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Theory article

The synergy degree measurement and transformation path of China's traditional manufacturing industry enabled by digital economy

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Abstract: With the development of science and technology, digital economy has penetrated into traditional manufacturing industry extensively and deeply, which has motivated the progress of the digital transformation for traditional manufacturing industry. Through comparative analysis of theoretical mechanism of synergetic development, this paper researches the order degree model and the synergy degree model based on the social shaping of technology theory to evaluate the synergetic degree of the digital transformation for China's traditional manufacturing industry. An empirical study is presented based on the proposed models and the spatial analysis method by using the statistical data of Yangtze River Delta in China from 2014 to 2019. The results were consistent with the actual situation and indicated that the model fully reflect the dynamic interaction between systems，which is a sound basis for scientific judgment and effective decision-making when seeking to the digital transformation of traditional manufacturing industry.

Keywords: traditional manufacturing industry; digital economy; digital transformation; the social shaping of technology theory; synergetic theory; entropy method

1. Introduction

With the intensification of a new round of industrial competition in the global economy and the strategy of "Made in China 2025", the digital economy has been integrated into all areas of society and become the new driving force for transformation of traditional manufacturing industry [1]. The digital economy can optimize the way of resource allocation, and further stimulate the coupling effect and dual-wheel driving role of the market and the government in resource allocation. The digital transformation of traditional manufacturing industry, as complex systems, the involves many diverse factors. Digital transformation is not just digitization, but digitization plays a significant role in it, which will create some demand for the digital industry and the manufacturing organization's IT department. In the process of digital transformation, China's traditional manufacturing enterprises need to change the original value creation mode, seek cross-boundary partners from a larger value network, and transform from focusing on their own interests to focusing on the value maximization of the entire network [2], which can overcome the double resistances that the manufacturing reflux in the developed countries and the rapid development of emerging economies manufacturing in the world [3]. If the efforts from digital industry are not adapted to the key structure of manufacturing industry, digital technology is difficult to play its important role in manufacturing industry transformation and upgrading, which leads to the "IT paradox" [4]. The coordination between regional economic, social development and digital industry are the key factor for the digital transformation of traditional manufacturing industry. This paper research how to coordinate various factors based on the synergistic theoretical framework and proposed the upgrading mechanism of China's traditional manufacturing industry driven by digital economy.

In order to effectively measure the digital transformation situation, this paper proposes the synergetic theory and the entropy weighting method to study and measure the order degree and synergy degree of China's traditional manufacturing digitalization transformation system, which the synergy model is constructed from the perspectives of technology subsystem, industrial subsystem and economic subsystem based on the synergistic theory. The main research contribution of this paper are as follows. First, an order parameter system of the digital transformation synergy system is developed based on the social shaping of technology theory, after that a quantitative analysis model is established based synergetic theory. The subsystem order degree and composite system synergy degree are analyzed to study the digital transformation efficiency of China's traditional manufacturing industry within the system according to the statistical data of Yangtze River Delta in China from 2013 to 2019.

2. Literature review

The digital economy refers to a broad range of economic activities that use digitized information and knowledge as key factors of production. The internet, cloud computing, big data, Fintech, and other new digital technologies are used to collect, store, analyze, and share information digitally and transform social interactions. Digital transformation is an important approach to the digital economy society. The digital transformation of traditional manufacturing industry creates benefits and efficiencies as digital technologies drive innovation and fuel job opportunities and economic growth. Many studies have focused on digitized process with the aim of finding solutions to deep integration of IT technology and society so as to provide new development paths, which can be summarized from three perspectives:

1) Analyses of the changes brought about by the digital economy. Bojnec, Ferto investigated the impact of the number of Internet users on the bilateral manufacturing export growth among OECD countries based on the gravity model using panel and cross-section regressions, which the empirical results suggest that the Internet stimulates manufacturing export [5]. Huang discovered several bottleneck problems of China's manufacturing from a big towards a power in the world, and put forward four development directions such as the re-factoring the basic producing ability of IE, cultivating the lean management innovation power, optimizing the industrial structure and promoting

its value chain upgrade [6]. Gaputo, et al. proposed that Industry 4.0. connected everything and Internet of Things technology have become important driving forces for the digital transformation of manufacturing industry [7]. Zeng, et al. proposed that digital transformation is a process that starts from the infrastructure of digital technology, digital products and digital platform, and then leads to changes in individual, organizational, industrial and other levels [8].

2) Construction of digital transformation measurement indices. Wang analyzed the active influence of Internet plus on Chinese enterprise productivity based on the survey data of the world bank [9]. The empirical results show that actively promote manufacturing Internet plus should take different measures and modes according to the different industries and regions. The digital transformation of traditional manufacturing industry, as a dynamic, open and complex system included political, social organizational, cultural factors and so on. It is, rather, a social product defined by the external conditions that create and use it. However, there are few researches evaluate the digital transformation of traditional manufacturing enterprises from the social and economic factors as well as technical considerations. In contrast to technical determinism, the social shaping of technology (SST) theory is a new perspective in which technology is not viewed as developing by its own inherent logic [10]. The SST theory has developed as a response to techno-economically rational and linear conceptions of technology development and its consequences, which examines the content of technology and the processes involved in innovation [11]. The SST theory emphasizes the mutual connections between technology and society and avoids the unilateralism and extremity in the technological determinism and the social determinism, and so it is more close to the external instance between technology and society [12].

