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Evaluation of Digital Transformation of the Regional Manufacturing Industry Based on the Entropy Weight TOPSIS Method

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ABSTRACT

Manufacturing digital transformation capability is a key factor in the orderly advancement of digital upgrading in the manufacturing sector. Effective identification and evaluation of this capability can help grasp the core aspects of manufacturing digital transformation and upgrading, thereby improving the efficiency and effectiveness of the transformation process. Based on the definition of manufacturing digital transformation capability, this study constructs an evaluation index system across three dimensions: digital transformation support, digital transformation potential, and digital transformation benefits. The entropy-weighted TOPSIS method is adopted, with empirical analysis based on digital transformation data from the manufacturing industry across 30 mainland Chinese provinces. The study finds that digital innovation capability is critical to the digital transformation of the manufacturing industry, and that the benefits of digital transformation are more directly reflected in economic than in environmental outcomes. While individual provinces and cities are exceptions, the overall level of manufacturing digital transformation in China shows a pattern of eastern regions leading, central regions following, and western regions lagging. In terms of specific digital transformation dimensions, provinces and cities exhibit varying performance in digital transformation support, potential, and benefits.

Keywords: Regional manufacturing industries, Digital transformation evaluation, Entropy weight TOPSIS.

1. INTRODUCTION

Manufacturing is the foundation of a country's development. It is both the engine of economic growth and the foundation of national power. Achieving high-quality manufacturing development is a key path to enhancing a country's comprehensive strength and core competitiveness. Nowadays, digital technologies such as artificial intelligence, cloud computing and big data are developing rapidly. The wave of digital transformation, driven by data resources and network infrastructure, is reshaping business models. It exerts an unprecedented and disruptive impact on the economy and society [1-3]. Enterprise organizational structures, resource allocation models and production methods have all undergone optimization and upgrading. The resulting cross-industry competition is becoming increasingly fierce, forcing manufacturing enterprises to meet adaptability challenges.

Therefore, digital transformation has become an inevitable path for manufacturing enterprises to keep pace with the digital age [4-5]. Enhancing their digital transformation capabilities and supporting their upgrading and transformation are not only key to developing countries seizing

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opportunities in the new round of technological and industrial revolution, but also an important way to build a new pattern of domestic manufacturing. It can not only promote high-quality economic development and deepen supply-side structural reform, but also inject new momentum into manufacturing. Although digital transformation offers opportunities to manufacturing enterprises, developing the related capabilities is complex and systematic.

At present, there is an urgent need to explore the driving factors behind the direction of digital transformation in manufacturing enterprises and effective methods to evaluate their digital development levels. Establishing an evaluation system for their digital transformation capabilities, objectively analyzing their digital strength, helping the government formulate precise policies and effectively guiding the sustainable and efficient progress of manufacturing digitalization, these measures have far-reaching strategic significance and practical value.

2. LITERATURE REVIEW

Scholars at home and abroad have not yet reached a consensus on the precise definition of digital transformation. Digital transformation relies on digital technologies. It improves operational efficiency by breaking data barriers between industries, thereby optimizing enterprises' overall performance [6]. Enterprise digital transformation usually includes three key steps: formulating a digital transformation model, implementing a comprehensive digital transformation driven by digital technologies and customer needs, and reshaping enterprises' overall organizational structure. The goal of manufacturing enterprises' transformation is to deploy various technologies, establish digital connections across all links of business processes, and cultivate learning organizations that can flexibly adapt to environmental changes [7].

Enterprise digitalization is the foundation for the intelligent development of manufacturing. Platforms serve as a bridge between big data services and artificial intelligence applications, while digitalization and platformization form the "two pillars" that support enterprises to successfully achieving digital transformation [8]. The core value of enterprise digital transformation lies not only in technological innovation but also in talent strategy innovation. This change in talent strategy will reshape enterprises' operating models, value-creation strategies, and business models, thereby enhancing their competitiveness in the digital economy. It is worth noting that the key to enterprise digital transformation is talent transformation rather than technological upgrading [9]. In conclusion, this paper asserts that digital transformation in the manufacturing industry aims to achieve high-quality development by leveraging digital infrastructure, such as information and communication technology, harnessing digital technology to bolster enterprises' innovation and application capabilities, and driving industry-wide evolution from rudimentary to advanced stages. The ultimate objective is to achieve intelligent, sustainable growth.

The digital transformation process is now a key research topic in academia. Some scholars believe that the parts of digital transformation can be divided into two groups. The first group focuses on the development of digital technology, including digital components, platforms, and infrastructures. These are together called digital elements [10-12]. The second group emphasizes improving organizational capabilities for digital transformation, including digital technology application, organizational change management, and digital domain governance [13-16]. Some scholars also support a comprehensive framework of enterprise digital transformation capabilities that includes both objective and subjective elements. In this framework, objective capabilities include an enterprise's digital technology and digital management skills. This specifically means the enterprise's ability to fully understand dynamic changes in technology, industry, markets, and related information, so that it can make proper integrations and decisions [17]. On the other hand, the ability to promote internal organizational change belongs to the subjective capability elements of digital transformation. This area is hard to copy, leading to clear “heterogeneity” [18]. The continuous adjustment of the subjective and objective aspects of enterprise capabilities helps integrate and restructure internal and external resources, organizational skills and operational functions. This adaptability enables manufacturing enterprises to effectively respond to challenges brought by environmental changes.

