the city during holidays. For example, a transportation hub should be built on the south bank of the Hun River to achieve the planning goal of bridging the north and south banks so that residents can travel across the Hun River and thus achieve the integrated development of the north and south banks of the Hun River. The development and construction of residential functions are chosen around transportation junction as much as possible, and leisure functions are mainly configured in residential areas, as well as in the areas around transportation hinge, etc. In addition, there is an urgent need to enhance traffic management in the central business center on weekends and holidays to maintain the traffic order in the parking lots and business center, thus alleviating the traffic problems in the city.

5. Conclusions

This study makes full use of the complementary nature of different kinds of data and combines the questionnaire for judging the characteristics of urban residents' leisure activities with the point of interest data on location and other attribute information, which can make up for the shortcoming that mobile phone signaling data cannot directly clarify the purpose of users' activities and can further classify the actual types of the residents' leisure activities. From this, two types of residence–leisure networks are constructed. The following conclusions are obtained from the study of the structure of the residence–leisure network in Shenyang from a network perspective.

First, both residence–shopping and residence–park leisure networks constructed from travel flows characterizing residents' actual leisure activities have the small-world characteristics and scale-free properties of complex networks.

Second, the characteristics of the nodes of the residence–leisure network for different leisure trip purposes indicate that residents go more to Taiyuan Street, New North Station, and other shopping areas for shopping activities, and only the shopping leisure facilities within Dao Yi Street of Shenbei New District in the periphery are attractive to residents. The parks that attract residents to go out for a walk are concentrated in the central part of the city, and the number of parks that are attractive to residents in the outer north and south areas is low.

Third, different types of network structures have strong correlations with residential functions and the number of leisure facilities, and weak correlations with the differences in the number of the residential population and the distance of leisure trips. The spatial structure of the residence–shopping leisure network has the weakest correlation with the number of bus stops. There is an obvious lack of large leisure facilities in the Hunnan district on the outskirts of the city. It is suggested that based on the leisure needs of the residents in the Hunnan district, different levels of leisure functions should be allocated in suitable districts and new leisure clusters should be cultivated.

The development of information technology made it possible to use big data and new methods to realize urban spatial research, so the research paradigm of this dissertation has planning inspiration for other urban research. This dissertation still has the limitation of analyzing and studying urban residents' leisure trips at only one point in time (2018), neglecting the comparative study with multiple periods of residents' leisure trips, and is yet to form a time series study. In the future, we will obtain travel flow data based on mobile phone signaling data or other types of urban big data for different periods of residence–leisure functional relationships, thus realizing multi-temporal urban spatial structure research.

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