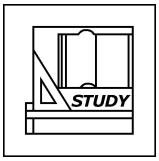

Characteristics of industrial spatial organization and optimization strategy of Wuhan metropolitan area under the perspective of industrial clusters

long robe (old) Mangan Zhang Xuan Shan Zhuoran Huang Yaping

Abstract Under the background of building a new development pattern of "double cycle", it is of great significance to study the organizational characteristics of industrial space in the metropolitan area and put forward corresponding optimization strategies, so as to promote the in-depth integration of industrial chain and supply chain in the metropolitan area. Based on the data of micro enterprises, we adopt the research methods of "place space" and "flow space" to analyze the organizational characteristics and functional synergy of industrial space in Wuhan metropolitan area from the perspective of industrial clusters, and diagnose the existing problems. The results show that the industrial space of Wuhan metropolitan area presents a "point-axis" pattern in terms of "place space", and is characterized by "big dispersion and small concentration" of manufacturing industry and centralization of productive service industry. The results show that: in "place space", the industrial space of Wuhan metropolitan area shows a "point-axis" pattern, and is characterized by "large dispersion and small concentration" of manufacturing industry and concentration of productive service industry; in "flow space", the network of Wuhan metropolitan area is significantly polarized, and the level of functional synergy is yet to be improved. We discuss the perceptual diagnosis and simulation methods based on "place space" and "flow space" from the aspects of shape-flow combination, shape-flow simulation and shape-flow determination, and summarize the " It also summarizes the layout optimization rules of "core+axis" structure, division of labor between inner and outer circles, and cooperation and co-construction of critical zones for the industrial space of strong-core growth metropolitan area.

Keywords Wuhan metropolitan area; industrial space; place
Space; flow space
Chinese graphic classification number TU984 Literature symbol code A DOI
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Characteristics of Industrial Spaces and Strategies for Optimization in Wuhan Metropolitan Area: A Perspective of Industrial Clusters

YUAN Man, ZHANG Xuan, SHAN Zhuoran, HUANG Yaping

Abstract: In the context of establishing a new development pattern for dual circula- tions, it is of great significance to examine and optimize the organization of indus- trial spaces in metropolitan areas to foster the deep integration of industrial and supply chains. Based on micro-level business data , this study analyzes the character- istics and functional synergies of industrial spaces in Wuhan Based on micro-level business data , this study analyzes the character- istics and functional synergies of industrial spaces in Wuhan Metropolitan Area by in- voking the concepts of space of places and space of flows. Concerning the space of places, the study shows that Wuhan's industrial spaces exhibit a "point-axis" pattern, indicating significant dispersion with limited agglomeration. Concerning the space of places, the study shows that Wuhan's industrial spaces exhibit a "point-axis" pattern, indicating significant dispersion with limited agglomeration in the manufacturing sector and spa- tial concentration in producer services. terms of the space of flows, Wuhan Metro- politan Area displays clear network polarization and weak functional synergy. Finally, methods for perceiving and simulating the space of flows in Wuhan Metro- politan Area are not yet available. In terms of the space of flows, Wuhan Metro- politan Area displays clear network polarization and weak functional synergy. For metropolitan space economies with robust growth momen- tum and a strong center, the paper suggests shared strategies of spatial optimization These include the following For metropolitan space economies with robust growth momen- tum and a strong center, the paper suggests shared strategies of spatial optimization These include forming a "core and axal belt" structure, facilitating the division of la- bor and These include forming a "core and axal belt" structure, facilitating the division of la- bor and cooperation between inner and outer circles, and fostering collaborations be- tween boundary areas in proximity.

Keywords: Wuhan metropolitan area; industrial space; space of place; space of flow

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Over the past year, the international situation has been changing, the trend of anti-globalization has been strengthening, and the global industrial chain and supply chain are facing the danger of chain breakage[1] . In order to cope with the great changes that have not been seen in a century, General Secretary Xi Jinping has proposed to "build a large domestic cycle of

A new development pattern with the main body and the domestic and international double cycle promoting each other". Under the background of building a new development pattern, the industrial chain and supply chain have gradually changed from the original externally-oriented economy-led development pattern to regionalization and localization[2] , and at the same time show a trend of reorganization in urban agglomerations and metropolitan areas[3] . Therefore, how to rationally arrange industrial space within the scope of city clusters and metropolitan areas, break the administrative barriers between regions, strengthen the division of labor and cooperation between regions, optimize the pattern of "region-industry" linkage and interaction, and build a closely connected industrial space

network with perfect functional structure is the focus of the current research on the integration of city clusters and metropolitan areas. It is the focus of the current research on the integration of urban agglomerations and metropolitan areas. As a typical growing metropolitan area in China, Wuhan Metropolitan Area is also the first metropolitan area approved by the National Development and Reform Commission (NDRC).

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The Wuhan metropolitan area is one of the seven national metropolitan areas with clear goals and demands for integrated industrial development. Therefore, it is necessary to conduct an in-depth study on the characteristics and problems of the industrial spatial organization of the Wuhan metropolitan area, so as to guide the planning of the industrial spatial layout of the growing metropolitan area and help the formation of an integrated development pattern.

1 Review of relevant studies

1.1 "Space of place" vs. "space of mobility"

Early research on industrial space-related organization was mainly based on the theory of industrial clusters[4-5] , focusing on the study of the geographical scope, geographic location and spatial pattern of industrial agglomeration; when studying the spatial organization characteristics of city clusters and metropolitan areas, most scholars are based on the theory of "central place" or "core-edge" theory, focusing on the hierarchical level among different cities. -Most scholars, when studying the spatial organization characteristics of city clusters and metropolitan areas, are mostly based on the "center" theory or the "core" theory, focusing on the hierarchical levels among different cities, and believe that there are "center-subcenter-hinterland-periphery The theory focuses on the hierarchical levels among different cities, and considers that there are "center-subcenter-hinterland-periphery" regions with different levels of development within city clusters or metropolitan areas, and that spatial spreading is characterized by diffusion along circles or axes.[6] In essence, these studies are based on the place space based on geographical proximity. In 1996, Castell[7] put forward the concept of "mobility space", and he believed that with the continuous development of globalization and informatization, the flow of various "mobility factors", such as technology, information, capital, etc., between cities has become a major factor in the development of the city. He believed that with the continuous development of globalization and informationization, the flow of various "mobile elements" such as technology, information, capital and so on between cities has become an important force dominating the regional spatial organization, and the importance of the territory tends to be weakened, and the cities have become the nodes of the network of "de-spatialization", and the development of the city is more reliant on the connection between cities. Under the influence of the theory of "mobility space", domestic scholars have carried out empirical research on city circles and metropolitan areas based on the enterprise affiliation network[8] , innovation network[9] , transportation network[10] , regional cooperation network[11-13] , and industrial chain spatial network[14] , etc. They have analyzed the characteristics of the network spatial structure of city clusters and metropolitan areas, the spatial and temporal evolution of the network and the network externalities.

Adopting the "mobility space" approach alone to study the organizational characteristics of regional industrial space also has limitations, and may ignore the geospatial attributes of industrial space. Although "mobility space" dilutes "place space", "mobile elements" still need to be concentrated, transformed and redistributed in specific cities[15] , and geographical distance plays an important role in the organization of industrial space, not only affecting transaction costs, but also influencing the organization of industrial space. and geographical distance plays an important role in the organization of industrial space, which not only affects the transaction cost, but also influences the strength of association between the two parties. Therefore, this paper combines "place space" and "flow space" when studying the characteristics of regional industrial space organization, analyzing the characteristics of industrial space layout and functional association, so as to provide guidelines for the subsequent planning and optimization of industrial space.

1.2 Progress of research on the spatial organization of industries in metropolitan areas

On February 19, 2019, the National Development and Reform Commission (NDRC) issued the Guiding Opinions on Cultivating and Developing Modernized Metropolitan Circles, which calls for the promotion of specialized division of labor and collaboration among cities in the metropolitan circles as an orientation, the promotion of high-end development of industries in the central cities, the consolidation of the manufacturing base of small and medium-sized cities, and the promotion of complementary functions, staggered layout of industries, and development of characteristics of the cities. In the construction of new urbanization, the metropolitan area will serve as an important spatial carrier to play the role of radiation driving of the central city, and play an important role in the circle of the tripod group, carrying on the important role of the next[16] . Especially in the context of building a new development pattern of "double cycle", the metropolitan area, as an important spatial scope for the reorganization of industrial chain and supply chain[17-18] , has become a hot spot in the study of industrial space in urban areas.

