IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received July 28, 2019, accepted August 22, 2019, date of publication September 4, 2019, date of current version September 20, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2939504

Village-Town System in Suburban Areas Based on Cellphone Signaling Mining and Network Hierarchy Structure Analysis

JI-ZHE ZHOU, QUAN-HUA HOU, XIAO-YANG FAN, AND YANG DU
School of Architecture, Chang'an University, Xi'an 710061, China

Corresponding author: Quan-Hua Hou (houquanhua@chd.edu.cn)

This work was supported in part by the National Natural Science Foundation of China under Grant 51978058, in part by the Fundamental Research Funds (Social Science) for the Central Universities of China under Grant 300102419631, and in part by the China Scholarship Council under Grant 201906560052.

ABSTRACT Suburban villages are strongly influenced by cities. Understanding the relationship between urban and rural as well as the hierarchy of villages contributes to optimizing the structure of village-town, allocating resources effectively as well as coordinating the relationship between urban and rural areas. Taking the rural area of Qin and Han New City as the research object, this paper obtained the number of contact flows between urban and rural areas from cellphone signaling data mining and constructed a network with hierarchical system. The influence scope and hierarchy of city and village nodes in the network could be measured by conducting the primary linkage analysis. The effect intensity and radius of the central villages as well as the relationship between villages could be calculated by the multiple linkage analysis. Furthermore, according to the urbanization potential and the characteristic regions of cites, the regional village-town system could be finally determined. This study has shown that 89.4% of the villages were influenced by the surrounding cities strongly, and the influence range of the cities was 6.2-28.3km. There were 13 ''Centrality'' villages in this region, which was lean to city, traffic convenience and divisional centralized. Totally, 19 groups of villages should be merged and 3 groups should be developed together. Besides, two kinds of village-town systems were formed in this region, and the villages were classified into five categories for guidance. Moreover, the research results could not only provide a helpful method to determine the village-town system structure under the strong influence of cities but also offer a better way for resources allocation between urban and rural smartly and equally.

INDEX TERMS Suburban villages, cellphone signaling data, contact flow, village-town system.

I. INTRODUCTION

With frequent urban-rural contact, diverse travel destinations, and complex spatial characteristics [1], production and life in suburban villages are significantly influenced by economic production, cultural activities and public services of central cities [2]. According to the stage urbanization theory, urban development generally experiences four stages including urbanization, suburbanization, reverse urbanization and re-urbanization [3]. However, urbanization and suburbanization are coexisted in numerous suburban villages in China. The rapid urban development has attracted a large number of suburban populations into cities [4], [5] and urbanization has been realized. Additionally, the outward development of cities is economical [6]. Suburban villages are affected by the excessive expansion of cities and face the dilemma of ''passive urbanization'' [7], [8]. Under the policy guidance, ''national new districts'' have been established in China. As a kind of unnaturally formed urbanized areas, it includes the first two stages and reverse urbanization also occurs [9], leading to chaos in village-town system in suburban areas. The rapid urbanization has intensified the contradiction between urban and rural development in suburban villages [10], [11]. There are not only emerging industrial bases, leisure and entertainment centers, commercial and trade logistics centers, but also abandoned land, idle public service facilities and population hollowing in suburban villages. Therefore, suburban village planning should balance the needs of different

The associate editor coordinating the review of this manuscript and approving it for publication was Chun-Wei Tsai.

stakeholders [12], equalize the resource allocation as well as coordinate urban and rural development [13]. In the previous solutions, the United States focused on the coordination of workers and peasants and the joint development of urban and rural areas [14]. The United Kingdom adopted urban and regional planning to guide urban and rural development [15]. Netherlands and Germany formulated a rural renewal plan based on the land consolidation [16], [17]. In the 1990s, China launched a village-city system plan to determine the village level at the regional level, lead rural development, and optimize the resource allocation. The complex structure [18] of suburban rural land leads to diverse purposes of population migration [19], [20], and strong demands are raised for urban public services [21]. Through measuring regional city-village relationship and the village level system accurately, the village level structure and public facility allocation can be optimized, and rural development can be guided and controlled more accurately to achieve regional urban and rural sustainable development. The Qin and Han New City, located in the north of the Xi'an and Xianyang urban built-up areas, is affiliated to the Xixian National New District. Currently, approximately 90% of the Qin and Han New City is rural areas. Since rural areas are influenced by cities, it is the primary issue in rural planning to establish a suitable village system and rationally determine the control and development areas.

II. LITERATURE REVIEW

The earliest research on suburban village-town system is based on the evaluation of rural development "potential", including land potential [22], [23], building site selection [24], sustainability [25], tourism function evaluation [26], [27], etc. Later, the "minimum cost" algorithm is included, such as the gravity model [28] and the service radius [29], [30] to optimize the evaluation results. There are two major problems in the above-mentioned research which fails to consider the relevance and integrality of urban-rural relations and village-to-village relationships. First, the regional service and driving level of the "central village" selected for preferential development are much lower compared with the surrounding cities, and the population migrates to cities, causing rural resource allocation waste. Second, the guidance method of land use and population does not match the actual production and life, resulting in the lack or waste of land and facilities. In recent years, some scholars have studied the relationship and village level between villages and towns by setting a network hierarchy of tourism, society, and population [31]–[33]. The interaction between villages and towns is measured by the "Centrality". Based on the central place theory, "Centrality" is also taken as an indicator for measuring the central level and village-town system. For example, Hui measured the village-town system based on the contact degree, the contact direction and the contact trend between villages and towns [32]. The research emphasizes the regional integrity and relevance. However, 450 pieces of travel data collected from questionnaires can hardly measure the complex urban-rural relationship in suburban villages. Yang introduced commuting distance to measure the urban-rural relationship in suburban villages [34]. However, commuting distance cannot represent the actual urban-rural relationship, which should be measured based on time-space behaviors of human beings [35].

Therefore, to study the contact level between villages and surrounding areas, it is necessary to establish a regional contact network based on accurate time-space contact data. The village-town system can be measured through the "Centrality" and level of villages. Hierarchy is the basic feature of the contact network. Studying the network hierarchy helps to understand the relationship between network nodes and the structural characteristics of the network [36]. It provides a common way to divide the regional hierarchical structure according to the centrality of nodes in the mobile network by taking the flow intensity as the strength of the relationship between regions. For example, the port hierarchy structure is determined by analyzing the freight traffic in the shipping network [36], [37]. The hierarchical structure of provincial capitals is determined by analyzing passenger and cargo flow volume in aviation and railway networks [38]–[40]. The urban hierarchy structure can be measured by analyzing the visitor flow volume in the population mobility network [41]. Combined with relevant research findings, the construction of network hierarchy at different levels raises different requirements for data sensitivity and accuracy, and more dynamic, continuous and accurate population flow information is required for suburban villages. The mobile phone signaling data can accurately measure the time-space behaviors of the suburban population [1], [42], [43]. Due to various advantages such as vector, large sample, full coverage, and continuous space-time attributes, it has been extensively used in regional urban system research and population flow characteristics analysis [44]. The existing research on the construction of contact networks based on mobile phone signaling data focuses on towns and cities, and suburban villages are seldom reported. Therefore, with the Qin and Han New City as an example, this paper constructs a network hierarchy by taking the mobile phone signaling data as the basic data to calculate the contact strength between the rural and surrounding areas. The centrality of villages is measured based on primary linkage analysis and multiple linkage analysis. Moreover, the influence strength and influence range of central villages are determined to predict rural development potential and urbanization characteristic areas. Finally, the regional village-town system is determined, hoping to provide reference and basis for rural facilities arrangement and overall urban and rural planning in suburban villages.

III. DATA AND METHODS

A. RESEARCH CASE AND BASIC DATA

With a total area of 302.2 square kilometers, the Qin and Han New City is located among the urban built-up areas of Xi'an, Xianyang and Konggang New City. It has jurisdiction over 142 administrative villages with a registered population of

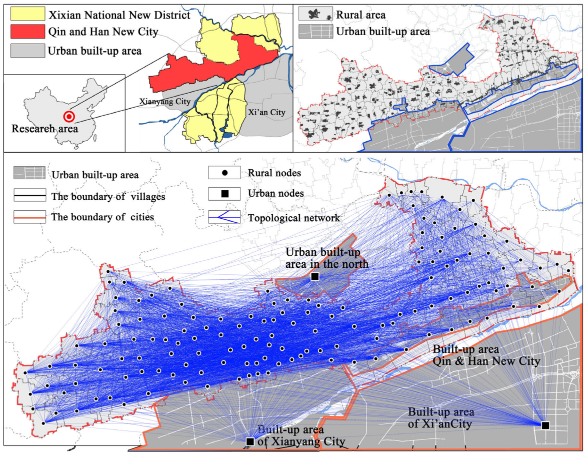


FIGURE 1. **Research object and its topology network diagram of population contact.**

approximately 221,000. The planned new city is in the southwest of the area. At present, urban construction is underway. The present study aims to explore the population mobility between each village and the surrounding cities and villages. With 142 villages and 3 urban built-up areas as nodes and the contact between objects as edges, the topological network diagram of regional population contact is constructed as shown in Figure 1.