3) Digital transformation development measures. Yan used the benevolent DEA cross efficiency model to evaluate the integration efficiency between high-tech industry and traditional industry of urban agglomeration during the period of 2001–2013， which put forward some policies to promote the integration development of the middle reaches of Yangtze River [13]. Tan employed the GMM model to analyze the impact informatization upgrading mechanism of manufacturing industry based on the panel data from 283 cities of China during 2004–2014 year, the empirical results show that urban informatization will promote upgrading of the manufacturing industry [14]. Haken applied the synergy theory to study the self-organization of unstable open system by its own coordination mechanism under the external energy and material exchange [15]. Xie conducted a multi-case study to explore strategic risk identification and control mechanisms of Internet-oriented transformation for the traditional enterprises based on the synergistic degree model [16].

This paper investigates the industrial digital transformation mechanism based on SST, expounding the digital economy influence on traditional manufacturing industry from its essence, characteristics, functions, values to development. Combined with the synergetic theory and entropy weighted method, the synergy degree model was used to study the order degree of all subsystems and the synergetic degree model of the digital transformation for traditional manufacturing industry from the aspects of technology, industry and economy subsystems. in order to reveal the digital transformation mechanism of China’s traditional manufacturing industry.

3. The order parameter system of digital transformation based on SST

Digital transformation is the innovation process form the multiple levels of the individual, organization and industry supported by the infrastructure of digital technology, digital product and digital platform, which digital transformation has impacted the development path, organizational model and national strategy [17]. The collaborative mechanism of the system is analyzed under the view of order parameter. The order degree model defines the order parameter and investigates the internal coordination of the affecting subsystems, which the co-evolution state of integrated system is controlled by the order parameter [18].

Table1. The order parameter system for digital transformation of manufacturing industry.

System	Subsystem	Oder Parameters of Each Subsystem	Effect
Digital Transformation of The Traditional Manufacturing Industry	X_1 (Technology Subsystem)	X_{11} (The number of Internet Connected Devices) (ten thousand port)	+
		X_{12} (The number of invention patents) (ten thousand item)	+
		X_{13} (R&D talent training) (ten thousand people)	+
		X_{14} (R&D funds) (ten thousand yuan)	+
		X_{15} (The number of R&D project) (ten thousand Item)	+
		X_{16} (Internet broadband subscribers) (ten thousand people)	+
		X_{17} (The number of enterprise websites) (ten thousand site)	+
	X_2 (Industry Subsystem)	X_{21} (The employment number of manufacturing industry) (ten thousand people)	+
		X_{22} (Total wages of manufacturing employees) (Hundred million yuan)	+
		X_{23} (The Employment Number of IT service industry) (ten thousand people)	+
		X_{24} (Total salary of IT employees) (Hundred million yuan)	+
		X_{25} (The number of NPI project) (ten thousand item)	+
		X_{26} (The software business income) (ten thousand yuan)	+
		X_{27} (New product development funds of manufacturing industry) (ten thousand yuan)	+
	X_3 (Economy Subsystem)	X_{31} (Total selling expenses in manufacturing industry) (Hundred million yuan)	+
		X_{32} (Local financial expenditure in manufacturing industry) (Hundred million yuan)	+
		X_{33} (Local financial expenditure in science and technology) (1Hundred million yuan)	+
		X_{34} (Trading volume of technology market) (Hundred million yuan)	+
		X_{35} (The current assets of manufacturing industry) (Hundred million yuan)	+
		X_{36} (The total profit of manufacturing industry) (Hundred million yuan)	+
		X_{37} (High-tech products revenue) (Hundred million yuan)	+

*Note: "+"means that the index has a positive effect on the system.

The construction of an effective synergistic measurement index system is essential to accurately assess the synergy degree, which means that appropriate order parameters need to be identified and selected for each subsystem. According to synergy theory, variables that determine the system are called order parameters. The order parameter is generated by each single subsystem, which in turn dominates the behavior of each subsystem, reflecting the evolutionary trend of subsystems and composite system. The relationship diagram of digital transformation for traditional manufacturing industry based on the SST are constructed and shown in Figure1.

