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Measurement of the Development Level of Regional Digital Economy

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***Abstract* – Based on four dimensions of digital infrastructure, digital industrialization, industrial digitization, and digital innovation capability, this paper constructs an evaluation index system with 14 secondary indicators to measure the development level of regional digital economy. Using the entropy weight method, this paper scientifically measures the digital economy development level of 16 regions in Shandong Province from 2018 to 2022. According to the measurement results, the paper evaluates the digital economy development level of Shandong Province from both vertical and horizontal levels.**

***Keywords* – Digital Economy, Evaluation Index System, Measurement of Development Level, Entropy Weight Method.**

I. INTRODUCTION

The digital economy takes digital knowledge and information as key production factors, digital technology as the core driving force, modern information networks as important carriers, achieves deep integration of digital technology and the real economy through information and communication technology and artificial intelligence, greatly improves economic efficiency and optimizes economic structure, continuously improves the level of digitization, networking and intelligence of the economy and society, and accelerates the reconstruction of a new economic form of economic development and governance model [1]. China attaches great importance to the development of the digital economy and elevates it to a national strategy. From the 14th Five Year Plan, to the 20th National Congress of the Communist Party of China, and to the 2023 National People's Congress, the top-level design and industry guidelines for developing the digital economy and building a digital China have been repeatedly mentioned and continuously clarified. According to the Digital China Development Report (2022), the scale of China's digital economy reached 50.2 trillion yuan in 2022, accounting for 41.53% of GDP. All provinces (autonomous regions, municipalities directly under the central government) in China prioritize the layout and development of the digital economy.

In 2023, the total digital economy of Shandong Province reached 4.3 trillion yuan, accounting for over 47% of GDP. The digital economy has taken up half of the province's economy. However, Shandong Province still faces problems such as incomplete digital infrastructure construction, weak industrial digital transformation, weak digital innovation capabilities, and insufficient digital professionals. Therefore, facing the great opportuni--ty for the development of the digital economy, Shandong Province faces both opportunities and challenges. Analyzing the current situation of digital economy development in Shandong Province, scientifically evaluating and measuring its level of digital economy development, is of great theoretical significance and practical value for deepening the implementation of "Digital Shandong" construction and achieving high-quality economic and social development in Shandong.

II. Selection of Evaluation Indicators

Based on the connotation of the digital economy, this papers draws on representative evaluation indicators for the development of the digital economy constructed by authoritative institutions and scholars [2-5], and comprehensively considers the principles of scientificity and operability, and selects indicators with low relevance and repeatability, We have constructed an evaluation index system for the development level of regional digital economy (see Table 1 below), including 4 primary indicators (four dimensions) and 14 secondary indicators. The four primary indicators are digital infrastructure, digital industrialization, industrial digitization, and digital innovation capability.

(1) Digital infrastructure is the foundation for high-quality development of the digital economy and an important carrier for the development of the digital economy. This dimension selects indicators based on the construction and use of hardware facilities and Internet resources. The development indicators corresponding to informatization and the Internet can well reflect the infrastructure construction of the digital economy. Therefore, we select two statistical indicators, the number of mobile phone users and the number of Internet broadband access users, to measure the development of digital infrastructure.

(2) As a fundamental part of the digital economy, digital industrialization mainly refers to various economic activities that provide digital related products and technological services [6]. It provides support in digital technology and product services for the development of the digital economy. This paper focuses on the selection of indicators for digital industrialization in industries such as information and communication and software services. Therefore, we choose three indicators to measure the dimension of digital industrializati--on: the total business volume of the postal industry, the total telecommunications business volume, and the number of employees in the information transmission, software, and information technology service industries.

(3) Industrial digitalization reflects the importance and investment of enterprises in digital transactions. It is a concrete embodiment of the integration of digital technologies such as the Internet with various industries and fields. It is the core content of the digital economy and an important way to achieve industrial transformation and upgrading [7]. This paper selects five secondary indicators for industrial digitization: the number of computers used per hundred people, the number of websites owned by each hundred enterprises, the proportion of e-commerce transaction activities of enterprises, e-commerce sales, and the Digital Inclusive Finance Index [8].

