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Study on the Development Trend and Reform Path under the Framework of Guangdong-Hong Kong-Macao Education Cooperation

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SUMMARY: *This paper studies the research cooperation network of Guangdong, Hong Kong and Macao Greater Bay Area, analyzes its cooperation patterns at three levels: intra-regional, domestic and international, and predicts inter-institutional research cooperation relationships. Through the elements of the cooperation framework of the Guangdong-Hong Kong-Macao Greater Bay Area University Consortium and the characteristics of the multi-level governance of education, it proposes a method of predicting institutional cooperative relationships by complex network and link prediction, utilizing the combination of the attention mechanism and the deep learning method, and extracts the three major factors affecting the development of scientific research cooperative relationships in the framework of educational cooperation by combining the scientific research data of Guangdong-Hong Kong-Macao Greater Bay Area in the period of 2017-2024. For the education cooperation framework of Guangdong-Hong Kong-Macao Greater Bay Area University Consortium, the patent cooperation network among universities is structurally analyzed and the development path of research cooperation is proposed. The network structure factor, the scholar factor, and the thesis factor are used as the estimation results of the Guangdong-Hong Kong-Macao research cooperation network link prediction model to influence the development of Guangdong-Hong Kong-Macao research cooperation relationship. Under the support of the education cooperation framework, the thesis support can be further provided to scholars in Guangdong, Hong Kong and Macao, and research conditions can be created to promote the progress of scientific research development in Guangdong, Hong Kong and Macao.*

KEYWORDS: *attention mechanism; research cooperation network; complex network; institutional partnership prediction; link prediction; Guangdong-Hong Kong-Macao education cooperation*

1 Introduction

With the release of relevant national policies, the development and construction of the Guangdong-Hong Kong-Macao Greater Bay Area has been highly valued by the state. From the national perspective, the construction and development of the Greater Bay Area can promote the good development of "one country, two systems", and is conducive to the realization of the comprehensive opening up of the new era [1, 2]. From the local perspective, the development of Guangdong, Hong Kong and Macao Greater Bay Area needs to seize the opportunity to build itself into a highly dynamic, innovative and competitive city, which is one of the goals to be achieved in the development of the Greater Bay Area, and in order to achieve this goal, it is necessary to rely on the internationalized education system [3-5]. The cooperation between

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mainland universities and universities in Hong Kong and Macao in the Guangdong, Hong Kong and Macao Greater Bay Area plays an important role in promoting the integrated development of the Guangdong, Hong Kong and Macao Greater Bay Area, enhancing the comprehensive strength of higher education in the Guangdong, Hong Kong and Macao Greater Bay Area, and promoting the Guangdong, Hong Kong and Macao Greater Bay Area to become an international science and technology innovation center [6].

In the past, the non-cooperative game and disordered mutual competition for resources among higher education institutions have brought obstacles to communication and cooperation among universities, and the resulting waste of resources and loss of efficiency [7]. The traditional way of higher education management can not adapt to the new trend of today's synergistic development, and higher education cluster development adapts to the objective requirements of the current synergistic development of colleges and universities [8]. Regarding the cooperation among regional higher education institutions, Knight conducted a theoretical analysis of regionalized cooperation among higher education institutions based on the "function-organization-politics" three-dimensional framework. Taking cross-border regional universities as an example, he systematically expounded the functional collaboration, organizational carriers, and political coordination mechanisms of regional higher education cooperation, as well as its global practice [9]. Akhir elaborated on the framework for cooperation in higher education in Southeast Asia and the wider East Asian region, focusing on the various cooperative programs and activities in higher education that have been implemented, are underway, and are being planned under the ASEAN, ASEAN+3 (China, South Korea, and Japan), and East Asia Summit (EAS) frameworks covering Australia, New Zealand, India, and the U.S. and Russia [10]. Hirosato proposed a framework for expanding interregional cooperation in higher education in Southeast Asia, examining the multiple levels of key actors (stakeholders) involved in regional cooperation in higher education in Southeast Asia, including university/higher education institution level cooperation, governmental/intergovernmental cooperation, and intra-regional/trans-regional cooperation [11]. Focusing on academic collaboration in the Baltic Sea region, Ewert focused on the regional collaborative networks of 70 higher education institutions in the region, and found that the higher education system in the region exhibits significant heterogeneity, and the degree of regional integration of institutions is closely related to their academic positioning, and participation in regional networks [12]. Qi et al. explain how these European HEIs establish and maintain collaborative relationships with their Chinese partners, sort out the mechanisms of interaction between universities, government agencies and policies, and identify specific challenges encountered in the process of cooperation, and the results of this research provide empirical data for the cooperation between European and Chinese higher education institutions, [13]. Da Conceição Rego et al. believe that cooperation between higher education institutions and other stakeholders is one of the effective ways to promote local development. This is because it can introduce innovative knowledge into various activities, thereby enhancing the competitiveness of enterprises and the operational efficiency of institutions. To facilitate the collaboration process and partnerships between higher education institutions and stakeholders, and thereby promote local development, higher education needs to utilize innovative teaching methods to open up new educational horizons [14].

In China, higher education mainly adopts the competitive development paradigm based on the market regulation mechanism, while the mainstream development paradigm that has been advocated nowadays, the collaborative development of higher education emphasizes win-win cooperation, and the collaborative development of higher education among regions adapts to the objective requirements of the collaborative development of higher education nowadays [15]. The proposal of the Guangdong-Hong Kong-Macao Greater Bay Area has put forward new requirements for the cooperative development of higher education in Guangdong, Hong Kong and Macao, and studies on topics related to higher education in the Guangdong-Hong Kong-Macao Greater Bay Area have also emerged with the proposal of the Guangdong-Hong Kong-Macao Greater Bay Area strategy in recent years [16, 17]. Xie et al.'s research on higher education in the Guangdong-Hong Kong-Macao Greater Bay Area shows that the Bay Area, as a typical model of economic and cultural development relying on geography and regional linkage, has a unique complexity in the construction of its higher education system due to the special institutional environment of “one country, two systems and three jurisdictions” [18]. Chen believes that cooperation among regional universities should pay more attention to the complementarity and coordination of resources, and that the cooperation of higher education in the Guangdong-Hong Kong-Macao Greater Bay Area is carried out in the special context of “one country, two systems, three tax zones, and three legal systems”, which makes it especially necessary to examine and analyze the cooperation in the context of the national major development strategies [19]. Zeng, the study found that cooperation between guangdong higher education has experienced from the "one-way output" to "multidirectional interaction", and "win-win fusion" three stages of evolution course, points out that the education cooperation should with large bay area construction as an opportunity to accelerate in the framework of "one country, two systems" in into the nation's overall development, Push the teachers' education cooperation towards the community sharing, common fate deepening development [20]. Liang explored the policy evolution of higher education cooperation in the context of the Guangdong-Hong Kong-Macao Greater Bay Area strategy, analyzing 65 relevant policy texts, and found that the overall evolution path of higher education cooperation policies among Guangdong, Hong Kong and Macao is highly consistent with the national strategic orientation of open development, coordinated development and innovative development [21].