Currently, the empirical evidence on the spatial organization of regional industries in the

In terms of research, domestic scholars mainly focus on the agglomeration characteristics, organization pattern, pattern evolution and power mechanism of industrial space (Table 1). In the research of "flow space" perspective, most scholars still refer to the research paradigm of "flow space" in urban agglomerations, with county

Administrative districts at the county level are used as the basic unit to study the characteristics of industrial spatial organization in the metropolitan area, but it is difficult for this scale to guide the current industrial development planning that needs to be spatially grounded. Although the data at the county-level administrative district scale are more accessible, the large differences in the size of administrative districts may affect the comparability of the results of the study among districts and counties[19] . More importantly, for metropolitan area, which is a meso-scale between city clusters and cities, the planning is more concerned with the optimization of the morphology and layout of comprehensive industrial clusters such as development parks, and it is too macroscopic to take counties as the research unit, which focuses on analyzing the positioning of the industrial functions, and the conclusions of the study can hardly be used as the basis for the morphology and layout of the development parks. In this paper, we shift the scale downward in the county-level administrative districts, take the development parks as the basis, identify and delineate the industrial clusters through the research method of "space of place", and use them as the nodes to construct the network of industrial clusters, so as to analyze the level of synergy between industrial clusters in Wuhan metropolitan area and the problems that exist in them.

2 Research data and methodology

2.1 Scope of the study and study data

2.1.1 Scope of the study

Since the scope of Wuhan metropolitan area has not yet been announced, this paper chooses the nine cities involved in the Three-Year Action Program for the Construction of Wuhan Metropolitan Area (2023-2025) as the scope of the study, i.e., Wuhan, Ezhou, Huangshi, Huanggang, Xiaogan, Xianning, Xiantao, Tianmen, and Qianjiang. In order to facilitate the subsequent analysis, the Wuhan metropolitan area is divided into five circles of 15 km, 30 km, 60 km, 80 km and 150 km, in which the main city of Wuhan is within 15 km, the core circle of industrial development of Wuhan metropolitan area is within 30 km, and the peripheral circle of industrial development is beyond 30 km.

2.1.2 Sources of research data

This paper obtains research through March, 2023

Table 1 Results of research on the spatial organization of industry in selected regions

Tab.1 Research results on spatial organizations of selected regions

author	Research Perspectives	research scale	Basic units of study	Main elements of the study

Huang, Yaping et al. (2016)	space	urban district	corporations	The spatial evolution of manufacturing industry in Wuhan metropolitan area since 1990s and its driving mechanism using enterprise data.[20]
Zhang Yishuai et al. (2018)	Spaces of place and spaces of mobility	city cluster	district and county	Utilizing remote sensing, industrial census and other data to study the spatial development of places, and utilizing enterprise "headquarters-branch" data to construct and analyze the characteristics of network development on a district and county basis.[21]
Yawen Ren et al. (2022)	space	city cluster	corporations	Analyze the spatial pattern and location association characteristics of the upstream, midstream and downstream semiconductor industry chain by using enterprise data[22]
Cheng Yao et al. (2016)	fluid space	city cluster	district and county	Quantitative analysis of the network linkages of county and city units using "headquarters-branch" data of enterprises to derive spatial characteristics and evolutionary trends[6]
Tian Lin (2021)	fluid space	metropolitan area	district and county	districts and counties as nodes, constructed a city network based on the association of productive service industry enterprises, and analyzed the industrial space of Shanghai metropolitan area [23]
Zhang, Zhenguang et al. (2023)	fluid space	metropolitan area	district and county	The spatial analysis of the industrial chain, supply chain and innovation chain in the Shanghai metropolitan area were analyzed separately using microenterprise data, with districts and counties as units [24]

Data on enterprises in the region, the data information includes basic information such as enterprise name, enterprise location, industry code, etc., as well as "headquarters-branch" association between enterprises, "investment" association and "Customer-supplier" association. The data come from the National Enterprise Credit Information Publicity System, the Industry and Commerce Bureau, the Intellectual Property Office and the National Public Resources Trading System.

2.2 Research methodology

2.2.1 "Spaces of Place" Research Methodology

One is to use ArcGIS to calculate the number of enterprises of different industry types in the 1 km×1 km grid, so as to identify the enterprise number agglomeration area, and to draw the curve diagram of the enterprise density change with distance, so as to analyze the density distribution characteristics of the industrial space; the second is to use the kernel density analysis method to identify the enterprise scale agglomeration area based on the number of people employed by the enterprises, and to analyze the scale distribution characteristics of the industrial space. The agglomeration area identified by the place space is also the basis for determining the location and functional division of industrial groups.

2.2.2 Network construction methodology

This paper utilizes three types of enterprise association data, such as "headquarter-branch, investment, and customer-supplier", and constructs nine types of industry group association networks according to three types of enterprises, such as manufacturing industry, dominant industry and productive service industry. The direction of constructing the directed weighted network is "headquarters enterprise - branch enterprise", "investment enterprise - invested enterprise", "customer enterprise - supplier enterprise", and the weights are "investment enterprise - branch enterprise" and "customer enterprise - supplier enterprise". -supplier enterprises", and the weight is the total number of enterprise linkage pairs between industrial clusters. The leading industries are selected based on Hubei Province's "Implementation Opinions on Accelerating the Construction of the Pioneer Zone of National Construction of New Development Pattern", and optoelectronic information, high-end equipment manufacturing, life health and new energy automobile industries are selected, while the productive service industries are selected based on the "Statistical Analysis of Productive Service Industries". Classification (2019) and references to related papers.

3 Characterization of industrial spatial pattern and division of industrial clusters in Wuhan metropolitan area

3.1 Characterization of the spatial pattern of the industry

3.1.1 Spreading out along transportation axes, showing a "point-axis" distribution pattern

As can be seen from Fig. 1, the industrial space of Wuhan metropolitan area is centered on the main city of Wuhan, and spreads to the peripheral circles along the axes such as traffic arteries, and forms a number of industrial agglomerations, showing a "point-axis" spatial distribution pattern. In the process of spreading industrial space outward, the scale of industrial clusters also shrinks outward along the circles. In the core circle, the optoelectronic information industrial park in Wuhan East Lake High-Tech Zone, the intelligent manufacturing industrial park in Wuhan Economic Development Zone and Wuhan Airport Port Economic Development Zone have formed large-scale industrial clusters; in the circle of 30-80 km, the Gedian Economic Development Zone in Ezhou, Huanggang High-Tech Zone, Huangshi Economic Development Zone and Xiaogan High-Tech Zone have also formed industrial clusters with a certain scale. The industrial cluster is also formed with certain scale. At the same time, in accordance with the direction of the four major co-cities of Wuhan-Erzhou-Huangzhou-Huangzhou, Hanxiao-Huangzhou, Wuhan-Hamburg and Wuhan-Xian, and relying on the large-scale industrial agglomerations in the core circle, the industrial space of Wuhan metropolitan area along the main transportation corridors forms

Four industrial development axes, among which, the industrial space in the direction of Wu'er Huanghuang has the characteristics of the layout of the development of close to the edge of the contiguous, integrated development trend is more obvious.

3.1.2 "Large fragmentation, small concentration" in manufacturing versus the centralized pattern characteristic of the service sector

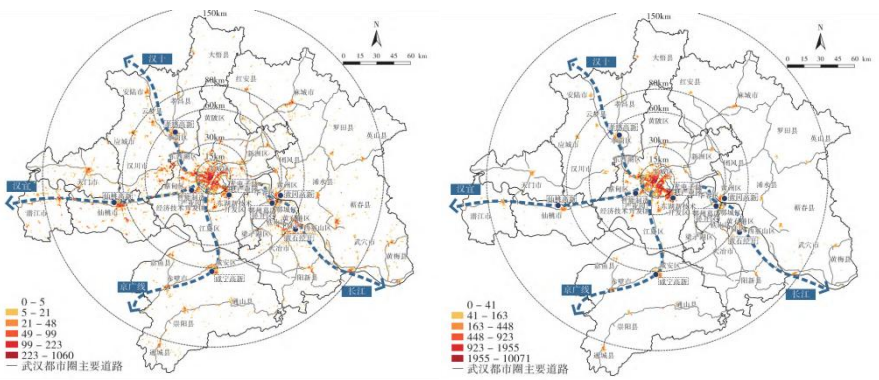
Considering that although the number of enterprises can reflect the layout characteristics of industrial space to a certain extent, the level of regional industrial development as well as the center of gravity of development often depends on large-scale enterprises. Therefore, on the basis of analyzing the distribution characteristics of enterprise density, a kernel density analysis is carried out based on the size of enterprises, i.e., the number of people employed by enterprises (Fig. 2). Comparing the results of kernel density analysis and enterprise density layout characteristics, it can be found that there is a certain difference between the quantity agglomeration and scale agglomeration characteristics of manufacturing enterprises, which is mainly reflected in the fact that the main urban area of Wuhan is the quantity agglomeration center of the metropolitan area, but is mainly dominated by the agglomeration of small-scale manufacturing enterprises, and the large-scale manufacturing enterprises are laid out in the periphery of the main urban area; whereas, the quantity agglomeration characteristics of the production service enterprises and the scale agglomeration characteristics are more consistent, both of which are Wuhan main city and the optoelectronic information industrial park in the East Lake High-tech Zone as the agglomeration center.