(4) Digital innovation capability is the driving force for the sustained and rapid development of the digital economy. The updating and iteration of digital technology cannot be separated from the improvement of digital innovation capability, and R&D expenditure is the basic prerequisite for the improvement of digital innovation capability. The number of patent applications and research and development units (personnel) largely reflect the regional digital innovation capability. Therefore, this paper selects four secondary indicators to measure digital innovation capability: the number of patent applications authorized, the proportion of research and development expenditure to GDP, the number of units with research and experimental development activities, and the number of research and experimental development personnel [9].

III. Measurement of the Development Level of Digital Economy

Compared to traditional subjective weighting methods such as Analytic Hierarchy Process, the entropy weighting method used in this paper is an objective weighting method, and the indicator weight only depends on the discreteness of the development data itself [10]. The specific calculation steps of the entropy weight method are as follows [11]:

Measur n evaluation objects through k indicators, with a statistical measurement of x_{ij}, where x_{ij} represents the j（$j=1,\cdots,k$）indicator value of the i（$i=1,\cdots,n$）region.

Step 1: Data standardization processing, also known as data normalization processing (homogenization of heterogeneous indicators). The development of the digital economy involves multiple indicators, and the issue of indicator dimensionality affects the comparison between indicators. Therefore, in order to unify the caliber of each indicator, the range method is used to eliminate dimensional differences, and the raw data of each indicator is standardized to compress it between 0 and 1. Since the selected indicators in this paper are all positive indicators, only positive processing is required. The processing method is as follows:

$$y_{ij}=\frac{x_{ij}-\min\{x_{1j},\cdots,x_{nj}\}}{\max\{x_{1j},\cdots,x_{nj}\}-\min\{x_{1j},\cdots,x_{nj}\}},\quad i=1,\cdots,n,\ j=1,\cdots,k \tag{1}$$

Step 2: Calculate the proportion of statistical indicators P_{ij}.

$$P_{ij}=\frac{y_{ij}}{\sum_{i=1}^{n}y_{ij}},\quad i=1,L,n,\ j=1,L,k \tag{2}$$

Step 3: Calculate information entropy value e_j.

$$e_j=\frac{-\sum_{i=1}^{n}P_{ij}\ln P_{ij}}{\ln n},\quad j=1,L,k \tag{3}$$

Step 4: Calculate information entropy redundancy (difference) d_j.

$$d_j=1-e_j,\ j=1,L,k \tag{4}$$

Step 5: Calculate the entropy weight (weight) of each indicator R_j.

$$R_j=\frac{d_j}{\sum_{j=1}^{k}d_j},\quad j=1,L,k \tag{5}$$

Step 6: Calculate the index of digital economic development level in each region (comprehensive score) D_i.

$$D_i=\sum_{j=1}^{k}R_j y_{ij} \tag{6}$$

IV. Calculation and Analysis of the Development Level of Digital Economy

A. *Data Sources*

Taking into account the timing of the development of the digital economy and the availability of local statistical data, the research period is determined to be from 2018 to 2022. The statistical data comes from the National Economic and Social Development Statistical Bulletin, the Shandong Provincial Statistical Yearbook, and the Tai'an Statistical Yearbook. The digital inclusive finance index comes from the Peking University Digital Inclusive Finance Index compiled by the Peking University Digital Finance Research Center. The missing data is filled in using interpolation method. In addition, the proportion of R&D expenditure to GDP is calculated by (internal R&D expenditure + external R&D expenditure)/regional GDP. The original data for 2022 is shown in Table 1 below, and data for other years are omitted here.

Table 1. The sources of data (2022).

