Research on Measuring the Digital Level of Equipment Manufacturing Enterprise in Liaoning Province

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Abstract: Equipment manufacturers are under enormous pressure to transform and upgrade, so is the arduous task of comprehensive revitalization in Liaoning province. The only way to solve the development problems of Liaoning's equipment manufacturing companies is through digital transformation. The paper investigates the digitization level of Liaoning Equipment Manufacturing Enterprises, which has theoretical and practical significance for promoting the digital transformation of Liaoning equipment manufacturing enterprises. Based on the three dimensions of digital foundation, digital application and digital benefits, this paper constructs a digital level measurement index system for equipment manufactures in Liaoning Province. Through the entropy method, it is found that the digital level of the equipment manufacturers in the province of Liaoning has shown accelerated growth in the past decade. The rapid growth of digital infrastructure has provided a favorable digital environment and foundation for the digital application and digital benefits of Liaoning equipment manufacturing enterprises. Digital application is the most direct manifestation of equipment manufacturers' digital transformation. The development of digital efficiency level shows a relatively stable growth trend.

Keywords: Digital Transformation; Measuring the Digital Level; the Entropy Method; Equipment Manufactures

1. Introduction

The digital evolution of equipment manufactures in Liaoning can drive the coordinated development of regional economy, which is of great significance for leading high-quality economic development and building a modern economic system. Liaoning is a key research base for the equipment manufactures supported by China. The equipment manufacturing industry has made significant progress in recent years, but at present, there still exists the problem of being large but not strong, which hinders its further development. With the continuous development of equipment manufacturing enterprises, problems such as lack of core competitiveness, insufficient independent innovation ability, and low-end industry have gradually become prominent.

Scholars measure the levels of digitisation from different perspectives according to the features of the industry. At present, scholars mainly measure the level of digitalization from the following three perspectives: first, using industrial robots. Industrial robots are a representative application of artificial intelligent technological application and have an outstanding function in promoting the digital development. Considering the caliber and availability of indicators, the utilisation of industry robots is used as a substitute proxy for digital transformation; Liu Jun. et al[1] used the relation of enterprise output values to industry total output value to obtain the number of industrial robots at the manufacturing enterprise level, which is used for measuring the degree of enterprise digitalisation. Qi Huaijin et al. [2] used the ratio of the amount relating to information technology in the detailed items of intangible assets of enterprises to the total amount of intangible assets to measure the level of digitalisation of enterprises; Yuan Chun et al. [3] and Zhao Chenyu [4] used text analysis techniques to determine the degree of digitalisation in companies based on the number of digital-related keywords in annual reports, and used them as explanatory variables for empirical analysis. Secondly, by constructing a digital level evaluation index system. Using

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methods such as principal component analysis, entropy method, and entropy method to calculate weights, the degree of digital development can be obtained through the calculation results. However, with the expansion of digital content, some scholars believe that a single indicator cannot fully measure the level of digitalization. On the basis of fully considering the characteristics of the industry, Li Lianshui et al. [5] selected indicators such as digital development personnel investment, equipment investment, and digital research and development funds to construct a digital level measurement system to study the digital level at the industry level; Gu Guoda and Ma Wenjing [6] constructed an indicator system to evaluate the degree of AI from three aspects: environmental support, knowledge creativity, and industrial competitiveness; Sun Zao and Hou Yulin [7] incorporated industrial digitization, cost of living, and employment needs of labor with different skills into the digital measurement indicator system based on task based theoretical models.The third method is to use field research. Collect digital data of individual enterprises through surveys, expert interviews, and other methods. Meng Fansheng, Gong Bingzheng, and others [8] proposed widely applicable evaluation indicators for various types of digital manufacturing enterprises. They used methods such as expert interviews and questionnaires to evaluate the level of digitalization from multiple aspects such as the efficiency, development level, and ecological environment of manufacturing enterprises.

In summary, in response to the shortcomings of previous research, this study is based on the innovation value chain theory and utilizes survey data of manufacturing enterprises in Liaoning Province to construct a multi-dimensional indicator degree of manufacturing enterprises on the basis of the entropy weight method. On the basis of entropy weight method. The purpose is not only to reflect the overall digitalization level of enterprises, but also to depict the current situation of each stage, directly targeting various links in the digital transformation of enterprises.

