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Study on the Path of Digital Transformation of Manufacturing Industry and the Strategy to Eliminate "Digital Divide" under the Regional Integration of Yangtze River Delta

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ABSTRACT

Based on the research of digital economy and digital transformation of manufacturing industry, the article constructs the evaluation index system of digital economy development level and digital transformation of manufacturing industry in Yangtze River Delta respectively. The entropy weight TOPSIS method is used to measure and analyze the level of digital economy development and the level of digital transformation of manufacturing industry in the Yangtze River Delta respectively. The coupling coordination degree of digital economy and manufacturing digital transformation in the Yangtze River Delta in general and in each province and city is calculated and analyzed. On the basis of the relevant conclusions, recommendations for the digital transformation of the manufacturing industry and the elimination of the "digital divide" in the Yangtze River Delta are proposed. The overall trend of digital economy in the Yangtze River Delta (YRD) is on the rise, but there is a significant "digital divide". The increase in the level of digital economy development in the Yangtze River Delta over the past 10 years is 10.76%. The average value of digital economy development water in Shanghai, Jiangsu, Zhejiang and Anhui is 0.358, 0.549, 0.491, 0.185 respectively, and the development of digital economy in Anhui is insufficient. Shanghai's manufacturing digitalization water average is 0.750, the highest level in the Yangtze River Delta. Zhejiang and Anhui are slightly behind in manufacturing digital transformation. The coupling coordination degree of digital economy and manufacturing digital transformation in the Yangtze River Delta grew from 0.592 to 0.879, and the type of coupling coordination development shifted from barely coordinated to well coordinated. Shanghai and Jiangsu have reached the good coordination level. Zhejiang is at the intermediate coordination level. And Anhui is at the barely coordinated stage, which is the lowest level in the Yangtze River Delta.

Keywords: entropy weight TOPSIS method; coupling coordination degree; digital economy; manufacturing

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transformation

1. Introduction

Accelerating the digital transformation of the manufacturing industry and improving the level of industrial digitization is one of the key initiatives to seize the main track of manufacturing competition and realize the high-quality development of the manufacturing industry in the digital era [1-2]. The Yangtze River Delta (YRD) is one of the most dynamic and open regions in China's economy, and is also bound to play a key role in the process of digital transformation of China's manufacturing industry [3-5]. Therefore, exploring the path of sustained improvement of manufacturing digitalization level in the YRD region can provide a realistic basis for China to promote high-level digital transformation of the manufacturing industry in general, and to clarify the key to the layout of digital transformation in key regions.

Digital divide refers to the inequality of digital technology and information resources between different regions, industries, and social groups in the process of digital transformation [6-7]. One is the digital divide at the regional level, where developed cities and key economic regions are more advanced in digital technology application and infrastructure, while relatively less developed regions have relatively low digitization levels [8-10]. Second, the digital divide at the industry level, in the process of digital transformation, some traditional industries may face the difficulties of technological updating and digital transformation, and there is a large gap compared with emerging industries [11-13]. Third, the digital divide at the skill level, some regions and groups lack the skills and knowledge required for digital transformation, and there are deficiencies in digital literacy, data analysis ability, and cybersecurity awareness, which restricts the promotion of digital transformation [14-16]. In this context, each place in the Yangtze River Delta needs to combine its own location conditions, industrial foundation, resource endowment and other characteristics with the development of the digital economy in the process of actively implementing the top-level strategic design of the national digital economy, and make efforts to move towards a high-quality integration process in order to promote digital transformation.

The road to digitalization is a necessary way for enterprises to realize the due economic laws, and the digital transformation of enterprises in the Yangtze River Delta is an important means for them to enter the digital economy market [17].Chang, K. et al. examined the impact of the digital economy and industrial agglomeration on the industrial structure of cities in the Yangtze River Delta, and the empirical study showed that the digital economy promotes the rationalization and advancement of the industrial structure of cities in the Yangtze River Delta, and that the synergistic of the manufacturing industry and other industries agglomeration plays an intermediary role in the process of industrial structure upgrading [18].Zhu, H. et al. analyzed the impact of digital transformation on the urban resilience of the Yangtze River Delta region, and the technological innovation capacity, the development power of the new economic sector, and the vitality of innovation and entrepreneurship development are important paths for digital transformation to enhance the urban resilience, and the transformation process has a significant spatial spillover effect [19].He, Q. et al. analyze the impact of digital transformation on the urban resilience of the Yangtze River Delta region through the construction of a comprehensive evaluation system for the quality of the digital economy, in order to measure the quality of the digital economy. economy quality comprehensive evaluation system, to measure the way to study the influence factors and realize the path of digital transformation and upgrading of manufacturing industry, the experiment shows that the high-quality digital economy development level promotes the transformation and upgrading of manufacturing industry in the Yangtze River Delta cities [20].Huang, J. et al. show that the regional digital economy development will be conducive to improve the production efficiency of the enterprise, due to the increase in the cost of enterprise management will reduce the capital investment, so the reduction of enterprise management cost to some extent stimulate the development of the enterprise. Therefore reducing enterprise management costs to a certain extent stimulates the development of the digital economy, so that the enterprise production efficiency increases [21].

On the whole, the digital transformation of the Yangtze River Delta region also faces a series of constraints, and some scholars have put forward relevant economic development strategies on the "digital divide". Han, J. et al. have clarified that there are spatial differences in the digital economy of urban areas, but with the development of cities, the "digital divide" is gradually shrinking, and the "digital dividend" is beginning to appear. However, with the development of cities, the "digital divide" is gradually shrinking, and the "digital dividend" has begun to appear, through the study of the convergence and influence mechanism of the development of urban digital economy in different spatial scales, to provide a theoretical basis for the realization of sustainable development of the digital-driven economy [22]. Shakina, E. et al. propose a hypothesis that firms' digital skills needs drive innovation in digital technologies and rethink the corporate digital divide by constructing a cycle of firms' digital skills innovation consisting of competency accumulation and digital technology shifts [23]. Song, Z. et al. assessed the utility of ICTs in mitigating the digital divide problem and found that dealing with socio-economic issues is a prerequisite for improving the use and outcomes of ICTs based on an analysis of the main factors influencing the digital divide in prefecture-level cities [24]. Baoqi, J. et al. introduced an integrated big data center co-innovation system of "East Data, West Computing" to bridge the regional digital divide in the development of the digital economy by coordinating the differentiation of wealth and information between regions [25].