To sum up, scholars at home and abroad have formed a systematic understanding of the concept, components and impacts of digital transformation. Research focuses mainly on its influence on enterprise performance [19], the innovation of business models, and the promotion of organizational innovation. In addition, scholars have further explored directions such as the construction of digital platforms [20] and the cultivation of digital innovation ecosystems [21]. However, obvious deficiencies remain in research on the evaluation of digital transformation in manufacturing enterprises. Current research on digital transformation evaluation primarily remains at the micro level, largely based on architectural concepts and maturity models. It is worth noting that regional evaluation research on the digital transformation of manufacturing remains very rare. Existing evaluation methods mostly rely on traditional methods, such as questionnaire surveys and text analysis. Such research methods often ignore the elements, capabilities and advantages contained in the evaluation index system of digital transformation. This disconnection between theory and practice neither meets practical needs nor impedes the in-depth development of research on manufacturing digitalization.

To fill these research gaps, this study uses the entropy-weighted TOPSIS method to develop an evaluation system for the digital transformation of regional manufacturing. The system conducts an evaluation across three key dimensions: digital transformation support, digital transformation potential, and digital transformation benefits. This system can systematically assess the progress of manufacturing digital transformation in each province. By comparing and analyzing the current state of digital transformation in manufacturing across the eastern, central, and western regions, this paper aims to provide a reference and practical suggestions for promoting the digital transformation of regional manufacturing in China.

3. EVALUATION INDEX SYSTEM

Based on the dynamic capability theory, the digital transformation capability of manufacturing is defined as the inherent dynamic competitiveness of manufacturing enterprises. This capability not only enables enterprises to adapt to a rapidly changing market environment but also improves their market competitiveness by leveraging digital concepts, technologies, and methods. The primary prerequisite for enterprises’ digital transformation is to build a sound digital infrastructure and to be able to obtain external information. Enterprises also need to have certain innovation and digital technology application capabilities to allocate strategic resources based to existing resource conditions and maintain competitive advantages. The core of this research is to establish a comprehensive evaluation system for the digital transformation capability of the manufacturing sector. This framework covers three core dimensions: digital transformation support, digital transformation potential, and digital transformation benefits, as shown in Figure 1. To ensure the accuracy of the results, the indicators were selected to minimize overlap, as shown in Table 1.

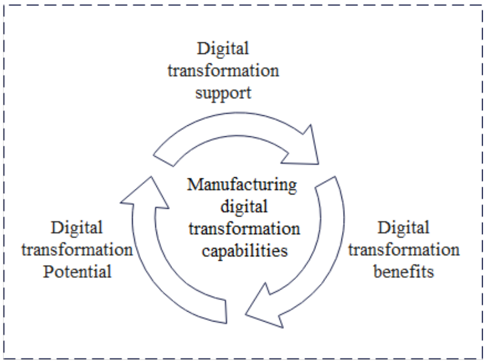

Figure 1: Manufacturing digital transformation capability composition.

Table 1: Evaluation index system for manufacturing digital transformation capability.

Secondary indicators	Tertiary indicators	Units	Indicator Attributes	Reference Source
Digital Transformation Support（A）	Fiber optic line length（A1）	Kilometers	Positive	[12], [22], [23]
	Internet broadband access port（A2）	10,000 ports	Positive	
	Cell phone penetration rate（A3）	Subscriptions per 100 persons	Positive	
	Websites per 100 businesses（A4）	Items	Positive	
	Share of enterprises with e-commerce trading activities（A5）	%	Positive	
	Growth rate of fixed asset investment in ICT industry（A6）	%	Positive	
Digital Transformation Potential（B）	Full-time Equivalent of R&D Personnel of Industrial Enterprises Above Scale (B1)	Person/year	Positive	[2], [17], [24], [25]
	Expenditures for developing new products of industrial enterprises above designated size (B2)	10,000 CNY	Positive	
	Number of Effective Invention Patents of Industrial Enterprises Above Scale (B3)	Items	Positive	
	Breadth of digital inclusive financial coverage (B4)	Index	Positive	
	Depth of coverage of digital inclusive finance (B5)	Index	Positive	
	Degree of digitalization of inclusive finance (B6)	Index	Positive	
	Industrial Internet Development and Application Index (B7)	Index	Positive	
Digital Transformation Benefits（C）	E-commerce sales (C1)	Billions CNY	Positive	[26], [27]
	Total Profit of Industrial Enterprises Above Scale (C2)	Billions CNY	Positive	
	Value added of industry (C3)	Billions CNY	Positive	
	Technology Market Turnover(C4)	Billions CNY	Positive	
	Completed investment in industrial pollution treatment (C5)	10,000 CNY	Negative	
	Completed investment in projects for treating wastewater (C6)	10,000 CNY	Negative	
	Completed Investment in Treatment of Waste Gas Projects (C7)	10,000 CNY	Negative	

3.1 Digital transformation support

The start of digital transformation lies in building a strong digital infrastructure, which serves as a foundation for the development of the digital economy [22]. Scholars agree that the infrastructure of digital transformation systems includes software, hardware, and networks, among other components. Previous studies have shown that digital infrastructure capabilities are generally universal in nature and function primarily as foundational enablers rather than direct sources of competitive advantage [23]. Therefore, evaluating digital transformation support capabilities requires selecting indicators that cover both physical and information infrastructure essential to information transmission. The capacity for supporting digital transformation is measured using indicators such as the length of fiber-optic cable lines, the number of Internet broadband access ports, mobile phone penetration rates, the number of websites per 100 enterprises, the share of enterprises engaged in e-commerce trading activities, and the growth rate of investment in information transmission, software, and information technology services.