The basic data is the 2G, 3G and 4G mobile phone signaling data of China Unicom collected from active and passive interaction between users and the base stations, including turning on/off, making calls, sending and receiving text messages and surfing the Internet, periodic location updates, location changes, conversion between 3G and 4G, etc. The recording time was 28 consecutive days in October 2018 (we also checked the October data by the recording of March). A total of 35 to 40 million records was collected. The records involved 88,000 permanent residents in suburban villages, accounting for 40% of the total registered population. In addition, the data also included the household registration data of 142 administrative villages, which were collected from the household registration offices of towns and streets. The road system data were collected from the Qin and Han New City New City Management Committee. The total area, cultivated land area, per capita income, infrastructure level, public service facility level, historical and cultural resources, and natural resources of the administrative villages was obtained from the basic material compilation in the village layout planning of Qin and Han New City in 2018. To check the regional population data, the actual population data of some regions were collected through the sample survey.

B. ANALYSIS METHOD AND DATA PROCESSING

1) ANALYSIS FRAMEWORK

The overall research framework of ''linkage features - spatial features - system construction'' is shown in Figure 2. Firstly, based on the mobile phone signaling data, the primary linkage analysis method was used to preliminarily determine the influence range and the influence level of urban and rural nodes in the network hierarchy. Secondly, the multiple linkage analysis method was used to measure the influence intensity and the service radius of ''Centrality'' and analyze the relationship between rural nodes. Thirdly, the regional flow spatial features were obtained by analyzing the urbanization potential of rural nodes and urban characteristic regions. Finally, the ''minimum cost'' method based on public service facilities was introduced according to the regional space characteristics to check and improve the regional village-town system.

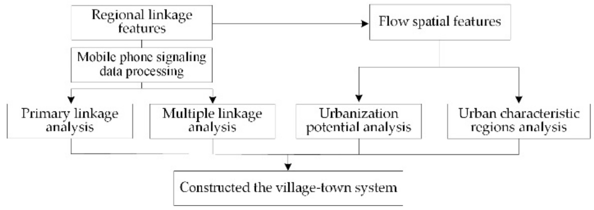


FIGURE 2. **Analysis framework.**

2) LINKAGE FEATURE ANALYSIS METHOD

(1) Cellphone signaling data processing

Urban and rural population mobility were determined in two steps: analyzing users' stay points and the change of stay points. The changes of the stay points were mobility [1]. The stay points were located joint with the ''Intelligent Footprint'' company. Firstly, based on the location, power and coverage of the base stations, the area was divided into some square ''base areas'' (which may overlap). Generally, there were about 3 to 5 base stations in or around the ''base area''. When the user accessed a new base station and continued to contact the next base station within the ''base area'', or frequently cutting back to the original base station (signal overlap), and this state remained unchanged for half an hour, the user was identified as a ''stay point''. The stay point was initially identified to be located in the ''base area''. Secondly, according to the communication frequency and distance between the users in the ''base area'' and their neighboring base stations, the Location centroid algorithm was used to interpolate and calculate more accurate coordinates of the stay points [45]. The permanent stay point should be identified by gradually correcting the coordinate based on the data of next month. In general, the accuracy error of the coordinates of the stay point obtained by interpolation was 200-500 meters [1], [45], and the corrected stop point error was less than 200 meters. There were two kinds of mobility: a user's stay point changed in an hour and the new stop point was identified as the end point; When a user completed a travel but the stay point (within a threshold of 500m) had not changed in an hour, the farthest point he had reached was identified as the end point. If two different nodes recorded stay behaviors of the same user in one day, it was recorded as a flow between nodes (Figure 3). Due to the complex migration characteristics of

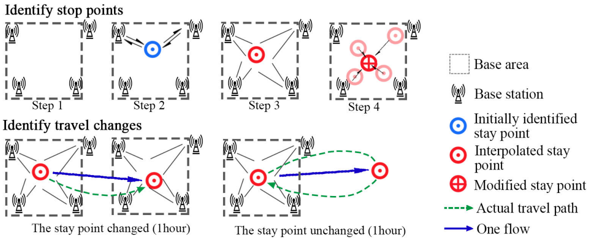


FIGURE 3. "Flow" identification method based oncellphone signaling data.

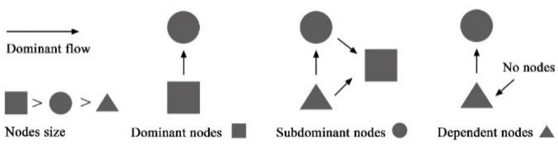


FIGURE 4. Diagram of primary linkage analysis.

suburban areas, multiple "flows" of the same user might be recorded in a day. The "flows" between the nodes in 28 days were counted in the present study.

Where, the 28-day city-village contact flow is X_{l_c}, and the village-village contact flow is $X_{l\_l'}$. The formula is presented as follows:

$$X_{l\_c} = (C, V)_{l\_c} = \sum_{i=1}^{i} X_{l\_c\_i} \quad (1)$$

$$X_{l\_l'} = (L, L')_{l\_l'} = \sum_{i=1}^{i} X_{l\_l'\_i} \quad (2)$$

where: l and l' are the village node numbers (l', l = 0, 1, 2 ... 141), and c is the city node number (c = 142, 143, 144); $X_{l\_c\_i}$ is the contact flow between the village node l and the city node c on the i day, and $X_{l\_l'\_i}$ is the contact flow between the village nodes l and l' on the i day (i = 1, 2 ... 28); $(C,V)_{l\_c}$ indicates that the starting point of the flow is the village and city. $(L, L')_{l\_l'}$ denotes that the starting point is the village l and l'.

(2) Primary linkage analysis in urban and rural areas

The level of urban and rural nodes reflected their positions in spatial interaction. In order to study the regional urban-rural network structure, Nystuen et al proposed the primary linkage analysis (PLA) method [46]. The core idea was to determine the node level according to the flow direction of the maximum flow, that was, the dominant flow. As shown in Figure 4, if the dominant flow of a node flowed to a less important node, the node was called a dominant node. If the dominant flow of a node only flowed to more important nodes, and there was no dominant flow of other nodes flowed into, the node was called a dependent node. When the dominant flow of a node flowed to a more important node, and also had dominant flow of other less important nodes flowed into, the node was called a subdominant node. The importance degree of nodes refers to the relevant references [36], [47]. Based on the external connection strength of urban and rural nodes, the importance degree of the nodes was calculated by the sum of formulas (1) and (2). In general, the largest or the top few dominant flows in suburban villages flowed to the surrounding cities. Therefore, this study should also include the number and direction of rural dominant flows in which urban flow was eliminated as the judgment standard for the "Centrality" of regional villages.

PLA could reflect the clustering and dominance of regional urban and rural nodes. In this study, the dominant flow of the rural node l and the surrounding area m (m = c, l') was calculated. Additionally, the second and third largest dominant flows were also counted as the checking method. Statistical vector was Q_l, and the formula was as follows:

$$Q_l = \{X_{c\_1}, X_{c\_2}, X_{c\_3}, X_{l'\_1}, X_{l'\_2}, X_{l'\_3}\} \quad (3)$$

where X_{c_1} takes the village node l as the end point of the flow, contacts with the city node with the largest flow volume. $X_{l'\_1}$ takes the village node l as the end point of the flow, and contacts with the village node with the largest flow volume.

(3) Multiple linkage analysis in urban and rural areas

Multiple linkage analysis (MLA) was the extended method based on the primary linkage analysis. Compared with the primary linkage flow analysis method, MLA could analyze the influence range and interaction of nodes. It was mainly determined by significant flows, that was, flows were greater than a given threshold. Initially, the flow volume flowing out of each node was arranged from large (X_1) to small (X_k), and the flow expectation set of the nodes was $\{\hat{X}_j\}, j \in K$, K was the set of nodes in the network, and the calculation formula [36], [48] was as follows:

Step 1: $\hat{X}_1 = \sum_{j=1}^{k} X_j, \hat{X}_2 = \hat{X}_3 = \ldots = \hat{X}_k = 0$

Step 2: $\hat{X}_1 = \hat{X}_2 = \frac{1}{2}\sum_{j=1}^{k} X_j, \hat{X}_3 = \hat{X}_4 = \ldots = \hat{X}_k = 0$

Step i: $\hat{X}_1 = \hat{X}_2 = \ldots \hat{X}_i = \frac{1}{i}\sum_{j=1}^{k} X_j, \hat{X}_{i+1} = \hat{X}_{i+2} = \ldots = \hat{X}_k = 0$

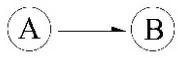
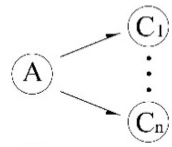
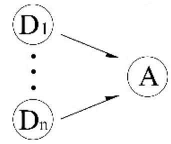
Step k: $\hat{X}_1 = \hat{X}_2 = \ldots \hat{X}_k = \frac{1}{k}\sum_{j=1}^{k} X_j$

Second, the degree of fit between the expected value and the true value of the flow volume was determined by the decision coefficient r^2, and the calculation formula was shown in Equation (4). If the decision coefficient r_j^2 in step j was the largest, the flows before j (include j) were all significant flows.

$$r^2 = 1 - \frac{\sum_{j=1}^{k}\left(X_j - \hat{X}_j\right)^2}{\sum_{j=1}^{k}\left(X_j - \bar{X}\right)^2} \quad (4)$$

According to the number and flow direction of the significant flow, the importance degree and influence range of the village nodes could be judged. Table 1 presented the meanings of the nodes corresponding to different significant flow relationships, which could be taken as a basis for determining the relationship between villages and towns. For example, if there was a certain type of village in the region was the significant flow direction of multiple villages, it had "Centrality" and regional service function, and could be taken as a candidate central village. If two adjacent villages A and B had significant rural flows to each other, they could coordinate development and even merged. If the significant flow of village A only flowed to B, B should be the incorporation destination of A (migration).