2. Setting up a Measuring System

The digitalization of the equipment manufacturing sector is the profound interaction between highly developed production engineering and the new information technology of the next century, which extends to all areas of the life cycle of goods, production and services, as well as the integration of manufacturing systems. The purpose of digitizing the equipment manufacturing sectors is to achieve informatization, networking, intelligence, and greenization, continuously improve the product quality, efficiency, and service standards of enterprises, and promote the green, coordinated, open, and shared development of equipment manufacturers.

2.1 Digital Foundation

The digital foundation is a prerequisite for in-depth involvement of equipment industry and the new round of IT. Both digital applications and the digital effects are built on the foundation of digitalization, so by measuring the level of digital foundation, the digital level of equipment manufacturing enterprises can be indirectly demonstrated. Therefore, this article measures the basic digital level from two aspects: information transmission guarantee and talent guarantee. Drawing on the approach of Liu Zhihao and Yu Xiuyan [9], the length of optical cable lines is selected as one of the indicators to measure the level of information transmission guarantee. Industrial Internet is the carrier of intelligent technology applications, and it cannot do without the use of long-distance optical cables. The lengths of fiber optic cables reflects the physical foundation of intelligent equipment manufacturing industry, and is the prerequisite and guarantee for intelligent application and output efficiency in equipment manufacturing industry. Meanwhile, Selection of R&D funds from industrial companies above a certain size to reflect the level of innovation in the region. Intelligent technology also relies on the operation and supervision of talents, so this article selects talent guarantee indicators to indirectly demonstrate the digital foundation level of equipment manufacturing industry. In the talent security indicators, R&D personnel from industry companies above a certain size are selected. This is done to fully reflect the talent pool in the region.

2.2 Digital Applications

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Digital application is the most direct manifestation of a digital transition in equipment engineering companies. From collaborative robots to industrial internet, machine vision to intelligent detection, these changes are all transforming the extensive traditional production mode into a refined intelligent production mode. Lin Kong Tuan and other scholars believe that digital applications can be measured using total factor productivity and production capacity indicators [10]. Total factor productivity takes the total labor and assets as inputs and the value of total industrial production as output, which can effectively evaluate the production efficiency of the equipment manufacturing industry. At the same time, in order to follow the systematic principle of establishing an indicator system, this article selects the total profit of the equipment industry and understands the production profitability level of the equipment manufacturing enterprise through the total profit.

2.3 Digital Benefits

Digital benefits are a direct reflection of the market environment for companies in the equipment industry to undergo digital transformation and upgrading. The integration of digital factors enables precise marketing and real-time feedback to be achieved. Digital benefits are measured by the sales revenue of new products and intelligent output of industrial enterprises above designated size [11]. With the improvement of digital level, digital new products have established the connection between people, devices, and enterprise services, which realizes the full lifecycle of consumer participation in digital products. Therefore, the revenue of digital new products is an important indicator of service digitization. Equipment manufacturing enterprises master the core technology of manufacturing enterprises, and the process of promoting their digitalization is also a process of advanced and rational core technology. Therefore, an important indicator of digital output for industrial enterprises above a certain size is the number of effective invention patents. The system of the measurement index for the digital scale in the engineering sector is presented in Table 1.

Table 1. Index System for Measuring the Digital Level of Equipment Manufacturing Enterprises

Primary indicators	Secondary indicators	Measurement indicators
Digital Foundations	Information transmission guarantee	Fiber optic cable line length X1
	Talent security	R&D personnel in industrial companies of specified sizes X2
	Innovation intensity	R&D funding for industrial firms over certain thresholds X3
Digital applications	Total factor productivity	Labor force X4
		Total capital X5
		Value of total industrial production X6
	production capacity	Total profit of equipment manufacturing enterprises X7
Digital benefits	Service digital level	Sales of new products by industry above the specified size X8
	Digital output	Number of effective inventive patents for industry above a certain size X9

3 Methodology

3.1 Entropy Method

Following the principles of Theory of Information, the information is a measurement of the extent of order in a situation, while entropy is a degree of disorder in a structure. Information entropy is used in information theory to describe the uncertainty of various possible events that may occur in an information source, and can also be understood as the probability of the occurrence of a specific type of information. For a certain indicator, the lower the informational entropy measure, the higher the variance of the metrics, which means that the influence (i.e. weight) of the metric on the overall score is higher. If the scores of all the indicators are the same, the indicator does not play a role in the overall assessment. Thus, to provide a basis for a comprehensive assessment of multiple factors, the entropy of information can be applied to calculate the weight of individual factors.