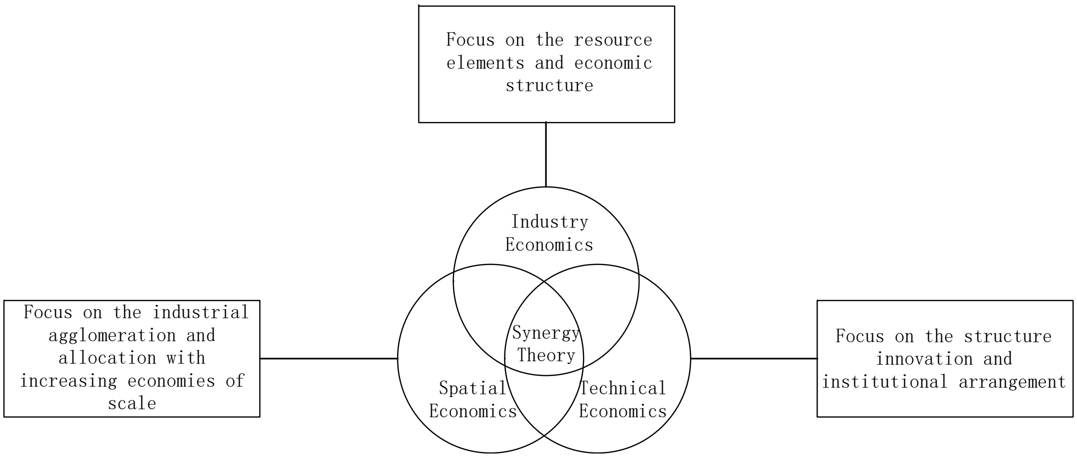

Figure 1. The digital-transformation of manufacturing industry based on SST.

Based on the inter-relationship analysis in Figure 1 and the "China Statistical Yearbook" from the national bureau of statistics over the years, the proper order parameters were selected and the order parameter system for the manufacturing industry digital transformation from the collaborative subsystem of technology, economy and manufacturing industry is constructed and shown in Table 1.

4. Synergetic degree measurement model by entropy weighting method

The detailed approaches and Eqs (1)–(7) about the synergy degree measurement model by entropy weighting method for the digital transformation of traditional manufacturing industry are as following:

1) The order degree of order parameter X_{ij}

The collaborative development of digital economy enabling traditional manufacturing industry is regarded as the composite system S composed by multiple collaborative subsystems, $S = (S_1, S_2, \ldots, S_k)$.

The composite system of technology, industry and economy subsystem is set to be $S = \{S_1, S_2, S_3\}$, where S_1 is the technology subsystem, S_2 is the industry subsystem, and S_3 is the economy subsystem. The order parameter X_{ij} $(X_{i1}, X_{i2}, \ldots, X_{im})$ of the subsystem represents the state variable of the order parameter in the subsystem. where $m \geq 1$, $X_{min} \leq X_{ij} \leq X_{max}$, $j = 1, 2, \ldots, m$. Let X_{max} and X_{min} be the upper and lower limits of the order parameter component X_{ij} at the system stability critical point respectively.

In the order parameters $\{X_{i1}, X_{i2}, \ldots, X_{im}\}$ as positive index, the larger value of order parameter indicates, the greater the effect of X_{ij} on the ordering degree of the subsystem. The other order parameters $\{X_{i(m+1)}, \ldots, X_{in}\}$as negative index, the larger value indicates the lower the effect of X_{ij} on the ordering degree of the subsystem. The Eq (1) of order degree of the order parameter X_{ij} in the subsystem X_i is expressed as:

$$U_i(X_{ij}) = \begin{cases} \dfrac{X_{ij}-X_{min}}{X_{max}-X_{min}} & j = 1,2,\ldots,m \quad \text{where } X_{ij} \text{ is a positive indicator} \\ \dfrac{X_{max}-X_{ij}}{X_{max}-X_{min}} & j = m+1, m+2, \ldots\ldots, n \quad \text{where Xij is a negative indicator} \end{cases} \tag{1}$$

From Eq (1) represent the effect of order parameter on the subsystem, $0 \le U_i(X_{ij}) \le 1$, which the larger value of the $U_i(X_{ij})$ reflect that X_{ij} has greater influence for the X_i subsystem.

2) The synergy degree of the S_i subsystem

This paper to calculates the order degree of collaborative system X_i for digital economy enabling traditional manufacturing industry by linear weighted sum method. The order degree of subsystem X_i can be expressed by the state of order parameters X_{ij}, which can be obtained by the Eq (2).

$$U_i(X_i) = \sum_{i=1}^{n} \lambda_j U_i(X_{ij}) \tag{2}$$

where λj is the weight of Xij in the subsystem and reflects the importance of the component Xij in maintaining the ordering degree of system, $\lambda_j \ge 0,\ \sum_{i=1}^{n} \lambda_j = 1$.

3) The synergy degree of the composite system

In order to calculate the order model of coordinated system for the digital industry enabled traditional manufacturing industry, this paper set the order parameter of each subsystem is $U_i^0(X_i)$ (i = 1, 2, 3) at the assumed starting time t_0 time, $U_1^0(X_1)$ represents the ordering degree of the technology subsystem, $U_2^0(X_2)$ represents the ordering degree of the industry subsystem, and $U_3^0(X_3)$ represents the ordering degree of the economy subsystem.. After development t_1 time, the order parameter of each subsystem becomes $U_i^1(X_i)$ (i = 1, 2, 3). The definition of the order parameter for the composite system from the $t_0 \sim t_1$ period is as following:

$$C = \theta \times \sqrt[m]{\prod_{i=1}^{m} |\,[U_i^1(X_i) - U_i^0(X_i)]\,|} \tag{3}$$

where

$$\theta = \begin{cases} 1 & U_i^1(X_i) - U_i^0(X_i) > 0 \\ -1 & others \end{cases} \tag{4}$$

From Eqs (3) and (4), The synergy degree of the composite system C∈[-1,1] is actually a state where two subsystems forming the composite system can cooperate and develop. The greater the C, the greater the synergy effect of the composite system, and vice versa. Therefore, the synergy degree of system within C∈[-1,0] can be inferred at the non-cooperative state. If $U_i^1(X_i) - U_i^0(X_i) > 0$, then the complex system of traditional manufacturing and digital industry evolves synergistically, else the subsystem does not develop at the coordinative direction.