TABLE 1. Flow directions and meanings of significant flows.

Description	The significant flow of A only flows to B	The significant flows of both A and B flow to each other	The significant flow of A flows to two or more nodes	The significant flows of two or more nodes flow to A
Spatial structure				
Meaning	Village A has strong dependence on B	When adjacent, village A and B are complementary or dependent.	Potential competition exists between the target villages in village A	Village A has centrality

3) SPATIAL FEATURE ANALYSIS METHOD

The analysis of flow spatial characteristics involved urbanization potential and development trend. Urbanization level was analyzed by employing the method of studying information flow in American metropolitan areas proposed by James O. Wheeler [49]. The villages with urbanization potential were classified by the natural breakpoint method [41]. Rural urbanization potential C_l was calculated as follows:

$$C_l = ln\frac{X_{l\_c}}{X_{l\_l'}} \tag{5}$$

where X_{l_c} and $X_{l\_l'}$ were calculated by Formulas (1) and (2).

The previous research of our research team demonstrated that there existed no inevitable connection between population density and rural development potential, but the linkage strength was related [1]. Therefore, this study distributed the flow volumes of villages and cities to each grid space by kernel density interpolation method, and identified hot regions and development corridors [44]. Based on rural administrative boundaries, relevant planning and major functional areas, urban development trends and urban characteristic areas were predicted.

4) CONSTRUCTION METHOD OF VILLAGE-TOWN SYSTEM

In the suburban village-town system, the "central village" had the functions of connecting urban functions, driving regional development, and serving the surrounding villages as well as had a concentrated advantageous resource allocation [50], [51]. To establish a village-town system, it was necessary to highlight the leading role of the "central village" and control the cost while maximizing the utility. The "minimum cost" algorithm should be introduced to improve the layout results. In suburban villages, the villagers were primarily concerned with the equalization of educational facilities in urban and rural areas [52]. Primary schools, as the major public facilities with high frequency of use by villagers and also the public facilities with the farthest daily service radius in rural areas [53], [54], often served as the service radius threshold of the "minimum cost" algorithm [55], [56]. Field research results indicated that the commuting time that could be endured by local residents was 15∼25 minutes, and the commuting mode was motor vehicles (the local motor vehicle penetration rate was as high as 91%, and its speed was 15km/h). The "minimum cost" algorithm based on the primary school service radius was completed on the GIS platform to establish regional residential areas and road network models. Referring to the service radius index of the primary school in the adjacent Jingyang County [53], high-quality primary schools would be established in villages with "Centrality" feature as the candidate central village. The radius was calculated from 3750m to 6250m, and increased by 50m each time. The calculate could be cut off until the full coverage of urban and rural public services as well as the serviced population of each "central village" was over 4000 (the minimum indicators of population that need for primary school). The radius for cut off was the "minimum cost" of public service. According to the result, the number of the candidate central villages would be increased or decreased to determine the regional village-town system of Qin and Han New City.

IV. ANALYSIS RESULTS

A. REGIONAL LINKAGE FEATURES

1) REGIONAL LINKAGE ANALYSIS RESULTS

With the regional cities and villages nodes as the end points, the contact flows between villages and cities were calculated in pairs and the contact flows in 28 days were summarized as shown in Figure 5. The flows from villages to cities accounted for 73.4% of the total urban-rural linkages, indicating that cities strongly affected the development of villages. The contact of Xi'an, Xianyang, and the northern city with villages accounted for 53.2%, 29.3% and 17.4%, respectively. Based on the attraction scale of the village nodes in the network, the importance of the nodes was determined. The natural breakpoint method [41] was employed to divide the 142 villages into five important degrees. Through checking according to the basic data, the rural areas with high importance were the main employment, tourism and transportation hubs in Qin and Han New City. The rural classification and main functional areas were presented in Figure 6.

TABLE 2. Influence degree and influence range of surrounding cities on villages.

City	Villages influenced by dominant flow	Villages influenced by the second dominant flow	Villages influenced by the third dominant flow	Maximum influence radius
Xi'an	51	46	18	28.3km
Xianyang	51	22	14	15.2km
Northern city	25	34	25	6.2km

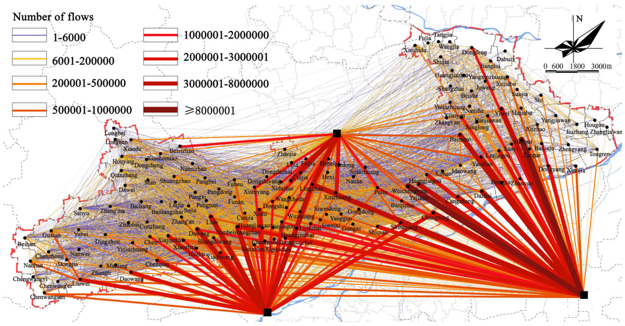


FIGURE 5. Analysis of urban-rural contact strength in Qin and Han New City.

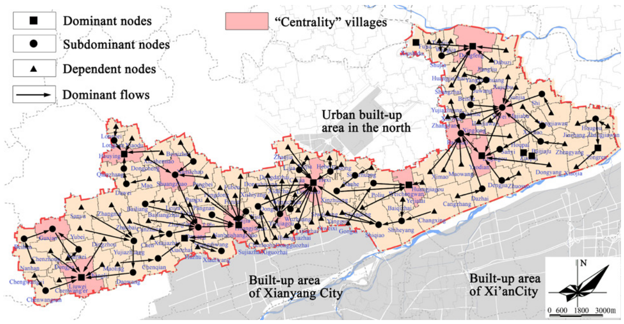


FIGURE 8. Primary linkage analysis results based on rural dominant flows.

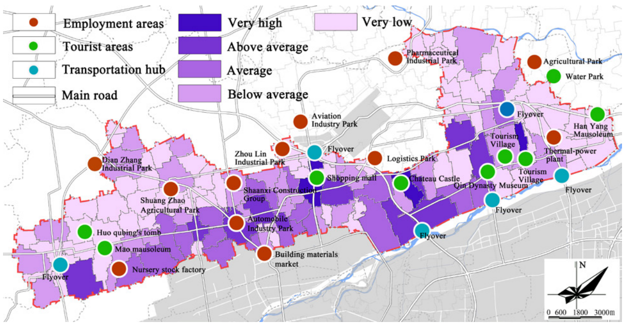


FIGURE 6. Main functional areas and rural node importance degree.

FIGURE 7. Primary linkage analysis results based on urban and rural dominant flows.

2) PRIMARY LINKAGE ANALYSIS RESULTS

The dominant flow of villages and cities in Qin and Han New City were analyzed to determine the influence degree and influence range of cities on villages, as presented in Figure 7 and Table 2. Among the 142 administrative villages in Qin and Han New City, the targets of rural dominant flows of 127 villages were cities, and 89.4% villages were within the strong influence range of cities. Through analyzing the commuting distances of the farthest dominant flow from villages to cities, the maximum influence radiuses of the regional urban centers in Xi'an, Xianyang and northern urban areas were 28.3km, 15.2km and 6.2km, respectively. The regional urban-rural contact volume was positively correlated with the maximum impact radius and the size of the surrounding cities. According to the primary flow analysis results, the dominant linkage flows between 40 villages and the surrounding cities were much greater than those with other rural areas. They were generally located at urban fringe or the border areas, having the initial functions and characteristics of cities. In addition, the villages which frequent contact were also surrounding other cities, and the contact between villages reflects trans-regional characteristics.

The dominant flow of regional villages was analyzed to determine the centrality and rank of villages at the network level. According to the analysis results in Figure 8, there were 12 dominant nodes, 42 subdominant nodes and 88 dependent nodes in the region. In the analysis of dominant nodes, two dominant villages near the Xi'an built-up area on the southeast side of the region had a high degree of contact with cities. However, the contact with the surrounding villages was weak without dominant flow from other sub-villages. It could be preliminarily determined that they had a tendency of integrating to cities. There were three such villages in Qin and Han New City. The remaining nine dominant villages were the end points of regional rural flows, and seven of them were judged to have "Centrality" due to the large number of dominant flows or regional centralized flow direction.

TABLE 3. Village "Centrality" analysis results.