Comparing manufacturing and productive services it can be concluded that the layout of the manufacturing space is more decentralized, in the metro

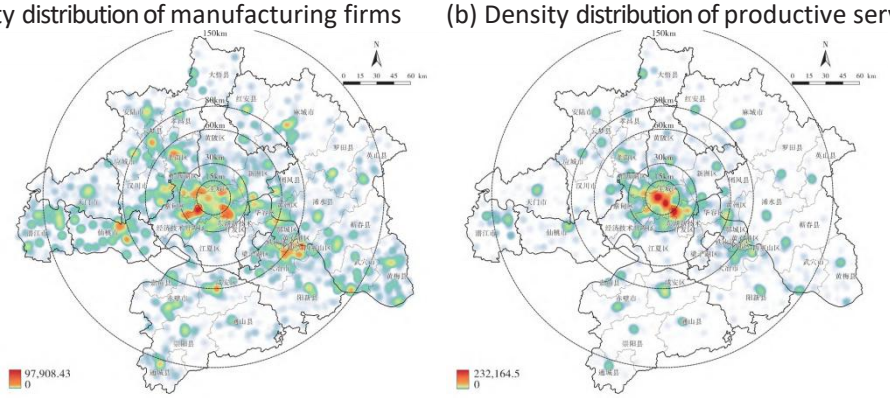
The text is available at[23, 25] , and the industrial classification of enterprises is based on the Classification of Strategic Emerging Industries (2018) and the National Economic Industry Classification (2017).

2.2.3 Network analysis methods

This paper mainly uses UCINET software, adopts social network analysis method, analyzes the overall characteristics of industrial cluster association network and node status. In the analysis of the overall characteristics of the network, the network density, central potential and average path length are mainly analyzed, and the cohesive subgroup clustering analysis is carried out; in the analysis of the node status, the outward control ability and inward absorption ability of the nodes are analyzed through the calculation of node's outward and inward degree, and the "bridge" played by the nodes in the network is analyzed through the calculation of node's intermediary central degree " role.



(a) Density distribution of manufacturing firms (b) Density distribution of productive services firms



(c) Manufacturing business size kernel density (d) Productive services business size kernel density

Fig.1 Characteristics of business agglomeration in Wuhan Metropolitan Area

Multiple agglomerations have been formed in different circles of the metropolitan area, while the productive service industry shows the characteristics of strong center. Figure 2 reflects the density changes of productive service, manufacturing and leading industry enterprises in Wuhan metropolitan area from the center of the metropolitan area to the periphery, and it can be found that, compared with the productive service industry, the density change curve of manufacturing and leading industry enterprises is more gentle and the density peak is more consistent, while the density peak of productive service enterprises is located mainly in the core circle, and there is a big difference in the peak, which further shows the relatively decentralized characteristics of manufacturing enterprises and the highly concentrated characteristics of productive service enterprises. indicates the relatively decentralized characteristics of manufacturing enterprises and the highly concentrated characteristics of productive service enterprises. In the post-reform and opening-up growth era, in order to realize the economies of scale of agglomeration, the construction of development zones was launched nationwide, and the development zones provided policy incentives and perfect facilities, attracting a large number of manufacturing enterprises to cluster in the development zones and parks[26] . At present, the Wuhan metropolitan area has built a large number of industrial parks of different scales, which has resulted in a pattern of "large dispersion and small concentration" in the manufacturing space.

The distribution of scientific and technological innovation resources, productive service enterprises, leading industry enterprises, and the industrial planning and positioning of the region where the industrial cluster is located, determine the scientific and technological innovation center, comprehensive service, advanced manufacturing and innovative industry clusters. For example: Cluster 1-2, where scientific and technological innovation resources are concentrated, assumes the function of scientific and technological innovation center in Wuhan Metropolitan Area; Cluster 1-13, 1-21, etc., as the cluster of leading industries, assumes the function of advanced manufacturing; Cluster 1-1, 1-7, etc., where the productive service enterprises are concentrated, mainly develops the modern service industry and assumes the function of integrated service in the industrial planning; Cluster 1-4, 1-6, 6-2, etc., where the leading industries have formed a certain scale, and have been established and are in a certain position in the industrial planning and positioning of the area where the cluster is located. The leading industries have formed a certain scale, and some of the clusters are adjacent to science and innovation resources, as innovative industry clusters. In addition, various policy documents of Wuhan metropolitan area in recent years have proposed to promote the industrial collaboration of the metropolitan area through cooperation and joint construction, park outside the park and enclave economy, etc. Therefore, this paper takes the industrial

clusters where the cooperative parks are located as the cross-border industrial clusters, which are mainly developing modern service functions.

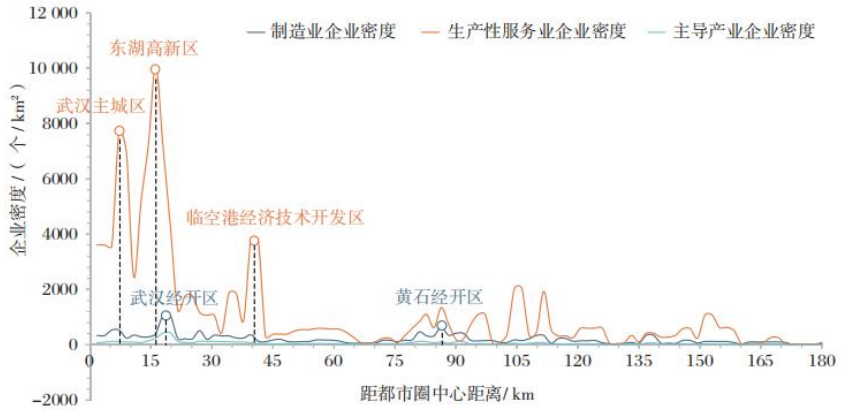


图2 武汉都市圈企业密度空间分布变化

Fig.2 Changes in business density in Wuhan Metropolitan Area

(c) Industry cooperation groups in the sector.

4 Network analysis of industrial clusters in Wuhan metropolitan area

4.1 Characterization of the overall network of industry cluster associations

4.1.1 Polarization of the cluster network is obvious, and there is an east-west development trend

The network density, centrality potential and average path length of the manufacturing network, the dominant industry network and the productive service network are calculated by binarizing the group networks based on the "HQ-branch" link, the "investment" link and the "customer-supplier" link. The network density, central potential, and average path length of the manufacturing network, the dominant industry network, and the productive service industry network are calculated by binarization (Table 2). The network density of the three types of networks is relatively low and the central potential is relatively high, which indicates that the network links among industrial clusters are incomplete and unevenly developed, and the power of the network is highly concentrated. Among them.

3.2 Identification and Functional Classification of Industrial Clusters

3.2.1 Identification of industrial clusters

In identifying industrial clusters, the location of industrial clusters is first determined based on the industrial clusters identified in the previous spatial analysis of places (Figure 1). In the identification of the boundaries of industrial clusters, two main approaches are adopted. For example, in Wuhan Economic-Technological Development Zone, since this paper focuses on manufacturing and productive service industries, the boundaries of the intelligent manufacturing industrial park, modern service industry industrial park, intelligent network and electric vehicle industrial park, and general aviation and electric vehicle industrial park are removed from the residential and living area of Junshan New Town and the agricultural development area of Modern Science and Technology Agricultural Park. Electric Vehicle Industrial Park and General Aviation and Satellite Industrial Park as the boundaries of industrial clusters. Secondly, for industrial clusters without a clear planning of the park, the boundaries are formed by roads or administrative boundaries according to the scope of the enterprise clustering area.

3.2.2 Functional division of industrial clusters

In order to facilitate the subsequent analysis, the industrial clusters are numbered and named, and divided into different functions (Figure 3). In the numbering, the first digit represents the city where the cluster is located, 1 represents Wuhan, 2 represents Ezhou, 3 represents Huangshi, 4 represents Huanggang, 5 represents Xiaogan, 6 represents Xianning, 7 represents Xiantao, 8 represents Qianjiang, and 9 represents Tianmen.

In determining the functions to which the industrial clusters belong, the combination of the

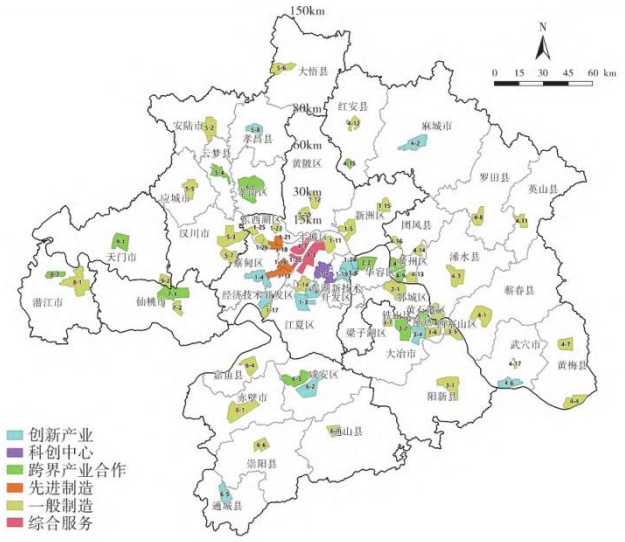


Fig.3 Layout of industrial clusters in Wuhan Metropolitan Area

The manufacturing network has the highest central potential, more significant polarization characteristics, the longest average path length of the dominant industry network, and poorer network accessibility and transmission efficiency.