4) Determination of indicator weights by entropy weighting method

Step 1: Assuming that the proportion of the i-th plan under the index j is

$$c_{ij} = \frac{U_i(X_{ij})}{\sum_{i=1}^{n} U_i(X_{ij})} \tag{5}$$

Considering that the order parameters has positive and negative directions, and the entropy method handles the positive and negative indexes in the same way as the Eq (1),so the order degree is used for calculation c_{ij} in Eq (5). Calculating the entropy value of the j-th index by $H_j = -\frac{1}{\ln n}\sum_{i=1}^{n} c_{ij} \ln c_{ij}$, if $c_{ij} = 0$, then $c_{ij} * \ln c_{ij} = 0$.

Step 2: For the j-th index, the greater the difference between the indexes, the greater the effect on the solution evaluation, and the corresponding entropy value is naturally low. Calculate the utility value of index j-th:

$$d_j = 1 - H_j \tag{6}$$

Step 3: Calculating the weight of index j-th by

$$\lambda_j = \frac{d_j}{\sum_j^n d_j} \tag{7}$$

where λ_j is the weight of j-th index.

To sum up the detailed calculation steps, the synergy degree measurement model of digital economy enabling traditional manufacturing industry is shown in Figure 2.

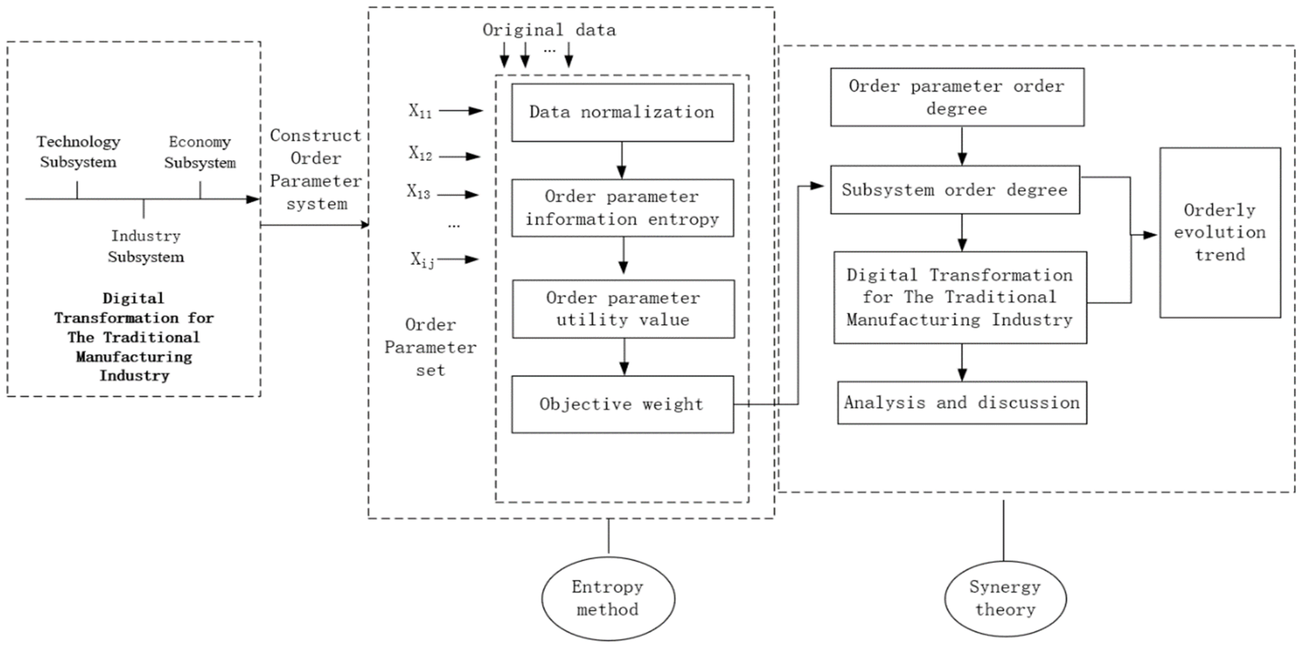

Figure 2. The synergy degree measurement model of digital transformation.

5. The empirical case analysis

According to the established synergy degree model and order parameter system, this paper research the synergy development degree of digital Transformation for traditional manufacturing industry from the technology, industry and economy subsystem in the Yangtze River Delta of China. The order parameter normalization and the entropy value were calculated by using Stata software to find order parameters information quantity and weights for the digital transformation system.