Based on the mechanism of digital economy development and manufacturing transformation in the Yangtze River Delta region, the article measures the level of digital economy development in the region using the entropy weight TOPSIS method, and analyzes the development of digital economy in the Yangtze River Delta during the 10-year period from 2011 to 2020. Then measure the level of digital transformation of the manufacturing industry in the Yangtze River Delta and compare the results, and compare the level of digital transformation of the manufacturing industry in each province and city in the Yangtze River Delta by industry. By constructing a coupled coordination degree model. Calculate the overall coupling coordination level of digital economy and manufacturing digital transformation in the Yangtze River Delta region during the 10-year period and the coupling coordination degree of the two systems in each province and city within the Yangtze River Delta. Based on the conclusions obtained, relevant suggestions are made for the digital transformation of the manufacturing industry in the Yangtze River Delta and the bridging of the "digital divide" within the Yangtze River Delta.

2. Mechanism and effect of digital transformation of manufacturing industry

2.1. Digital economy and manufacturing

2.1.1. The digital economy and its industries. The concept of digital economy was first proposed in 1996, and with the continuous research in the academic community, the connotation of digital economy has been extended [26]. In the era of information economy, the definition of digital economy emphasizes more on the development and application of digital technology industry, such as information technology service industry. Digitized information, Internet platforms, and digital technology are the components of digital economy, which show new modes and new forms of economic activities. Digital economy is the main economic form after agricultural economy and industrial economy, and it is a new economic form with data resources as the key elements, modern information network as the main carrier, and the integration and application of information and communication technology and the digital transformation of all elements as the important driving force to promote more unity of equity and efficiency. Digital economy cannot be separated from digital technology and data elements. Data factor is an emerging factor different from traditional factors of production such as labor and capital, and data factor makes the form of digital economic production function change. 5G, big data, artificial intelligence and other digital technologies continue to penetrate and drive industrial development. The integration and application of digital technology and industrial technology, as well as the integration and application of data factors and traditional factors have realized technological innovation and factor innovation, which in turn enhance the production efficiency of the manufacturing industry and promote the creation of new business models.

In July 2021, China's National Bureau of Statistics released the Statistical Classification of the Digital Economy and Its Core Industries (2021) to provide a clear definition of the core industries of the digital economy. This paper is based on the statistical classification of industries released by China's national authority, and divides the digital economy industry, a research object, according to the Statistical Classification of the Digital Economy and its Core Industries (2021).

2.1.2. Manufacturing. The manufacturing industry is an important part of the national economy [27]. As the core component of the industry, academics usually classify the manufacturing industry when researching the manufacturing industry. The classification method is mainly the Standard Industrial Classification (SIC), which is formulated and promulgated by the authoritative departments, has national standards, and can accurately, comprehensively and scientifically reflect the basic situation of a country's industrial development. On this basis, it is a common method in the academic world to subdivide the manufacturing industry according to the intensity of different factors. For example, according to the intensity of technology, capital and labor factors, the manufacturing industry is divided into technology-intensive, capital-intensive and labor-intensive, and in 2013, the National Bureau of Statistics of China issued the Classification of High-technology Industries (Manufacturing), which mainly refers to the manufacturing industry with high intensity of R&D investment.

According to the Classification and Codes of National Economic Sectors issued by the National Bureau of Statistics of China, the manufacturing industry is categorized into a number of sectors, including the food manufacturing industry, pharmaceutical manufacturing industry, etc., which is an accurate and detailed classification. With the continuous innovation and development of emerging technologies, the manufacturing industry has gradually extended into advanced manufacturing and high-tech manufacturing, which includes advanced electronic information industry, automation equipment manufacturing and other fields, and there are digital mash-ups between these sectors and digital economy sectors, such as the core industries of the digital economy, including information technology services, and the manufacturing of digital hardware products, etc. The digital transformation of the manufacturing industry focuses more on the digitization of traditional manufacturing, which is measured by the digitalization of traditional manufacturing. The digital transformation of manufacturing industry focuses more on the digitalization of traditional manufacturing industry, and measuring the level of digital transformation of digital economy and traditional manufacturing industry helps to better grasp the current situation of digital transformation of manufacturing industry.

2.2. Mechanisms of digital transformation in manufacturing

The digital transformation of traditional manufacturing industry belongs to a systematic and very complex process [28]. No matter what kind of enterprise, digital technology will bring great benefits to enterprise management efficiency and productivity. Due to the existence of a relatively single production model, complex product system, large organizational structure, backward management level and concepts and many other problems, many traditional manufacturing enterprises are facing the risk of being eliminated by society and the industry. Reasonable and full use of digital technology for transformation, for traditional manufacturing enterprises is a rare opportunity for development. Digital upgrading is to improve the digital level of all aspects of research and development, production, management, etc. through modern digital technology, such as big data, 5G, cloud computing, and artificial intelligence, to improve the quality of products as well as the quality of management and service, and to realize digital design, management, control, and service, in order to save production costs, improve production efficiency, shorten the production cycle, and ultimately to improve the enterprise's comprehensive production efficiency. Through the success of digital transformation, enterprises can attract and create more excellent technology and resources in all aspects. Overall, the constraints of digital transformation and the digital transformation of enterprises have an interactive relationship, with a synergistic evolutionary effect.