The integration and development of higher education in Guangdong, Hong Kong and Macao Greater Bay Area has been a hot topic, and also many related scholars have given different perspectives in their research to analyze the results [22]. The higher education community of Guangdong, Hong Kong and Macao is an intrinsic requirement for the modernization and internationalization development of higher education in the three regions.Ma et al. quantitatively analyzed the correlation between the discipline layout and industrial structure of Guangdong, Hong Kong and Macao Greater Bay Area, and found that Guangdong and Hong Kong both have structural deviation in the secondary industry, where the supply of Hong Kong's scientific and technological talents exceeds the local demand, and the relevant talents in Guangdong fail to satisfy the industrial needs, which shows that the two places have potential complementarities, but the The flow of talents is still constrained by regional selection preferences [23]. Fumasoli and Shen's research found that the higher education cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area has rapidly advanced in terms of function and academic aspects due to the alignment with the country's economic and technological goals and the proactive adaptation of universities. However, in terms of structure and culture, it has been slow due to deep-seated institutional differences and regional autonomy demands, resulting in a cooperation model of "national-led promotion" and "university autonomous collaboration" [24]. Wang and Liu used UCINET software to visualize and analyze the Guangdong-Hong Kong-Macao university cooperation network, and found that the current cooperation network of universities in the Greater Bay Area has a high density (density = 0.746), but the cohesive trend is not significant (network centrality = 26.92%), and a clear circle structure has been formed [25]. Huang and Xie explored the opportunities and challenges that Hong Kong faces in the promotion of the internationalization of higher education in the Greater Bay Area opportunities and challenges faced by Hong Kong in promoting the internationalization of higher education in the Greater Bay Area, as well as the role that its universities can play, and found that Hong Kong's higher education sector can enhance its influence in the Greater Bay Area by exporting education programs and cultivating global talents, etc. [26]. Nie explored the path of synergistic development of the higher education clusters in the Guangdong, Hong Kong and Macao Greater Bay Area, and then constructed an internationalized higher education network system with clear hierarchy, gradient articulation, and close interactions, which would be the an important engine to drive the high-quality development of the world-class Greater Bay Area [27].

This paper summarizes the elements of university alliance cooperation under the education cooperation framework of Guangdong-Hong Kong-Macao Greater Bay Area, points out the multi-level governance characteristics of education in Guangdong-Hong Kong-Macao Greater Bay Area, regards the research partnership network of Guangdong-Hong Kong-Macao Greater Bay Area as a complex network, utilizes the prediction method of institutional partnership based on the attention mechanism and deep learning to conduct the analysis of the development trend of the scientific research partnership and uses the Machine learning cooperation network to validate the prediction method. Capture and process the scientific research data of Guangdong, Hong Kong and Macao Greater Bay Area, get the results of academic cooperation network indicators of cities within the Greater Bay Area, with domestic cities, and with major countries, use prediction method to obtain the main factors affecting scientific research cooperation relationship, analyze the characteristics of the development of university-school patent cooperation network in Guangdong, Hong Kong and Macao Greater Bay Area, and briefly propose the path of scientific research development under the framework of educational cooperation.

2 Development trends under the framework of education cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area

2.1 Collaborative Framework of the Federation of Universities in the Greater Bay Area of Guangdong, Hong Kong and Macao

The cooperation framework of the 25 Guangdong, Hong Kong and Macao Greater Bay Area university alliances is shown in Figure 1. According to the cooperation framework of the university alliances, it is shown that the 25 university alliances initially established in the Guangdong-Hong Kong-Macao Greater Bay Area have basically set the objectives of alliance cooperation, the scope of cooperation, and determined the corresponding modes of action and organizational systems according to the characteristics of the objectives and scope. The objectives of the alliance are centered on different aspects such as resource sharing, talent cultivation, scientific and technological cooperation, and collaborative innovation. The scope of cooperation covers a wide range, from the overall level of system construction to the specific level of courses, credits, literature transfer and so on. The actions taken according to the objectives and scope are diverse, including not only the construction of joint laboratories among universities, but also the exchange and training of teachers and the organization of special competitions among students. The organizational system, on the other hand, covers the constitution of the alliance, the decision-making body, the exchange mechanism and other aspects.

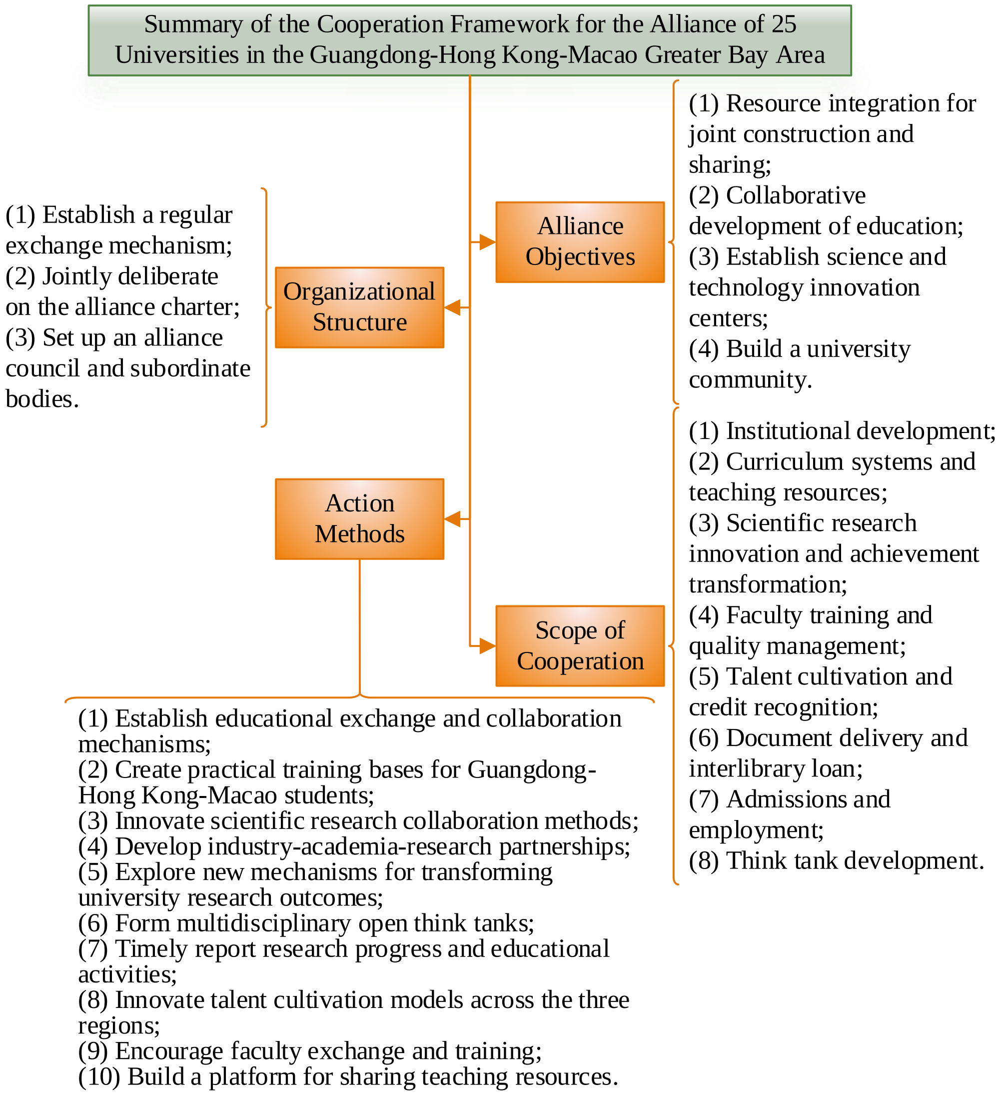


Figure 1: 25 cooperation framework of Hong Kong and Macao university alliance

The construction of the Guangdong-Hong Kong-Macao Greater Bay Area University Alliance has the following three main characteristics at the current stage:

First, the type of alliance universities has consistency.