5.1. Data source and pre-processing

This paper makes the empirical study based on the statistical data, processed by Z-score standardization, from the statistical yearbook of Jiangsu Province, science and technology yearbook of Jiangsu Province, China statistical yearbook on science and technology, and the other official websites. The standardized data (2013–2019) about the technology, manufacturing industry and economy collaborative subsystem of the Jiangsu Province have shown at Tables 2–4.

Table 2. The normalized data of technology subsystem.

Year	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}
2013	-0.2309	0.8963	0.9337	0.6340	0.3308	-0.1871	1.9497
2014	-0.0065	0.4789	1.1146	0.8789	0.4960	-0.0903	1.3612
2015	0.6023	1.0085	1.2300	1.1112	0.4457	0.7760	1.3990
2016	1.1018	0.8056	1.2962	1.3813	0.7270	1.1328	1.3888
2017	1.5377	0.7651	1.3186	1.6965	1.0031	1.5758	1.2836
2018	1.8436	1.6060	1.3190	2.0373	1.1910	1.8346	1.2207
2019	1.9035	1.6840	1.6495	2.3620	2.0123	2.0807	1.2417

Table 3. The normalized data of manufacturing industry subsystem.

Year	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	X_{26}	X_{27}
2013	1.5549	0.8937	0.8959	-0.1982	0.4846	0.4184	0.9090
2014	1.8925	1.3697	0.7435	-0.1464	0.6225	0.7582	1.0520
2015	1.7910	1.5547	0.6724	0.0158	0.4445	1.0621	0.9725
2016	1.6261	1.5661	0.5709	0.1064	0.6826	1.4388	1.2675
2017	1.4825	1.6667	0.6318	0.2822	0.8788	1.7020	1.6288
2018	1.2114	1.7348	1.0482	0.5179	1.2720	1.6667	2.1035
2019	0.9515	1.7171	1.0888	0.6131	1.7911	1.9898	2.4523

Table 4. The normalized data of economy subsystem.

Year	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}	X_{36}	X_{37}
2013	0.9267	0.1447	-0.1433	-0.0711	0.9413	1.3606	0.6380
2014	1.2945	0.2485	0.0726	-0.0309	1.0797	1.6033	0.7039
2015	1.6087	0.7219	0.4677	0.0455	1.1755	1.8289	0.6797
2016	1.8801	0.6589	0.5475	0.2065	1.3987	2.1467	0.9666
2017	1.8899	0.1542	0.9614	0.5730	1.6030	1.9598	1.4825
2018	1.7397	0.0154	1.6599	1.1198	1.8218	1.4009	1.3902
2019	1.6374	-0.0793	2.2301	2.3520	1.9625	0.8146	2.4681

5.2. The order degree calculation model

In order to obtain synergy degree of each subsystems, the information entropy method is applied to calculate the order parameter weight of every indicators. Then, the first step is to calculate the order degree of order parameters in each subsystems in Jiangsu Province based on the normalized data.

According to the order degree of the above order parameters, the weight matrix of order parameters of technology subsystem is $\{X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17}\} = \{0.1148, 0.1510, 0.1765, 0.1197, 0.1671, 0.1316, 0.1392\}$， the weight matrix of order parameters of industry subsystem is $\{X_{21}, X_{22}, X_{23}, X_{24}, X_{25}, X_{26}, X_{27}\} = \{0.1943, 0.1171, 0.0958, 0.1254, 0.1871, 0.1303, 0.1501\}$, the weight matrix of order parameters of economy subsystem is $\{X_{31}, X_{32}, X_{33}, X_{34}, X_{35}, X_{36}, X_{37}\} = \{0.1697, 0.1421, 0.0696, 0.1465, 0.1305, 0.2158, 0.1258\}$, The calculation results are shown in Table 5.

Table 5. The order degree about order paramters of each subsystems.

Subsystem	Order Parameter	Year							Weights
		2013	2014	2015	2016	2017	2018	2019	
Technology subsystem	X_{11} (The number of Internet Connected Devices)	0.3165	0.3884	0.5834	0.7433	0.8829	0.9808	1	0.1148
	X_{12} (The number of invention patents)	0.719	0.5701	0.759	0.6866	0.6722	0.9722	1	0.1510
	X_{13} (R&D talent training)	0.7324	0.8001	0.8432	0.8679	0.8763	0.8764	1	0.1765
	X_{14} (R&D funds)	0.5065	0.5764	0.6427	0.7199	0.8099	0.9073	1	0.1197
	X_{15} (The number of R&D project)	0.4295	0.4819	0.4659	0.5551	0.6427	0.7023	0.9628	0.1671
	X_{16} (Internet broadband subscribers)	0.2993	0.3292	0.5969	0.7071	0.844	0.924	1	0.1316
	X_{17} (The number of enterprise websites)	1	0.8079	0.8203	0.817	0.7826	0.7621	0.7689	0.1392
Manufacturing industry subsystem	X_{21} (The employment number of manufacturing industry)	0.8845	1	0.9653	0.9088	0.8597	0.7669	0.678	0.1943
	X_{22} (Total wages of manufacturing employees)	0.7264	0.8812	0.9414	0.9451	0.9778	1	0.9942	0.1171
	X_{23} (The Employment Number of IT service industry)	0.6826	0.6404	0.6208	0.5927	0.6096	0.7247	0.736	0.0958
	X_{24} (Total salary of IT employees) (Hundred million yuan)	0.2708	0.2838	0.3243	0.3469	0.3909	0.4497	0.4735	0.1254
	X_{25} (The number of NPI project)	0.4596	0.5009	0.4476	0.5189	0.5777	0.6954	0.8509	0.1871
	X_{26} (The software business income)	0.5246	0.6274	0.7193	0.8333	0.9129	0.9023	1	0.1303
	X_{27} (New product development funds of manufacturing industry)	0.5658	0.606	0.5837	0.6667	0.7683	0.9019	1	0.1501