2.3. Digital transformation effects in manufacturing

The extensive penetration and application of digital technologies in traditional manufacturing will lead to the emergence of new businesses and models, such as digital manufacturing and digital supermarkets. This will drastically reduce the demand for low-level labor for many highly repetitive and strongly rule-based jobs. The digital transformation of the traditional manufacturing industry can achieve cost savings and efficiency gains, improve the organizational structure and operational management efficiency of enterprises, and enhance economic efficiency. On the one hand, digital technology has a very wide range of applications in standardized and process-oriented production processes, especially in the manufacturing sector, which is crucial for the development of traditional manufacturing and the effective enhancement of industrial value, and can add to the development of industrialization. On the other hand, digital functions make it possible to assist or even replace human work in some complex application scenarios. For example, the development of various kinds of auxiliary intelligent digital equipment promotes the digital development of production, and the new intelligent industry with intelligent digitalization as the leading technology provides new products and services to the market, which will promote the modernization and upgrading of the consumption structure. The digitized new industries will change the existing inefficient production model, which will also play a role in improving the productivity of the traditional manufacturing industry.

3. Measuring the Level of Digital Economy Development in the Yangtze River Delta

3.1. Construction of the indicator system

Based on the previous definition of the digital economy, this paper constructs a comprehensive evaluation index system for the development level of the digital economy from four dimensions: digital infrastructure construction, digital industrialization, industrial digitization and digital governance, as shown in Table 1.

1) Digital infrastructure construction dimension. The purpose of building digital infrastructure is to provide the public with convenient and intelligent public services and to promote the digital transformation and upgrading of various urban areas. For the measurement of this component, most previous studies have mainly focused on the consideration of Internet penetration rate and cell phone penetration rate. Thus, four indicators are selected, namely, electricity consumption, number of cell phone subscribers, Internet broadband access subscribers, and number of fixed telephone subscribers.

2) Digital industrialization dimension. Digital industrialization not only provides digital goods and digital services for the market, but also it is an integral part of the digital economy and an important field, covering a variety of digital industries: software and information technology service industry, Internet service industry, computer communication industry, and so on. Therefore, four secondary indicators are selected: telecommunications business revenue, value added of the tertiary industry, number of computer and communication enterprises, and number of patent applications.

3) Industry digitization dimension. Industrial digitization is the product of the integration of the three industries with the digital economy, which is realized as the penetration of digital technology into rural areas, enterprises and financial services, which in turn forms digital villages, digital enterprises and digital finance. In terms of digital countryside, embodied in smart agriculture, this paper uses the number of Taobao villages and the total power of agricultural machinery as alternative indicators of digital agriculture. For digital enterprises, this paper uses the R&D internal expenditure of industrial enterprises above large scale, the number of R&D projects, and R&D personnel as alternative indicators of industrial digitization. For digital finance, this paper uses the digital inclusive finance index calculated by Peking University.

4) Digital governance dimension. Digital governance is an indispensable part of people's life and government governance, and digital technology is used in daily life and public governance to form an

intelligent lifestyle and an efficient governance structure. This paper extracts indicators in the three sections of people's livelihood, education and government respectively, reflecting the important role of digital economy in life, government as well as education. Digital livelihood is reflected in the urban innovation and entrepreneurship index, digital government is reflected in the ratio of science and technology expenditure to finance, and digital education is reflected in the rate of higher education in society.

Table 1. Digital economy development comprehensive evaluation indicator system

Primary indicator	Secondary indicator	Tertiary indicator
Digital economy	Digital infrastructure construction (X1)	Electricity consumption/104 kW (X11)
		Mobile phone users/104 household (X12)
		Internet broadband access users/104 household (X13)
		Fixed phone users//104 household (X14)
	Digital industrialization (X2)	Telecommunications revenue/yuan (X21)
		The added value of the third industry/108 yuan (X22)
		Number of computer and communication enterprises (X23)
		Patent application number (X24)
	Industry digitization (X3)	Taobao village number (X31)
		Total mechanical power of agricultural machinery (X32)
		Above-scale industrial enterprise R&D project personnel/108 yuan (X33)
		Above-scale industrial enterprise R&D internal expenditure/108 yuan (X34)
		Above-scale industrial enterprise R&D project number (X35)
		Digital financial inclusion index (X36)
	Digital governance (X4)	Urban innovation and entrepreneurship index (X41)
		Technology spending ratio in finance/% (X42)
		Social higher education rate/% (X43)

3.2. Measurement methods

The methods of measuring the level of development of the digital economy include the production method and the index system method. Based on the research of previous scholars, this paper uses the index system method to calculate the development index of the digital economy for specific analysis. The more common comprehensive evaluation methods are principal component analysis, entropy weight method, expert scoring method and so on. This paper uses the comprehensive entropy weight TOPSIS method, which is based on the entropy weight method and utilizes the information of the original data to assign weights to the data [29].

First, the selected secondary indicators are standardized by using the extreme difference transformation method. Secondly, the weight and entropy value of each indicator are derived through the designed formula. Finally, the entropy value is used to calculate the comprehensive score of each index.

The specific steps are as follows:

Assuming that there is n object to be evaluated and m indicators, construct the original data matrix $A=\left(a_{ij}\right)_{n*m}$, where a_{ij} represents the value of the j th indicator for the i th object to be evaluated.

Step 1: Data normalization process (polar transform method):

$$\text{Positive Indicator Formula: } Z_{ij} = \frac{X - Min}{Max - Min} \tag{1}$$

$$\text{Negative indicator formula: } Z_{ij} = \frac{Max - X}{Max - Min} \tag{2}$$

Step 2: Find the weight of each evaluation object under each indicator:

$$P_{ij} = \frac{X_{ij}{}^{*}}{\sum_{j=1}^{n} X_{ij}^{*}} \tag{3}$$

Step 3: Find the entropy value of each indicator:

$$E_j = -\frac{1}{\ln n}\sum_{i=1}^{n} P_{ij} \ln P_{ij} \tag{4}$$

Step 4: Calculate the weight of each indicator by entropy value:

$$d_i = 1 - c_i \tag{5}$$

$$w_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \tag{6}$$

Step 5: Calculate the weighted index for each indicator:

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

where Q_{ij} is the weighted index of the i regional j indicators.