Node type	Name of the village	Dominant flow	Second dominant flow	Third dominant flow	Judgment reason
Dominant	Nanbeishangzhao	10	0	9	Large number of dominant flows
	Liuwei	7	6	1	Large number of dominant flows
	Houying	4	1	2	Regional core
	Dongfeng	6	3	1	Large number of dominant flows
	Weichengwan	4	1	2	Regional core
	Yaodian	5	2	4	Large number of dominant flows
	Lingzhao	13	14	5	Large number of top two dominant flows
Subdominant	Yanjiagou	5	6	4	Large number of dominant flows
	Baimiao	6	7	2	Large number of top two dominant flows
	Yiwei	8	2	4	Large number of dominant flows
	Dawang	6	3	5	Large number of third dominant flows
	Shuangzhao	3	3	7	Large number of dominant flows
	Guxian	2	4	5	Regional core

Since some subdominant villages were also the concentrated flow direction of regional dominant flows, the rural areas to which the second dominant and third dominant flows flowed should be counted to determine their level in the network system.

A total of 13 villages had "Centrality" in this region (Table 3). The analysis results demonstrated that "Centrality" villages were generally located in the flow path from secondary villages to the city which biased toward the city as well as regional centers far from cities. "Centrality" villages had strong regional concentration characteristics and were the ending point of regional people flow. The village-village dominant flow line in the network hierarchy fitted well with the main road network, and 76.9% "Centrality" villages were located around important intersections.

3) MULTIPLE LINKAGE ANALYSIS RESULTS

Primary flow analysis could simplify the regional urban-rural linkage network structure, yet lead to the loss of information about the important edge, which flow was second only to the dominant flow but significantly superior other flow [36]. The multiple linkage analysis method could analyze the flow which exceeds a certain threshold as a significant flow to solve the above problem effectively. The central village in the village-town system should have the ability to drive the development of the surrounding area, and provide high-quality public services. Consequently, the more the significant flow of other villages flowed to the central village, the more important it was in the network level, should develop with superior resources. For the villages in Qin and Han New City, since the inflow of cities was much larger than that of the surrounding villages, the significant flows of cities and villages should be calculated and summarized separately.

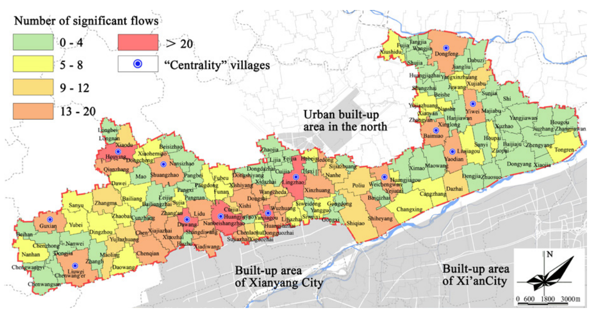


FIGURE 9. Multiple linkage analysis results.

The multiple linkage analysis results were shown in Figure 9, which checked the judgement of the "Centrality" village by the dominant flow. Based on the number of significant flows, the regional network hierarchy was divided into five levels. The "Centrality" village was located in the first two levels, and the number of influent significant flows was greater than 12. The "Centrality" village only had regional centrality. It was the direction of regional significant flow and also had the maximum number of flows compared with the surrounding areas. The rural areas in the urban fringe had more significant flows. Some "Non-centrality" villages even had more significant flows than the "Centrality" villages in suburbs and this phenomenon was attributed to the attraction of cities to regional population.

Based on the direction of significant flow, the main affected scope (villages) of the "Centrality" villages was further determined. If a village had two significant flows flowing to different "Centrality" villages, the one with larger significant flow was the village to which it belonged. There were 13 centralized areas and 1 non-centralized areas, which can be found Figure 10. "Centrality" villages had a large

TABLE 4. Analysis results of influence intensity and influence scope of "Centrality" villages.

Location	Name of village	Number of significant flows	Number of influence villages	Maximum influence radius	Average influence radius
Urban fringe	Nanbeishangzhao	37	14	7400m	2800m
	Dawang	27	10	5600m	3900m
	Yanjiagou	27	6	4800m	4100m
	Lingzhao	36	22	9200m	5100m
Non-urban fringe	Guxian	14	5	4000m	3100m
	Liuwei	15	11	6300m	3500m
	Houying	23	8	5500m	3300m
	Shuangzhao	17	4	3300m	2500m
	Weichengwan	13	6	6100m	4100m
	Yaodian	13	8	7200m	4000m
	Yiwei	17	11	6100m	3400m
	Baimiao	16	7	5800m	5200m
	Dongfeng	13	9	4800m	3200m

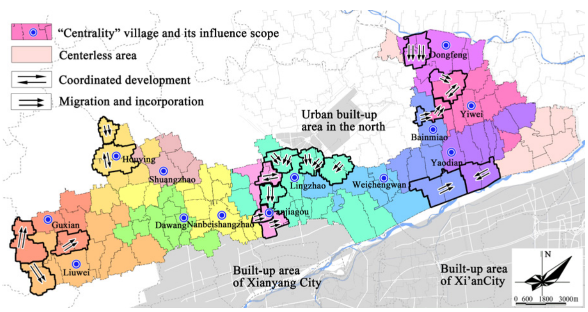


FIGURE 10. Influence scope of "Centrality" villages and relations.

difference in influence ability. The largest "Centrality" village was Lingzhao, which was located in the regional center and had 22 villages. The smallest "Centrality" village was Shuangzhao, located in the northwest of the region and had 4 villages. The "Centrality" villages in the region were generally not located in the geometric center, yet in the regional contact hub or middle and lower reached areas of urban-rural linkages. Although some villages were located in remote areas or enclaves, they make frequent communication with the "Centrality" villages, and the commuting time was equivalent to that of other villages. Combined with the actual commuting distance between rural settlements, the influence intensity and the service radius of "Centrality" villages could be obtained. As shown in Table 4, there were 4 "Centrality" villages in the urban fringe area, which had 27-37 significant flows and affected 6-22 villages. The average maximum influence radius was 6,750 meters. There were 9 non-urban fringe "Centrality" villages, which had 13-23 significant flows and affected 4-11 villages. The average maximum influence radius was 5400 meters. The "Centrality" villages in the urban fringe had higher significant flow intensity and better regional influence ability. The average significant flow doubled that of the "Centrality" villages on the non-urban fringe. The number of affected villages was 1.7 times, and the influence radius was 1.25 times. However, the difference in the average influence radius was small. Based on the flow of significant flows between villages, their relationship could be further judged. As shown in Figure 10, 19 groups of villages had the merger potential. They were either located in the outer suburbs and driven by urbanization (farther one immigrated to the nearer one) or in the urban fringe, which led to the extremely complex urban-rural linkages and the urbanization trend. There were 3 groups of rural areas with the synergistic development potential. They either had similar sizes, resources and traffic conditions, or shared industrial, commercial facilities and infrastructure.

B. FLOW SPATIAL FEATURES

1) URBANIZATION POTENTIAL ANALYSIS RESULTS

The villages with the urbanization potential were shown in Figure 11, which was divided into six levels. The average urbanization potential of the villages was 0.68, and the urban-rural linkages in villages on both sides of the value were balanced. The villages in the first two levels had outstanding urbanization potential. Totally, they were 40 such villages, accounting for 28.6% of the total. The areas with high urbanization potential were mainly concentrated in the urban fringe of Xi'an, Xianyang and the northern city; Qin and Han New City was carrying out urban construction areas and its northern affected areas. Among the 17 villages with the urbanization potential at the first level, 14 villages had carried out urbanization construction within its scope of administration, and 8 rural settlements have completed the demolition and resettlement work. The 23 villages with

TABLE 5. Structure of village-town System in Qin and Han New City.

Village-town system type	Urbanized central village	Urbanized village	Central villages	Reserved villages	Demolished villages	Total
Urbanized central village - urbanized village - village	7	37	--	29	11	84
Central village - village	--	--	7	43	8	58

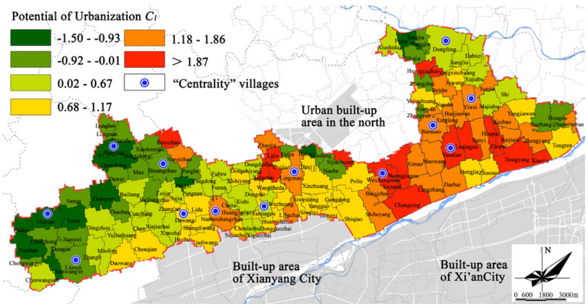


FIGURE 11. Villages with urbanization potential.

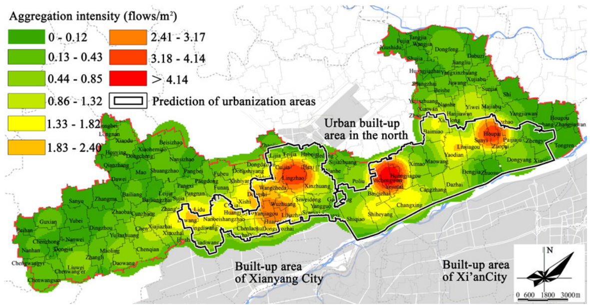


FIGURE 12. Regional flow space aggregation intensity and urbanization feature regions.

the urbanization potential at the second level were mainly concentrated in or around large industrial parks, large commercial facilities, leisure and holiday attractions, ruins & museums, and tourist villages.