3.2 Digital transformation potential

The potential for digital transformation depends on the innovation capacity of manufacturing enterprises, and it is also affected by the current digital transformation landscape. Innovation ability is a necessary condition for the success of digital transformation in manufacturing enterprises. What's more, it is an important way to solve China's main problem: the core technology "bottleneck" [24-25]. Innovation ability is shown in both input and output aspects of innovation. In the context of digital transformation, this ability is reflected by metrics such as the number of full-time research and development (R&D) personnel in large-scale industrial enterprises, the money these enterprises spend on new product development, and the number of effective invention patents they hold. At the same time, the digital transformation environment shows how much digital technology is used in the economy. This is an important sign of the digital economy. It reflects the ability of manufacturing enterprises to use and promote digital technologies. This study measures this environment through two key indicators: digital technology integration and digital technology application. Metrics such as digital financial inclusion coverage range, digital financial inclusion coverage depth, the level of digitalization in financial inclusion, and the index of industrial Internet development and application are used to describe the digital transformation environment.

3.3 Digital transformation benefits

The benefits of digital transformation come from the application of digital technologies in all links of the manufacturing value chain, helping enterprises gain higher returns. In addition, as the manufacturing industry operates daily, it must consider resource use and emissions while balancing economic growth. So, the ecological efficiency of the manufacturing industry's "green" efforts is an important standard for evaluating its digital transformation [26]. Drawing on existing research on manufacturing transformation and upgrading, the benefits of digital transformation are categorized into two dimensions: economic benefits and ecological benefits [27]. Economic benefits include indicators such as enterprise e-commerce turnover, the total profit of large-scale industrial enterprises, technology market turnover, and industrial added value. Similarly, ecological benefits include completed investments in wastewater treatment, exhaust gas treatment, and industrial pollution treatment projects.

4. EMPIRICAL STUDY ON DIGITAL TRANSFORMATION OF MANUFACTURING INDUSTRY

4.1 Data sources

For this study, 30 provinces in mainland China were selected for 2023. This choice was based on data availability and excluded regions such as Hong Kong, Macao, Taiwan, and Tibet. The main goal was to analyze the level of digitalization in the regional manufacturing industry. The data mainly comes from reliable sources, including the National Bureau of Statistics, government work reports, China Statistical Yearbook, China Digital Economy Development Index Report, White Paper on the Development and Application Index of the Industrial Internet, China Science and Technology Statistical Yearbook, Peking University Digital Inclusive Finance Index Statistical Yearbook and Peking University's Digital Financial Inclusion Index. These sources together provide the basic data needed for the analysis.

4.2 Research method

The Entropy Weight-TOPSIS method uses the entropy-weighting technique to determine the weight of each index in the evaluation system. Next, a standardized weighting matrix is built for these indexes. Then this matrix is entered into the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) model to evaluate the target subject. The TOPSIS method is often called the "Ideal Point Method". It works by judging the relative advantages and disadvantages among different evaluation subjects. This is done by ranking the degree of closeness of multiple evaluation subjects to the ideal value. The TOPSIS method produces relatively simple, easy-to-understand evaluation results. The specific steps to carry out this evaluation with the Entropy Weight-TOPSIS method are as follows:

(1) Standardize the raw data matrix.

$$\mathrm{X} = \left(x_{ij}\right)_{m\times n} \tag{1}$$

Positive indicators are:

$$\mathrm{y}_{ij}^{+} = \frac{x_{ij} - \min\left(x_{ij}\right)}{\max\left(x_{ij}\right) - \min\left(x_{ij}\right)}, \left(1 \le i \le m, 1 \le j \le n\right) \tag{2}$$

Negative indicators are:

$$\mathrm{y}_{ij}^{-} = \frac{\max\left(x_{ij}\right) - x_{ij}}{\max\left(x_{ij}\right) - \min\left(x_{ij}\right)}, \left(1 \le i \le m, 1 \le j \le n\right) \tag{3}$$

Normalization is performed:

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}, \left(1 \le i \le m, 1 \le j \le n\right) \tag{4}$$

(2) Calculate the entropy value of the indicator E_j, and determine the weight of the indicator W_j.

$$E_j = -\frac{1}{\ln m}\sum_{i=1}^{m} P_{ij} \ln P_{ij}, \left(j = 1,2,\ldots,n\right) \tag{5}$$

$$W_j = \frac{1 - E_j}{\sum_{j=1}^{n} G_j}, \left(j = 1,2,\ldots,n\right) \tag{6}$$

(3) A standardized weighting matrix Z_{ij} is created from the standardized matrix and the weights of each indicator.

$$Z_{ij} = W_j \times Y_{ij} \tag{7}$$

(4) Determine the positive ideal solution values S_j^+ and negative ideal solution values S_j^-

$$S_j^+ = \max_{1 \le i \le m}\{Z_{ij}\}, (j = 1,2,\ldots,n) \tag{8}$$

$$S_j^- = \min_{1 \le i \le m}\{Z_{ij}\}, (j = 1,2,\ldots,n) \tag{9}$$

(5) Calculate the distance to the positive ideal solution and the distance to the negative ideal solution for each year.