The cluster linkage networks were categorized into six classes according to linkage strength in terms of natural breakpoints and visualized by ArcGIS (Figure 4). The high-intensity links of all three classes of networks are mainly found between core-circle clusters, followed by the

In the industrial network, the cluster network linkage is mainly along the direction of Wu'er Huanghuang, and strong links between the peripheral circle clusters have emerged; in the productive service industry network, the cluster network linkage is mainly along the direction of Wu'er Huanghuang, Wu'xiao, Wu'xian and Wu'xian. At the same time, the

Table 2 Indicators of industrial clusters related network in Wuhan metropolitan area

For manufacturing and leading industries, there are obviously links from peripheral circle groups flowing to core circles, but in the productive services network, most of the high-intensity links are from core circles to peripheral circles, which shows that in the case of productive services, the core circles have a higher degree of control.

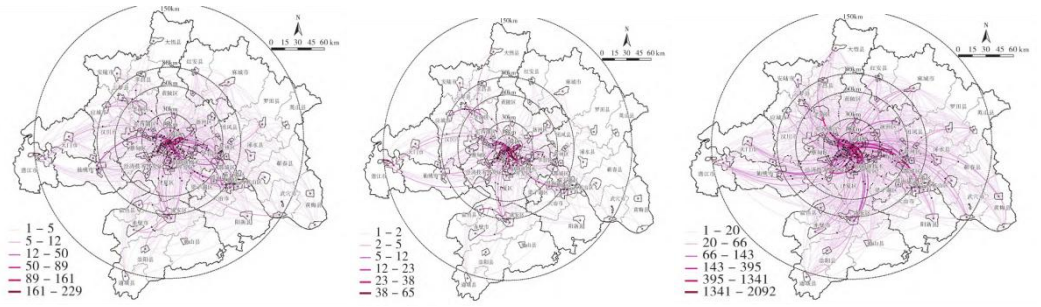
Core circle clusters with peripheral innovative industries and cross-border

Between industrial cooperation clusters, east-west linkages are predominant in these links. From the viewpoint of group linkage network of subdivided industries, manufacturing industry, leading industry and productive service industry networks have their own focus on industrial organization characteristics. In the manufacturing network, the cluster network links are mainly along the direction of Wu'e Huanghuang and Wu'xian; in the leading

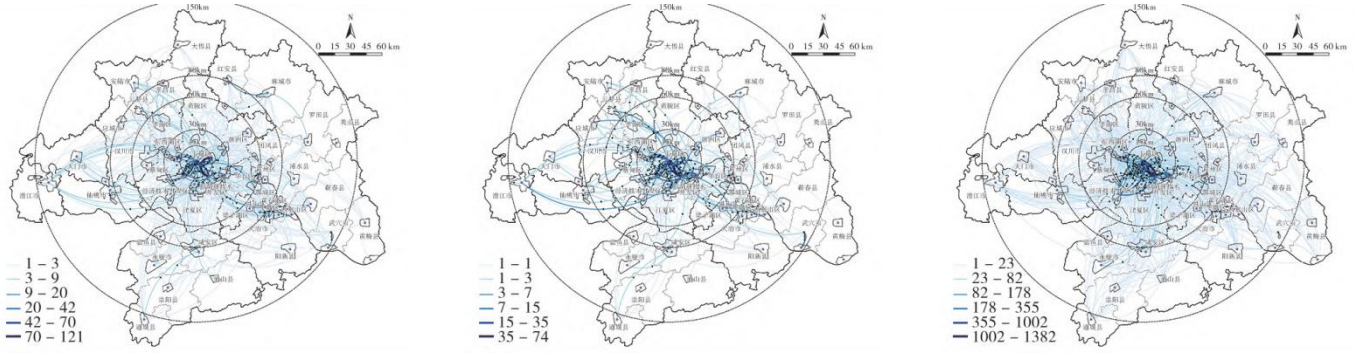
Tab.2 Network indicators of industrial clusters in Wuhan Metropolitan Area

norm	Manufacturing companies			Leading Industrial Companies			Productive service enterprises		
	Headq	invest	provi	Headq	invest	provide	Headqu	invest	provide

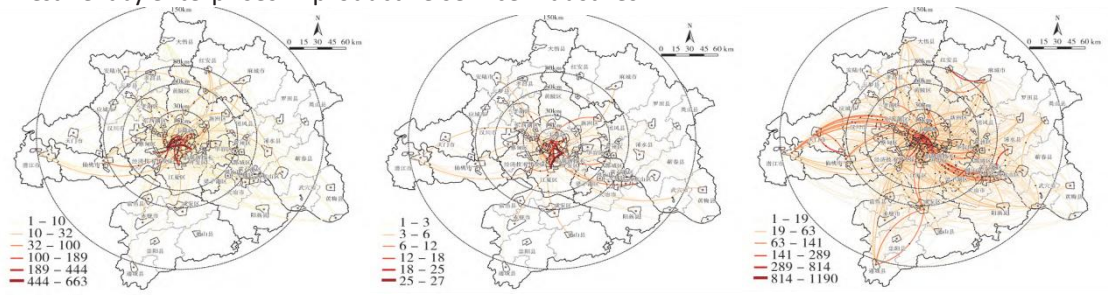
	uarter s branch	ors	der	uarter s branch	ors	r	arters branch	ors	r
network density	0.241 2	0.210	0.151 4	0.129 0	0.112 6	0.076 1	0.407 5	0.331 8	0.354 6
center potential	0.670 0	0.630	0.700 0	0.510 0	0.540 0	0.450 0	0.570 0	0.660 0	0.610 0
Average path length	1.815 0	1.842	1.963 0	2.057 0	2.184 0	2.300 0	1.598 0	1.689 0	1.663 0



(a) Headquarters branches of manufacturing enterprises (b) Headquarters branches of enterprises in leading industries (c) Headquarters branches of enterprises in productive service industries



(d) Investment by manufacturing enterprises (e) Investment by enterprises in leading industries (f) Investment by enterprises in productive service industries



(g) Suppliers to manufacturing firms (h) Suppliers to leading industry firms (i) Suppliers to productive service firms

Fig. 4 Industrial cluster association network of Wuhan metropolitan area

Fig.4 Network of industrial clusters in Wuhan Metropolitan Area

4.1.2 Administrative divisions and geographic locations influence the functional synergy pattern of the network

According to Fig. 4, it can be preliminarily analyzed that in the connection of industrial cluster network in Wuhan metropolitan area, the close connection generally occurs between industrial clusters with higher level of industrial development or geographic proximity, which suggests that the geographic advantage plays an important role, and the level of industrial development and geographic location also affect the organization of industrial cluster network.

In order to further analyze the level of functional synergy of the Wuhan metropolitan area's industrial cluster linkage network, the industrial cluster linkages are divided into six types, and among the six linkage types, other city linkages and Wuhan city linkages, other

The network density of "customer-supplier" network is lower, and the centrality potential and average path length are higher, which indicates that the nodes of "customer-supplier" network are less tightly connected (Table 2). This indicates that the nodes of "customer-supplier" networks are less tightly connected, the development of the network is uneven, the control structure of the network tends to be more centralized, and the accessibility of the network is relatively poor (Table 2) Meanwhile, comparing the connection types of the three types of networks, it is found that the supplier network has the lowest proportion of two-way links and the highest number of empty links except for the production service industry, which indicates that most of the industrial clusters in the Wuhan metropolitan area have not yet established the "customer-supplier" link (Table 2).

Table 3 Types of linkage networks associated with industrial clusters in Wuhan metropolitan area

linkage, and the direction of linkage is mostly unidirectional, with less bidirectional interaction, which further suggests a more pronounced hierarchical difference between industrial clusters. See Table 4.

The "supplier-customer" relationship reflects the upstream and downstream relationship of the supply chain.[24] Therefore, in order to analyze whether there is a perfect division of labor in the supply chain in Wuhan metropolitan area, in addition to constructing the "customer-supplier" relationship network in Wuhan metropolitan area, we also constructed the "customer-supplier" relationship network in Wuhan metropolitan area, so as to calculate the supply chain share in Wuhan metropolitan area. Therefore, in order to analyze whether there is a perfect supply chain division of labor system in Wuhan metropolitan area, in addition to constructing a "customer-supplier" network within Wuhan metropolitan area, a "customer-supplier" network is also constructed, in which the customers are located in Wuhan metropolitan area and the suppliers are located outside of Wuhan metropolitan area, and the supply chain share in Wuhan metropolitan area is calculated. The results show that.

Inter-city linkages are best represented as cross-municipal linkages

Functional synergy level of industrial cluster network in metropolitan area. As shown in Table 3, other cities have the least number of industrial clusters, and cross-city links are dominated by Wuhan, accounting for only about 10%, which indicates that the interaction between low-capacity cities has not yet been established, and that administrative divisions have an important impact on the cross-regional synergy of the Wuhan metropolitan area. In terms of different industry type networks, compared with manufacturing and leading industries, the production service industry network has a higher proportion of cross-cluster as well as cross-regional links, indicating that the radiation-driven effect of the production service industry is stronger. Meanwhile, compared with the "enterprise headquarters-branch" linkage, the linkage within clusters in the "customer-supplier" linkage is significantly less than the linkage between clusters, and the linkage across administrative districts and the proportion of linkages between low-energy cities has also increased, indicating that the distance factor has a relatively low degree of influence on inter-enterprise linkages.