The Entropy Method is an objectively

weighted multi indicator comprehensive valuation methodology based on the idea of information entropy, which determines objective weights based on the magnitude of indicator variability. In this method, the information entropy of different indicators is calculated and then the weight of the indicators is determined on the basis of their relative changes and their impact on the system as a whole, the corresponding weights of each indicator are obtained. Indicators with greater relative changes have greater weights. Therefore, on the basis of the variation rate of different metrics, the research object can be objectively and accurately evaluated, which is the basis for the composite assessment of different metrics[12].

3.2 Identification Step and Process

The entropy weight method for determining weights mainly involves the following 6 steps:

3.2.1 Standardized processing

If there are n evaluation objects and m digital measurement indicators, it forms the digital measurement indicator system matrix P=(bij) n × m. b_{ij} represents the evaluation data of the jth indicator corresponding to the i-th evaluation object (i=1, 2, 3,..., m, j=1, 2, 3,..., n), and the digital measurement indicator B for equipment manufacturing industry is (bij) n × M can be expressed as:

$$B = \begin{Bmatrix} b_{11}\ b_{12} \dots b_{1m} \\ b_{21}\ b_{22} \dots b_{2m} \\ \dots\ \dots\ \dots\ \dots \\ b_{n1}\ b_{n1} \dots b_{nm} \end{Bmatrix}_{n\times m} \quad (1)$$

For positive indicators:

$$C_{ij} = \frac{b_{ij} - \min_j \{b_{ij}\}}{\max_j \{b_{ij}\} - \min_j \{b_{ij}\}} \quad (2)$$

For negative indicators:

$$C_{ij} = \frac{m\text{ax}_j \{b_{ij}\} - b_{ij}}{\max_j \{b_{ij}\} - \min_j \{b_{ij}\}} \quad (3)$$

The standardized indicator matrix is as follows:

$$R = (X_{ij})_{m\times n} = \begin{Bmatrix} X_{11} & X_{12} \cdots & X_{1m} \\ X_{21} & X_{22} \cdots & X_{2m} \\ \cdots & \cdots \quad \cdots & \cdots \\ X_{n1} & X_{n2} \cdots & X_{nm} \end{Bmatrix} \quad (4)$$

3.2.2 Calculate entropy value

The entropy value of the jth indicator is ej.

$$\mathrm{e}_j = -\varepsilon(\textstyle\sum_{\mathrm{i}=1}^{n} P_{ij} \ln P_{ij}) \quad (5)$$

Among them, $\varepsilon = \frac{1}{\ln n}$, $P_{ij} = \frac{C_{\mathrm{ij}}}{\sum_{\mathrm{i}=1}^{m} C_{\mathrm{ij}}}$,

the percentage of the i-th index of P_j out of the j-th index.

Determine indicator weights through information entropy.

$$W_j = \frac{1-e_j}{\sum_{\mathrm{i}=1}^{n}(1-e_j)} \quad (6)$$

Linear weighting method.

$$\mathrm{V_i} = \textstyle\sum_{j=1}^{n}(w_j \times y_{ij}) \quad (7)$$

Among them, y_{ij} is the standardized data.

3.3 Measurement Process and Results

3.3.1 Data sources

This article mainly selects relevant data on the equipment industry from 2012 to 2021 as the sample in Liaoning Province, which is mainly taken from Liaoning State Statistical Yearbook, National Statistical Yearbook, and Bulletin. In this article, the entropy method is used to weight each indicator data and obtain measurement values for three dimensions: digital foundation, digital application, and digital benefits. Use interpolation to supplement a small amount of missing data.

3.3.2 Data processing

Firstly, search for the maximum and minimum values of each indicator, subtract the minimum value from the maximum value of each indicator, and obtain the difference between each indicator. The difference is represented by DV, and the scores are presented in Table.2.

Table 2. Maximum and Minimum Values of Each Indicator

	X1	X2	X3	X4	X5	X6	X7	X8	X9
Max	1743545.2	63374	3672792	736618	14161.8	16458.4	1002	50108739	31740
Min	442167.8	49097	2418803	456553	11222.4	7174.3	362.5	31936021	5054
DV	1301377.4	14277	1253989	280065	2939.4	9284.1	639.5	18172718	26686

Secondly, to determine whether the indicator is positive or negative, name the positive index P and the negative index N, where the positive indicator refers to a positive correlation with intelligence level and the negative indicator is a negative correlation with digital level. The selected indicators in this article are positively correlated with the development of data level,

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and with the improvement of these indicators, it can promote the development of data level.