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(S_j^+ - Z_{ij}\right)^2}, (i = 1,2,\ldots,m) \tag{10}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(S_j^- - Z_{ij}\right)^2}, (i = 1,2,\ldots,m) \tag{11}$$

(6) Calculate the closeness of the evaluation object to the ideal solution C_i

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}, (i = 1,2,\ldots,m) \tag{12}$$

4.3 Evaluation results of the digital transformation capability of the manufacturing industry

With the assistance of SPSS-AU software, the entropy(e_j), information utility value (d_j), and weighting coefficient (w_j) of the sample evaluation indicators were calculated. The calculation follows the entropy-weighting method outlined in the previous section, and these indices reflect the digital transformation capability of the manufacturing industry across 30 provinces and cities. The results are shown in Table 2.

Based on the information presented in Table 2, the indicators with the highest weights are the number of effective invention patents held by large-scale industrial enterprises (B3), the full-time equivalent of research and development (R&D) personnel in these enterprises (B1), and the funding for new product development in these enterprises (B2). These indicators have weights of 11.72%, 10.46%, and 9.78%, respectively. This result proves that the key factor for manufacturing companies to use digitalization to play a transformational role is their digital innovation capabilities. This shows that R&D personnel and capital investment are crucial to R&D. By increasing R&D investment, enterprises can apply new digital strategies and technologies faster, thus accelerating the process of digital transformation. They can then integrate digital achievements into daily operations to deliver better products and services to customers. In addition, the economic benefits brought by digital transformation play an important role in the indicator system. The weights of indicators such as the proportion of e-commerce sales, technical market turnover, industrial added value, and total profits of industrial enterprises above a designated size all exceed 5%. There are two main explanations for this. First, digital transformation effectively improves production and operation efficiency by strengthening enterprises' internal value chains. This brings higher efficiency, lower costs and better quality. The actual value of these improvements ultimately helps enhance enterprises' overall value. Second, the growth of enterprise value provides strong financial support for enterprises' digital transformation, thus effectively promoting the implementation of digital initiatives. This positive interaction between value growth and the transformation process indicates that economic benefits strengthen the digital process.

Table 2： Summary of the results of weight calculation by the entropy method.

Secondary indicators	Tertiary indicators	Information entropy value (e_j)	Information utility value(d_j)	Weighting coefficients(w_j)
Digital transformation support（A）	Fiber optic line length (A1)	0.9251	0.0749	4.20%
	Internet broadband access port (A2)	0.9301	0.0699	3.92%
	Cell phone penetration rate (A3)	0.9114	0.0886	4.96%
	Websites per 100 businesses (A4)	0.9652	0.0348	1.95%
	Share of enterprises with e-commerce trading activities (A5)	0.9285	0.0715	4.01%
	Growth rate of fixed asset investment in the ICT industry (A6)	0.9828	0.0172	0.97%
Digital Transformation Potential（B）	Full-time Equivalent of R&D Personnel of Industrial Enterprises Above Scale (B1)	0.8132	0.1868	10.46%
	Expenditures for developing new products of industrial enterprises above a designated size (B2)	0.8254	0.1746	9.78%
	Number of Effective Invention Patents of Industrial Enterprises Above Scale (B3)	0.7907	0.2093	11.72%
	Breadth of digital inclusive financial coverage (B4)	0.9183	0.0817	4.57%
	Depth of coverage of digital inclusive finance (B5)	0.9236	0.0764	4.28%
	Degree of digitalization of inclusive finance (B6)	0.9487	0.0513	2.87%
	Industrial Internet Development and Application Index (B7)	0.9488	0.0512	2.87%
Digital transformation benefits（C）	E-commerce sales (C1)	0.8324	0.1676	9.39%
	Total Profit of Industrial Enterprises Above Scale (C2)	0.8335	0.1665	9.33%
	Value added of industry (C3)	0.8972	0.1028	5.76%
	Technology Market Turnover(C4)	0.9043	0.0957	5.36%
	Completed investment in industrial pollution treatment (C5)	0.9729	0.0271	1.52%
	Completed investment in projects for treating wastewater (C6)	0.9880	0.0120	0.67%
	Completed Investment in Treatment of Waste Gas Projects (C7)	0.9747	0.0253	1.42%

Based on the indicator weights in Table 2, the steps for evaluating the digital transformation capability of manufacturing enterprises using the TOPSIS method are as follows:

(1) Calculate the distance to the positive ideal solution (D+): This step aims to determine the distance between each evaluation object and the positive ideal solution. It measures how well each object matches the ideal values in various indicators.

(2) Calculate the distance to the negative ideal solution (D-): This step is used to compute the distance between each evaluation object and the negative ideal solution. It reflects the degree of deviation of each object from the worst values in various indicators.

(3) Calculate the Relative Proximity (C): The relative proximity is found by comparing the D- and D+ values. It shows how close each subject is to both the positive and negative ideal solutions, giving a full view of their performance.

After completing these calculations, the process parameter list and evaluation results were obtained, as shown in Table 3.