Second, the scale, structure and level of the alliance universities are different.

Third, the cooperation framework of the alliance universities is comprehensive.

2.2 Multi-level Governance Framework for Education in the Guangdong-Hong Kong-Macao Greater Bay Area

The so-called multilevel governance theory, or "multilevel governance" in EU studies, was initially used to explain the phenomenon of European integration, and has "evolved into an important theoretical school and practical model of EU governance, referring to the interconnections and interactions between the regional (in this case intra-national regions), national and supranational levels.".

(1) From the perspective of political science, the Guangdong-Hong Kong-Macao Greater Bay Area is a new political geographic space constructed on the basis of transcending administrative districts, with the existence of multi-level governments and diversified education subjects across the region.

(2) The institutional environment of "one country, two systems", multi-level governments and diversified governance subjects make the education cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area face multiple conflicts between the homogeneity of administrative power and the plurality of local space, top-down government drive and bottom-up social participation, and the boundaries of administrative regions and the mobility of cyberspace. The conflict.

(3) The Guangdong-Hong Kong-Macao Greater Bay Area itself is an institutional attempt to innovate national governance, and this institutional framework involves various strategic issues at the governance level.

(4) The multi-level governance of education in the Guangdong-Hong Kong-Macao Greater Bay Area is embodied in the structural dimension as both territorial and functional governance, which requires both a clear division of labor and a structurally stable administrative system at the central, provincial, municipal, county, and township levels of government, as well as flexible means of governance. Therefore, education cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area should, on the one hand, establish a coordination mechanism and a linkage mechanism based on administrative territory, and on the other hand, provide task-oriented and problem-oriented functional platforms and operational projects. The multi-level governance framework for education in the Guangdong-Hong Kong-Macao Greater Bay Area is shown in Figure 2.

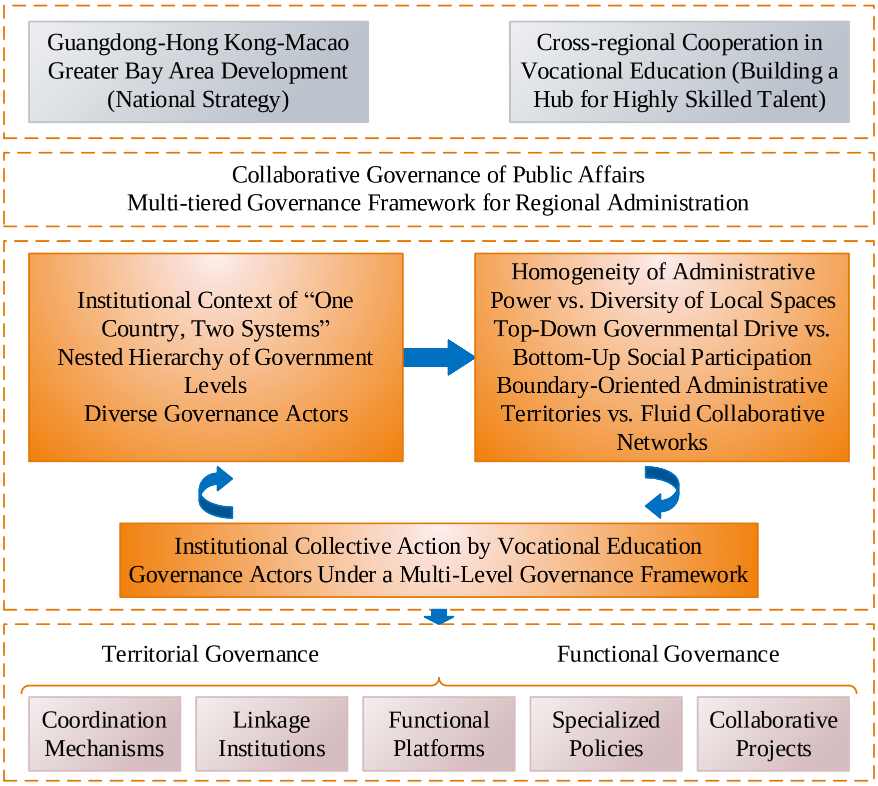


Figure 2: Multi-level governance framework of Hong Kong and Macao education

3 Forecasts of scientific and research partnerships in the framework of educational cooperation

Based on the analytical framework of multi-level governance of education in the Guangdong-Hong Kong-Macao Greater Bay Area, this section analyzes and predicts the path of scientific research development under the framework of education cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area, using scientific research partnership as a base point.

In this paper, research cooperation network is defined as the network between individual scholars, disciplinary fields, organizations, geographic regions or countries due to cooperation (or co-authorship) in the form of scientific research results such as scientific and technological papers, patents and projects.

3.1 Complex Networks and Link Prediction

Complex network can describe the route map between cities, people's friendship in real society, the connection relationship between computers in the Internet and the combination relationship between words in the language and so on. And complexity characteristics are the most prominent features in complex networks, complexity is mainly manifested in the following aspects:

(1) Network size is huge. Complex networks are often useful for a large number of nodes, and in and in the structure of the network presents a variety of features.

(2) Network evolution. Network evolution leads to constant changes in the network structure, which will produce new connecting edges or nodes, and will also disappear some old connecting edges or nodes.

(3) Connection diversity. The weights of connected edges are not fixed and may follow different weight rules. And the connected edges may have directionality.

(4) Dynamic complexity. Specifically, the state of the node changes over time in a complex way.

(5) Node complexity. In a network, there are multiple types of nodes, and different nodes can represent different things.

(6) Multiple complexity fusion. That is, the above complexities are combined with each other to form more complex results.

Average Distance: mathematically defined, the straight line distance between two points is the shortest, and in a complex network, the length of the shortest path between two nodes is called the distance between two nodes. The average distance is then the average of the distances of all pairs of nodes.