Then, according to formula (1), standardize the raw data of the indicators. For the positive indicator P, according to formula (2), subtract the minimum value of the selected data from the corresponding indicator and divide it by the difference between the two indicators; For the negative indicator N, refer to formula (3), subtract the selected data from the maximum value in the indicator, divide it by the difference in the indicator, and calculate the standardized data. To prevent the occurrence of zero values after standardization, the data is now translated, adding 0.0001 to each item. The translated data is shown in Table 3.

Once again, calculate Pij, refer to formula (5), divide the translated data by the total number of each indicator. In this paper, we have chosen a number of years of 10, divided by -1 by ln 10, which gives this value; based on these values, we calculate entropy value of jth indicator. At the same time, multiply the total number of Pij for each indicator by the logarithmic amount of Pij, and finally calculate the entropy value of the jth indicator.

Table 3. Standardization Results of Indicator Data

	X1	X2	X3	X4	X5	X6	X7	X8	X9
2012	0.0001	0.2079	0.3795	0.0791	0.1692	0.8511	0.8712	0.0001	0.0001
2013	0.0620	0.7000	0.7278	0.0001	0.5690	1.0001	1.0001	0.4951	0.0701
2014	0.1480	1.0001	0.6568	0.1450	0.6462	0.9402	0.8915	0.4642	0.1500
2015	0.2526	0.0001	0.0001	0.3460	0.6042	0.4013	0.2618	0.0792	0.1994
2016	0.4559	0.0111	0.0016	0.5566	0.3105	0.0108	0.0001	0.1067	0.3424
2017	0.5627	0.0257	0.2638	0.7749	0.4057	0.0066	0.1493	0.2767	0.5237
2018	0.7013	0.2828	0.4684	0.6994	0.0001	0.0001	0.2808	0.7502	0.6010
2019	0.8128	0.2107	0.5453	0.6299	0.6206	0.1051	0.3885	0.5999	0.6669
2020	0.9243	0.7622	0.7453	0.9669	0.6730	0.4144	0.7063	0.6865	0.8895
2021	1.0001	0.9848	1.0001	1.0001	1.0001	0.4144	0.7505	1.0001	1.0001

Table 4. Entropy Values of Each Indicator Information

Indicator	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	e_9
Information Entropy	0.8663	0.7907	0.8745	0.8784	0.9161	0.7863	0.8917	0.8713	0.8607

The calculation results are shown in Table 4.

Finally, the indicator weights are determined through information entropy; Referring to formula(5) , (6) and (7), obtain the weight of each indicator, and then use linear weighting method to multiply the weight by the standardized data. By summarizing and summing up, obtain the weight of each primary indicator.

3.2.3 Measurement results

This article mainly selects relevant data on digital of equipment manufacturing enterprises in Liaoning Province from 2012 to 2021 as the sample inspection interval, and uses entropy method to measure the digital level of equipment manufacturing industry. The measurement results are shown in Table 5. and figure 1.

The research results of the entropy method show that the weight ranking of the second level indicators of digital level in equipment manufacturing enterprises in Liaoning Province is as follows: R&D personnel from industrial enterprises above designated size is 0.1784, the weight of R&D personnel in industrial enterprises above designated size is 0.1070, the weight of optical cable line length is 0.1140, and the weight of Labor force is 0.1247, The weight of total capital is 0.0715, the weigh of Total profit of equipment manufacturing enterprises is 0.0834, and the weight of new product sales revenue for industrial enterprises above designated size is 0.1097.

Table 5. The Weight of Various Indicators for Equipment Manufacturing

Primary indicators	weight	secondary indicators	measurement indicators	weight
Digital Foundations	0.3994	Information transmission guarantee	Fiber optic cable line length X1	0.1140

		Talent security	R&D personnel in industrial companies of specified sizes X2	0.1784
		Innovation intensity	R&D funding for industrial firms over certain thresholds X3	0.1070
Digital applications	0.3722	Total factor productivity	Labor force X4	0.1247
			Total capital X5	0.0715
			Total industrial output value X6	0.0834
		production capacity	Total profit of equipment manufacturing enterprises X7	0.0926
Digital benefits	0.2284	Service digital level	Sales of new products by industry above the specified size X8	0.1097
		Digital output	Number of effective inventive patents for industry above a certain size X9	0.1187