Region	***X*1**	***X*2**	***X*3**	***X*4**	***X*5**	***X*6**	***X*7**	***X*8**	***X*9**	***X*10**	***X*11**	***X*12**	***X*13**	***X*14**
Jinan	1274	523	93.3	152	8	48	49	11	52052434	319	64777	0.56	1828	123802
Qiangdao	1345	498	92.1	153	3	45	50	41	71150088	319	81753	0.19	3050	142338
Zibo	558	186	19.8	52	1.4	28	45	8.7	13437341	302	15982	0.18	1274	50007
Zaozhuang	408	151	17.6	36.6	0.4	28	39	6.7	1236380	298	7827	0.11	459	15258
Dongying	296	109	8.5	29.9	0.5	37	47	7.4	25903985	308	8931	0.12	612	26152
yantai	896	333	37.1	82	0.8	33	46	7.8	16897652	302	22760	0.29	1592	66885
Weifang	1092	366	58.4	94.4	1.2	32	49	6.6	13875845	297	30224	0.45	1476	67441
Jining	862	303	37.3	74.1	0.6	27	39	6.4	1851049	294	16666	0.26	1114	36055
Tai'an	569	201	20.8	47.6	1.2	21	40	7.7	1620683	290	10973	0.14	836	30942
Weihai	409	154	18.8	37	0.4	33	45	7.5	1664382	302	13484	0.18	815	33914
Rizhao	332	126	14.5	31.1	0.3	35	43	6.5	20023087	300	6706	0.10	647	17516
Linyi	1148	418	121	104	0.5	25	27	5.3	6925182	295	19801	0.37	1894	45338
Dezhou	571	211	41.6	45.8	0.5	29	50	7.9	6170524	274	13257	0.16	1120	39154
Liaocheng	619	215	34.3	51.8	0.3	23	40	6.9	5249506	282	12136	0.17	937	24246
Binzhou	430	166	16.6	39.7	0.4	23	40	8.9	6747620	290	9339	0.10	1103	35796
Heze	884	297	36.6	71.2	0.3	21	31	7.7	10196491	272	8692	0.11	1142	23353

B. *Measurement of the Development Level*

The statistical calculations in this section are mainly implemented using R software.

Based on the evaluation index system of regional digital economy development level constructed in this paper, we first use the statistical data of 16 regions in Shandong Province in 2022 as samples, and use the entropy weight method to calculate the statistical indicator weights for measuring the level of digital economy development in 2022, as shown in Table 2.

Table 2. Evaluation index system and indicator weights for digital economy development level (2022 data).

Target Layer	**Primary Indicators**	**Secondary Indicators**	**Unit**	**Weight**
Development	Digital infrastructure	Number of mobile phone users X_1	10000	0.047

Target Layer	Primary Indicators	Secondary Indicators	Unit	Weight
Level of Digital Economy	(0.096)		households	
		Number of Internet broadband access users X_2	10000 households	0.049
	Digital industrialization (0.293)	Total business volume of the postal industry X_3	Billion yuan	0.061
		Total telecommunications services X_4	Billion yuan	0.068
		Employment in information transmission, software, and information technology services X_5	Ten thousand people	0.164
	Industrial digitization (0.315)	Number of computers used per hundred people X_6	Pc	0.051
		Number of websites owned by every hundred enterprises X_7	Pc	0.018
		Proportion of e-commerce transaction activities in enterprises X_8	%	0.124
		E-commerce sales revenue X_9	Ten thousand yuan	0.096
		Digital Inclusive Finance Index X_{10}	—	0.026
	Digital innovation capability（0.295）	Number of patent applications authorized X_{11}	Pc	0.103
		R&D expenditure as a percentage of GDP X_{12}	%	0.081
		Number of units with research and experimental development activities X_{13}	Pc	0.043
		Number of research and experimental development personnel X_{14}	People	0.068

According to Table 2, the weight of digital infrastructure is 0.096, the weight of digital industrialization is 0.293, the weight of industrial digitization is 0.315, and the weight of digital innovation capability is 0.295. Among them, the weight of industrial digitization is the highest, and the weight of digital innovation capability and digital industrialization is at a high level, while the weight of digital infrastructure is slightly lower.

Using the statistical data of 16 regions in Shandong Province in 2022 as the sample, the entropy weight method was used to calculate the digital economy development level index and provincial rank of the 16 regions in Shandong Province in 2022, as shown in Table 3.

Table 3. Measurement and rank of digital economy development level in 16 regions in Shandong Province.