Table 3： Summary of the results of weight calculation by the entropy method.

Area	Positive ideal solution distance (D+)	Negative ideal solution distance (D-)	Relative proximity (C)	Ordering results
Beijing	0.185	0.158	0.460	4
Tianjin	0.235	0.054	0.188	15
Hebei	0.228	0.054	0.192	14
Shanxi	0.244	0.040	0.142	20
Neimenggu	0.248	0.036	0.126	23
Liaoning	0.235	0.043	0.154	18
Jilin	0.255	0.032	0.112	25
Heilongjiang	0.254	0.030	0.107	28
Shanghai	0.187	0.129	0.408	5
Jiangsu	0.122	0.174	0.586	2
Zhejiang	0.152	0.137	0.473	3
Anhui	0.206	0.072	0.260	9
Fujian	0.213	0.074	0.258	10
Jiangxi	0.232	0.053	0.186	16
Shandong	0.167	0.113	0.403	6
Henan	0.221	0.063	0.221	11
Hubei	0.207	0.074	0.262	8
Hunan	0.217	0.061	0.219	12
Guangdong	0.068	0.241	0.781	1
Guangxi	0.242	0.041	0.146	19
Hainan	0.256	0.041	0.138	21

Area	Positive ideal solution distance (D+)	Negative ideal solution distance (D-)	Relative proximity (C)	Ordering results
Chongqing	0.232	0.052	0.182	17
Sichuan	0.214	0.076	0.263	7
Guizhou	0.251	0.032	0.114	24
Yunnan	0.248	0.039	0.137	22
Shaanxi	0.225	0.061	0.214	13
Gansu	0.255	0.030	0.105	29
Qinghai	0.262	0.031	0.107	27
Ningxia	0.259	0.031	0.107	26
Xinjiang	0.256	0.029	0.101	30

When evaluating the overall state of digital transformation in the manufacturing industry, some provinces in the central regions have been able to surpass those in the eastern regions. Also, some provinces in western regions have made significant progress, which is changing the current situation. However, the basic characteristics remain the same, and the spatial distribution pattern still follows the gradients of the eastern, central, and western regions.

This distribution can be explained in more detail through three different gradients:

First Gradient (Higher Digital Transformation Level): This level includes provinces such as Guangdong, Jiangsu, Zhejiang, Beijing, Shanghai and Shandong. Among these, Guangdong Province has a relative proximity of 0.781, followed by Jiangsu Province at 0.586. These provinces are leaders in the digital transformation of China's manufacturing industry. Zhejiang Province, Beijing Municipality, Shanghai Municipality, and Shandong Province also have relative proximity values above 0.4, placing them above the national average in digital transformation.

Second Gradient (Continued Progress): The second-tier provinces include Sichuan, Hubei, Anhui, Fujian, Henan, Hunan, Shaanxi, Hebei and Tianjin. Most of the provinces in this group are from the west, and they have made great economic progress in catching up.

Third Gradient (Challenges and Struggles): Provinces in the third gradient are Jiangxi, Chongqing, Liaoning, Guangxi, Shanxi, Hainan, Yunnan, Inner Mongolia, Guizhou, Jilin, Ningxia, Qinghai, Heilongjiang, Gansu and Xinjiang. Among these, some regions like Gansu and Xinjiang face great difficulties in the digital transformation of their local manufacturing industry. The reasons include poor climate conditions, remote locations, underdeveloped industrial infrastructure, and a lack of skilled workers.

In short, the digital transformation of the manufacturing industry is developing faster in the eastern region. The central region makes good progress to narrowing the gap, while the western region tries to catch up. This situation is clearly shown in Figure 2.

To identify the specific differences in digital transformation levels across provinces and cities, digital transformation support, digital transformation potential, and digital transformation benefits were calculated according to formulas (7) to (12). The proximity of each evaluation object to the positive ideal solution was calculated using the same procedure as that applied to the overall digital transformation level. The results are presented in Table 4.

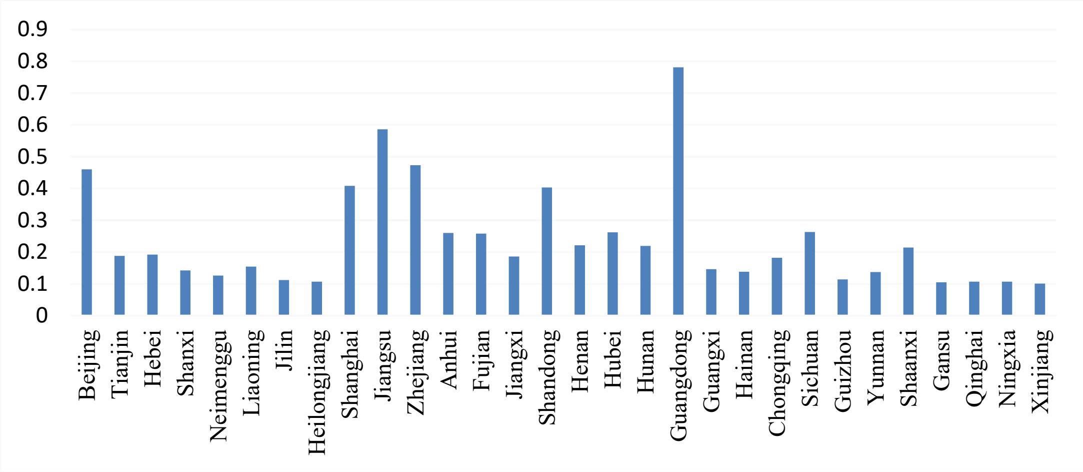

Figure 2: Comprehensive evaluation of digital transformation in manufacturing.

