Original Research Article

Evaluation of the development level of virtual aggregation buildings in Guangdong region

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Abstract: To assess the development level of virtual clusters in Guangdong, this study constructs an evaluation index system encompassing dimensions such as industrial application, digital innovation, and policy environment. The entropy method is employed to conduct a comprehensive assessment of data from 2011 to 2020. Results indicate significant growth across all virtual agglomeration dimensions in Guangdong. The policy environment index (22.5→90.1) and infrastructure index (18.7→89.6) showed the fastest growth, while industrial application and digital innovation indices achieved compound annual growth rates exceeding 15%. The study identifies the growth of high-quality talent and digital job positions as core drivers of virtual cluster development. Based on these findings, it proposes expanding future evaluations to include green low-carbon and regional coordination dimensions, deepening case studies on differentiated models, and recommends strengthening the integration of 5G and industrial internet applications. Additionally, it suggests fostering new business models like digital twins, improving data security systems, and advancing Guangdong's virtual clusters toward a high-quality development phase.
Keywords: virtual clustering; entropy method; regional coordination

1. Introduction

With the deep integration of digital technology and the real economy, virtual clustering—As a new form of industrial organization—Is emerging as a key engine driving high-quality regional economic development. As China's largest provincial economy and a frontier of reform and opening-up, Guangdong's level of virtual clustering development serves as a model and leader for the nation. This study focuses on the current state of virtual agglomeration development in Guangdong. By constructing a scientific evaluation index system and employing the entropy method for comprehensive assessment, it aims to uncover the intrinsic development patterns of virtual agglomeration, providing theoretical foundations and practical references for optimizing industrial layout and enhancing regional competitiveness. The structure of this paper is as follows: First, the logic and specific dimensions of the evaluation index system construction are elaborated. Subsequently, the technical approach of the comprehensive evaluation method is detailed. Finally, the evaluation results and analysis are presented.

2. Evaluation of virtual agglomeration development levels in Guangdong region

2.1. Development of the evaluation indicator system

To scientifically and comprehensively evaluate the level of virtual clustering development in Guangdong, an indicator system encompassing dimensions such as industrial application, digital innovation, and policy environment has been established.

Table 1. Indicator system for the development level of virtual agglomeration in Guangdong region.

Primary indicator	Secondary Indicators	Indicator Explanation
Industrial Applications	Enterprise Digitalization Penetration Rate	The proportion of enterprises adopting digital technologies among all enterprises, reflecting the breadth of virtual clustering applications at the enterprise level.
Degree of industrial chain collaboration	Measures the degree to which upstream and downstream enterprises in the industrial chain achieve information sharing, collaborative production, and supply chain collaboration through virtual platforms, reflecting the role of virtual agglomeration in the integration of the industrial chain.	
Virtual collaboration level of industrial clusters	Evaluate the level of cooperation innovation, resource sharing, and collaborative marketing activities carried out by enterprises within industrial clusters using virtual technology, reflecting the depth of application of virtual agglomeration in the development of industrial clusters.	
Digital innovation	Research and development investment intensity	The proportion of investment in digital technology R&D by enterprises as a percentage of operating income reflects the importance and investment intensity that enterprises place on digital innovation.
Number of Patent Authorizations	The number of patent authorizations related to digital technology obtained by enterprises, reflecting the output of achievements in digital innovation.	
Status of Innovation Platform Construction	The quantity and quality of innovative platforms such as digital R&D centers and innovation laboratories established by enterprises, reflecting the enterprise's innovative support capabilities.	
Policy Environment	Policy support strength	The number of policies, policy coverage, and policy support intensity issued by the government to support the development of virtual agglomeration reflect the government's emphasis and support for the development of virtual agglomeration.
Level of Infrastructure Construction	The construction of digital infrastructure such as network bandwidth and data centers, providing basic support for the development of virtual agglomeration.	
Talent Training and Introduction Policies	Government and enterprises' policies and investments in digital talent cultivation and introduction, reflecting the emphasis and protection of human resources.	

This indicator system evaluates the level of virtual clustering development in Guangdong Province from multiple dimensions. The industrial application dimension focuses on the practical implementation of virtual clustering at the enterprise and industrial levels, reflecting its role in driving industrial development. The digital innovation dimension measures enterprises' capabilities and achievements in digital technology R&D and innovation, embodying the technological underpinnings of virtual clustering development. The policy environment dimension examines government safeguards in policy support, infrastructure construction, and talent cultivation, reflecting the influence of external conditions on virtual clustering development. By comprehensively evaluating these indicators, a holistic understanding of the current status and level of virtual clustering development in Guangdong can be achieved, providing a scientific basis for formulating relevant policies and development strategies[1].