As can be seen from Fig. 5, the same subgroup of spatial

The layout is more in line with the delineation of administrative boundaries, which further indicates that administrative divisions play a certain role in hindering the connection between

industrial clusters, and that the industrial development of Wuhan metropolitan area has not yet broken down the administrative barriers, which in turn affects the level of functional synergy of the network. However, some industrial clusters with different administrative divisions are also divided into the same subgroups, which are mainly manifested in proximity diffusion and hierarchical diffusion. It is worth noting that industrial clusters located in critical areas tend to have neighborhood diffusion, which suggests that strengthening the integration of critical areas is important for breaking down administrative barriers and improving the level of functional synergy of the network.

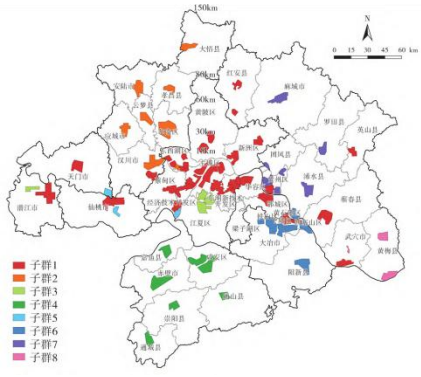
"Client-supplier" network development water

Relatively low level, supply chain division of labor system is not yet complete

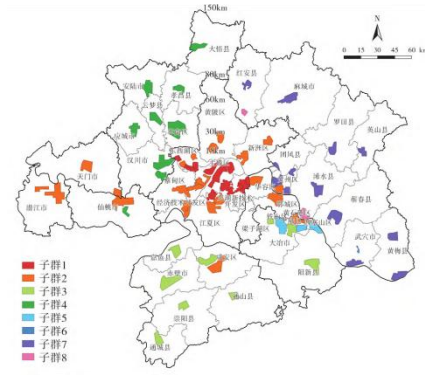
Based on the previous analysis, it can be seen that in terms of the three indicators of network density, central potential, and average path length, compared to "HQ-Branch" and "Investment"

Tab.3 Types of network linkage between industrial clusters in Wuhan Metropolitan Area

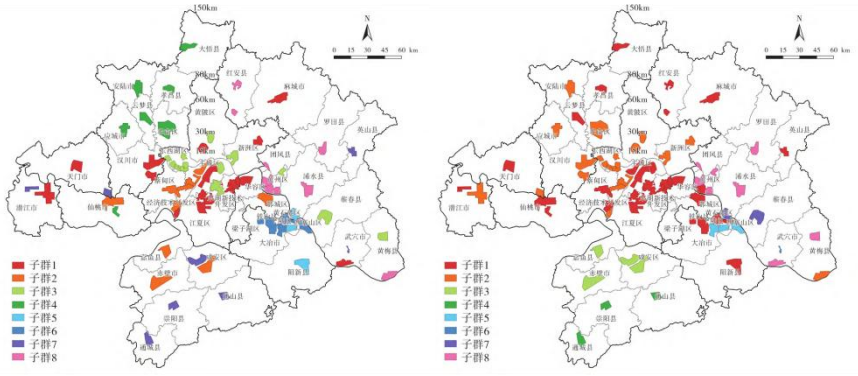
Network type		Wuhan Intra-cluster linkages Percentage/%	Intergroup contacts within Wuhan Percentage/%	Wuhan's links with other cities Percentage/%	Other intra-city cluster linkages Percentage/%	Other intra-city inter-cluster linkages Percentage/%	Percentage of other inter-city links/%
Manufacturing companies	Headquarters branch	38.88	20.34	7.82	26.58	4.96	1.42
	provider	18.40	62.17	10.20	5.52	2.13	1.58
Leading Industrial Companies	Headquarters branch	51.02	20.43	7.97	15.72	3.93	0.93
	provider	11.66	47.64	22.01	10.15	3.52	5.03
Productive service enterprises	Headquarters branch	27.93	39.69	13.46	13.22	4.71	0.99
	provider	14.81	34.68	20.93	17.66	8.70	3.22



(a) Branch headquarters of manufacturing enterprises



(b) Branch headquarters of productive service



(c) Investment by manufacturing firms (d) Investment by productive service firms

Fig.5 Subgroups within industrial clusters in Wuhan metropolitan area

The supply chain localization of manufacturing industry, leading industry and production service industry in Wuhan metropolitan area is only 5.5%, 15.19% and 4.6% respectively. On the whole, the raw materials and markets in Wuhan metropolitan area are still in the state of "outside", and a perfect supply chain network has not yet been formed within the metropolitan area; from the point of view of different industries, the dominant industry has the highest supply chain localization, which indicates that Wuhan metropolitan area puts the emphasis on the dominant industry in the construction of supply chain network at present.

4.2 Nodal analysis of industry cluster network

4.2.1 Functional differentiation has occurred in the core circles, while the peripheral circles are still at a low level of homogeneous development

As can be seen from Fig. 6, there is an obvious difference between the degree centrality of the groups in the core circle and that of the groups in the peripheral circle, and the development level of the groups in the peripheral circle is lower. Meanwhile, from the perspective of peripheral circles, the groups with higher degree centrality are mainly distributed in the vicinity of 60 km circle and 80 km circle, which indicates that the 60 km circle and the surrounding area of 80 km circle are the main development areas of industries in the peripheral circles of Wuhan metropolitan area.

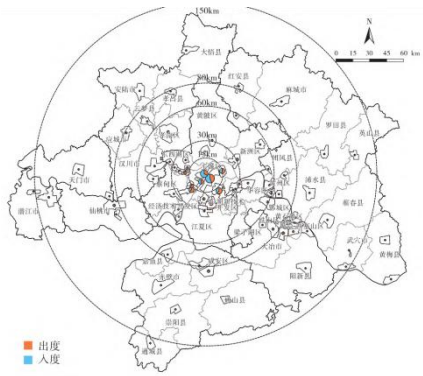
In terms of different types of networks, compared with "customer-supplier" networks, "headquarters-branch" networks show obvious industry differences in the direction of linkage. For example, in the manufacturing industry, although the centrality of cluster 1-1 and cluster 1-7 is the highest, their out-degree is smaller than the in-degree, while the out-degree of clusters 1-13 and 1-11 is larger than the in-degree, which indicates that their outward control ability is stronger and their manufacturing industry is more developed. On the contrary, in the network of production service industry, the out-degree of cluster 1-1 and 1-7 is greater than the in-degree, which indicates that, as an integrated service cluster, it has stronger outward control in production service industry, and its production service function is more prominent. It is worth noting that the centrality of Cluster 1-2 is ranked third, and the outward degree is greater than the inward degree in both manufacturing and productive services, which has a stronger core control ability in the network. This is due to the fact that Cluster 1-2, as a science and innovation center, has 32.38% of the research-based innovation entities and 35.96% of the industry-based innovation entities in Wuhan metropolitan area, which is the highest among all clusters, and at the same time, the proportion of manufacturing enterprises within 10 km of innovation entities is higher than the proportion of manufacturing enterprises within 10 km of innovation entities.

Table 4 Types of links of industrial clusters associated networks in Wuhan metropolitan area

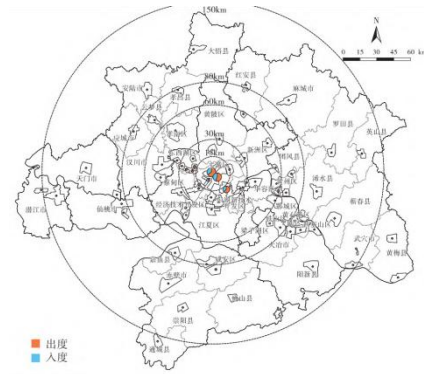
Tab.4 Types of links between industrial clusters in Wuhan metropolitan area

Network type	Bi-directional	Unidirectional link	Percentage of two-	Percentage of one-	Number of empty

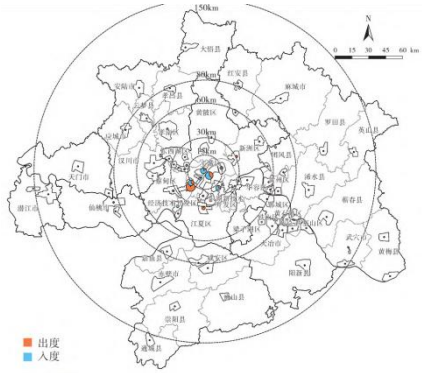
		l link volume / classifier for individual things or people, general, catch-all classifier	volume / classifier for individual things or people, general, catch-all classifier	way links /%	way links /%	connections/pc
Manufacturing companies	Headquarters branch	214	420	33.75	66.25	1994
	investors	170	382	30.80	69.20	2076
	provider	93	305	23.37	76.63	2230
Leading Industrial Companies	Headquarters branch	76	263	22.42	77.58	2289
	investors	85	211	28.72	71.28	2332
	provider	18	182	9.00	91.00	2428
Productive service enterprises	Headquarters branch	414	657	38.66	61.34	1557
	investors	397	475	45.53	54.47	1756
	provider	308	624	33.05	66.95	1696