Region	Digital Economy Development Level Index (2022)	Rank (2022)
Jinan	0.798	2
Qingdao	0.804	1
Zibo	0.194	7
Zaozhuang	0.066	16

Region	Digital Economy Development Level Index (2022)	Rank (2022)
Dongying	0.126	10
Yantai	0.294	5
Weifang	0.361	3
Jining	0.196	6
Taian	0.115	13
Weihai	0.122	11
Rizhao	0.097	14
Linyi	0.315	4
Dezhou	0.149	8
Liaocheng	0.117	12
Binzhou	0.094	15
Heze	0.130	9

Below, we take the five-year data from 2018 to 2022 as the total sample, and use the entropy weight method to uniformly calculate the five-year digital economy development level index and provincial rank of 16 regions in Shandong Province, as shown in Table 4. The average index of the five-year digital economy development level of each region is shown in Fig. 1.

Table 4. Measurement of digital economy development level in 16 regions in Shandong Province.

Region	2018		2019		2020		2021		2022		Average	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank
Jinan	0.495	2	0.487	2	0.696	1	0.629	1	0.686	1	0.599	1
Qingdao	0.528	1	0.515	1	0.631	2	0.616	2	0.667	2	0.591	2
Zibo	0.173	6	0.178	6	0.204	7	0.193	7	0.203	6	0.190	6
Zaozhuang	0.044	16	0.065	16	0.095	16	0.086	15	0.092	16	0.076	16
Dongying	0.078	10	0.108	10	0.119	13	0.116	14	0.143	10	0.113	12
Yantai	0.191	4	0.220	4	0.302	5	0.260	5	0.281	5	0.251	5
Weifang	0.199	3	0.228	3	0.353	3	0.323	3	0.332	3	0.287	3
Jining	0.133	7	0.143	7	0.220	6	0.203	6	0.199	7	0.180	7
Taian	0.078	11	0.098	11	0.131	12	0.119	13	0.142	12	0.114	11
Weihai	0.071	12	0.091	12	0.132	11	0.127	11	0.132	13	0.111	13
Rizhao	0.050	15	0.065	15	0.095	15	0.085	16	0.121	15	0.083	15
Linyi	0.183	5	0.212	5	0.323	4	0.262	4	0.300	4	0.256	4
Dezhou	0.084	9	0.113	9	0.158	9	0.140	9	0.165	8	0.132	9
Liaocheng	0.064	14	0.089	13	0.147	10	0.129	10	0.143	11	0.114	10

Region	2018		2019		2020		2021		2022		Average	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank
Binzhou	0.069	13	0.084	14	0.119	14	0.119	12	0.126	14	0.103	14
Heze	0.117	8	0.135	8	0.178	8	0.146	8	0.163	9	0.148	8

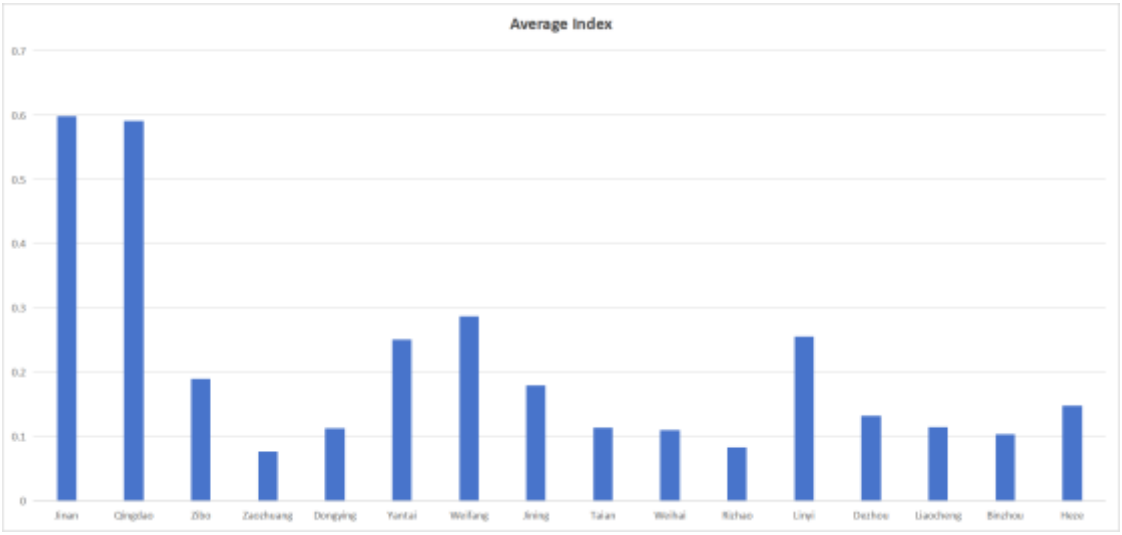

Fig. 1. Average index of digital economy development level in 16 regions in Shandong Province.