Continued on next page

Subsystem	Order Parameter	Year							Weights
		2013	2014	2015	2016	2017	2018	2019	
Economy subsystem	X_{31} (Total selling expenses in manufacturing industry)	0.676	0.7998	0.9054	0.9967	1	0.9495	0.9151	0.1697
	X_{32} (Local financial expenditure in manufacturing industry)	0.3754	0.4035	0.5318	0.5147	0.3779	0.3403	0.3146	0.1421
	X_{33} (Local financial expenditure in science and technology)	0.4172	0.4703	0.5673	0.5869	0.6885	0.86	1	0.0696
	X_{34} (Trading volume of technology market)	0.3209	0.3321	0.3535	0.3987	0.5014	0.6546	1	0.1465
	X_{35} (The current assets of manufacturing industry)	0.6862	0.7287	0.7582	0.8267	0.8895	0.9567	1	0.1305
	X_{36} (The total profit of manufacturing industry)	0.7457	0.8242	0.8972	1	0.9395	0.7587	0.5691	0.2158
	X_{37} (High-tech products revenue)	0.5273	0.5444	0.5381	0.6122	0.7455	0.7216	1	0.1258

5.3. Results analysis of order degree and synergy degree

Equations (3)–(7) can calculate the synergy degree of each subsystem from the technology, economy and manufacturing industry subsystem by input the weight and order degree of order parameters. The synergy degree of composed subsystems in the Yangtze River Delta are shown at Table 6 and Figure 3.

The order degree of these three economic circles in the Yangtze River Delta region all falls within [0,1], which has lower order degree at 2013 year and higher order degree at 2019 year. In the technology subsystem, the order degree of Jiangsu is the average reached 0.74, which has the overall upward trend from 0.5853 in 2013 up to 0.9616 in 2019. For Anhui Province, its order degree is 0.09. The order degree of Shanghai and Zhejiang Province is relatively high, with no large fluctuations. The order degree of the industrial systems of Yangtze River Delta showed an overall growth trend from 2013 to 2019, and the development process of Jiangsu and Zhejiang Province is slightly undulating and stable. The order degree of economy subsystems of Jiangsu and Zhejiang Province have the overall upward trend and undulating process from 2013–2019. In the economy subsystem, the order degree of Shanghai is only from 0.2282 up to 0.4916, Jiangsu from 0.5609 up to 0.7952, Zhejiang from 0.1826 to 0.4855, Anhui from 0.032 up to 0.123 from 2013 to 2019 year.

Table 6. Synergy degree of each subsystems in Yangtze River Delta.

Province	Year	Technology Subsystem	Industry Subsystem	Economy Subsystem
Shanghai	2013	0.0338	0.2031	0.2282
	2014	0.0407	0.2379	0.2608
	2015	0.0442	0.2387	0.2972
	2016	0.0534	0.2595	0.3353
	2017	0.0670	0.2957	0.3719
	2018	0.0810	0.3443	0.4304
	2019	0.1041	0.3990	0.4916
JiangSu	2013	0.5853	0.5955	0.5609
	2014	0.5773	0.6608	0.6159
	2015	0.6780	0.6629	0.6807
	2016	0.7280	0.6932	0.7422
	2017	0.7820	0.7312	0.7574
	2018	0.8678	0.7749	0.7446
	2019	0.9616	0.8175	0.7952
ZheJiang	2013	0.3764	0.2950	0.1826
	2014	0.4004	0.3218	0.2127
	2015	0.5150	0.3368	0.2686
	2016	0.5380	0.3734	0.2812
	2017	0.5908	0.4371	0.3159
	2018	0.6946	0.4847	0.3755
	2019	0.7779	0.5872	0.4855
AnHui	2013	0.0106	0.0060	0.0193
	2014	0.0245	0.0188	0.0320
	2015	0.0707	0.0203	0.0508
	2016	0.0970	0.0340	0.0804
	2017	0.1259	0.0469	0.0826
	2018	0.1577	0.0781	0.0994
	2019	0.1981	0.0831	0.1230

The traditional manufacturing industry of Yangtze River Delta has the technology and the regional economy advantages, which the penetration of digital R&D servers in government, academia, and industry promote from 48.8 to 73%, the digital control rate in key processes of manufacturing industry increased from 24.6 to 52.1% in the period of 2013 to 2019 year. Shanghai has the capacity of undertake the international industry transfer and become the center of Asia-Pacific regional headquarters of multinational corporations in the manufacturing industry.