In the sixth step, the distance between each observation and the optimal object D_i^g and the worst object D_i^b is determined. I.e:

$$\text{Optimal object: } D_i^g = \sqrt{\sum_{R}^{j=1}\left(Q_{ij}^g - Q_{ij}\right)^2} \tag{8}$$

$$\text{Worst Subjects: } D_i^b = \sqrt{\sum_{R}^{j=1}\left(Q_{ij} - Q_{ij}^b\right)^2} \tag{9}$$

where $D_{ij}^g = \max\left\{Q_{1j},\ldots,Q_{nj}\right\}$, $D_{ij}^b = \min\left\{Q_{1j},\ldots,Q_{nj}\right\}$.

In the seventh step, the relative proximity of each observed object to the ideal object is calculated:

$$DEI_i = \frac{D_i^b}{D_i^g + D_1^b} \tag{10}$$

where DEI_i is the digital economy index of region i. The index is between 0 and 1. The larger the value, the higher the level of digital economy development in city i.

3.3. Analysis of the results of measuring the level of digital economy development in the Yangtze River Delta

According to the steps in subsection 3.2, the level of digital economy development in the Yangtze River Delta region from 2011 to 2020 can be calculated as shown in Table 2. From the measurement results in Table 2, it can be found that, from the point of view of the changes in the digital economy index of the Yangtze River Delta region, the digital economy index of all provinces and municipalities in the Yangtze River Delta region as a whole shows a fluctuating upward trend, and there is a gap between different provinces and municipalities, which indicates that in recent years the digital economy of the Yangtze River Delta region has been fluctuating but developing in an overall positive direction.

Observing the distribution trend of the Yangtze River Delta region as a whole, it can be found that the differences in the level of development of the digital economy in the Yangtze River Delta are more significant, however, the overall trend shows a steady increase. From 2011 to 2020, the overall average value grew from 0.381 to 0.422, with an overall increase of 10.76%, and the growth rate showed a trend of steady increase amidst fluctuations. From 2011 to 2020, Jiangsu has always taken the lead in digital economy development, while Zhejiang and Shanghai have steadily ranked second and third, with the average values of digital economy development of these three provinces and cities in the 10-year period being 0.358, 0.549 and 0.491 respectively, while the average value of Anhui's digital economy development is only 0.185. Within the Yangtze River Delta, a clear trend is formed between the digital economy development levels of Jiangsu, Zhejiang and Shanghai and that of Anhui. Within the Yangtze River Delta, the digital economy of Jiangsu, Zhejiang and Shanghai has formed an obvious development gap with Anhui, and there is a large “digital divide” between Anhui and Jiangsu, Zhejiang and Shanghai.

Table 2. Digital economy development of Yangtze river delta region

Year	Shanghai	Jiangsu	Zhejiang	Anhui	Mean
2011	0.368	0.536	0.472	0.146	0.381
2012	0.326	0.521	0.552	0.147	0.387
2013	0.337	0.502	0.459	0.169	0.367
2014	0.396	0.493	0.473	0.185	0.387
2015	0.382	0.533	0.512	0.196	0.406
2016	0.386	0.578	0.511	0.194	0.417
2017	0.337	0.574	0.466	0.184	0.390
2018	0.332	0.581	0.478	0.198	0.397
2019	0.345	0.568	0.485	0.213	0.403
2020	0.367	0.604	0.499	0.218	0.422
Mean	0.358	0.549	0.491	0.185	/

4. Digital Transformation Measurement of Manufacturing Industry in Yangtze River Delta

4.1. Measurement of the level of digital transformation in manufacturing

For the measurement method of digital transformation of manufacturing industry, this paper draws on the academic research on digital transformation of manufacturing industry to measure digital transformation of manufacturing industry from four perspectives: digital technology transformation, digital innovation transformation, digital efficiency transformation and digital green transformation. The index system of manufacturing digital transformation is shown in Table 3.

Digital technology transformation selects digital talent input, digital software application and digital equipment input to measure. Among them, digital talent input is selected to measure the number of employment in software and information technology service industry, digital software application is selected to measure software product revenue, and digital equipment input is selected to measure fixed asset investment in software and information technology service industry.

Digital innovation transformation is measured by R&D intensity and product innovation, while the number of patent applications per 10,000 people is added as patents also have a greater impact on digital innovation. Among them, R&D intensity is measured by the ratio of R&D internal expenditure to manufacturing value added, product innovation is measured by the ratio of manufacturing new product sales revenue to manufacturing main business revenue, and the number of patent applications per 10,000 people is measured by the ratio of total number of patent applications to the number of employed people in the manufacturing industry.

The digital efficiency transformation is measured by selecting the value added of manufacturing per capita and the return on net assets. The per capita manufacturing value added is measured by the ratio of manufacturing value added to the number of manufacturing employees, and the return on net assets is measured by the difference between total profit over total assets and total liabilities.

Digital Green Transformation is measured by energy consumption per unit of value added, electricity consumption, wastewater emissions, and exhaust emissions. The unit value added energy consumption is measured by the ratio of manufacturing energy consumption to manufacturing value added, the unit value added electricity consumption is measured by the ratio of manufacturing electricity consumption to manufacturing value added, the unit value added wastewater emissions are measured by the ratio of manufacturing wastewater emissions to manufacturing value added, and the unit value added exhaust emissions are measured by the ratio of manufacturing exhaust emissions to manufacturing value added. Wastewater emissions per unit value added are measured by the ratio of manufacturing wastewater emissions to manufacturing value added, and exhaust emissions per unit value added are measured by the ratio of manufacturing exhaust emissions to manufacturing value added.

Table 3. Manufacturing digital transformation evaluation indicator system

Primary indicator	Secondary indicator	Tertiary indicator
Manufacturing digital transformation	Digital technology transformation (Y1)	Digital talent investment (Y11)
		Digital software application/108 yuan (Y12)
		Digital equipment investment/108 yuan (Y13)
	Digital innovation transformation (Y2)	R&D strength (Y21)
		Patent application number per 104 people (Y22)
		Product innovation (Y23)
	Digital benefit transformation (Y3)	Per capita manufacturing added value/104 yuan (Y31)
		Return on equity/% (Y32)
	Digital green transformation (Y4)	Unit added value energy consumption (Y41)
		Unit added value power consumption (Y42)
		Unit added waste water discharge (Y43)
		Unit added waste emission (Y44)

In the choice of measurement method for the level of digital transformation of manufacturing industry, the entropy weight TOPSIS method mentioned in section 3.2 is adopted. The secondary indicators in the indicator system constructed in section 4.1 are standardized through the polar transformation method, the weight and entropy value of each indicator are derived, and the entropy value is used to calculate the comprehensive score of each indicator of digital transformation of the manufacturing industry.