Table 4: Ranking of 30 regions in terms of manufacturing digital transformation level.

Area	Digital transformation support		Digital Transformation Potential		Digital transformation benefits	
	Relative proximity (C)	Ordering results	Relative proximity (C)	Ordering results	Relative proximity (C)	Ordering results
Beijing	0.585	3	0.527	5	0.644	2
Tianjin	0.382	16	0.341	10	0.534	5
Hebei	0.467	10	0.238	17	0.5	15
Shanxi	0.331	23	0.188	20	0.505	14
Neimenggu	0.348	20	0.161	23	0.282	30
Liaoning	0.345	21	0.196	19	0.468	22
Jilin	0.21	30	0.175	22	0.494	18
Heilongjiang	0.313	26	0.142	25	0.466	24
Shanghai	0.531	6	0.556	4	0.509	11
Jiangsu	0.605	2	0.692	2	0.701	1
Zhejiang	0.582	4	0.637	3	0.523	8
Anhui	0.512	8	0.358	8	0.43	28
Fujian	0.364	18	0.434	7	0.519	10
Jiangxi	0.46	11	0.261	16	0.507	13
Shandong	0.525	7	0.463	6	0.296	29
Henan	0.362	19	0.331	11	0.528	7
Hubei	0.471	9	0.347	9	0.509	12
Hunan	0.455	12	0.288	13	0.486	19
Guangdong	0.622	1	0.752	1	0.548	4
Guangxi	0.318	25	0.187	21	0.451	27
Hainan	0.371	17	0.207	18	0.497	17
Chongqing	0.408	15	0.268	15	0.523	9
Sichuan	0.553	5	0.322	12	0.528	6

Guizhou	0.324	24	0.135	27	0.467	23
Yunnan	0.426	14	0.137	26	0.484	20
Shaanxi	0.43	13	0.286	14	0.57	3
Gansu	0.342	22	0.129	28	0.48	21
Qinghai	0.309	27	0.096	29	0.498	16
Ningxia	0.292	28	0.153	24	0.463	26
Xinjiang	0.261	29	0.073	30	0.463	25

To examine the specific differences in digital transformation levels across provinces and cities, the proximity of each evaluation object to the positive ideal solution was calculated. As shown in Figure 3, the three provinces with the best evaluation results in digital transformation support are Guangdong, Jiangsu and Beijing. These provinces stand out across the country for their excellent digital infrastructure and hardware environments. This achievement comes not only from the strong economic foundation of these regions but also from their solid manufacturing industry bases. In addition, their strong human resources, comprehensive infrastructure, and sufficient financial support provide the necessary conditions for promoting the digital transformation of local manufacturing industries. However, Tianjin, with a well-developed manufacturing industry in eastern China, ranks outside the top 10. The reason is that the combination of information technology and industry is not close, and the level of industrial technological innovation has weakened. This leads to a low degree of industrial integration, which has seriously affected the digital transformation of the manufacturing industry. Similarly, in the western region, Sichuan and Shaanxi have achieved high rankings. This is because these two regions are part of high-quality manufacturing industry clusters. For example, Shaanxi Province has a strong presence in the automotive and equipment manufacturing sectors. Sichuan Province has a good reputation at home and abroad in the electronic information industry and equipment manufacturing field.

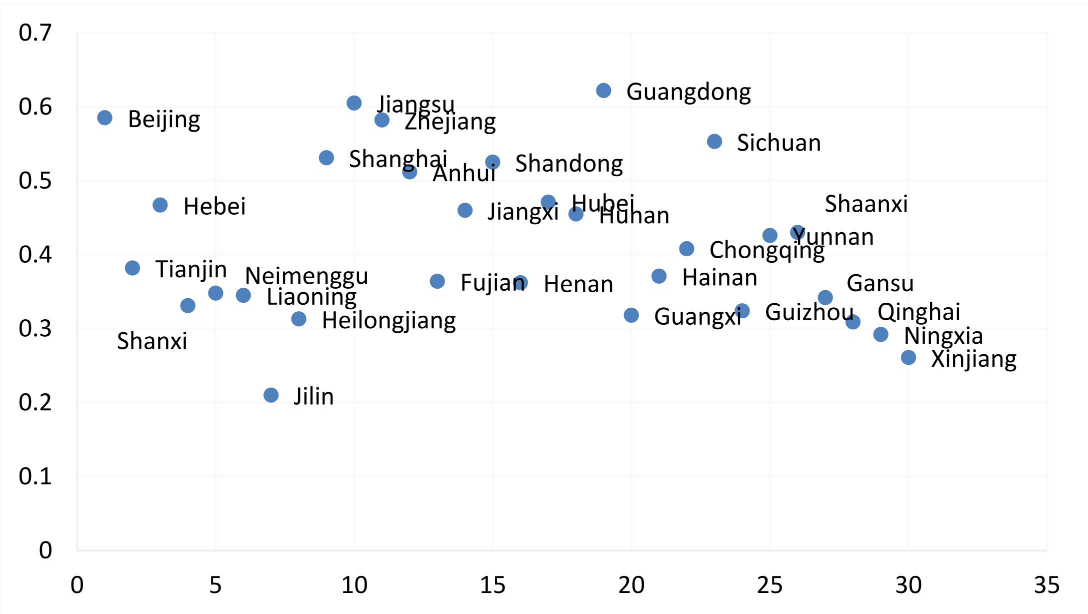

Figure 3: Digital Transformation Support Evaluation Results.