Table7. The synergy degree of composed subsystems in Yangtze River Delta.

Province	Year	C_{123}	C_{12}	C_{13}	C_{23}
ShangHai	2014	0.0199	0.0155	0.0150	0.0337
	2015	0.0047	0.0017	0.0113	0.0054
	2016	0.0194	0.0138	0.0187	0.0282
	2017	0.0262	0.0222	0.0223	0.0364
	2018	0.0341	0.0261	0.0286	0.0533
	2019	0.0426	0.0355	0.0376	0.0579
JiangSu	2014	-0.0306	-0.0229	-0.0210	0.0599
	2015	0.0239	0.0145	0.0808	0.0117
	2016	0.0453	0.0389	0.0555	0.0432
	2017	0.0315	0.0453	0.0286	0.0240
	2018	-0.0363	0.0612	-0.0331	-0.0237
	2019	0.0587	0.0632	0.0689	0.0464
ZheJiang	2014	0.0269	0.0254	0.0269	0.0284
	2015	0.0458	0.0415	0.0800	0.0290
	2016	0.0220	0.0290	0.0170	0.0215
	2017	0.0489	0.0580	0.0428	0.0470
	2018	0.0665	0.0703	0.0787	0.0533
	2019	0.0979	0.0924	0.0957	0.1062
An Hui	2014	0.0131	0.0133	0.0133	0.0127
	2015	0.0109	0.0083	0.0295	0.0053
	2016	0.0220	0.0190	0.0279	0.0201
	2017	0.0094	0.0193	0.0080	0.0053
	2018	0.0255	0.0315	0.0231	0.0229
	2019	0.0168	0.0142	0.0309	0.0109

*Note: C_{12} is technology and industry composite system; C_{13} is technology and economy composite system; C_{23} is industry and economy composite system; C_{123} is technology, industry and economy composite system.

Considering the statistical data from 2014 to 2019, we build the collaborative analysis system to estimate the relationship between the economic growth with the regional industrial development in the Yangtze River Delta of China. The synergy degree of the manufacturing industry development can be calculated through the panel data, and the results are shown in Table 7.

From Table 7, the synergy coefficient of the industrial-digital ecosystem in the Yangtze River Delta has mostly positive values within [-0.1, 0.1]. The integration of traditional manufacturing and digital industries in Jiangsu Province and Zhejiang Province has the higher quality development, which show steady growth the overall rising from 2014 to 2019. Specifically, Anhui Province reached a negative value in 2015 and 2017, but in the following year, negative positive and substantial growth, indicating that Anhui Province has great development vitality. The spatial analysis results by using the statistical data as Figure 4 show that: The coordination degrees of traditional manufacturing industry integrated with digital industry in the Yangtze River Delta of China are increasing, but the synergy effect of social subsystem and technology subsystem aren't obvious due to the industry isomorphic, lack of digital literacy or digital-socioeconomic barriers.

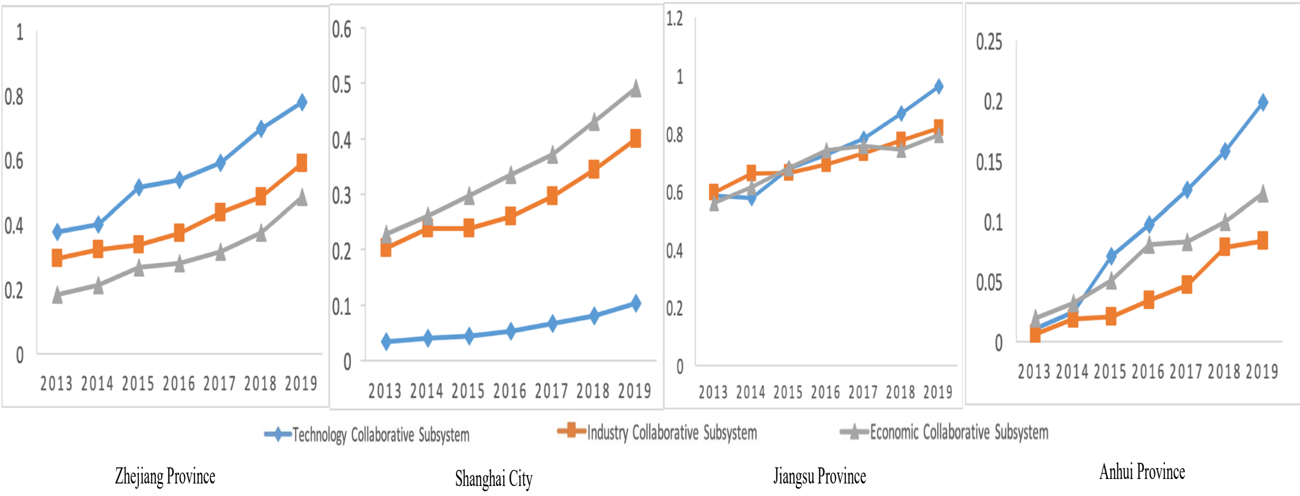

Figure 3. The Synergy Degree Trend of the Yangtze River Delta.