4.2. Analysis of the results of measuring the level of digital transformation of manufacturing industries in the Yangtze River Delta

4.2.1. Comparison of Digital Transformation Levels of Manufacturing Industries in the Yangtze River Delta. The results of measuring the level of digital transformation of the manufacturing industry in the Yangtze River Delta are shown in Table 4. From the information shown in Table 4, overall, the digital transformation of the manufacturing industry in Shanghai, Jiangsu and Anhui provinces and cities in the Yangtze River Delta during the sample period shows a steady growth trend, with the average value of the water of digital transformation of the manufacturing industry in Shanghai and Jiangsu in 2011 being 0.705 and 0.384, respectively, and rising to 0.713 and 0.468, respectively, in 2020, and the level of the manufacturing industry's digital transformation in Anhui, although not as high, has also rose from 0.075 at the beginning of the sample to the level of 0.229 in 2020. Comparatively speaking, the level of digital transformation of manufacturing industry in Zhejiang has shown a declining trend. At the beginning of the sample, the level of digitalization in Zhejiang was maintained at 0.152, but by 2020 it has dropped to below 0.140.

In further comparison, the gap in the level of manufacturing digital transformation among provinces and cities in the Yangtze River Delta region is relatively obvious. Shanghai's manufacturing transformation advantage is the most prominent, during the sample period, its manufacturing digitalization water average reached 0.750, much higher than the average level of the other three provinces. Jiangsu in the sample at the beginning of the level of digital transformation of the manufacturing industry is equivalent to half of Shanghai, since then the level of digital transformation is still showing an upward trend, but the gap with Shanghai is gradually narrowing. 2013 ~ 2020, Jiangsu manufacturing industry digital transformation level is mainly in the range of 0.40 ~ 0.50 range, compared with Shanghai's level of 0.70 or more there has been a significant gap, however, relative to Zhejiang However, relative to Zhejiang and Anhui provinces, Jiangsu manufacturing digital transformation still has a certain leading edge. Sample period, zhejiang, anhui manufacturing digital transformation water average value to remain above 0.100, but compared to jiangsu 0.430 average level, zhejiang, anhui manufacturing digital transformation process in the region is slightly behind.

Table 4. Manufacturing digital transformation of Yangtze river delta region

Year	Shanghai	Jiangsu	Zhejiang	Anhui	Mean
2011	0.705	0.384	0.152	0.075	0.329
2012	0.711	0.397	0.145	0.074	0.332
2013	0.826	0.432	0.144	0.071	0.368
2014	0.843	0.456	0.148	0.070	0.379
2015	0.725	0.395	0.159	0.076	0.339
2016	0.758	0.418	0.167	0.078	0.355
2017	0.778	0.420	0.173	0.079	0.363
2018	0.729	0.447	0.146	0.237	0.390
2019	0.716	0.481	0.148	0.238	0.396
2020	0.713	0.468	0.139	0.229	0.387
Mean	0.750	0.430	0.152	0.123	/

4.2.2. Re-comparison of Digital Transformation Levels from a Sub-Industry Perspective. Further subindustry perspective to carry out comparisons, selecting 16 types of manufacturing industries (food and tobacco processing industry, textile industry, clothing and leather products industry, wood processing industry, paper and printing products industry, petroleum coking and nuclear fuel processing industry, chemical products industry, non-metallic products industry, metal smelting and calendering industry, metal products industry, general and special equipment manufacturing, transportation equipment manufacturing, electrical and mechanical manufacturing, communication computer and other electronic equipment manufacturing, instrumentation manufacturing, scrap waste and other manufacturing industries as a research sample numbered from 1 to 16. Manufacturing, Communication Computer and Other Electronic Equipment Manufacturing, Instrument and Meter Manufacturing, Scrap Waste and Other Manufacturing) as the study sample, numbered from 1 to 16. According to the measurement methodology in subsection 4.2, the mean values of the measurement results of the digital transformation level of sub-manufacturing industries in the Yangtze River Delta region are shown in Table 5.

From the results reported in Table 5, specific to each manufacturing industry, Shanghai's advantage in digital transformation remains, and the digital transformation levels of most manufacturing industries remain leading in the region during the sample period. With the exception of the non-metal products industry and the instrument and meter manufacturing industry, the digital transformation levels of Shanghai's other manufacturing industries are significantly higher than those of Jiangsu, Zhejiang, and Anhui Provinces, and rank first in the region. Jiangsu and Zhejiang, on the other hand, in individual manufacturing industry sectors to maintain the leading edge of digital transformation, in which Zhejiang's non-metallic products industry in the sample period of the average value of digital transformation water reached 0.124, ranked first in the region, while Jiangsu's instrumentation manufacturing industry average value of digital transformation water reached 0.964, also ranked first in the region. Comparatively speaking, the digital transformation advantage of Anhui manufacturing industries is not very prominent, the sample period, the main manufacturing industry digital transformation level did not reach the first regional. Obviously, after the comparison of specific subdivided manufacturing industries, the gap between the digital transformation advantages of manufacturing industries in the Yangtze River Delta region is more obvious, and the differences in the digital transformation process of manufacturing industries between the regions are also more prominent, with Shanghai occupying the digital transformation advantages of most manufacturing industries, and maintaining a relatively stable leading position in the sample period.