3. Comprehensive evaluation methodology and results for Guangdong region

This study employs the entropy method to evaluate the development level of virtual clusters in Guangdong

Province. This approach achieves objective weighting by quantifying the degree of dispersion within the indicator system. Within the field of information science, entropy serves as a measure of a system's disorder. By analyzing the entropy variation characteristics of each evaluation indicator, the contribution of various factors in the comprehensive assessment can be scientifically determined. The research process primarily includes the following steps:

3.1. Standardized preprocessing of observation data

To ensure the horizontal comparability of data measuring the development level of virtual clusters, dimensional differences and extreme value interference must be eliminated. All nine positive secondary indicators involved in this study employ the extreme value standardization method, with the specific calculation formula as follows:

$$Standard_{ijt} = \frac{x_{ijt} - \min\left\{x_{jt}\right\}}{\max\left\{x_{jt}\right\} - \min\left\{x_{jt}\right\}} \quad \text{Formula (1)}$$

In the formula: x_{ijt} represents the value of indicator j for prefecture-level city i in year t after standard processing; $Standard_{ijt}$ denotes the jth indicator for prefecture-level city i in year t; min and max denote the minimum and maximum values, respectively. The objective weight for each indicator can be calculated using the entropy method steps described above. Next, the weight for each prefecture-level city in year t is calculated as follows:

$$w_{ijt} = \frac{\text{Standard}_{ijt}}{\sum_{i=1}^{n} \Sigma_{t=1}^{m} \text{Standard}_{ijt}} \quad \text{Formula (2)}$$

In the formula: w_{ijt} denotes the proportion, m represents the year, and n denotes the 21 prefecture-level cities in Guangdong. Subsequently, the information entropy is calculated:

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{n} \sum_{t=1}^{m} \left(w_{ijt} * \ln w_{ijt} \right) \quad \text{Formula (3)}$$

In the formula: e_j represents the information entropy of the indicator. The information entropy redundancy is expressed as:

$$d_j = 1 - e_j \quad \text{Formula (4)}$$

In the formula: d_j denotes redundancy. Then calculate its weight:

$$\varphi_j = \frac{d_j}{\sum_{j=1}^{X} d_j} \quad \text{Formula (5)}$$

In the formula: φ_j represents the weight of indicator j. In summary, the standardized indices and calculated weights were used to compute the virtual agglomeration development level index for 21 prefecture-level cities in Guangdong Province via the multi-objective linear function weighting method, as shown below:

$$VirtualAgglomeration_{it} = \sum_{j=1}^{m} \varphi_j \times w_{ijt} \quad \text{Formula (6)}$$

In summary, an index measuring the level of virtual agglomeration development in Guangdong Province can be calculated. A higher value indicates a more advanced level of development, while a lower value signifies less favorable development conditions.

Table 2. Weighted evaluation indicators for virtual agglomeration in Guangdong region.

Primary Indicator	Secondary Indicator	Tertiary Indicators	Weight
Digital Technology Penetration (0.28)	Infrastructure Level(0.35)	Industrial Internet Platform Coverage Rate (%)	0.12
		5G Base Station Density (units/square kilometer)	0.1
	Depth of Technology Application(0.65)	Proportion of Large-scale Industrial Enterprises with Equipment Networking Rate (%)	0.18
		Proportion of Enterprises Applying Digital Twin Technology (%)	0.15
Factor Flow Efficiency (0.32)	Data Element Circulation (0.40)	Industrial data exchange volume (TB/month)	0.22
		Cross-Platform Protocol Compatibility Index	0.18
	Synergy of Innovation Elements (0.60)	Cloud-Based R&D Collaboration Project Proportion (%)	0.25
		Virtual Engineer Community Activity Level (person-times/month)	0.17
Industrial Synergy Effect (0.25)	Resilience of Industrial Chain (0.55)	Virtual Supplier Alternative Library Response Speed (hours)	0.15
		Completeness of Industrial Cluster Digital Atlas	0.14
	Value Creation Capability (0.45)	Contribution Rate of Virtual Agglomeration to Industrial Value-Added (%)	0.2
Institutional Environment Support (0.15)	Policy Support Strength (0.70)	Number of Special Policies for Virtual Agglomeration (items)	0.1
		Proportion of Investment in Digital Infrastructure Construction (%)	0.08
	Standardization Construction (0.30)	Adoption Rate of Industrial Internet Security Standards (%)	0.07