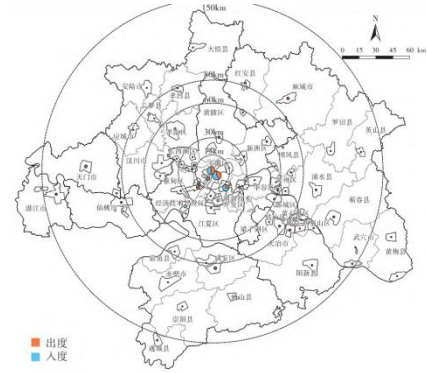


(a) Branch headquarters of manufacturing enterprises



(b) Branch headquarters of productive service enterprises





(c) Suppliers to manufacturing firms (d) Suppliers to productive services firms

Fig.6 Degree centrality of industrial clusters in Wuhan Metropolitan Area

reached 67%, the science and innovation function with production and service functions

This shows that regional innovation strength plays an important role in driving industrial development.

The centrality rankings of the "customer-supplier" networks show clear industry differences compared to the "headquarters-branch" networks. For example, Clusters 1-13 have the highest centrality in manufacturing and the fourth highest in productive services, indicating that their manufacturing sector is the most centralized.

The level of development is high, but a little weak in terms of supporting services;

Clusters 1-16, 1-3, 1-11, etc. are ranked in the top ten in terms of manufacturing but not in the top ten in terms of productive services, indicating that they are dominated by manufacturing functions, while the opposite is true for Clusters 3-3, 9-1, 6-2, etc., indicating that they are dominated by productive service functions. See table 5.

To further analyze the functional differences between the core and peripheral circles, each of the core and peripheral circles was selected in the

Five high-centeredness clusters, combined with the China Development Zone

The leading industry information in the "Audit Bulletin Catalogue (2018 Edition)", the industry maps of each city, and the introduction of industry development in the development zone portals are further analyzed to find out the types of leading industries (Table 6) Within the core circle, the industrial clusters have different preferences for industry development and have become functionally differentiated, with clusters located in the main urban area of Wuhan playing the function of comprehensive services, and clusters outside of the main urban area

Table 5 Top 10 Industry Groups in terms of Degree of Centrality

Tab.5 Top 10 industry clusters in terms of degree centrality

Branch network of headquarters of manufacturing companies				Branch network of headquarters of companies in the productive services sector			
serial number	location	Type of group	Direction of contact (degrees out - degrees in)	serial number	location	Type of group	Direction of contact (degrees out - degrees in)
1-1	Wuhan main city	Integrated services	-181	1-1	Wuhan main city	Integrated services	1193
1-7	Wuhan main city	Integrated services	-444	1-7	Wuhan main city	Integrated services	2845
1-2	Wuhan East Lake High-Tech Zone, subprovincial district of Wuhan, China	science creation center	118	1-2	Wuhan East Lake High-Tech Zone, subprovincial district of Wuhan, China	science creation center	1409
1-20	Wuhan main city	Integrated services	-35	1-20	Wuhan main city	Integrated services	-734
1-11	Qingshan District, Wuhan	General Manufacturing	32	1-21	East and West lake district of Wuhan, subprovincial city and capital of Hubei province	advanced manufacturing	247
1-13	Wuhan Economic	advanced manufacturing	91	1-9	Wuhan Economic	innovative industries	-544

	Development Area (WEDA)				Development Area (WEDA)		
3-3	Huangshi main city	Cross-border industrial cooperation	23	3-3	Huangshi main city	Cross-border industrial cooperation	-272
1-8	Jiangxia district of Wuhan, subprovincial city and capital of Hubei province	innovative industries	77	4-9	Huanggang Huangzhou district of Huanggang city	Cross-border industrial cooperation	106
4-9	Huanggang Huangzhou district of Huanggang city	Cross-border industrial cooperation	-18	1-8	Jiangxia district of Wuhan, subprovincial city and capital of Hubei province	innovative industries	-195
1-18	East and West lake district of Wuhan, subprovincial city and capital of Hubei province	advanced manufacturing	67	1-16	Wuhan Economic Development Area (WEDA)	advanced manufacturing	119
Supplier Networks for Manufacturing Companies				Supplier networks for productive service enterprises			
1-13	Wuhan Economic Development Area (WEDA)	advanced manufacturing	2364	1-1	Wuhan main city	Integrated services	-1632
1-1	Wuhan main city	Integrated services	-530	1-7	Wuhan main city	Integrated services	-190
1-7	Wuhan main city	Integrated services	-829	1-2	Wuhan East Lake High-Tech Zone, subprovincial district of Wuhan, China	science creation center	-1871
1-16	Wuhan Economic Development Area (WEDA)	advanced manufacturing	-283	1-13	Wuhan Economic Development Area (WEDA)	advanced manufacturing	633
1-2	Wuhan East Lake High-Tech Zone, subprovincial district of Wuhan, China	science creation center	-400	3-3	Huangshi main city	Cross-border industrial cooperation	505
1-3	Jiangxia district of Wuhan, subprovincial city and capital of Hubei province	innovative industries	438	1-20	Wuhan main city	Integrated services	105
1-11	Qingshan	General	-53	1-9	Wuhan	innovative	-906

	District, Wuhan	Manufacturing			Economic Development Area (WEDA)	industries	
1-20	Wuhan main city	Integrated services	-240	9-1	Tianmen sub-prefecture level city in Hubei	Cross-border industrial cooperation	328
1-9	Wuhan Economic Development Area (WEDA)	innovative industries	-259	6-2	Xian'an District, Xianning, China	innovative industries	244
1-8	Jiangxia district of Wuhan, subprovincial city and capital of Hubei province	innovative industries	98	1-8	Jiangxia district of Wuhan, subprovincial city and capital of Hubei province	innovative industries	139

Groups mainly play the functions of advanced manufacturing and innovative industries, and there are obvious development focus differences, for example, Groups 1-2 focus on the development of optical core, screen end network and life and health industries, and Groups 1-13 focus on the development of new energy automobile and new material industries. In the peripheral circles, the leading industries are optoelectronic information, life and health, and intelligent manufacturing, and there is isomorphism in the industrial structure. Although the convergence of the industrial structure and the deepening of the regional division of labor can coexist at the same time[27] , the peripheral circles are in the state of low-level duplication of construction, which makes it difficult for them to form a perfect industrial chain division of labor with the core circles, and it may even lead to the decline in the efficiency of the resource allocation.

4.2.2 Cross-border industrial cooperation groups have a strong synthesis interlinkability

Point degree centrality is primarily based on the number of relationships

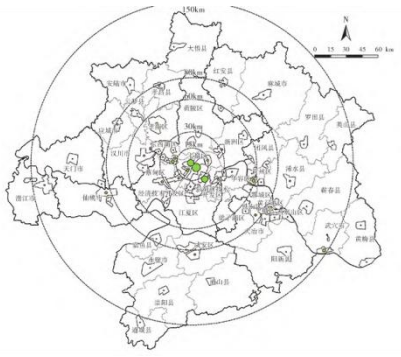
Table 6 Types of dominant industries in high centrality industrial clusters

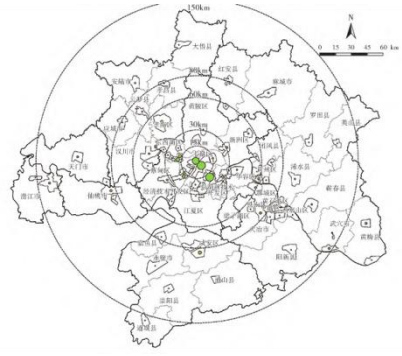
Tab.6 Types of dominant industries in industrial clusters with high degree of centrality

coterie	Group name	Location of the group	Type of group	Leading industries of the group
Within the inner circle	1-1	Wuhan main city	Integrated services	Financial services, scientific and technological services, engineering design, cultural creativity
	1-2	Wuhan East Lake High-Tech Zone, subprovincial district of Wuhan, China	science creation center	Optical core screen end network, life health, intelligent manufacturing
	1-7	Wuhan main city	Integrated services	Creative design, financial services, technology services, trade and logistics
	1-13	Wuhan Economic Development Area (WEDA)	advanced manufacturing	New Energy Vehicles, New Materials, Life and Health, Electronic and Electrical Appliances
	1-20	Wuhan main city	Integrated services	Health services, industrial services, e-commerce
Outside the inner circle	3-3	Huangshi main city	Cross-border industrial cooperation	Optoelectronic information, equipment manufacturing, biomedicine
	4-9	Huanggang Huangzhou district of Huanggang city	Cross-border industrial cooperation	Optoelectronic information, intelligent manufacturing, biomedicine
	5-1	Xiaogan Xiaonan district of Xiaogan city, Guangdong	Cross-border industrial cooperation	Optoelectronic information, advanced manufacturing
	6-2	Xian'an District,	innovative industries	Optoelectronic information, big health, intelligent manufacturing