Cluster factor: the ratio of the number of connected edges between all neighboring nodes of any node to the number of all possible connected edges. Suppose a node has v_i has k_i neighbors with which it is directly connected. That is, in an undirected graph, k_i nodes can have a maximum of $k_i(k_i-1)/2$ connected edges, whereas in reality there are only N_i connected edges, so the cluster coefficient C_i of node v_i is:

$$C_i = 2M_i \big/ \left[k_i\left(k_i - 1\right)\right] \tag{1}$$

In a directed network, k_i node may have $k_i(k_i-1)$ connected edges, when the cluster factor is:

$$C_i = M_i \big/ \left[k_i\left(k_i - 1\right)\right] \tag{2}$$

The mean value of the cluster coefficients of all nodes is defined as the average cluster coefficient of the network C, C is calculated as follows:

$$C = \frac{1}{N}\sum_{i=1}^{N} C_i \tag{3}$$

Clearly, $0 \le C \le 1$. When $C = 0$, there are no connected edges in the network and each node exists independently. When $C = 1$, two edges exist between any two nodes in the network, which constitutes a complete graph.

3.2 Prediction method of scientific research cooperation relationship in Guangdong, Hong Kong and Macao Greater Bay Area

3.2.1 Data modeling and problem definition

Based on the cooperation information in the research paper cooperation network, this paper proposes a heterogeneous dynamic network $G = (A, P, E)$, where the set $A = \{a_1, a_2, ..., a_j\}$ contains all the research institutions in the network, and $P = \{p_1, p_2, ..., p_n\}$ is the set consisting of all the paper nodes in the network. E is the set of undirected edges, representing the relationship between institutions and papers.

A sample of the heterogeneous dynamic paper collaboration network proposed in this paper is shown in Fig. 3, from which it can be seen that at the moment t the research institution numbered 3 collaborated with the institution numbered 1 and the institution numbered 2 in writing papers p_1 and p_2, respectively.

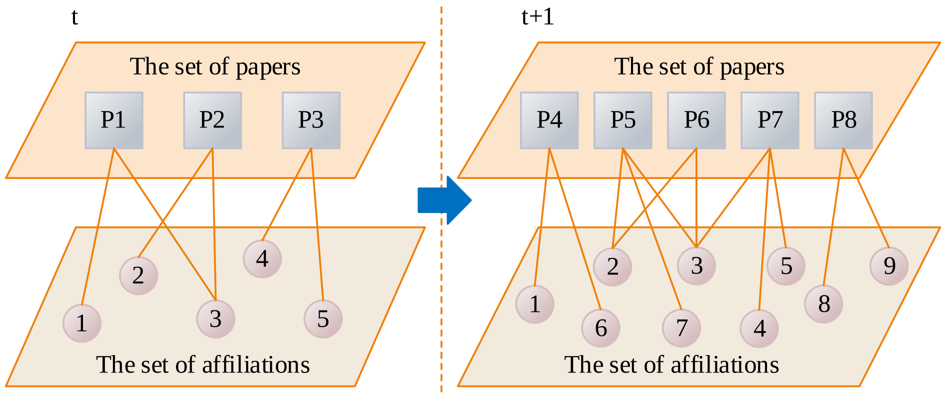


Figure 3: Dynamic heterogeneous network examples

In this paper, the number of times a paper is cited is recalculated as $N_{citation} = n_c / t$, where n_c is the number of times the paper has been cited from the year of publication, and t is the difference between the year in which the data was obtained and the year in which the paper was published. Similarly, the number of times the paper was downloaded was defined as follows $N_{download} = n_d / t$, where n_d is the number of times the paper was downloaded from the year of publication. Based on the number of citations and downloads, the impact of a co-authored paper is defined as follows:

$$I_{paper} = soft\max\left(N_{citation}\right) + \alpha N_{download} \tag{4}$$

$$soft\max(z_i) = \frac{e^{z_i}}{\sum_{k=1}^{K} e^{z_i}} \tag{5}$$

where α is the parameter of $N_{download}$.

The set of research institutions with which research institution U_x has collaborations is $\{d_1, d_2, ..., d_n\}$. Based on the impact of papers published by institution U_x and collaborating institution d_j, the following matrix based on the impact of papers can be constructed:

$$I_{U_x} = \begin{bmatrix} I^0_{U_x,d_1} & \cdots & I^{T-1}_{U_x,d_1} \\ \cdots & & \cdots \\ I^0_{U_x,d_m} & \cdots & I^{T-1}_{U_x,d_m} \end{bmatrix} \tag{6}$$

where $I^t_{U_x,d_j} = \sum I^t_{paper_{U_x,d_j}}$, $(0 \le t \le T-1)$ are the sum of the impacts of papers published by institution U_x and collaborating institution d_j in t time, and t represents the year.

Similarly, based on the number of paper collaborations we can get the collaboration matrix N_{U_x} of institution U_x based on the number of paper collaborations:

$$N_{U_x} = \begin{bmatrix} N^0_{U_x,d_1} & \cdots & N^{T-1}_{U_x,d_1} \\ \cdots & & \cdots \\ N^0_{U_x,d_m} & \cdots & N^{T-1}_{U_x,d_m} \end{bmatrix} \tag{7}$$

where $N^t_{U_x,d_j} = \sum number^t_{paper_{U_x,d_j}}$, $(0 \le t \le T-1)$ represent the sum of the number of times institutions U_x and partner institutions d_j have collaborated with each other in t time, and t represents the year.

According to the dynamic heterogeneous network G , the cooperation matrix of institutions U_x based on the influence of papers and the cooperation matrix based on the number of times of paper cooperation can be obtained. Based on the above two cooperation matrices, the paper cooperation relationship between research institutions is predicted. The main problem studied in this paper i.e. to calculate the cooperation probability matrix P_r based on the cooperation matrices I_{U_x} and N_{U_x} . the formal expression is the following equation:

$$\varphi : (I_{U_x}, N_{U_x}) \to P_r \tag{8}$$

3.2.2 Deep learning based relationship prediction

(1) Collaboration prediction based on LSTM modeling

After extracting and processing the citation counts of the collaborative papers in the collaboration network, the raw information is converted into a sequence of paper-based influences containing time-series information, and thus the sequence can be modeled with the help of LSTM network to extract the paper collaboration features.LSTM is usually used for the modeling of sequence data, and the memory unit saves the memory of the c_t at the t st time point, and at this time, the output of the state of the hidden unit of the recurrent layer is:

$$h_t = o_t \cdot \tanh(c_t) \tag{9}$$

where o_t is the output gate cell value, i.e., the vector, calculated as shown in the following equation:

$$o_t = \sigma\left(W_o[h_{t-1}, x_t] + b_o\right) \tag{10}$$

$$\sigma(x) = \frac{1}{1+e^{-x}} \tag{11}$$

where W_o is the weight b_o is the bias term, and the above two parameters need to be obtained through training. The memory value c_t in the memory unit can remember the state value of the previous time point of the recurrent neuron, which is weighted and updated over time, and the computational expression of c_t is:

$$c_t = f_t \odot c_{t-1} + i_t \odot \tanh(\tilde{c}_t) \tag{12}$$

where f_t records the information in the forgetting gate cell, c_{t-1} is the value of the memory cell at the previous time point, and f_t determines how much of the memory cell's value at the previous time point will go into the current time point. The formula for f_t is as follows:

$$f_t = \sigma\left(W_f \cdot [h_{t-1}, x_t] + b_f\right) \tag{13}$$

For the computation of the information f_t in the forgetting gate cell a sigmoid function is also used, where W_f can control the weights associated with the forgetting gate and b_f is the bias term. The value as input unit can control how much of the input at the current time t can go into the memory unit, and the computational expression is as follows:

$$i_t = \sigma\left(W_i \cdot [h_{t-1}, x_t] + b_i\right) \tag{14}$$

where connection weight W_i controls the connection weight associated with the input gate and b_i is a bias term. The input gate i_t, the forgetting gate f_t, the output gate o_t and the memory cell state c_t are jointly determined.