2) URBAN CHARACTERISTIC REGIONS ANALYSIS RESULTS

Based on the urban-rural contact intensity, with the average flow impact distance of 2700m as the search radius, and 100*100m as the smallest unit, the kernel density difference analysis was performed in GIS [40]. The flow space aggregation intensity was presented in Figure 12. The regional flow space was characterized by hierarchy, multi-center, urban-rural differences, forming three first-level cores of Lingzhao, Weichengwan and Houpai, and three second-level cores of Dawang, Nanbeishangzhao and Yanjiagou. There were two urban development corridors from Xianyang to the northern city and along the new urban built-up area of Qin and Han. The urban areas and rural areas in the region had obvious differences. Based on the analysis results of urbanization potential and related urban and rural planning, by referring to the multi-core urbanization development model in suburbs [57], [58], the urbanization characteristic regions of Qin and Han New City were determined, which can be found in Figure 12. A total of 55 villages was covered. To be specific, 7 of the 13 "central" villages were located in urbanized areas, and the affected areas were divided into three levels of "urbanized central village - urbanized village - village". Other 6 villages were located in non-urbanized areas, and the affected areas have a "central village - village" two-level village-town system structure.

C. RESULTS OF VILLAGE-TOWN SYSTEM

According to the above analysis, primary schools could be established in 13 "Centrality" villages. The maximum

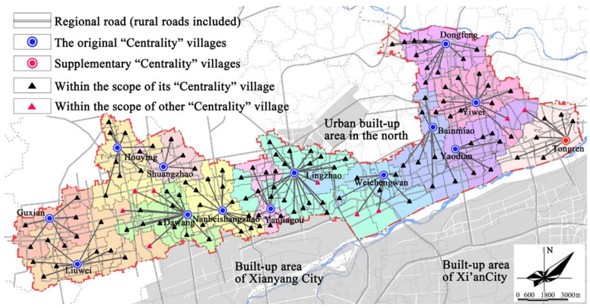


FIGURE 13. Evaluation of public service capacity of "Centrality" villages.

service radius was 6000 meters. As shown in Figure 13, the service range of the originally selected centrality village could not satisfy the needs of full coverage of public service, and it was necessary to add a central village. Based on the primary linkage and multiple linkage analysis results, the central village added should be Tongren, located in the southeast of the region. The study results demonstrated that 93.7% of the serviced villages were in the "Centrality" village service area, and could both meet the needs of service radius and commuted preferences.

The result of village-town system was shown in Table 5. There were two types of village-town systems and five types of rural guidance in the Qin and Han New City. The three-level system of "urbanized central village - urbanized village - village" was located on the side of the cities in the region, covering seven urbanization central villages and their range of influence. The main public services in the region were provided by the urbanized central villages. Urban facilities allocation standards were adopted. All of public service facilities in the region were shared by villages and cities. Urbanized villages should be urbanized recently, and the

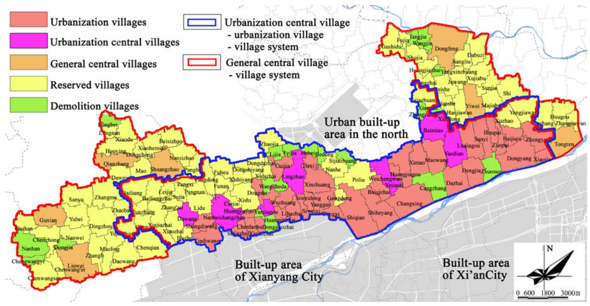


FIGURE 14. **Development guidelines for rural classification under two types of village-town systems.**

general village should develop towards cities gradually. The two-level system of ''central village - village'' was located on the west and north sides of the region, covering seven central villages and their range of influence. Although basic public services were provided by the central villages, important public services were provided by cities. The general village should gradually develop towards regional central village.

Development guidelines for rural classification under two types of village-town systems were shown in Figure 14. The detailed construction guidelines were as follows:

① Urbanized central village. They were taken as the regions that relieve the population and function of surrounding cities, developing business and service industries, and should drive regional development. Public facilities such as hospitals, vocational schools, primary and secondary schools, cultural and sports centers, large department stores, and nursing homes would be provided to achieve the equalization of public services in urban and rural areas.

② Urbanized villages. They should promote the construction of urban communities and building the community public service facilities. Encourage the land transfer, gradually introduce secondary and tertiary industries; should provide skill training and guide the urbanization of rural residents. A certain proportion of low-cost buildings would be established recently in local areas to solve the housing needs of migrant workers.

③ Central Villages. They should optimize the industrial structure, improve the industry quality, provide preferential condition, guide the gathering of surrounding villages, and build new rural communities. Besides, kindergartens and primary schools, the old-age service stations, health service centers, supermarkets, farmers' markets and other public facilities should be deployed according to rural standards to serve the surrounding villages.

④ Reserved villages. They should optimize industrial structure, improve farming methods, upgrade basic public services and infrastructures, and improve the rural living environment which could reflect unique characteristics. Kindergartens, elderly activity rooms, health stations and outdoor event venues should be established.

⑤ Demolished villages. Villages gradually merge into the target village (Figure 10). Residents could work in cities and towns through the land transfer. Additionally, thery could also farm in other villages, through land replacement. Housing construction should be restricted, and public facilities should meet the basic needs of daily life.

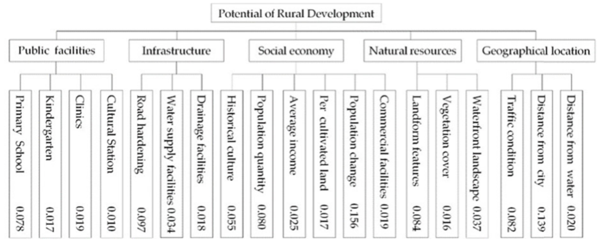


FIGURE 15. **Potential evaluation index system and weight of villages in Qin and Han New City.**

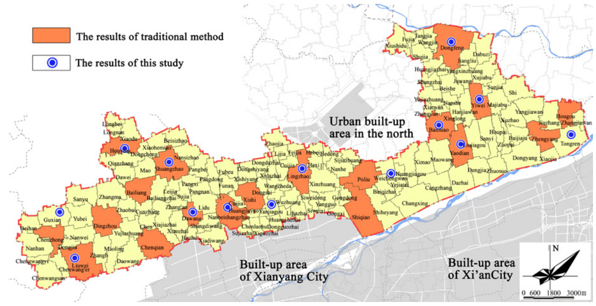


FIGURE 16. **Comparison of the results of the proposed method and traditional methods.**

V. DISCUSSIONS AND CONCLUSION

A. DISCUSSIONS

1) SIMILARITIES AND DIFFERENCES BETWEEN THIS RESEARCH AND TRADITIONAL RESEARCH

People's space-time behaviors obtained through mobile phone signaling analysis could reflect the contact level [59], space-time characteristics and development potential [60], [61]. It could also comprehensively reflect regional development potential and public service level. Since the previous research on mobile phone signaling had not been applied in village-town systems, the present study needed to be checked by the results obtained by the traditional ''potential evaluation + minimum cost'' method. The influencing factors of the suburban village-town system generally included public service facilities, infrastructure, social economy, natural resources and geographical location, which was also the main evaluation indicators of traditional methods [29], [34]. The evaluation index and weight of Qin and Han New City were shown in Figure 15, and the factor weigh was obtained by the analytic hierarchy process (AHP) [29]. The traditional methods found 19 central villages. As shown in Figure 16, 10 of the 14 central villages obtained in the current work had the same results as the traditional methods, and the remaining four were adjacent to the villages obtained by employing the traditional methods. The villages with the same results generally had larger scales and the villages adjacent had small differences among in their respective evaluation systems. Due to insufficient population and arable land, the villages with smaller scales but larger contact amount got score lower in traditional methods. This study mainly measured the "Centrality" of the village-town system. However, the centrality of villages was not directly related to the size. The research showed that the village-town system based on the network hierarchy could accurately obtain the result of central village, effectively determined the level hierarchy of villages, and had higher resource allocation efficiency. The outstanding advantage referred to that it could identify villages which were small in size but had "Centrality" in the region. The most suitable application object of the proposed method was the region with little differences in village size. For areas with obvious differences in village size, the method should be checked with the traditional "potential evaluation" method.

2) APPLICATION OF MOBILE PHONE SIGNALING DATA IN VILLAGE-TOWN SYSTEM PLANNING

Based on the mobile phone signaling data, the population property and time-space distribution information in suburban villages could be obtained comprehensively, dynamically and accurately [62]–[64], and the contact level could be accurately measured. However, there still remained a problem of recognition accuracy. This study had some errors in taking the changes of stay point as the judgment standard of "flow". Although the flow of a user per day was within a limited range, there were 1-24 flows theoretically. Therefore, it was challenging to estimate the actual population flow from contact flow. The error was due to the use of desensitized cell phone signaling data. For the sake of privacy protection, the desensitized data could not reflect personal travel trajectories. Relevant research indirectly identified the flow of people with certain characteristics by determining the appearance conditions and intervals of users at different moments, identifying resident populations [1], permanent residences [1], [65], workplaces [65], [66], shopping populations [67], travel modes [68], etc. For the research on mobile phone signaling data of Qin and Han New City, our team had accurately identified the population composition, commuting characteristics, and urban-rural linkage characteristics of the region. Due to the complex composition of the regional population, the large number of external populations, the variety of travel modes as well as unfixed time for work, shopping and rest, the relevant human flow research would have large errors in local applications. However, by analyzing the flow amount, for the construction of regional network hierarchy, the study of regional village-town system could still obtain similar results compared with by actual population flow [41].