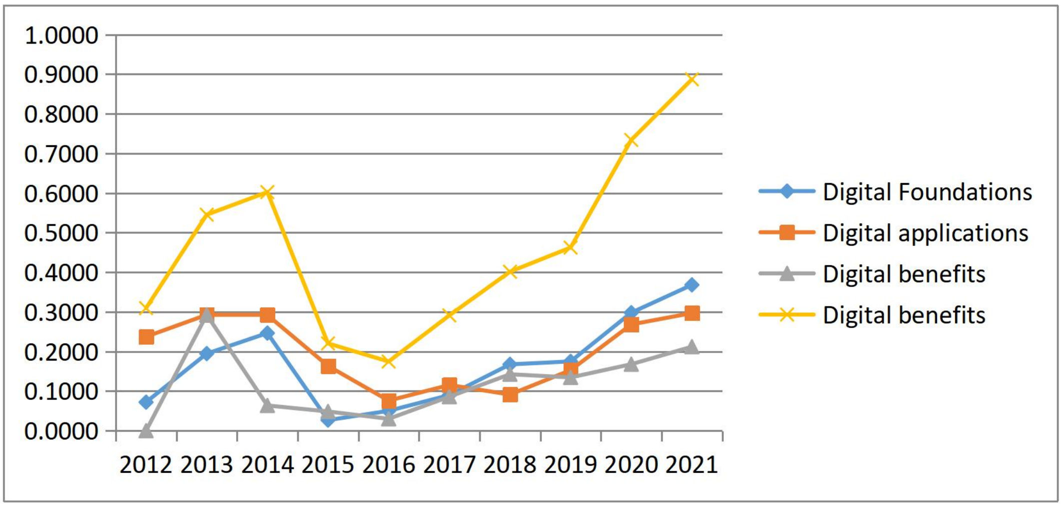

Figure 1. Digital Level of Equipment Manufacturing enterprises in Liaoning Province from 2012 to 2021

4. Conclusion

4.1 Digital Level

Overall, the digital level of equipment manufacturing enterprises in Liaoning Province showed an accelerating trend from 2012 to 2021. From 2012 to 2014, there was a continuous upward trend, followed by a downward trend and reaching its lowest point in 2016. Although there was a decline during these two years, the upward trend was evident. At the same time, with the national endeavour to enhance the layout of smart production and integration of informatization and industrialization increasing, The digital level of equipment industry has shown a positive growth trend and maintained good performance during this period in Liaoning Province. As the digital level of the provincial machinery industry develops, the digital foundation is also steadily increasing, laying a solid material foundation for the digital development of the provincial machinery industry. The excellent digital foundation provides a reliable development environment for intelligent production, and also to some extent promotes the rapid improvement of digital benefits. The rapid growth of digital applications has also led to the rapid development of digital benefits, which is conducive to the continuous improvement of the digital level and the rational development of intelligent production. However, the digital development of equipment manufacturing industry in Liaoning Province still needs to pay attention to the improvement of intelligent production efficiency. Improving intelligent production efficiency should be the core link to promote the rapid increase in the digital level of equipment industry.

4.2 Analysis of Factors Influencing Digital Level

(1) The overall trend of digital infrastructure is showing growth, and although there was a brief decline from 2014 to 2015, it has

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continued to grow since then. At the same time, with the support of relevant national policies and of strong growth of the information economy, equipment manufacturing enterprises are paying more attention to their own informatization, digitization, and intelligent development, which has led to a rapid improvement in their digital foundation level, thereby promoting the gradual improvement of the digital foundation standard of the equipment industry. The rapid growth of digital infrastructure has provided a favorable digital environment and foundation for the digital application and benefits of Liaoning's equipment manufacturing industry.

(2) The level of digital application is fluctuating compared to others. There was a downward trend from 2014 to 2016, and although there has been some growth since then, the growth rate has been relatively small. Digital application is the most direct manifestation of the equipment industry's digital transformation, but it has not been fully realized. Overall, the level of intelligent application has not been greatly improved. After the digital transformation, equipment companies need to continuously improve the level of digital application, increase the efficiency of intelligent production, and thus improve the production profitability.

(3) The development of digital benefits is showing a relatively stable growth trend. Overall, the Digital Advantage of Equipment Manufacturing fluctuates relatively little in Liaoning Province. This indicates that the numbers of active inventive protection granted to industrial companies above the specified size and the turnover of new products of industrial companies above the specified size have been relatively stable over the last ten years. With the optimization and improvement of the layout for the transformation of new and old kinetic energy, as well as the further improvement of the level of intelligent informatization and intelligent production, it is necessary to continuously improve the intelligent benefits brought by intelligent manufacturing.

Data Availability

The data used to support the findings of this study are available to anyone.

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