In this model, the actual output value of the neural network is a probability vector, and in order to better measure the difference in the probability distribution between the model output and the actual result, cross entropy is used as the loss function of the model.

(2) CNN model based on attention mechanism

Each row of the output in the network structure of the CNN model represents a unit, and an attention value is given for each unit of the output. The attention matrix $A \in R^{m \times T}$ is first initialized, during which A is computed from the cooperation matrix N_U based on the number of times of cooperation. The definition of $a_{ij} \in A$ is shown below:

$$a_{ij} = \begin{cases} 1, & if \quad N^{j}_{U_x,d_i} > 0 \\ 0, & otherwise \end{cases} \tag{15}$$

The outputs $F_{U_x} \in R^m$, $a_l = \sum A[l,:]$ of the fully connected layer of the CNN model are used as the attention weights of the l th unit in F_{U_x}. The outputs of the fully connected layer are combined with the attention matrix to compute the final output of the CNN model, where the outputs of the l th cell $P^{l}_{CNN} = a_l \times f_l$, $l = 1, 2, ..., m$.

In the above algorithm, the final output of the model P_r is computed by P_{LSTM} and P_{CNN} together, $P_r = soft\max\left(P_{LSTM} + P_{CNN}\right)$. From the LSTM model characteristics, the LSTM model is able to capture the influence data characteristics of inter-institutional collaborative papers from the temporal collaboration matrix. And the CNN model extracts the inter-institutional collaboration frequency information based on the collaboration matrix based on the number of collaborations, and the weights are adjusted by the attention matrix. As a result, the final probability matrix Pr is able to combine the temporal characteristics of collaboration as well as the topological information in the collaboration network.

3.3 Validation of the validity of the forecasting method of scientific cooperation

3.3.1 Experimental environment and data

The experimental environment and the main kits used are shown below:

(1) CPU: I5-720u processor
(2) Memory: 8G
(3) External storage: 1TB
(4) Operating system: Windows 64
(5) Python version: Python 3.7.4
(6) Integrated development environment: Spyder (Anaconda 3)

The experimental data for this paper is the Topic-coauthor dataset of the Aminer platform. This dataset contains information about scholarly co-authorship under eight topics in the field of computing, and the data under each topic consists of three parts:

a. Node information
b. Collaborative edge letter shoulders
c. Co-authorship triangle information

The above data is utilized to construct several cooperative networks, including Machine learning network, Database systems network, Web mining network, Web services network, Semantic web network, information retrieval network, Bayesian network, Data mining network.

3.3.2 Baseline methodology

In order to validate the effectiveness of research cooperation prediction using the institutional partnership prediction method based on attention mechanism and deep learning, five indicators, i.e., CN indicator, AA indicator, RA indicator, LP indicator, and PA indicator, are selected in this section for the comparative experiment of research cooperation prediction. The basic idea of PA indicator is based on the similarity of links, the basic idea of LP indicator is based on the similarity of paths, and the remaining three indicators are based on the similarity of common neighbors.

Similarity metrics based on common neighbors: for node v_i, N_i represents its set of neighbors, then the similarity of two nodes, v_i and v_j, is defined as the following equation, i.e., S_{ij}^{CN} denotes the number of common neighbors of v_i and v_j:

$$S_{ij}^{CN} = \left| N_i \cap N_j \right| \tag{16}$$

The basic idea of the AA metric is that if the degree value of the common neighbor of the predicted node to v_i and v_j is smaller, the more likely it is that these two nodes will establish a concatenated edge, which is defined as follows:

$$S_{ij}^{AA} = \sum_{z \in N_i \cap N_j} \frac{1}{\log k_z} \tag{17}$$

Similar to the AA metric, the RA metric also considers the degree value of a node's common neighbors to v_i and v_j, which is defined as follows:

$$S_{ij}^{RA} = \sum_{z \in N_i \cap N_j} \frac{1}{k_z} \tag{18}$$

Path-based similarity metric: The LP metric is defined as shown in the following equation, where α is an adjustable parameter, A is the adjacency matrix of the network, A^2 denotes the number of paths for node v_i to reach node v_j through one node, and A^3 denotes the number of paths for node v_i to reach node v_j through two nodes. Namely:

$$S_{ij}^{LP} = A^2 + \alpha A^3 \tag{19}$$

Connection-based similarity metric: The PA metric is a metric based on the similarity of preferred connections, and the basic idea is that in a network, the probability that a new edge about to be added connects to node v_i is proportional to the degree of node v_i k_i, and therefore the probability that the new edge connects two nodes v_i and v_j is proportional to the product of the degrees of the two nodes. It is defined below:

$$S_{ij}^{PA} = k_i k_j \tag{20}$$

3.3.3 Experimental results

The experimental results of the Machine learning network are shown in Fig. 4 when institutional partnership prediction method based on attention mechanism with deep learning and five other metrics are utilized for research collaboration prediction and the training set contains different proportions of positive edges.

The predicted metrics results of this paper's method are lower than the LP metrics results when the positive edge of the Machine learning network is 50%. However, it is optimal at 60%, 70%, 80%, and 90%, and the predicted metric results of this paper's method remain in the range of 0.79 to 0.80 at 70%, 80%, and 90%, and this paper's method predicts better results.

Overall, the prediction effect of each method becomes better with the increase of the proportion of positive edges. Compared with the traditional prediction method based on the similarity of network structure, the prediction effect is obviously optimal when utilizing the attention mechanism with the deep learning method for scientific research cooperation prediction, thus verifying the feasibility and effectiveness of this paper's method for scientific research cooperation prediction.