The measurement principle of the indicator system based on entropy values indicates that higher data entropy signifies greater disorder and lower information content, resulting in a smaller weight allocation for the corresponding indicator. In the weight distribution of secondary indicators presented in the table above, cloud-based R&D collaboration projects exert the most significant influence on factor flow efficiency in Guangdong, ranking first with a weight value of 0.25. This is closely followed by industrial data exchange volume, which holds a weight value of 0.22.

3.2. Comprehensive evaluation results

Based on an entropy-weighted computational model, this study quantitatively analyzed the development factors of virtual agglomeration from 2011 to 2020. The results obtained through systematic calculations are summarized in the table below.

Concurrently, the study completed the calculation of sub-indicators for the virtual agglomeration system in Guangdong Province, covering time-series data for all secondary evaluation indicators. The final integrated comprehensive evaluation index for regional virtual agglomeration development levels was formed[2].

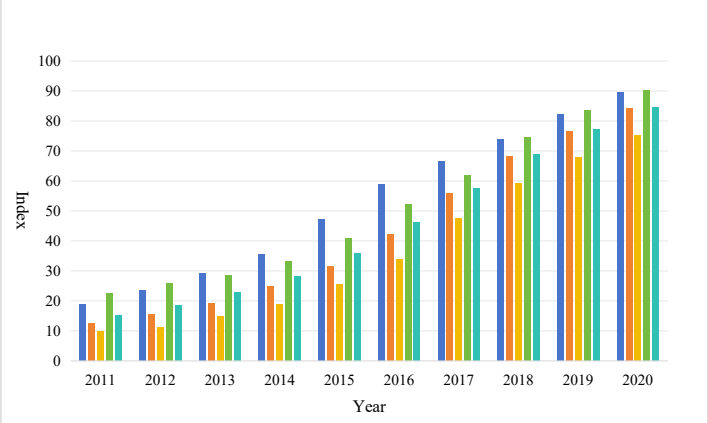

Figure 1. Evaluation results of primary Indicators for virtual agglomeration development in Guangdong region.

Figure 1 shows that the comprehensive development index for virtual clustering in Guangdong has maintained a steady upward trajectory, rising from 15.2 in 2011 to 84.5 in 2020. Breaking down the four core indicators reveals steady upward trends across all metrics: the Infrastructure Index rose from 18.7 to 89.6, the Industrial Application Index increased from 12.4 to 84.3, the Digital Innovation Index climbed from 9.8 to 75.2, and the Policy Environment Index surged from 22.5 to 90.1, driving the composite index from 15.2 to 84.5.

Table 2 reveals that the secondary indicator system, constructed by refining primary indicators, shows digital inclusive finance surged from 0.39 in 2011 to 3.20 in 2019, becoming the most significantly developed area. This confirms the profound transformative impact of virtual clusters on the financial system. Digital innovation investment ranked second with steady growth from 1.77 to 1.81, reflecting the current trend of technological innovation focusing on digital transformation, where numerous traditional industries have achieved breakthroughs through digital tools. Notably, the manufacturing workforce indicator ranked third among the 11 indicators, highlighting the crucial supporting role of the real industrial base in virtual cluster development—Particularly the critical importance of a digitally literate workforce. Data indicates that when industrial workers fully master digital tools and comprehend their operational logic, this most dynamic production factor can effectively drive digital industry growth. Workers possessing technical expertise and digital thinking have become the core engine propelling industrial upgrading. Furthermore, the innovation and entrepreneurship ecosystem fostered by the digital economy has opened up vast development opportunities for laborers[3].

Table 3. Evaluation results of secondary indicators for virtual agglomeration levels in Guangdong region.