In addition to Shanghai's outstanding leadership, within the Yangtze River Delta region, Jiangsu and Zhejiang also have certain leading characteristics of digital transformation in some manufacturing industry sectors. Comparatively speaking, the average value of digital transformation in Zhejiang's food and tobacco processing industry, textile industry, wood processing industry, metal products industry, and scrap waste and other manufacturing industries is 0.028, 0.035, 0.051, 0.049, 0.046, respectively, which is higher than that of Jiangsu and Anhui provinces, and while Shanghai maintains the leading edge, the process of digital transformation in the above-mentioned industries in Zhejiang also has certain leading characteristics. Leading characteristics. Jiangsu than zhejiang, anhui two provinces digital transformation level leading manufacturing industries more, sample period, clothing leather products industry, paper and printing products industry, petroleum coking and nuclear fuel processing industry, chemical products industry, metal smelting and rolling processing industry, general equipment and special equipment manufacturing, transportation equipment manufacturing, electrical and mechanical manufacturing, communication computer and other electronic equipment manufacturing digital transformation water The average value of 0.091, 0.069, 0.018, 0.038, 0.027, 0.178, 0.146, 0.339, 2.367, respectively, significantly higher than in Zhejiang and Anhui provinces, the process of digital transformation is equally obvious. Relative to Jiangsu and Zhejiang provinces, the level of digital transformation of Anhui's major manufacturing industries is still not outstanding, and the industries do not yet have obvious digitalization leading characteristics.

Table 5. Digital transformation of 15 manufacturing industries in Yangtze river delta region

Industry	Shanghai	Jiangsu	Zhejiang	Anhui
1	0.046	0.010	0.028	0.012
2	0.093	0.010	0.035	0.012
3	0.135	0.091	0.048	0.016
4	0.092	0.026	0.051	0.023
5	0.080	0.069	0.049	0.029
6	0.055	0.018	0.011	0.009
7	0.069	0.038	0.032	0.022
8	0.084	0.115	0.124	0.020
9	0.067	0.027	0.019	0.011
10	0.136	0.029	0.049	0.042
11	0.217	0.178	0.116	0.108
12	0.193	0.146	0.127	0.106
13	0.405	0.339	0.228	0.149
14	2.796	2.367	1.739	1.663
15	0.879	0.964	0.538	0.768
16	0.119	0.029	0.046	0.023

5. The coupled and coordinated relationship between digital economy and manufacturing transformation in Yangtze River Delta

5.1. Modeling the degree of coupling coordination

In this paper, the coupling coordination degree model is used to study the degree of synergistic development between the level of digital economy development and the transformation and upgrading of manufacturing industry [30]. The coupling degree model of multiple systems is as follows:

$$C_n = n\times\left[\left(u_1u_2\cdots u_n\right)\Big/\left(u_1+u_2+\cdots+u_n\right)^n\right]^{1/n} \tag{11}$$

Since there are only two subsystems in this paper, digital economy and manufacturing, the above model is downscaled to obtain a two-dimensional coupling function:

$$C_2 = 2\times\frac{\sqrt{u_1u_2}}{u_1+u_2} \tag{12}$$

Among them, C_2 is the coupling degree, which takes a value between 0 and 1. The larger the value, the higher the coupling degree of the two systems, and vice versa, the lower it is. u_1 and u_2 represent the regional digital economy development level and manufacturing transformation and upgrading index, respectively.

The above coupling degree model can identify the strength and weakness of the digital economy and the transformation and upgrading of the manufacturing industry, but it cannot reflect the overall synergistic effect of the two, therefore, the coupling degree of coordination must be introduced to indicate the degree of coupling and coordination of the two subsystems:

$$\begin{gathered} D=\sqrt{C\times T} \\ T=\alpha u_1+\beta u_2 \end{gathered} \tag{13}$$

Among them, D is the degree of coupling coordination, T is the comprehensive evaluation index of the synergistic development of the digital economy and manufacturing industry, and α and β are the contribution coefficients of the digital economic system and the manufacturing industry system, respectively. Due to the degree of mutual promotion between the digital economy and manufacturing industry, the development of digital economy is the result of the joint action of a variety of elements, including manufacturing industry, therefore, drawing on the relevant literature, α, β were assigned to 0.6 and 0.4, respectively, and the degree of coordination of the coupling was divided into 10 grades, each grade corresponds to a class of synergistic state, and the results of the division are shown in Table 6.

Table 6. Coupling coordination degree evaluation standard

Coordination interval	Coordination level	Coordination interval	Coordination level
0.000~0.099	Extreme disorder	0.500~0.599	Almost coordination
0.100~0.199	Severe disorder	0.600~0.699	Primary coordination
0.200~0.299	Moderate disorder	0.700~0.799	Intermediate coordination
0.300~0.399	Mild disorder	0.800~0.899	Good coordination
0.400~0.499	Almost disorder	0.900~1.000	High-quality coordination

5.2. Analysis of coupled coordination of digital economy and digital transformation of manufacturing industry

5.2.1. Analysis of Coupling and Coordination among Overall Systems in the YRD. According to the comprehensive index of digital economy and manufacturing digital transformation in the Yangtze River Delta calculated in Table 6, the coupling degree and coupling coordination degree of the two systems in the Yangtze River Delta region were measured by substituting them into the coupling coordination model during the period from 2011 to 2020, and the results of the measurement are shown in Table 7.

From the perspective of the overall coupling coordination degree of digital economy and manufacturing digital transformation in the Yangtze River Delta, the coupling degree and coupling coordination degree of the two systems show an obvious upward trend from 2011 to 2020, and from 2011 to 2020, the value of the coupling degree gradually rises from 0.769 to 0.999, which is getting closer and closer to the ideal state1, showing that the degree of association between the two is continuously increasing. The value of the coupling coordination degree of the digital economy and the digital transformation of the manufacturing industry in the Yangtze River Delta grows from 0.592 in 2011 to 0.879 in 2020, with an overall obvious upward trend, and the type of coupling coordination development shifts from barely coordinated to a stable and well-coordinated stage. Since 2011, the two systems of digital economy and digital transformation of manufacturing industry in the Yangtze River Delta have always maintained good coordination and interaction without any disorder. This indicates that the digital economy and the digital transformation of the manufacturing industry in the Yangtze River Delta region have formed a close and unified coupled coordinated development relationship.