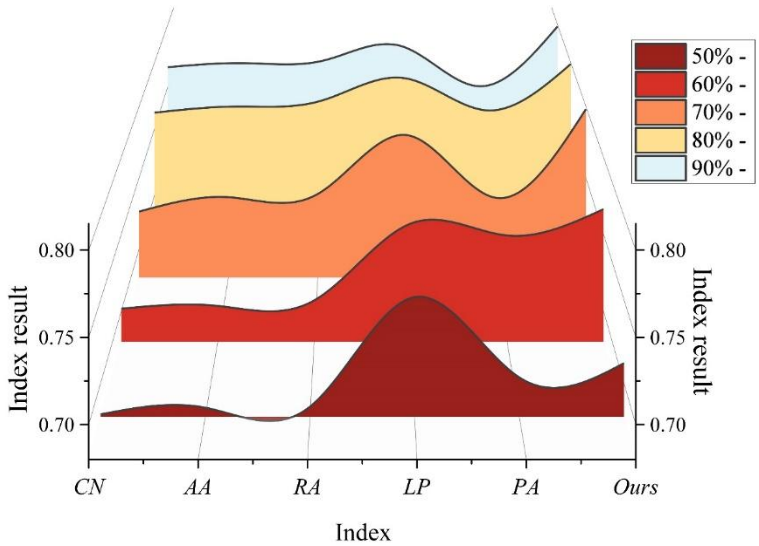


Figure 4: Experimental results of the machine learning network

4 Actual measurement of the development of scientific research cooperation under the framework of education cooperation between Guangdong, Hong Kong and Macao

4.1 Data processing

Since the Guangdong-Hong Kong-Macao Greater Bay Area includes mainland cities as well as the two special administrative regions of Hong Kong and Macao, the data source must be guaranteed to be of uniform statistical caliber all over the world. Therefore, this study chooses the 2017-2024 SCI or SSCI academic papers from the WOS database as the data source, with 11 cities as the main searching body, and the sample data includes a total of about 9,000 SCI or SSCI papers on the topics of information science and technology, life sciences, and biological sciences. Since the data of the papers downloaded by WOS, including dozens of fields such as title, author, author's unit, abstract, references, fund projects, etc., it is necessary to extract the data of the cities that are concerned by the research of this paper.

4.2 Complex network indicators

Java programming is used to preprocess the data of the paper, in which the toponymic database comes from the national toponymic information network, which contains the Chinese names and English names of the place names, and it is the basis of the data preprocessing, which is organized to get the complex network indicators.

According to the author information obtained from the previous paper, the information of the city can be extracted. Since the number of cities included in the author information of each paper is changing, multiple judgments are needed to complete the extraction. The number of connections between different cities is obtained through statistical analysis and processed according to the data structure of Gephi to generate a data table that meets the needs, which can be imported into Gephi to construct the academic cooperation network model of the cities within the Greater Bay Area (1), the academic cooperation network model between the Greater Bay Area and domestic cities (2) and the academic cooperation network model between the Greater Bay Area and major countries (3). Through the calculation and analysis of the data of the thesis, the specific data of each index of model (1), model (2) and model (3) are obtained. The results of the degree indicators of the academic cooperation network model of cities within the Greater Bay Area (1), the academic cooperation network model of cities in the Greater Bay Area and domestic cities (2), and the academic cooperation network model of cities in the Greater Bay Area cooperating with major countries (3) are shown in Figure 5. Model (3) shows that Guangzhou has the most number of academic cooperation with countries and Jiangmen has the least.

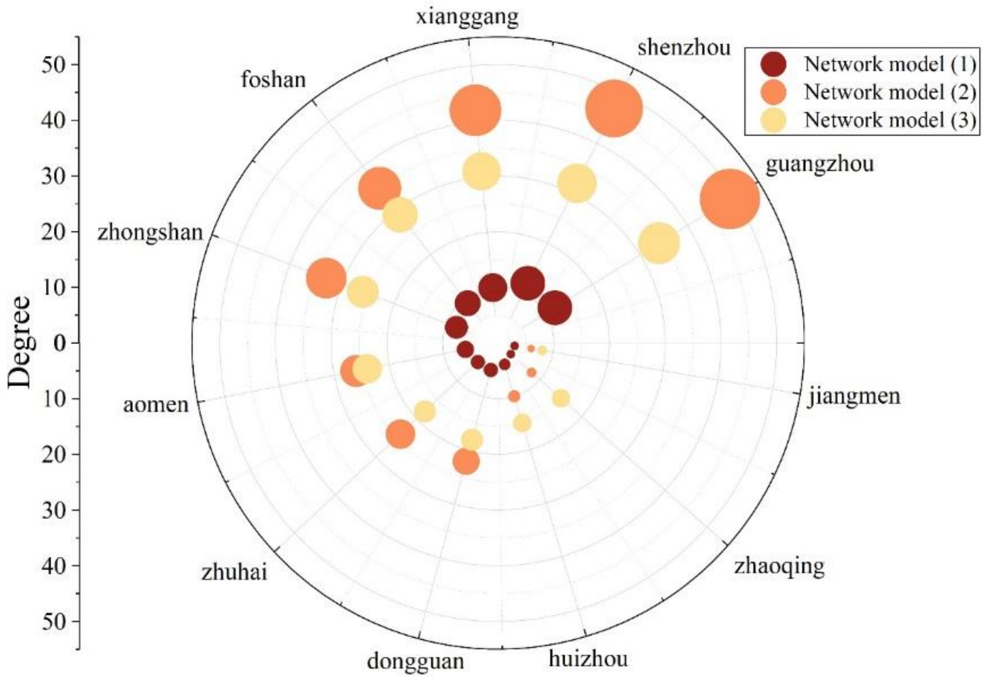
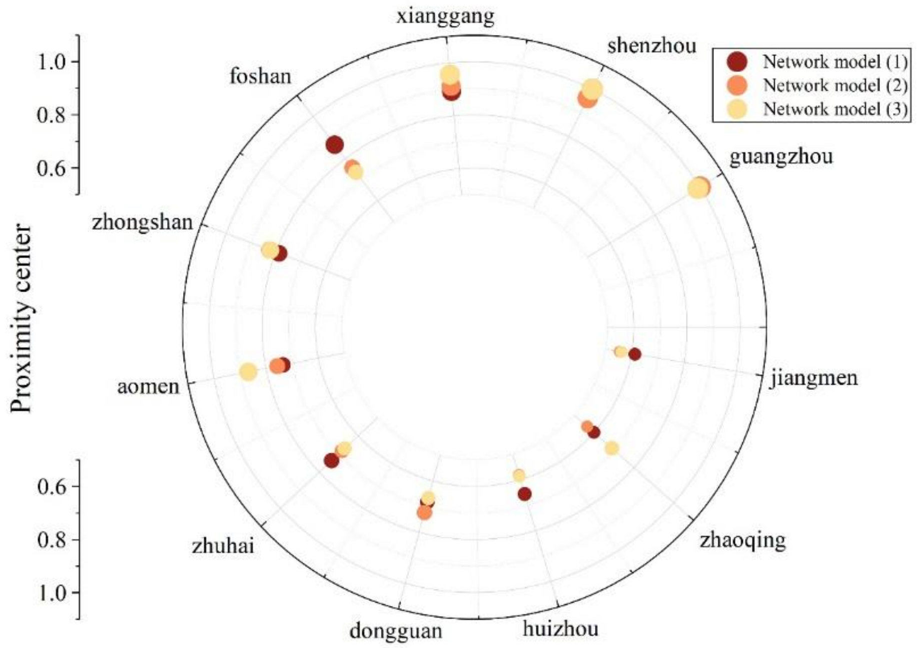