3) APPLICATION OF PRIMARY LINKAGE AND MULTIPLE LINKAGE ANALYSIS IN VILLAGE-TOWN SYSTEM PLANNING

The primary linkage analysis aimed to study the maximum flow and the flow direction of nodes in the network. It could not only effectively determine the intensity and direction of urban and rural population flow, the influence radius and the influence degree of cities, but also predict the levels and development trends of villages and cities. This study optimized the recording of multiple flows by Li *et al.* [36]. The results demonstrated that recording the inflow of significant flows from other villages could better reflect the importance of rural nodes in the region than recording significant flows in the received flow. It could effectively avoid the neglected the needs of vulnerable villages caused by overpopulation and resource-rich villages which led the proportion of significant flows, reflected the idea of "equality" in planning, and better guided the equalization of regional resources. Since the two analysis methods had different emphases, the results would be slightly different. Therefore, they should be jointly used in research. In the existing village-town system, the main role of "central villages and towns" was to provide goods and daily services to the surrounding villages as well as to guide the development of the region. It was essentially evolved from the "Central geographic model" proposed by W. Christaller. The existing research on village-town system planning gradually developed from the "Central geographic model" into a "Life circle model". After determining the regional core, the public service facilities would be arranged step by step in the inner and outer circles [56], [69]. The existing research methods of the village-town system based on "potential evaluation" or "minimum cost" selected the center of the living circle, divided the circle and determined the reasonable service radius, which was a continuation of the central geographic model. As shown in Fig. 16, the central villages and towns selected by the traditional method were biased toward the geometric center of the region. However, in the suburban areas of megacities or national new districts, the urban-village relationship and the village-village relationship had been beyond the scope of the central geographic model. Central villages were generally not in the geometric center of the region, and were located in an area with dense urban-rural flow. Public service facilities might not satisfy the principle of proximity, which might be distributed in remote enclaves or even cities based on road links. In such village-town system, the analysis method of primary linkage and multiple linkage would exert an important role.

4) APPLICATION OF THE RESEARCH IN URBAN AND RURAL PUBLIC SERVICE ALLOCATION

According to the survey results, it could be found that the vacancy rate of rural public service facilities was extremely high. For example, only 18 of the 44 primary schools in the region have reached the used capacity. Field interviews showed that rural households tended to use primary schools in further urban fringe areas. The allocation of public facilities in suburban villages depended largely on villagers' preferences rather than commuting distances. Based on usage preferences, the equipped public service facilities helped to the shrewd used of urban and rural public service facilities. Regional public services were mainly provided in urban fringe, which had the following advantages: ① Rural residents enjoy urban public services with minimal commuting distance; ② through bidirectional flow of urban and rural population [1], rural residents could enjoy urban public services during commuting hours, like sending children to school on the way to working; ③ rural areas had less serious traffic congestion. Although the theoretical commuting distance was greater, the actual commuting time was equivalent to that of urban areas. In this study, through analyzing linkage features and spatial features, and identifying urbanized central villages which provided regional services were also located in the fringe of urbanized areas.

B. CONCLUSION

Based on mobile phone signaling data, the research adopted theory of network hierarchy and the analysis method in transportation engineering field to measure the centrality of village and it's affected range through primary linkage analysis and multiple linkage analysis. Moreover, the village-town system was established according to urbanization potential and urban characteristic areas by taking Qin and Han New City as an empirical case. The results had shown that village-city contacts account for 73.4% of total contacts, and 89.4% villages were strongly influenced by cities. The influence radiuses of the surrounding Xi'an, Xianyang and the northern city were 28.3km, 15.2km and 6.2km, respectively. Villages in urban fringe began to have urban functions and characteristics, and external contact reflected cross-regional characteristics. The 13 "Centrality" villages were generally located in the flow path from secondary villages to the city which biased toward the city, or regional centers far from cities. They had the characteristics of convenient transportation and regional concentration. The average significant flow of "Centrality" villages on the urban fringe doubled the "Centrality" villages on the non-urban fringe, the number of influenced villages was 1.7 times, and the maximum affect radius was 1.25 times. However, they had small differences in the average influence radius. There were 19 groups of villages with merger potential, and 3 groups of villages with synergistic development potential. The rural areas with high regional urbanization potential were mainly concentrated on the fringe of three cities and the areas influenced by the new city. There were 55 villages which preliminary had urbanization characteristics. Finally, in the Qin and Han New City, a village-town system with "urbanized central village - urbanized village - village" and "central village - village" was established, which would be guided by five types of villages.

Compared with the previous research, firstly, the research methods of the existing village-town system were extended. The original intention of the village-town system planning was to centrally allocate superior resources and guided rural development smartly. Under the strong influence of cities, people's flow behaviors could reflect the complicated urban-rural relationship in the suburban areas. The disclosure of villagers' commuting preferences made up for the waste of resource allocation caused by the potential evaluation based on objective factors. Secondly, the object of network level was further expanded. The network level was analyzed from the perspectives of international aviation and the port system in the field of transportation engineering, which was gradually applied to study city-town systems and even village-town systems in the field of urban planning. Moreover, a more complete information analysis system of goods flow, information flow and people flow could be formed. Finally, this study had also solved the problem of village-town system planning under the strong influence of cities, made reasonable speculations on the urbanization characteristic areas, and determined the development guidelines for each village. Moreover, the research results could provide reference and basis for studying spatial structure optimization in suburban areas, public service facilities layout, urban and rural development, rural policy formulation, urban boundary speculation and demarcation.

Our team will further introduce urban and rural ecological flow, information flow and material flow into the network, and analyze the robustness and vulnerability of urban-rural networks based on complex network model. Moreover, by strengthening the ability of urban-rural network system to resist urban uncertain disturbances, the resilience of regional villages will be improved under the influence of severe urbanization. However, the research on the influence mechanism of urban and rural flow prediction, rural space characteristics, contact flow on villagers' livelihood also requires field research and analysis of villages in areas with different characteristics.

REFERENCES

[1] J. Zhou, Q. Hou, and W. Dong, "Spatial characteristics of population activities in suburban villages based on cellphone signaling analysis," *Sustainability*, vol. 11, no. 7, p. 2159, Apr. 2019. doi: 10.3390/su11072159.

[2] B. Dalal-Clayton, D. Dent, and O. Dubois, *Rural Planning in Developing Countries*. London, U.K.: Earthscan, 2003, pp. 7–29. doi: 10.4324/9781849774277.

[3] P. G. Hall and D. Hay, *Growth Centres in the European Urban System*. vol. 72, no. 3. London, U.K.: Heinemann Educational Books, 1980, p. 360. doi: 10.2307/214534.

[4] X. J. Yang, "China's rapid urbanization," *Science*, vol. 342, pp. 310–311, Oct. 2013. doi: 10.1126/science.342.6156.310-a.

[5] T. Scharping, "Urbanization in China since 1949," *China Quart.*, vol. 109, pp. 101–104, Mar. 1987. doi: 10.1017/S0305741000017495.

[6] T. Yang, H. Pan, G. Hewings, and Y. Jin, "Understanding urban sub-centers with heterogeneity in agglomeration economies—Where do emerging commercial establishments locate?" *Cities*, vol. 86, pp. 25–36, Mar. 2019. doi: 10.1016/j.cities.2018.12.015.

[7] D.-Y. Qu, J.-S. Zhuang, X.-F. Chen, and L. Hao, "Research on the impact of suburban urbanization on traffic in central area," in *Proc. 3rd Int. Conf. Digit. Manugacture Autom. (ICDMA)*, Guilin, China, Jul./Aug. 2012, pp. 711–715. doi: 10.1109/ICDMA.2012.168.

[8] Y. Pan and L. Hong, "Out of the plight of 'passive urbanization' by mid-western metropolitan suburban areas in China," *Urban Planning Forum*, vol. 4, pp. 42–48, May 2013. doi: 10.3969/j.issn.1000-3363.2013.04.007.

[9] Q. Fan and A. Guo, "Radiation power of national new area and its formation mechanism," *Reform Econ. Syst.*, vol. 5, pp. 46–51, Nov. 2018.

[10] D. Xu and G. Hou, "The spatiotemporal coupling characteristics of regional urbanization and its influencing factors: Taking the yangtze river delta as an example," *Sustainability*, vol. 11, no. 3, p. 822, Feb. 2019. doi: 10.3390/su11030822.

[11] M. Chen, W. Liu, and D. Lu, "Challenges and the way forward in China's new-type urbanization," *Land Use Policy*, vol. 55, pp. 334–339, Jul. 2016. doi: 10.1016/j.landusepol.2015.07.025.