When looking at the potential for digital transformation, the top ten provinces in this area are Guangdong, Jiangsu, Zhejiang, Shanghai, Beijing, Shandong, Fujian, Anhui, Hubei, and Tianjin. It is worth noting that Hubei and Anhui, which are central-region provinces, have also risen in the top ten rankings. Further analysis shows that these regions leverage their rich higher education resources and make effective use of the intellectual advantages of their universities. This advantage helps them continuously cultivate a large number of high-quality digital innovation talents. At present, Hubei has established a knowledge-innovation platform with key laboratories at its core. It has also set up a technological innovation platform focusing on engineering (technology) research centers and enterprise technology centers. This system has significantly improved Hubei's innovation and technological development level. Anhui, on the other hand, has 121 institutions of higher education focusing on scientific research, application or skill training. Among them, the University of Science and Technology of China, Hefei University of Technology, Anhui University and other institutions have played an important role in cultivating a large number of practical technical talents. They have strongly promoted the high-quality development of local manufacturing. Abundant higher education resources have laid a solid foundation for digital product innovation and breakthroughs in digital technology. These trends are clearly visible in Figure 4.

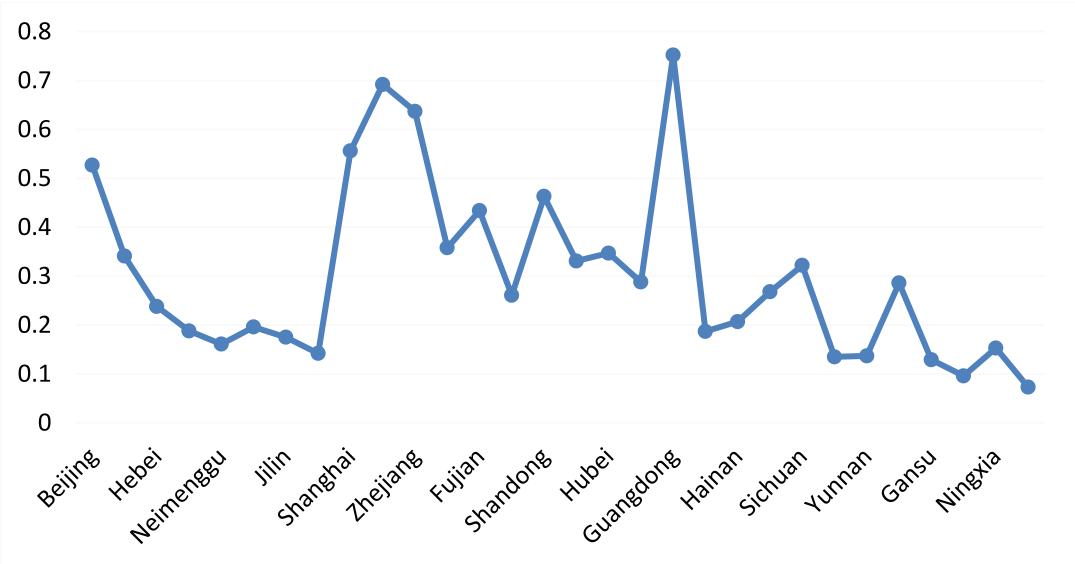

Figure 4: Digital Transformation Potential Evaluation Results.

In the field of digital efficiency transformation, Jiangsu Province ranks first. This leading position comes from its strategic cooperation with Shanghai, an economic metropolis. Shanghai is home to many foreign-funded enterprises. While setting up their headquarters in Shanghai, these enterprises also build production bases in Jiangsu. This mutually beneficial cooperation model, known as the "Jiangsu-Zhejiang-Shanghai cooperation model," has achieved remarkable results. In addition, manufacturing in Jiangsu Province has achieved in-depth integration of production and technology, resulting in significant industrial advantages. The province's development is both steady and high-quality. Provinces and municipalities in the top ten also include Shaanxi, Sichuan, Henan and Chongqing, all of which are located in central and western China. Several factors have helped them enter the top ten: Shaanxi's manufacturing industry has higher digital ecological efficiency, and its environmental impact is much smaller than that of Beijing, Shanghai and other regions; Henan's manufacturing industry has always been an important pillar of China's rapidly developing manufacturing and high-tech industries, and this stable performance has greatly increased the national industrial added value. For this reason, Henan has built multiple industrial bases valued at over one trillion yuan, mainly in equipment manufacturing and the modern food industry. These achievements show the province's good economic efficiency. Figure 5 clearly presents this detailed analysis, intuitively showing relevant trends and connections.