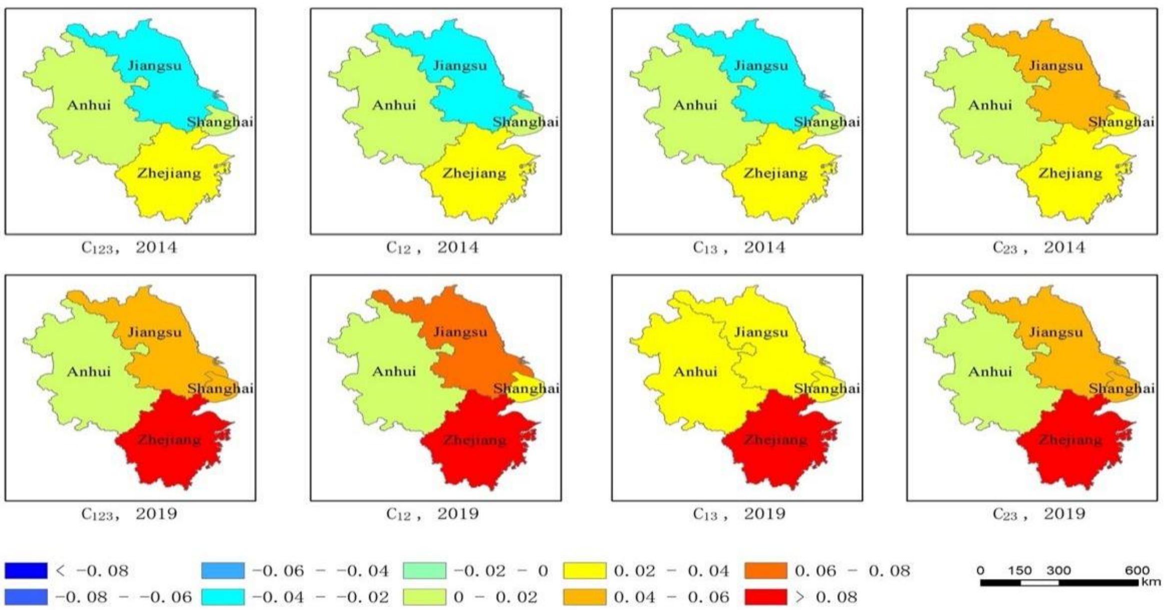

Figure 4. The spatial distribution of synergy degree in the Yangtze River Delta**.**

Such obstacles have diminished dramatically with IoT services and EI 4.0 solutions, which has effectively increased the value-added value of China's traditional manufacturing industry. With the application of AI and the Industrial Internet, it realizes the data sharing in productivity and production mode. Industrial Internet applications grant free access to enterprise data, which has redefined the life cycle of manufactured products. Through data sharing, the status monitoring, efficiency analysis, remote diagnosis and history tracing of the production site can be realized. In the age of digital economy, it is urgent for manufacturing enterprises to develop industrial internet and promote intelligent manufacturing, which they can bridge the physical-digital divide with the platform of Internet of things and make the China's manufacturing industry from big to power.

6. Conclusions and countermeasures

Through analysis of synergetic development theoretical mechanism, this paper researches the order degree model and the synergy degree model based on the social shaping of technology theory to evaluate the synergetic degree of digital industry and traditional manufacturing industry of China. Combined with the Entropy weighted method, the synergy degree model was used to study the order degree of all subsystems and the synergetic degree of the composite system. From this study, the digital transformation mechanisms of China's traditional manufacturing industry are mainly reflected in the following aspects:

1) China's government should lunch many new policies under the digital economy to reconstruct the value chain of traditional manufacturing industry, such as increase innovation investment, improve the transformation efficiency of the scientific and technological achievements and. The government can alleviate the innovation burden of enterprises by means of gradient tax cuts and fee reductions in order to encourage regional leading enterprises build a cross-border industrial chain system by supporting the adoption and enforcement of relevant laws and regulations.

2) With the China's super-large market, the traditional manufacturing industry should treat the digital resources as its primary factor of production, and digital technologies of Industrial Internet Consortium (IIC), cloud computing and artificial intelligence as its main driving force. The traditional manufacturing enterprises should build a digital economy industrial ecosystem and support the breakthrough of new frontier technologies by the mode of industry-institution cooperation with the universities, scientific research units and other important market players in a rational and orderly manner in order to reducing the digital divides.

3) China's manufacturing industry should deepen the integration with digital economy and solve the industries' "pain points" by digital infrastructure construction, digital market development and human capital cultivation. IT enterprises have rich digital experience and technical advantages of shorten the time cost in talent training and scientific innovation for traditional manufacturing enterprises. At the same time, the traditional manufacturing industry can apply digital technology of Industry 4.0 to improve the quality of product and increase the competitiveness in the market.

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Conflict of interest

The authors declare no conflict of interest.

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