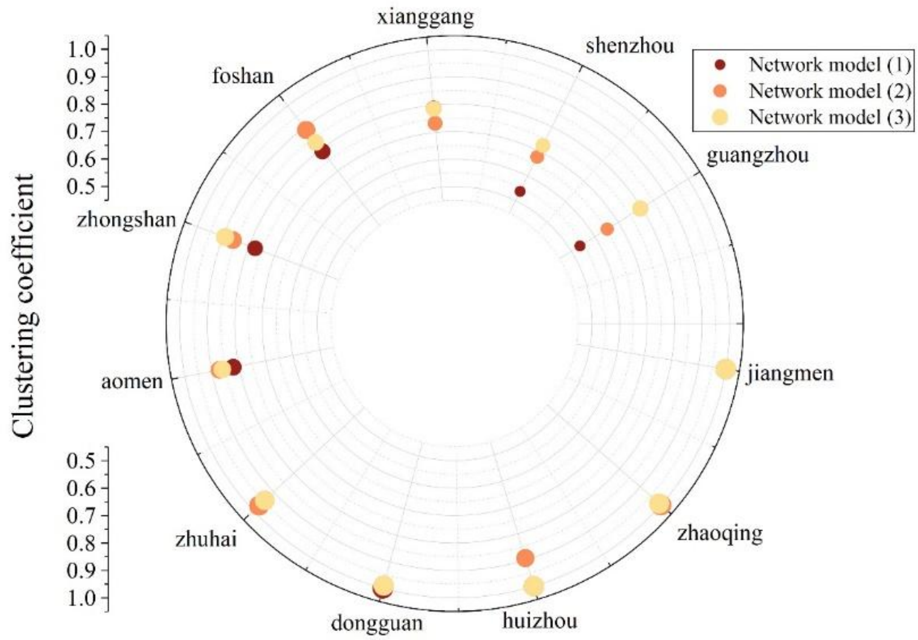
Figure 5: The results of the three models

The proximity centrality and clustering coefficients of the three models are shown in Fig. 6, and Figs. (a) and (b) show the proximity centrality and clustering coefficients, respectively.

The proximity centrality of Guangzhou in model (1) and model (2) is 1. The proximity centrality of Shenzhen in model (2) and model (3) is 1. Guangzhou has more academic cooperation with cities within the Greater Bay Area and domestic cities. Shenzhen has more academic cooperation with domestic cities and major countries.



(a) Proximity center



(b) Clustering coefficient

Figure 6: The proximity center and clustering coefficients of the three models

4.3 Projected results

In this paper, the collaboration network data from 2017-2020 is selected as the training set, and the data from 2021-2024 is used as the test set, and the estimation results of the Guangdong-Hong Kong-Macao research collaboration network link prediction model are shown in Table 1.

(1) The network structure factor, whether two scholars collaborate in that year is related to their previous years' collaboration and the number of co-collaborators, and the higher the number of co-collaborators, the greater the possibility of generating collaboration between the two scholars whose collaboration has occurred in the previous year.

(2) Scholar factor, the impact of the scholar's organization on collaboration is more significant than nationality, i.e., scholars working in the same organization are more likely to form a research team with each other. The estimated coefficients on the variable of the difference in the number of publications are all positive, indicating that the probability of two scholars' collaboration occurring is directly proportional to the difference in the number of their paper outputs, after controlling for the effects of other factors. This implies that mutual cooperation between high- and low-producing academics is a more common phenomenon.

(3) The paper factor, scholars who publish more papers in Biometrika have a higher likelihood of generating collaborations with others compared to other journals, and the higher the average number of references in the papers authored by scholars, the more likely they are to generate collaborations with other scholars.

Table 1: The prediction model of the research cooperation network is estimated

Variable dimension	Variable name		Estimation factor	Standard deviation	P value	Remark
Network structure	Whether the last year is cooperative		1.53	0.41	<0.001	Baseline: no
	Number of partners		7.11	0.26	<0.001	
Scholar	Nationality is the same		-0.39	0.23	0.05	Baseline: no
	Whether the units are the same		1.85	0.21	0.04	Baseline: no
	The sum of the papers		0.52	0.31	0.13	
	The difference in the number of papers		0.43	0.09	<0.001	
	The number of papers published in all areas	Domain II	0.17	0.13	0.34	Excluding "areas I"
		Domain III	0.26	0.28	0.36	
		Domain IV	0.21	0.16	0.18	
		Domain V	0.07	0.18	0.66	
		Domain VI	0.12	0.15	0.45	
	Research direction similarity		4.21	0.15	<0.001	
Paper	Is it published in the same journal		-0.36	0.21	0.33	Baseline: no
	Journals publish the number of papers	Biometrika	0.27	0.75	<0.001	Excluding "AoS"
		JASS	-0.22	0.09	<0.001	
		JRSS-B	-0.12	0.08	0.19	
	Mean number		0.52	0.21	0.03	
	Maximum reference number		-0.15	0.17	0.10	
	Average reference number		0.82	0.21	<0.001	

4.4 Analysis of School-School Patent Cooperation Networks

4.4.1 Structural hole indicators

The relationship between nodes in a social network can only be continuous or intermittent. Continuous specifically embodied in any one node is connected to other nodes in the network, the relationship between them is continuous. The intermittent relationship is specifically embodied in a node only and a certain node in the network has a direct connection, but the relationship with other nodes is intermittent, so the continuous or intermittent relationship phenomenon is called a structural hole. If a node happens to be on a structural hole, then the node is a mediator.

In this paper, we utilize two metrics, restriction system and hierarchy degree, to measure structural holes. The more structural holes a node has, the more the node is in the relative core of the network, the less it is restricted by the network, and the smaller the degree of hierarchy is. Using Ucinet software to arrange the calculated structural hole indexes in ascending order according to the restriction system, filtering out the universities ranked in the top 10, the results of the calculation of the structural hole indexes of the university patent cooperation network are shown in Figure 7.

In the thesis cooperation network, South China University of Technology has the smallest restriction system, followed by Sun Yat-sen University, South China Normal University, Guangdong University of Technology and so on. South China University of Technology is ranked first, with a limit system of 0.265 and a rank degree of 0.421. These universities are in the position of structural holes and connections of different groups, and they are in an advantageous position in the network, and these universities not only have access to more opportunities for cooperation and knowledge resources, but also control the direction and efficiency of the cooperation of the whole network. However, although these colleges and universities have a large number of structural holes, they also bring uncertainty to the whole patent cooperation network at the same time.