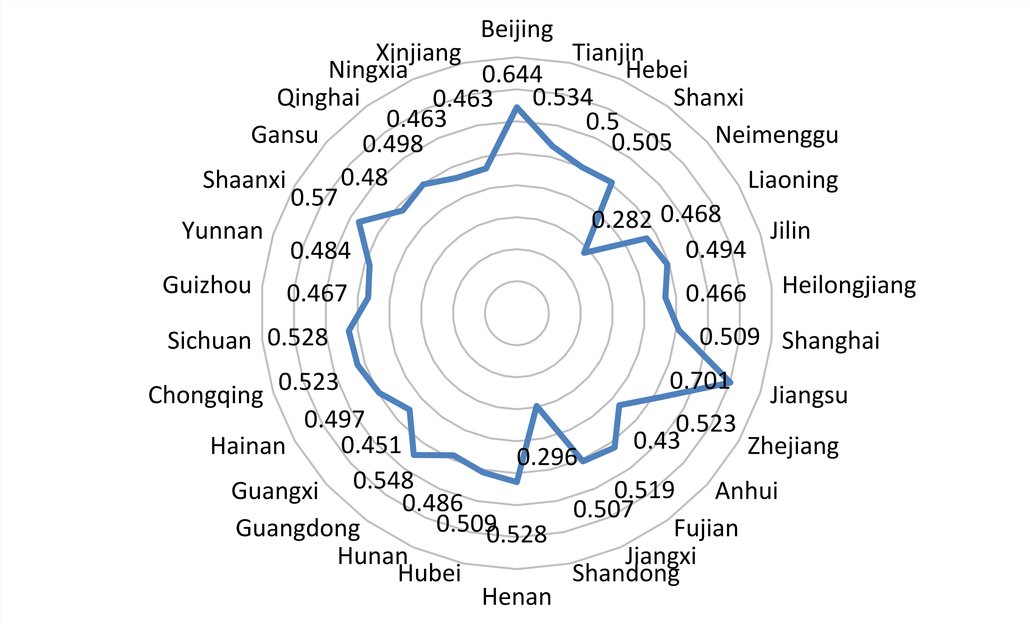

Figure 5: Digital Transformation Benefits Evaluation Results.

5. RESEARCH CONCLUSION AND PROSPECTS

5.1 Conclusions

Drawing on existing research on digital transformation in the manufacturing industry, this study develops a comprehensive method to build an evaluation index system for the sector. Based on dimensions such as digital transformation support, potential, and benefits, this system uses an evaluation framework to conduct a 2023 study of the digital transformation of manufacturing across 30 provinces, municipalities directly under the Central Government, and autonomous regions of China. The results of this study showed important insights:

(1) In the evaluation system for the digital transformation of manufacturing, results from the entropy weight method indicate that indicators related to digital innovation capability play an important role. These indicators rank among the top three, indicating that digital innovation capability is a core element of manufacturing's digital transformation. In addition, indicators reflecting the economic benefits of digital transformation also carry significant weight. This conclusion comes from the fact that digital transformation can optimize enterprises' internal production and operation processes, thereby enhancing enterprise value. At the same time, the growth in enterprise value provides strong financial support for digital transformation activities, enabling them to proceed smoothly.

(2) A comprehensive evaluation of China's manufacturing digital transformation reveals a clear three-tiered pattern. Although some central provinces have surpassed eastern regions and some western provinces have made progress in catching up with central regions, the overall pattern remains basically stable. Specifically, the eastern regions continue to lead, the central regions rank second, and the western regions remain relatively backward. It is worth noting that the digital transformation level of some western provinces, such as Shaanxi and Sichuan, is even higher than that of some eastern regions. This difference comes from the solid manufacturing foundation and abundant resource support in Western regions. These advantages have strongly driven their digital transformation.

(3) In-depth analysis of the specific dimensions of digital transformation reveals significant differences among provinces and municipalities in terms of support for digital transformation,

development potential, and actual benefits. In terms of digital transformation support, Guangdong, Jiangsu and Beijing have become national benchmarks thanks to their sound digital infrastructure and hardware systems. Regarding the potential for digital transformation, Hubei and Anhui, located in central China, have successfully entered the top ten. This achievement comes from the large number of higher education resources in these areas, which help train a skilled talent group suitable for digital new product development and technological innovation.

In the field of digital efficiency transformation, Jiangsu Province is the leader. This leading position stems from the province's strong geographic location and the successful implementation of the "Jiangsu + Shanghai" model. Besides, the manufacturing sector in Jiangsu has partly combined production and technology, leveraging its strong industrial advantages. The province's overall development path is stable and focuses on maintaining high-quality standards.

5.2 Research Prospects

The research in this paper has several limitations, which can be addressed and improved in future research. Paying attention to the following aspects may bring improvements:

(1) The method chosen to evaluate the digital transformation of the manufacturing industry across regions is the entropy weight TOPSIS method. However, this method assumes that indicators should be as close to a normal distribution as possible and relatively independent of each other. This may result in the obtained weights differing from their true importance. To improve the accuracy and scientific basis of indicator weights, future research may collect opinions from relevant experts to decide the importance of indicators. Using a combination of weighting methods may further improve the precision and validity of the weight assignment process.

(2) Although this paper considers factors that influence the digital transformation of the manufacturing industry from three dimensions, some factors may be missing. In future studies, deeper analysis can be conducted through group-based analyses and comparative assessments of factors influencing digital transformation across China's manufacturing industries in the eastern, central, and western regions. This will help gain a more comprehensive understanding of the unique situations and differences across these regions.

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