[12] E. Kerselaers, E. Rogge, E. Vanempten, L. Lauwers, and G. Van Huylenbroeck, "Changing land use in the countryside: Stakeholders' perception of the ongoing rural planning processes in Flanders," *Land Use Policy*, vol. 32, pp. 197–206, Oct. 2013. doi: 10.1016/j.landusepol.2012.10.016.

[13] X. Martínez-Filgueira, D. Peón, and E. López-Iglesias, "Intra-rural divides and regional planning: An analysis of a traditional emigration region (Galicia, Spain)," *Eur. Planning Studies*, vol. 25, no. 7, pp. 1237–1255, May 2017. doi: 10.1080/09654313.2017.1319465.

[14] B. P. Frederic, "Rural planning and development in the United States," *Econ. Geogr.*, vol. 66, no. 1, pp. 103–105, Jan. 2016. doi: 10.2307/144115.

[15] H. Thomas, "Town and country planning in the UK 15th edition and planning in the UK. An introduction," *Planning Theory Pract.*, vol. 16, no. 4, pp. 594–599, Oct. 2015. doi: 10.1080/14649357.2015.1082227.

[16] A. Bronstert, S. Vollmer, and J. Ihringer, "A review of the impact of land consolidation on runoff production and flooding in Germany," *Phys. Chem. Earth*, vol. 20, nos. 3–4, pp. 321–329, Jun./Aug. 1995. doi: 10.1016/0079-1946(95)00044-5.

[17] A. van den Brink and M. Molema, "The origins of Dutch rural planning: A study of the early history of land consolidation in The Netherlands," *Planning Perspect.*, vol. 23, no. 4, pp. 427–453, Sep. 2008. doi: 10.1080/02665430802319005.

[18] H. Dadashpoor, P. Azizi, and M. Moghadasi, "Land use change, urbanization, and change in landscape pattern in a metropolitan area," *Sci. Total Environ.*, vol. 655, pp. 707–719, Mar. 2019. doi: 10.1016/j.scitotenv.2018.11.267.

[19] Y. Chen and S. S. Rosenthal, "Local amenities and life-cycle migration: Do people move for jobs or fun?" *J. Urban Econ.*, vol. 64, no. 3, pp. 519–537, Nov. 2008. doi: 10.1016/j.jue.2008.05.005.

[20] P. Wang, A. L. Elliott, X. Chen, B. Yu, and J. Gong, "Social capital associated with quality of life mediated by employment experiences: Evidence from a random sample of rural-to-urban migrants in China," *Soc. Indicators Res.*, vol. 139, no. 1, pp. 327–346, Mar. 2017. doi: 10.1007/s11205-017-1617-1.

[21] J. D. Kasarda, "The impact of suburban population growth on central city service functions," *Amer. J. Sociol.*, vol. 77, no. 6, pp. 1111–1124, May 1972. doi: 10.1086/225260.

[22] A. T. Salau, "River basin planning as a strategy for rural development in Nigeria," *J. Rural Stud.*, vol. 2, no. 4, pp. 321–335, Nov. 1986. doi: 10.1016/0743-0167(86)90030-6.

[23] M. R. Wadodkar and T. Ravisankar, "Soil resource database at village level for developmental planning," *J. Indian Soc. Remote Sens.*, vol. 39, no. 4, pp. 529–536, Dec. 2011. doi: 10.1007/s12524-011-0095-1.

[24] J. S. Jeong, L. García-Moruno, and J. Hernández-Blanco, "A site planning approach for rural buildings into a landscape using a spatial multi-criteria decision analysis methodology," *Land Policy*, vol. 32, pp. 108–118, May 2013. doi: 10.1016/j.landusepol.2012.09.018.

[25] A. Bosshard, "A methodology and terminology of sustainability assessment and its perspectives for rural planning," *Agricult. Ecosyst. Environ.*, vol. 77, nos. 1–2, pp. 29–41, Jul. 2000. doi: 10.1016/s0167-8809(99)00090-0.

[26] S. Brooks, "Growth of tourism urbanisation and implications for the transformation of Jamaica's rural hinterlands," in *Emerging Urban Spaces*. Berlin, Germany: Springer, Feb. 2018, pp. 129–148. doi: 10.1007/978-3-319-57816-3_7.

[27] D. Turnock, "Tourism in Romania: Rural planning in the Carpathians," *Ann. Tourism Res.*, vol. 17, no. 1, pp. 79–102, Sep. 1990. doi: 10.1016/0160-7383(90)90116-9.

[28] Y. Liu, J. Fan, C. Li, H. Hou, and Y. Liu, "Town-based quantitative analysis of the town-and-village hierarchy system using an improved gravity model," *Res. Agricult. Modernization*, vol. 37, no. 1, pp. 158–165, Jan. 2016. doi: 10.13872/j.1000-0275.2015.0179.

[29] Y. Duan, J. Zhou, X. Zhang, and Q. Hou, "Layout planning for villages in river valley area between mountains in southeast of gansu," *Boletin Tecnico/Tech. Bull.*, vol. 55, no. 5, pp. 271–277, Jul. 2017. doi: 10.13872/j.1000-0275.2015.0179.

[30] S. Banerji and H. B. Fisher, "Hierarchical location analysis for integrated area planning in Rural India," *Papers Reg. Sci. Assoc.*, vol. 33, no. 1, pp. 177–194, Dec. 1974. doi: 10.1007/BF01943644.

[31] R. Baggio, N. Scott, and C. Cooper, "Network science: A review focused on tourism," *Ann. Tour. Res.*, vol. 37, no. 3, pp. 802–827, Jul. 2010. doi: 10.1016/j.annals.2010.02.008.

[32] Y. Hui, Z. He, E. Ma, and Z. Hui, "Study on the town-and-village system based on interpersonal contact in loess hilly-gully region: A case study in Angou Town, Yan Chang County, Yan'an," *Hum. Geogr.*, vol. 29, no. 1, pp. 108–112, Feb. 2014. doi: 10.13959/j.issn.1003-2398.2014.01.010.

[33] R.-Y. Zhang, J.-C. Xi, S.-K. Wang, X.-G. Wang, and Q.-S. Ge, "Village network centrality in rural tourism destination: A case from Yesanpo tourism area, China," *J. Mountain Sci.*, vol. 12, no. 3, pp. 759–768, Oct. 2014. doi: 10.1007/s11629-014-3129-7.

[34] X. Yang, X. He, X. Mao, and C. He, "Optimization of rural residential land from the urban-rural linkage perspective: A case study of Chongqing," *Acta Scientiarum Naturalium Univ. Pekinensis*, vol. 52, no. 2, pp. 336–344, Mar. 2016. doi: 10.13209/j.0479-8023.2015.132.

[35] W. Ma and Y. Chai, "Spatial-temporal Figures of suburban workers' daily activities from the perspective of employment suburbanization: Case of Shangdi area in Beijing City," *Areal Res. Develop.*, vol. 36, no. 1, pp. 66–71, Feb. 2017. doi: 10.3969/j.issn.1003-2363.2017.01.013.

[36] Z. Li, Y. Shi, M. Xu, X. Zhang, and S. Jiang, "Hierarchical structure in the global liner shipping network," *Syst. Eng.-Theory Pract.*, vol. 36, no. 4, pp. 981–988, Apr. 2016. doi: 10.12011/1000-6788(2016)04-0981-08.

[37] Y. Wang and K. Cullinane, "Traffic consolidation in East Asian container ports: A network flow analysis," *Transp. Res. A, Policy Pract.*, vol. 61, pp. 152–163, Mar. 2014. doi: 10.1016/j.tra.2014.01.007.

[38] A. R. Goetz, "Air passenger transportation and growth in the U.S. urban system, 1950–1987," *Growth Change*, vol. 23, no. 2, pp. 217–238, Apr. 1992. doi: 10.1111/j.1468-2257.1992.tb00580.x.

[39] H. Matsumoto, "International urban systems and air passenger and cargo flows: Some calculations," *J. Air Transp. Manag.*, vol. 10, no. 4, pp. 239–247, Jul. 2004. doi: 10.1016/j.jairtraman.2004.02.003.

[40] Z. Luo, C. Zhu, and W. Xue, "The analysis on spatial structure of yangtze river delta based on passenger flow of high-speed railway," *Shanghai Urban Planning Rev.*, pp. 74-80, Jul. 2015. [Online]. Available: http://www.wanfangdata.com.cn/details/detail.do?_type=perio&id=shcsgh201504013

[41] N. Xinyi, W. Yao, and D. Liang, "Measuring urban system hierarchy with cellphone signaling," *Planners*, vol. 33, no. 1, pp. 50–56, Jan. 2017. doi: 10.3969/j.issn.1006-0022.2017.01.008.

[42] R. Ahas, A. Aasa, S. Silm, and M. Tiru, "Daily rhythms of suburban commuters' movements in the Tallinn metropolitan area: Case study with mobile positioning data," *Transp. Res. C, Emerg. Technol.*, vol. 18, no. 1, pp. 45–54, Feb. 2010. doi: 10.1016/j.trc.2009.04.011.

[43] A. Murphy and P. W. Williams, "Attracting Japanese tourists into the rural hinterland: Implications for rural development and planning," *Tourism Manage.*, vol. 20, no. 4, pp. 487–499, Aug. 1999. doi: 10.1016/S0261-5177(99)00005-9.