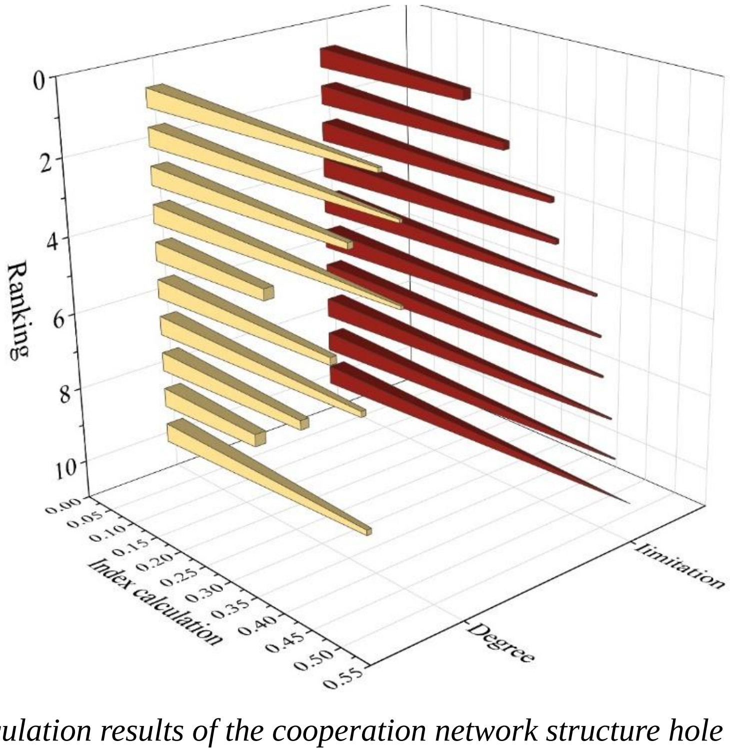


Figure 7: The calculation results of the cooperation network structure hole index

4.4.2 Network Block Model Structure

There is an obvious clustering phenomenon among the patent cooperation network structure among universities in Guangdong, Hong Kong and Macao Greater Bay Area. The in-depth mining of the relationship between and within different subclusters within the network can better handover the network structure. Cohesive subgroup analysis is to analyze the number of existing subgroups in the network. There are various methods to classify the subgroups in social network analysis method, in this paper we will take the CONCOR method, this algorithm actually utilizes the density between nodes within the subgroups and the density of relationships between the subgroups and outside the subgroups for comparison. This method style performs clustering in the sub-matrix after being divided to divide the cohesive subgroups.

The CONCOR method first calculates the correlation coefficients between the rows and columns of the matrix, calculates the correlation coefficient matrix, uses it as an input matrix, continues to calculate the correlation coefficients between the rows and columns of the input matrix, and then continues to do the calculations sequentially. The correlation coefficient matrix measures the similarity between pairs of individuals, and finally determines how many clusters are in the matrix. After calculating through several iterations, the similar nodes are made into a cohesive subgroup, which is presented in a tree diagram. Ucinet software was used to classify the cohesive subgroups of the patent cooperation network among universities in Guangdong, Hong Kong and Macao Greater Bay Area. The cohesive subgroup contact density matrix of patent cooperation network among universities in Guangdong, Hong Kong and Macao Greater Bay Area is calculated, and the larger the contact density value means the closer the connection within or between subgroups. The cohesive subgroup contact density matrix of patent cooperation network among universities in Guangdong, Hong Kong and Macao is shown in Figure 8.

There are eight cohesive subgroups in the patent cooperation network among universities in Guangdong, Hong Kong and Macao Greater Bay Area. It can be seen that the nodes in the cohesive subgroups have more obvious geographic proximity. Subcluster 7 and subcluster 8 have obvious geographic proximity. The maximum value of the linkage density within all the subgroups in the patent cooperation network among universities in Hong Kong and Macau Bay Area is 13.024.

Subgroups 5 and 6 have a low degree of internal proximity, which is 0.008. Subgroup 1 and 3 have a high degree of interconnectivity, which is 10.142. This indicates that South China University of Technology is very closely connected with other universities in Guangzhou, and relatively speaking, the universities with weak scientific research and innovation capacity have a low degree of proximity in the subgroups.

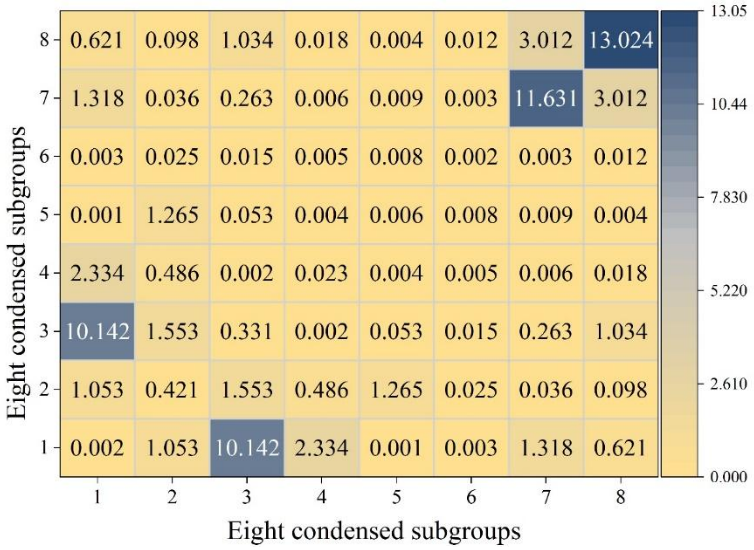


Figure 8: The contact density matrix of the network of university cooperation network

5 Conclusions and path-building

This paper analyzes the development trend of scientific research partnership in Guangdong, Hong Kong and Macau in the context of the development elements of the education cooperation framework of Guangdong, Hong Kong and Macau, and indicates the development path of scientific research under the education cooperation framework of Guangdong, Hong Kong and Macau by using the prediction method of institutional partnership based on the attention mechanism and deep learning.

(1) The prediction effect of the institutional partnership prediction method based on attention mechanism and deep learning is in the middle when the proportion of positive edges in the partnership network is 50%, and the prediction effect is the best when the proportion of positive edges is 60%, 70%, 80%, and 90%, respectively. The prediction effect of the organizational partnership prediction method based on attention mechanism and deep learning is better than that of the traditional prediction method based on the similarity of network structure. The prediction of Guangdong-Hong Kong-Macao Greater Bay Area research partnerships obtained from this method is mainly related to network structure factors, scholar factors, and thesis factors.

(2) Universities led by South China University of Technology have the least restrictive system and are in a dominant position in the network of scientific research cooperation relationship, which can obtain more cooperation opportunities and knowledge resources while controlling the direction and efficiency of the whole network cooperation.

Path of scientific research development under the framework of Guangdong-Hong Kong-Macao education cooperation:

(1) Universities in Guangdong, Hong Kong and Macao Greater Bay Area take the initiative to seek external cooperation opportunities and increase the number of external cooperation. As the core nodes of knowledge exchange and technological innovation, the cooperation intention of universities will affect the innovation and development of the Guangdong-Hong Kong-Macao Greater Bay Area.

(2) Starting from the cooperation framework of university alliances, optimize the multi-level governance of education, reduce the resistance to research cooperation, and create conditions for research cooperative relationships.

(3) Stimulate scholars' enthusiasm for research cooperation, and the Guangdong-Hong

Kong-Macao Greater Bay Area University Alliance provides scholars with guidance for research cooperation.

About the Author

Jingyu Niu came into the world in Ulanqab, Inner Mongolia, People's Republic of China, in 1995. She acquired a master's degree from The Education University of Hong Kong, which is in China. At present, I am engaged in studies at the Faculty of Humanities of The Education University of Hong Kong. The primary area of my research is Chinese Language Instruction and Research Approaches in Education.

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