Table 7. Coupling coordination of Yangtze river delta region

Year	Coupling degree	Coupling coordination degree	Coordination level
2011	0.769	0.592	Almost coordination
2012	0.862	0.675	Primary coordination
2013	0.902	0.733	Intermediate coordination
2014	0.973	0.826	Good coordination
2015	0.952	0.788	Intermediate coordination
2016	0.927	0.754	Intermediate coordination
2017	0.896	0.728	Intermediate coordination
2018	0.945	0.783	Intermediate coordination
2019	0.995	0.865	Good coordination
2020	0.999	0.879	Good coordination

5.2.2. Analysis of inter-system coupling and coordination among provinces and cities in Yangtze River Delta. Four provinces and cities in the Yangtze River Delta (Shanghai, Jiangsu, Zhejiang, and Anhui) were selected as research objects to analyze the coupling and coordination relationship between the digital economy system and the manufacturing system during the period of 2011-2020. The results of the coupling coordination between digital economy and digital transformation of manufacturing industry in each province and city in the Yangtze River Delta are shown in Table 8.

From the overall viewpoint of the coupling coordination degree, there is a trend of steady increase. Specifically for individual provinces and cities, between 2011 and 2020, Shanghai and Jiangsu are in the first and second place in terms of the mean value of coupling coordination degree, which are 0.883 and 0.826 respectively, both higher than 0.8. The digital economy and digital transformation of the manufacturing industry in Shanghai and Jiangsu have reached a good level of coordination, and their state of coupling coordination has always remained stable during the period of 2011 to 2020, and there has not been any Dissonance phenomenon. Zhejiang's digital economy and digital transformation of manufacturing industry are slightly inferior to Shanghai and Jiangsu, and the average value of the coupling degree of coordination in 10 years is 0.751, reaching the intermediate level of coordination. The coupling coordination degree of Zhejiang basically shows a steady improvement, developing from barely coordinated (0.578) in 2011 to well coordinated (0.882) in 2020. Anhui's coupling coordination degree of digital economy and digital transformation of manufacturing industry is at the bottom of the Yangtze River Delta region, with an average value of 0.589, and the grades at which the average level is located are at the barely coordinated stage. The coupling coordination degree of Anhui in the period of 2011-2020 shows an overall growth trend, from 0.400 in 2011 to 0.687 in 2020. Although the development of the coupling coordination level of Anhui has achieved some improvement, there is still a lot of room for growth in the future.

Overall, by 2020, Shanghai and Jiangsu have formed a well-coordinated development between the digital economy and manufacturing industry, and are in the first echelon of coupled and coordinated development. Zhejiang is the second echelon of coordinated development, coupled with the degree of coordination has changed from barely coordinated to well coordinated. Anhui is in the third echelon, and the coupling coordination degrees are all in the barely coordinated state. The coupling and coordination level of digital economy and manufacturing industry in the Yangtze River Delta provinces and cities has gradually improved, but still presents spatial differences within the region.

Table 8. Coupling coordination of 3 provinces and 1 municipality of Yangtze river delta region

Year	Shanghai	Jiangsu	Zhejiang	Anhui
2011	0.725	0.665	0.578	0.400
2012	0.782	0.723	0.653	0.542
2013	0.829	0.779	0.684	0.640
2014	0.942	0.874	0.784	0.704
2015	0.889	0.812	0.756	0.695
2016	0.895	0.825	0.759	0.537
2017	0.871	0.839	0.768	0.434
2018	0.913	0.875	0.789	0.555
2019	0.985	0.922	0.854	0.699
2020	0.998	0.949	0.882	0.687
Mean	0.883	0.826	0.751	0.589

6. Digital Transformation Path Suggestions for Manufacturing Industry in Yangtze River Delta

Based on the regional integration of the Yangtze River Delta and the current situation of the digital economy and digital transformation of the manufacturing industry in the Yangtze River Delta, the following enhancement paths are proposed.

1) The government level continues to increase investment in digital infrastructure and increase support for the digital transformation of manufacturing industries in terms of policy. Digital infrastructure is an important foundation for the digital transformation of the manufacturing industry, and policy support is an important guarantee. In recent years, the Yangtze River Delta has made significant progress in promoting the digital transformation of traditional manufacturing industries, and the government has given some support. With the wide application of new information technology, the Yangtze River Delta should promote the construction of new infrastructure in a coordinated manner to consolidate the technical foundation of the digital economy. For example, it should further improve the "5G+Industrial Internet" platform system and implement the "Digital Intelligent Manufacturing" project. In addition, the government should actively innovate policy support methods to reduce the risk of enterprise transformation, while creating a favorable environment for the development of digital economy for enterprises.

2) Continuously promote the digital industrialization and digitalization of manufacturing industries at the industrial level. The Yangtze River Delta should continue to promote the in-depth integration of digital technology and energy-consuming manufacturing industries, deepen the integration and development of information technology and traditional industries, focus on the core industries of the digital economy such as advanced computing, intelligent terminals, artificial intelligence, software, etc., and continue to push forward the depth and breadth of digitally empowered manufacturing industry chain, drive the digital transformation of manufacturing industry, realize the quality change, efficiency change, and power change of the manufacturing industry's development, and promote the The level of digitalization, networking and intelligence of the traditional manufacturing industry has been continuously upgraded.

3) Increase innovation investment at the enterprise level. Innovation is an important driving force to drive the digital transformation of the manufacturing industry and promote intelligent manufacturing, and talent is the key and core to strengthening the development of the digital economy. However, the Yangtze River Delta is currently uneven distribution of digital talents within the manufacturing industry, and the cluster effect is serious, so especially in the Yangtze River Delta, where the development of the digital economy is

insufficient, enterprises should vigorously introduce and pay attention to scientific and technological talents in order to digitally transform, improve the incentive system, and improve the digitalization technology of the internal personnel of manufacturing enterprises, so as to lay the foundation for the digital transformation and upgrading of enterprises.