[44] W. Zhong and D. Wang, "Urban space study based on the temporal characteristics of residents' behavior," *Prog. Geogr.*, vol. 37, no. 8, pp. 1106–1118, Aug. 2018. doi: 10.18306/dlkxjz.2018.08.010.

[45] Z. Feihu, W. Jinzhao, S. Qiang, and T. Yishu, "A weighted iterative centroid localisation algorithm for cellular base station," *Comput. Appl. Softw*, vol. 30, no. 7, pp. 1–3 and 61, Jun. 2013. doi: 10.3969/j.issn.1000-386x.2013.07.001.

[46] J. D. Nystuen and M. F. Dacey, "A graph theory interpretation of nodal regions," *Papers Reg. Sci. Assoc.*, vol. 7, no. 1, pp. 29–42, Dec. 1961. doi: 10.1007/BF01969070.

[47] J. O. Wheeler and R. L. Mitchelson, "The flow of information in a global economy: The role of the American urban system in 1990," , vol. 84, no. 1, pp. 87–107, 1994. doi: 10.1111/j.1467-8306.1994.tb01730.x.

[48] J. Kolars, "Reviewed work: Locational analysis in human geography by Peter Haggett," *Econ. Geogr.*, vol. 43, no. 3, pp. 276–277, 1967. doi: 10.2307/143300.

[49] J. O. Wheeler and R. L. Mitchelson, "Information flows among major metropolitan areas in the United States," *Ann. Assoc. Amer. Geogr.*, vol. 79, no. 4, pp. 523–543, Mar. 2010. doi: 10.1111/j.1467-8306.1989.tb00275.x.

[50] S. Zen and J. Tian, "The coupling of knowledge and action: Endogenous motivation research and planning response to rural development in urban fringe based on social survey," *Urban Develop. Stud.*, vol. 25, no. 5, pp. 21–28, May 2018.

[51] J. Liu, X. Jin, Y. Fan, X. Xiang, N. Ran, Y. Zhou, and C. Shen, "Rural residential land consolidation strategy from a perspective synthesizing towns, villages and land parcels: A case study in Xinyi city, Jiangsu province," *Geograph. Res.*, vol. 37, no. 4, pp. 678–694, Apr. 2018. doi: 10.11821/dlyj201804003.

[52] Z. Luo, J. Wei, and J. Zhang, "Study on the characters of equalization development of basic public service facilities in urban and rural areas—Changzhou as the case," *Urban Studies*, vol. 17, no. 12, pp. 36–42, Sep. 2010. doi: 10.3969/j.issn.1006-3862.2010.12.007.
[53] H. Cai, S. Wang, and K. Yu, "Preliminary study of basic education facility configuration in rural area under the perspective of fairness and beneficial result: A case study of Jingyang, Shaanxi," *Modern Urban Res.*, vol. 3, pp. 83–91, Mar. 2016. doi: 10.3969/j.issn.1009-6000.2016.03.013.
[54] Y.-K. Sun, B. Lv, and Y.-J. Zhao, "A study of county public service facilities distribution assessment based on behavior investigation and gis: A case study of medical facilities in dexing," *Hum. Geogr.*, vol. 30, no. 3, pp. 103–110, Jun. 2015. doi: 10.13959/j.issn.1003-2398.2015.03.016.
[55] C. Min and J. Wei, "Rural public service layout for urban-rural even development: Zhenping example," *Planners*, vol. 11, no. 27, pp. 18–23 Nov. 2011. doi: 10.3969/j.issn.1006-0022.2011.11.003.
[56] Z. Xinxin, W. Peizhen, Y. Fan, and X. Jiangang, "Life circle theory based vilage layout planning," *Planners*, vol. 4, no. 32, pp. 114–119, Apr. 2016. doi: 10.3969/j.issn.1006-0022.2016.04.019.
[57] J. Liu, J. Zhan, and X. Deng, "Spatio-temporal patterns and driving forces of urban land expansion in China during the economic reform era," *AMBIO, J. Hum. Environ.*, vol. 34, no. 6, pp. 450–455, Aug. 2009. doi: 10.1639/0044-7447(2005)034[0450:SPADFO]2.0.CO;2.
[58] H. Zhang, L. G. Zhou, M.-N. Chen, and W.-C. Ma, "Land use dynamics of the fast-growing Shanghai metropolis, China (1979–2008) and its implications for land use and urban planning policy," *Sensors*, vol. 11, no. 2, pp. 1794–1809, Jan. 2011. doi: 10.3390/s110201794.
[59] M. Zhou, Y. Yue, Q. Li, and D. Wang, "Portraying temporal dynamics of urban spatial divisions with mobile phone positioning data: A complex network approach," *ISPRS Int. J. Geo-Inf.*, vol. 5, no. 12, p. 240, Dec. 2016. doi: 10.3390/ijgi5120240.
[60] X. Yang, Z. Fang, Y. Xu, S.-L. Shaw, Z. Zhao, L. Yin, T. Zhang, and Y. Lin, "Understanding spatiotemporal patterns of human convergence and divergence using mobile phone location data," *ISPRS Int. J. Geo-Inf.*, vol. 5, no. 10, p. 177, 2016. doi: 10.3390/ijgi5100177.
[61] X. Yang, Z. Zhao, and S. Lu, "Exploring spatial-temporal patterns of urban human mobility hotspots," *Sustainability*, vol. 8, no. 7, p. 674, 2016. doi: 10.3390/su8070674.
[62] S. Silm and R. Ahas, "Ethnic differences in activity spaces: A study of out-of-home nonemployment activities with mobile phone data," *Ann. Assoc. Amer. Geogr.*, vol. 104, no. 3, pp. 542–559, May 2014. doi: 10.1080/00045608.2014.892362.
[63] S. Hoteit, S. Secci, S. Sobolevsky, G. Pujolle, and C. Ratti, "Estimating real human trajectories through mobile phone data," in *Proc. IEEE 14th Int. Conf. Mobile Data Manage. (MDM)*, vol. 2, Jun. 2013, pp. 148–153. doi: 10.1109/MDM.2013.85.
[64] R. Ahas, A. Aasa, Ü. Mark, T. Pae, and A. Kull, "Seasonal tourism spaces in Estonia: Case study with mobile positioning data," *Tourism Manage.*, vol. 28, no. 3, pp. 898–910, Jun. 2007. doi: 10.1016/j.tourman.2006.05.010.
[65] R. Ahas, S. Silm, E. Saluveer, and O. Järv, "Modelling home and work locations of populations using passive mobile positioning data," in *Location Based Services and TeleCartography II*. Berlin, Germany: Springer, 2009, pp. 301–315. doi: 10.1007/978-3-540-87393-8_18.
[66] X. Niu, L. Ding, and X. Song, "Analyzing suburban new town development in Shanghai from the perspective of jobs-housing spatial relationship," *City Planning Rev.*, vol. 41, no. 8, pp. 47–53, Aug. 2017. [Online]. Available: http://en.cnki.com.cn/Article_en/CJFDTotal-CSGH201708007.htm
[67] D. Wang, C. Wang, D. Can, Y. Zhong, M. Wu, W. Zhu, J. Zhou, and Y. Li, "Comparison of retail trade areas of retail centers with different hierarchical levels: A case study of East Nanjing road, Wujiaochang, Anshan Road in Shanghai," *Urban Planning Forum*, vol. 223, no. 3, pp. 50–60, Jun. 2015. doi: 10.16361/j.upf.201503007.
[68] Y. Du, J. Luo, K. Cheng, G. Tang, Z. Xu, K. Luo, and J. Yu, "Recognition of urban travel method based on cell phone signaling and navigation map data," *Appl. Res. Comput.*, vol. 35, no. 8, pp. 2311–2314, Aug. 2018. doi: 10.3969/j.issn.1001-3695.2018.08.018.
[69] F. Jiacheng, W. Min, Z. Huaqin, and T. Xin, "Research on rural system construction under Zoning guidance, Kaihua County-regional rural construction plan," *Planners*, vol. 35, no. 6, pp. 10–15, Jun. 2019. doi: 10.3969/j.issn.1006-0022.2019.06.002.

JI-ZHE ZHOU received the M.Eng. degree in urban and rural planning from Chang'an University, where he is currently pursuing the Ph.D. degree in urban and rural planning with the School of Architecture. He was a Visiting Student with the Sustainable Places Research Institute, Cardiff University, the visiting funded by China Scholarship Council. He has published two articles, which indexed by SCI and EI.

QUAN-HUA HOU received the Ph.D. degree in transportation planning and management from Chang'an University, where he is currently a Professor and the Deputy Dean of the School of Architecture. He has achieved numerous scientific researches of urban and rural planning and published more than 20 articles, which indexed by SCI and EI. He has led or participated in ten research projects at the national or provincial level. In recent years, he has focused on the rural planning and has rich theoretical and practical basis.

XIAO-YANG FAN is currently pursuing the degree in urban and rural planning with the School of Architecture, Chang'an University. Her main research direction in school is rural planning theory and method.

YANG DU is currently pursuing the degree in urban and rural planning with the School of Architecture, Chang'an University. Her main research direction in school is rural planning theory and method.