C. *Result Analysis*

According to the results of the digital economy development level of 16 regions in Shandong Province calculated based on the entropy weight method, from 2018 to 2022, the five-year ranking of the digital economy development level was relatively stable within the province. From a horizontal comparison within the province, the level of digital economy development in various regions in Shandong Province is uneven. Jinan and Qingdao have long been in a leading position in the digital economy development (the first tier within the province), while the digital economy development index of Jinan and Qingdao is far ahead of other cities (the "digital divide" phenomenon). However, the gap between other regions is not very large except for Jinan and Qingdao, Especially in the lower ranked regions, the differences are very small. The development level index of the digital economy roughly shows a phenomenon where the eastern cities are higher than the western cities, and the coastal cities are higher than the inland cities. The ranking change of the digital economy development level index in various regions within Shandong Province is not significant, and it has relative stability and low liquidity. From the annual longitudinal data of the past five years, the overall trend of digital economy development is good. Since 2018, various statistical indicators of digital economy development have steadily increased, and the index of digital economy development level has fluctuated slightly, showing a trend of increasing year by year. This indicates that although the digital economy has been inevitably affected by factors such as the epidemic in the past five years, it has still achieved certain achievements and development.

From the calculation results, it can be seen that some regions still has a long way to go in order to actively catch up and reach a leading level in the digital economy race. Entering the digital age, the development of the digital economy will become increasingly high-tech, innovative, and high-quality [12]. The development of the digital economy in Shandong must work hard and forge ahead to achieve this goal.

With the support and drive of the digital economy, the manufacturing industry is transformed and improved through digitization, networking, and intelligence, achieving the transformation from traditional manufacturing to intelligent manufacturing, actively promoting the comprehensive transformation and upgrading of the manufacturing industry. Digital technology provides an inherent driving force in service industries such as cultural tourism, offering new development platforms and service methods, and injecting new formats and business models into traditional service industries. The digital economy has improved the quality and efficiency of services by changing the production methods and processes of the service industry, and the user experience has also been greatly enhanced [13].

In 2021, the added value of the digital economy in Shandong Province was 3.4 trillion yuan, second only to Guangdong Province and Jiangsu Province, ranking third in the country. The digital economy accounted for 43% of GDP and was in the second tier, with a growth rate higher than the national average. The digital economy has become an important engine for high-quality economic development in Shandong Province. Shandong Province needs to strengthen digital empowerment, enhance the level of integration between data and reality, and provide "digital wings" for high-quality industrial development. 2023 is the year of comprehensive improvement in the development of Shandong's digital economy. This means that the digital economy, as a strong and new engine, must unleash new momentum and accelerate the activation of the potential of data elements, making digital a new variable for traditional enterprises and emerging industries in Shandong to seize market opportunities and achieve high-quality development.

V. Conclusion

Entering the digital age, the digital economy has become an important direction for the development of countries and regions, as well as a new engine for economic growth. The digital economy in Shandong Province is also showing a rapid development trend, becoming an important support for economic development. This is not only a trend, but also a new track and key increment for achieving high-quality development [14]. The digital economy in Shandong Province has good development prospects and broad development space. By doing a good job in top-level planning, formulating targeted guidance and support policies, adhering to targeted and precise implementation, accelerating the improvement of digital infrastructure construction, taking the path of industrial digitization and digital industrialization, accelerating the digital transformation and upgrading of manufacturing, promoting the integration of advanced manufacturing and modern service industries, supporting the development of high-tech enterprises, introducing and cultivating high-quality enterprises, promoting the implementation of a number of standardized, modular, and precise digital application scenarios, and better promoting the continuous development of Shandong’s digital economy industry, achieving digital, intelligent, and high-end economic growth, making Shandong’s economy healthier and more sustainable.

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