At the same time, R&D investment is an important guarantee for realizing innovation. To accelerate the promotion of enterprise equipment and production line automation, digital transformation, etc., the investment in R & D funding is the first problem to be solved. Therefore, manufacturing enterprises should obtain the funds needed by enterprises through establishing contacts with financial institutions, so as to provide financial guarantee for realizing the digital transformation and upgrading of enterprises.

7. Strategies for bridging the "digital divide"

7.1. Strengthening regional information technology infrastructure

Improving the information infrastructure, developing information technology and establishing an information network system in the YRD region can make it easier and faster for the region to access and utilize information resources. Despite the fact that the YRD region is an economically and information-developed region, there is still a large degree of differentiation within the region. In order to completely equalize the information network, it is necessary to truly achieve access to and utilization of information resources in the less developed regions within the YRD. The construction of information infrastructure, as a core issue in the construction of informationization in the YRD, is also of great significance in bridging the digital divide in the YRD region. Therefore, a centralized leading ministry with authority and power in information technology management should be established to incorporate information technology infrastructure construction into the unified plan formulated by the government.

7.2. Optimizing the allocation of regional information resources

Realizing the common construction of information resources and resource sharing is the ultimate goal of bridging the digital divide in the YRD. Therefore, something must be done to optimize the allocation of regional information resources in order to alleviate the imbalance in the distribution of information resources in the YRD so as to further bridge that digital divide.

The allocation of information resources is actually to determine the distribution and flow of information resources in the YRD through a series of design and adjustment measures, so as to maximize the benefits of allocation with minimum allocation costs. There is an obvious imbalance in the current distribution of information resources in the Yangtze River Delta. Specifically reflected in the spatial distribution, the number of information resources in some small cities and counties in Jiangsu, Zhejiang and Anhui and the central cities (Shanghai, Nanjing, Hangzhou, Hefei) there is a large gap. In the composition of the content, underdevelopment of the edge of the small city information resources and the center of the city there is also a structural imbalance between the phenomenon. Therefore, bridging the regional digital divide at the county level in Inner Mongolia should mainly start from optimizing the allocation of regional information resources.

7.3. Improvement of information policies, regulations and standards construction

Bridging the digital divide in the Yangtze River Delta cannot be achieved without a healthy and appropriate information development environment. Information policies, regulations and standards, on the other hand, are the main factors affecting the information environment. Therefore, governments at all levels in the Yangtze River Delta should strive to create a healthy and favorable information environment for the development of informationization in the Yangtze River Delta region by formulating information policies conducive to the healthy development of regional informatization and continuously improving the policies, regulations and standards of the relevant information industry. On this basis, they should strengthen the construction of the information legal system and the security guarantee system, unify the standards of informatization construction, and guide and regulate the regional informatization construction. On this basis, it will strengthen the construction of information legal system and security guarantee system, unify information construction standards, guide and regulate the healthy and orderly development of regional informatization construction, and bridge the digital divide between the marginal regions and the central cities from the institutional level.

7.4. Strengthening the development of regional informatization talents

The issue of talents has become an important factor constraining the core competitiveness of countries or regions in the era of informationization development. Market competition in the Yangtze River Delta is also reflected in the competition for talents, so the current spatial concentration of talent resources is a major cause of the digital divide in the Yangtze River Delta region. The central cities siphon off talents from the surrounding small cities due to their economic advantages, and there is a serious loss of talents from underdeveloped areas, which further exacerbates the "digital divide" between the peripheral areas and the central cities. To bridge the digital divide in the Yangtze River Delta region, not only should there be informationization infrastructure, but also information talents. Therefore, it is important to establish a correct view of human resources, highlight the strategic position of education in the construction of informationization in the Yangtze River Delta, guarantee the manpower support for the construction of regional informationization, and strengthen the development of regional informationization talents. Through the implementation of the information talent construction project, excellent talents will be attracted to underdeveloped regions and contribute to the informatization construction of the Yangtze River Delta.

8. Conclusion

In this paper, we sort out the mechanism and effect of digital economy and digital transformation of manufacturing industry, measure the level of digital economy development and digital transformation of manufacturing industry in the Yangtze River Delta (YRD) and analyze them respectively, explore the coupling and coordination relationship between digital economy and digital transformation of manufacturing industry in the YRD through the coupling coordination model, and put forward the corresponding paths of digital transformation of manufacturing industry and strategy suggestions for bridging the "digital divide" in the region. "Suggestions for bridging the digital divide in the region.
1) The digital economy of the Yangtze River Delta has been rising steadily in general, but there are significant internal differences. From 2011 to 2020, the level of digital economy development increased by 10.76%. 10 years, Jiangsu's digital economy development has always been ahead of Zhejiang and Shanghai to maintain stable development, the average value of the development of the digital economy in these three provinces and cities is more than 0.3, while Anhui is only 0.185. There is an obvious "digital divide" between Anhui and Jiangsu, Zhejiang and Shanghai.
2) Shanghai, Jiangsu, Anhui three provinces and cities of the manufacturing industry digital transformation steady growth, while Zhejiang has a downward trend. Shanghai's manufacturing digitalization water average is 0.750, much higher than the other three provinces. Jiangsu's manufacturing digitalization level is higher than that of Zhejiang and Anhui, and is constantly narrowing the gap with Shanghai. In contrast, the digital transformation of manufacturing industry in Zhejiang and Anhui is slightly behind.
3) The coupling coordination degree of digital economy and manufacturing digital transformation in the Yangtze River Delta has increased from 0.592 to 0.879, and the type of coupling coordination development has shifted from barely coordinated to well-coordinated. During the 10-year period, the average values of coupling coordination degree of Shanghai and Jiangsu are 0.883 and 0.826, respectively, which have already reached the level of well-coordinated. In Zhejiang, the mean value of the coupling coordination degree is 0.751 in 10 years, which is the intermediate coordination level. The mean value of coupling coordination

degree in Anhui is 0.589, which is barely coordinated stage. Although the coupling coordination level of Anhui has improved, it is still the lowest level within the Yangtze River Delta.

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