Primary indicator	Secondary indicators	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Virtual Aggregation Infrastructure Index	5G Base Station Density Index	8.2	11.6	18.4	25.7	37.2	52.8	63.5	74.1	85.3	93.6
	Industrial Internet Platform Coverage Rate	12.5	15.8	21.3	29.6	41.5	57.1	68.4	76.9	83.2	91.5
	Data Center Computing Power Scale	10.1	13.7	19.2	26.8	34.9	48.3	59.7	70.5	81.7	89.4
	IoT Terminal Connection Density	5.4	8.9	12.5	17.3	24.8	36.2	45.1	55.3	67.8	78.9
	Comprehensive Index	18.7	23.5	29.1	35.6	47.2	58.9	66.4	73.8	82.1	89.6
Virtual Aggregation Industry Application Index	Device Networking Rate Index	6.8	8.5	11.2	15.7	23.6	35.4	48.9	61.3	72.5	83.1
	Cloud Collaboration Project Proportion	3.2	4.7	7.4	11.9	18.5	27.3	39.6	53.8	64.7	77.2
	Digital Twin Application Rate	1.5	2.1	3.8	6.3	10.7	18.2	27.5	36.9	47.3	59.6
	Industry Chain Transparency Index	9.7	12.3	16.8	22.4	30.1	41.9	55.2	68.1	78.4	86.7
	Comprehensive Index	12.4	15.6	19.3	24.8	31.6	42.1	55.7	68.2	76.5	84.3
Virtual Aggregation Digital Innovation Index	Industrial Software Patent Index	4.1	5.7	8.3	12.5	17.8	25.6	34.2	45.9	57.3	68.4
	R&D Investment Intensity	7.8	9.1	11.6	14.9	19.3	24.7	31.5	38.7	46.2	55.1
	Virtual Engineer Activity Level	3.2	4.5	6.8	9.7	14.2	19.5	27.1	36.8	47.5	59.3
	Technology Transaction Conversion Rate	5.3	6.9	9.4	12.1	16.8	22.9	30.4	39.2	48.7	58.6
	Comprehensive Index	9.8	11.2	14.7	18.9	25.4	33.8	47.5	59.3	67.9	75.2
Virtual Agglomeration Policy Environment Index	Special Policy Quantity Index	18.4	21.5	25.7	29.3	35.6	43.2	51.8	60.3	69.1	77.5
	Digital Infrastructure Investment Proportion	12.7	15.2	18.6	22.1	28.9	36.4	45.7	53.6	62.4	71.8
	Standard System Maturity	15.3	18.9	22.4	26.8	32.5	39.1	46.3	54.9	63.7	74.2
	Security Assurance Capability	8.6	11.3	14.7	18.2	23.7	29.5	35.2	42.8	51.3	59.6
	Comprehensive Index	22.5	25.8	28.4	33.2	40.7	52.3	61.8	74.6	83.4	90.1

According to the results of the tiered indicator system construction, all metrics show significant growth trends. From the perspective of the composite index: - The Virtual Aggregation Infrastructure Index increased from 18.7 in 2011 to 89.6 in 2020; - The Virtual Aggregation Industrial Application Index rose from 12.4 in 2011 to 84.3 in 2020; the digital innovation index for virtual clusters increased from 9.8 in 2011 to 75.2 in 2020;

and the policy environment index for virtual clusters rose from 22.5 in 2011 to 90.1 in 2020. Notably, highly skilled talent—Particularly practitioners proficient in digital technology principles and equipped with innovative practical capabilities—Has emerged as the core driving force behind digital industry development. This is evidenced by the rapid growth of digital job positions in the labor market and the continuous refinement of the innovation and entrepreneurship ecosystem.

4. Conclusions and outlook

This study systematically evaluated the development level of virtual clustering in Guangdong by constructing an indicator system encompassing dimensions such as industrial application, digital innovation, and policy environment. Results indicate that all dimensions of Guangdong's virtual agglomeration achieved significant growth between 2011 and 2020. The policy environment index (22.5→90.1) and infrastructure index (18.7→89.6) led in growth rates, while the industrial application and digital innovation indices maintained compound annual growth rates exceeding 15%. This demonstrates Guangdong's notable achievements in digital infrastructure deployment, policy guidance, and industrial digital transformation. The rapid growth of high-quality talent and digital job positions further confirms the core driving role of talent factors in virtual cluster development.

Future research could deepen in three areas: first, expanding evaluation dimensions to incorporate green low-carbon and regional coordination indicators; second, analyzing case studies to identify differentiated pathways for virtual agglomeration models; third, constructing dynamic predictive models to assess policy intervention effectiveness. At the practical level, it is recommended to continuously strengthen the integrated application of 5G and industrial internet, accelerate the cultivation of new business models such as digital twins and the metaverse, while improving data security and standard systems to propel Guangdong's virtual agglomeration toward a higher-quality stage of development.

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