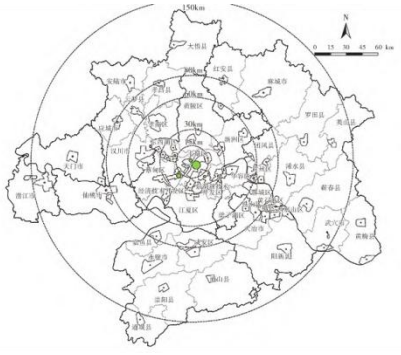
	Xianning, China		
7-1	Xiantao sub-prefecture level city in Hubei	innovative industries	New materials, biomedicine, electronic information

less to reflect the centrality of the node in the network, but the
This centrality is sometimes not as important as the position of bridging; mediational centrality portrays nodes based on the number of shortest paths they take, in response to the bridging role they play[28] .
In Table 5, the top five clusters in terms of degree of centrality are almost all located within the core circle, and the top ten clusters
There are also few of them that are not located in Wuhan. However, according to Figure 7
and Table 7, among the top ten groups in terms of intermediary centrality, there is an increase in the proportion of groups located in peripheral circles and not belonging to Wuhan, and the intermediary centrality of some groups is even higher than that of some highly centralized groups located in Wuhan. Although these clusters are not in the center of the network, they play the role of "bridge" in the network
Role, with strong and comprehensive contact skills for the web
The level of functional synergy of the network instead plays a more important role.
In addition, most of the highly intermediary centrality clusters located in the peripheral circles are cross-border industrial cooperation clusters, which indicates that the cooperation parks promoted by the Wuhan metropolitan area have strengthened the connection between the peripheral circles and the core circles.





(a) Branch headquarters of manufacturing companies (b) Investment in manufacturing companies



(c) Suppliers to manufacturing companies
Fig.7 Betweenness centrality of industrial clusters in Wuhan Metropolitan Area

Table 7 Top 10 industrial clusters in terms of intermediary centrality
Tab.7 Top 10 industry clusters in terms of betweenness centrality

Manufacturing enterprise headquarters branch			Investment by manufacturing firms			Suppliers to manufacturing companies		
serial number	location	Type of group	serial number	location	Type of group	serial number	location	Type of group
1-1	Wuhan main city	Integrated services	1-1	Wuhan main city	Integrated services	1-1	Wuhan main city	Integrated services
1-7	Wuhan main city	Integrated services	1-2	Wuhan East Lake High-Tech Zone, subprovincial district of Wuhan, China	science creation center	1-13	Wuhan Economic Development Area (WEDA)	advanced manufacturing
1-2	Wuhan East Lake High-Tech Zone, subprovincial district of Wuhan, China	science creation center	1-7	Wuhan main city	Integrated services	3-3	Huangshi main city	Cross-border industrial cooperation
3-3	Huangshi main city	Cross-border industrial cooperation	1-18	East and West lake district of Wuhan, subprovincial city and capital of Hubei province	advanced manufacturing	1-7	Wuhan main city	Integrated services
4-6	Huanggang Wuxia prefecture level city in Hubei	innovative industries	3-3	Huangshi main city	Cross-border industrial cooperation	1-2	Wuhan East Lake High-Tech Zone, subprovincial district of Wuhan, China	science creation center
4-9	Huanggang Huangzhou district of Huanggang city	Cross-border industrial cooperation	6-2	Xian'an District, Xianning, China	innovative industries	5-1	Xiaogan Xiaonan district of Xiaogan city, Guangdong	Cross-border industrial cooperation
1-18	East and West lake district of Wuhan, subprovincial city and capital of Hubei province	advanced manufacturing	1-21	East and West lake district of Wuhan, subprovincial city and capital of Hubei province	advanced manufacturing	1-21	East and West lake district of Wuhan, subprovincial city and capital of Hubei province	advanced manufacturing
1-20	Wuhan main city	Integrated services	1-13	Wuhan Economic Development Area (WEDA)	advanced manufacturing	5-5	Xiaogan Yingcheng city in Hubei	General Manufacturing
5-1	Xiaogan Xiaonan district	Cross-border industrial	5-1	Xiaogan Xiaonan district	Cross-border industrial	7-1	Xiantao sub-prefecture level	Cross-border industrial

	of Xiaogan city, Guangdong	cooperation		of Xiaogan city, Guangdong	cooperation		city in Hubei	cooperation
1-21	East and West lake district of Wuhan, subprovincial city and capital of Hubei province	advanced manufacturing	1-19	Wuhan East Lake High-Tech Zone, subprovincial district of Wuhan, China	innovative industries	1-16	Wuhan Economic Development Area (WEDA)	advanced manufacturing

Collaboration is important for improving the accessibility and transmission efficiency of the industrial cluster network. From the viewpoint of the twinning parties of the co-built parks, most of the cooperation is between the peripheral industrial clusters and Donghu Hi-Tech Zone, and a few of them are with Wuhan Economic-Technological Development Zone (WEDZ) and Lingkong Port Economic-Technological Development Zone (LKPEDZ), which explains that although clusters 1-2, 1-11, and 1-13 belong to the highly centralized clusters, the intermediary centrality of clusters 1-2 located in the Donghu Hi-Tech Zone is generally higher, and the intermediary centrality of clusters 1-11 in Qingshan District does not even rank in the top ten. Cluster 1-11 in Qingshan District does not even rank in the top ten in terms of centrality.

5 Conclusion and discussion

5.1 Perceptual diagnosis and simulation methods based on the "space of places" and "space of flows" are universal.

The key to studying and promoting industrial division of labor among cities from a spatial perspective lies in finding the industrial chain,

The correlation between the deep integration and development of supply chain and the spatial organization of industries in the metropolitan area, so as to realize the integrated development pattern through the supply or shaping of key spatial elements. When solving the above problems, the traditional planning method focuses on summarizing and refining from "planning practice" to "planning experience", and there are problems of lack of data, measurement and science. In the face of the complex giant system of metropolitan area, intelligent planning technology based on data and modeling is inevitable. In the face of the complex system of metropolitan area, the intelligent planning technology based on data and modeling is imperative. This paper proposes a comprehensive analysis method of "place space" and "flow space", which is expected to provide a set of scientific and feasible technical system for the diagnosis of perception and intelligent planning of the metropolitan area.

5.1.1 Combining shape and flow to develop industrial space in the metropolitan area

Feature Sensing and Problem Diagnosis

Comprehensively adopting the research methods of "place space" and "flow space", and measuring and evaluating from the dimensions of metropolitan area's industrial spatial agglomeration level and functional synergism level, we can perceive the metropolitan area's industrial spatial characteristics and diagnose the existing problems. Based on the geographical proximity of the field

The spatial analysis method can analyze the characteristics of industrial spatial agglomeration in terms of land use, employment, number of enterprises and capital density. The use of multi-type flow spatial data can reflect the network connection characteristics of different dimensions of industrial space, such as the "headquarters-branch" network mainly characterizes the vertical hierarchical relationship within the enterprises in the metropolitan area, while the "customer-supplier" network can measure the horizontal division of labor relationship among enterprises in the metropolitan area, thus providing an insight into the functional polarization of the network and the industrial chain. " network can measure the horizontal division of labor relationship among enterprises in the metropolitan area, so as to make a comprehensive evaluation of network function polarization, industrial chain division of labor, administrative division obstruction, and supply chain security toughness level. In addition, based on the calculation results of the indexes of out-degree, in-degree and intermediary center-degree of industrial

group nodes, it is able to diagnose the operation status of various types of industrial parks from the perspective of regional linkage, and to identify the hubs, key points, obstacles and other industrial group nodes that affect the development of industrial integration.

5.1.2 Shape flow simulation for metropolitan area industrial space

Typical scenario projections

Based on the results of the perceptual diagnostics, scenarios can be developed to predict trends in metropolitan areas and to simulate different scenarios

(b) Evolutionary characteristics of the "shape" and "flow" of industrial space. There are two common simulation scenarios: one is the scenario simulation under normal development, which refers to the existing drivers and path-dependent process to deduce the future state of industrial space in the metropolitan area; the other is the scenario simulation driven by major strategies, which integrates major spatial strategies or the construction of major projects into the simulation model as the key variables, such as Wuhan New City and Huahu Airport in Wuhan metropolitan area, and evaluates their impact on the industrial space of the metropolitan area. Role. A multi-intelligence system can be used to simulate the evolution of industrial space "shape", and the "flow space" data can be used to simulate the cooperation, competition, complementarity and other related relationships among industrial groups, so as to predict the key strategic spaces that may emerge in the metropolitan area in the future. Based on the complex network system, we can simulate the evolution of industrial space "flow" in the metropolitan area under different scenarios, and use the attack simulation method to test the resilience level of "flow space" under the situation of supply chain cut-off and cut-off of production.

5.1.3 Optimize the industrial space of the metropolitan area by shaping it with flows

opening (chess jargon)

The industrial spatial layout supports the compilation of industrial maps of the metropolitan area with park accuracy. In addition, the "customer-supplier" data in this paper comes from the public bidding information of enterprises, and the sample coverage is not good. In the future, we can collect the procurement invoice data of enterprises and the trajectory data of logistics trucks, so as to better measure the "flow space" characteristics of the industrial clusters in the metropolitan area and improve the accuracy of the flow-based shaping. " characteristics of the industrial clusters in the metropolitan area to better measure the "flow space" characteristics and improve the accuracy of flow-based shaping.

5.2 The optimization of industrial spatial distribution in strong-core growth metropolitan areas has certain regularities

Most of China's metropolitan areas belong to the strong core growth type metropolitan area with provincial capitals and mega cities as the core, and Wuhan metropolitan area is a typical representative of the strong core growth type metropolitan area from the perspectives of economic scale, industrial development, and regional connection. How to optimize the industrial spatial organization of the metropolitan area and promote the deep integration of industrial chain and supply chain of the metropolitan area from the perspective of spatial supply is the necessary path for the strong core growth metropolitan area to achieve high-quality development.

5.2.1 Creating a "core + axis" industrial spatial layout structure

In view of the problems of over-polarization of the network and the weakness of the outer circle that are common in strong-core growth metropolitan areas, the spatial layout pattern of "core + axis" should be adopted, making use of the radiation-driven effect of the core cities of the metropolitan area, relying on the industrial development axis to drive the periphery of the metropolitan area with multi-level nodes in the industrial space, and promoting the extension of the industrial chain supply chain from the core to the peripheral circle. It will promote the extension of the industrial chain supply chain from the core circle to the periphery, and promote the formation of a well-functioning industrial integration pattern with division of labor and coordination in the metropolitan circle. Wuhan Metropolitan Area should build an industrial space layout structure of "one core, four corridors and multiple nodes" (Fig. 8), and create the Wuhan-Ermenia-Huangzhou-Huangzhou "Optical Core, Screen, End Network" Science and Innovation Corridor,

Wuxian Life and Health Industry Development Axis, Hanxiao Airport Industry Development Axis, Wuxian Advanced Manufacturing Industry Development Axis, radiate and drive the sub-core nodes, important nodes and new nodes along the route, promote the free flow of capital, information,

technology, talents and other factors along the corridors, and form a spatial pattern of core-driven, node-supporting and axial-ribbon radiation.

5.2.2 Optimize the function of industrial clusters and deepen the division of labor and collaboration between industries in the inner and outer circles.

As an important spatial support for the construction of a new development pattern of "double cycle", the metropolitan area should not only become an important node of the domestic general cycle, but also form a reasonable system of division of labor within the area, so as to open up its own "internal cycle"[29] . For the strong core growth metropolitan area, a more perfect industrial chain supply chain system has not yet been formed within the circle, and since the peripheral circles are still at a low level of homogenization, the supply chain network is mainly concentrated in the core circle, or crosses the peripheral circles to be associated with the cities outside the circle. Therefore, it is necessary to actively guide the differentiated development of industrial groups in the peripheral circles, give full play to their comparative advantages, docking the core circle advantageous industries, undertake the transfer of the core region and the spillover of the production chain, to realize the metropolitan area industrial chain supply chain extension chain and complementary chain, and cultivate functional complementary industrial clusters in the peripheral circles. Wuhan Metropolitan Area can combine the advantages of core nodes with the local industrial foundation to differentiate and create 6 major industrial synergistic development zones, including optoelectronic information and intelligent manufacturing, new energy and intelligent networked automobile, airside industry, light manufacturing, intelligent mechanical and electrical manufacturing, and life and health, so as to improve the competitiveness of industrial clusters and improve the industrial chain supply chain division of labor system in the metropolitan area.

(Figure 8). The core circle group should continue to improve the comprehensive service

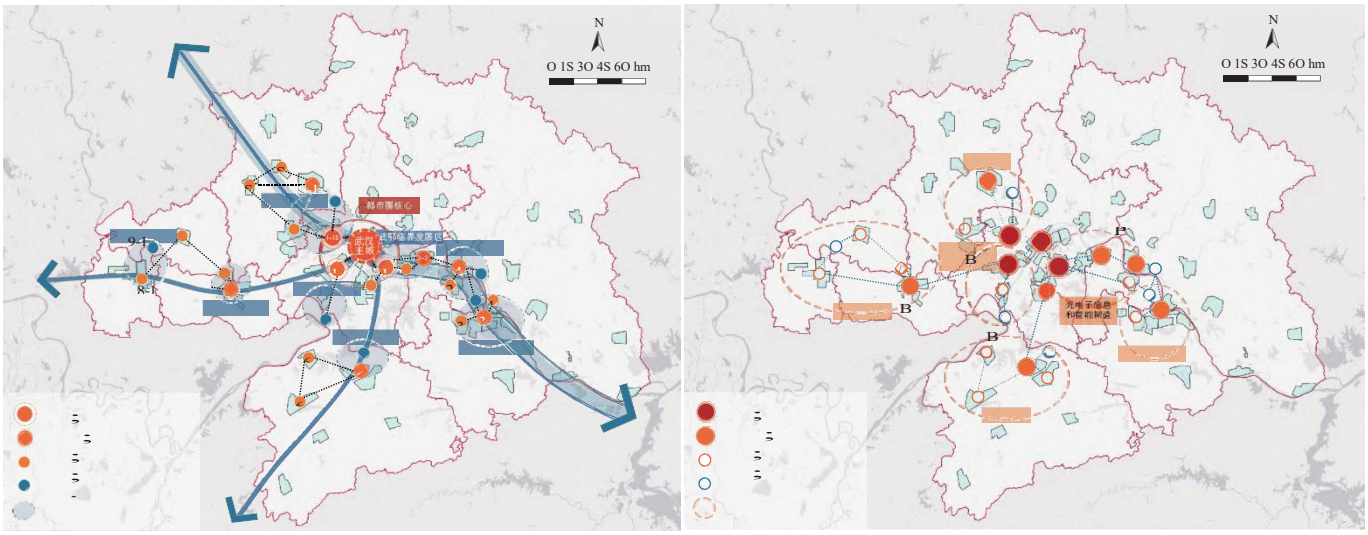


Fig.8 Model of industrial space optimization in Wuhan Metropolitan Area

The radiation-driven role of the synergistic development zone; the industrial clusters adjacent to the core circle may be affected by the shadow of agglomeration or the siphon effect, and it is advisable to cultivate the manufacturing industry in order to enhance the functional complementarity; the sub-center nodes far away from the core circle can rely on the synergistic development zone of the industry to promote the development of related productive service industries: thus forming the pattern of research and development, financing, head, and the main chain in the core, and the manufacturing, investment, chain, and supporting in the periphery.

5.2.3 Promote critical regional cooperation and co-construction, and enhance cross Functional linkage of administrative districts

Cross-border industrial cooperation groups play an important role as bridges in the industrial network of growing metropolitan areas, and are the key nodes linking peripheral and core circles, which help to break the barriers of administrative divisions and enhance the level of regional functional synergy. It should actively promote the synergistic development of critical areas and the co-construction of cooperative parks, take advantage of the price advantages of land and labor in peripheral cities, and promote the co-construction of parks and cooperation in critical areas such as Wu-Er, Han-Hsiao, Wu-Shan, Wu-Xian, Wu-Huang-Huang, and Xian-Tian, to enhance industrial cooperation and create a demonstration area for cross-border exchanges, cooperation and spatial integration in metropolitan areas (Fig. 8). The first is to build a perfect mechanism for the co-construction and cooperation of parks, strengthen information exchange and policy coordination among different regions, and avoid the decline of cooperation efficiency due to information asymmetry and conflict of interests; the second is to formulate targeted policy measures to encourage enterprises to participate in the co-construction and cooperation of parks through preferential policies such as taxation, land and financial support; the third is to customize co-construction and cooperation programs to match the development of local industries according to the local resource base and the status quo of industrial development. Third, according to the local resource base and industrial development status, we should customize the co-construction and cooperation programs to match the development of local industries, and promote the in-depth cooperation of the characteristic parks in the metropolitan area through the innovation of extra-parks and two-way enclaves, etc. Fourth, we should adopt a more open governance and encourage both parties to innovatively explore the mutually beneficial and win-win cooperation mode.

6 concluding remarks

This paper takes Wuhan metropolitan area as the research object, adopts industrial clusters as the basic unit, integrates the analysis methods of "place space" and "flow space" to analyze the organizational characteristics and problems of industrial space in Wuhan metropolitan area, and proposes the methods of perceptual diagnosis and simulation of "place space" and "flow space". It also proposes a method of

perceptual diagnosis and simulation of "place space" and "flow space", and summarizes the strategy of optimizing the industrial space layout of strong-core growth metropolitan area, in the hope that it can provide a reference for the territorial space planning of other metropolitan areas.

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