Research on Quality Measurement and Improvement Path of Shanxi Equipment Manufacturing Industry

Jie Gan[1,2,a], Yi Yang[1,2,b], Bin Liu[1,2,c], Xiaohong Zhang[1.2.d*]

[1]Institute of Industrial and System Engineering, Taiyuan University of Science and Technology, Taiyuan 030024, Shanxi, China
[2]Shanxi Key Research Base for Humanities and Social Sciences: Equipment Manufacturing Industry Innovation and Development Research Center, Taiyuan 030024, Shanxi, China

[a]ganj@tyust.edu.cn;[b]414512730@qq.com
[c]2919524577@qq.com;[d*]zhangxiaohong1111@126.com

Abstract. The equipment manufacturing industry is the third largest pillar industry in Shanxi Province, and its quality measurement index is an important reflection of the development of Shanxi's equipment manufacturing industry and a key factor in leveraging the new competitive advantages of Shanxi's industry. Based on the actual situation in 2011-2021, the specific evaluation indicators are formulated from the four links of "intelligent manufacturing - production level - green manufacturing - service awareness", and the equipment manufacturing industry in Shanxi Province is measured by the method of combining analytic hierarchy process and entropy method. Research has found that intelligent manufacturing and green manufacturing have contributed significantly to the quality measurement process in the equipment manufacturing industry. Intelligent manufacturing can improve the efficiency and reliability of green manufacturing, and green manufacturing can improve the environmental protection and sustainability of intelligent manufacturing. The two are complementary. Therefore, the improvement path for the equipment manufacturing industry in Shanxi Province lies in further developing intelligent manufacturing, continuing to promote high-end development, accelerating the promotion of green and low carbon upgrading and transformation, and achieving coordinated development of informatization, intelligence, and industrialization.

Keywords: intelligent manufacturing; Green manufacturing; Production level; Service awareness; Quality measurement; Upgrade Path

1   Introduction

The equipment manufacturing industry refers to the industry that provides various production technologies for the modernization of the national economy and the construction of the national defense industry [1]. It has become the third largest pillar industry in Shanxi, but faces difficulties such as insufficient order demand, slow economic growth,

and a significant decline in efficiency. To enhance the competitiveness of the equipment manufacturing industry in Shanxi Province and promote its high-quality development, it has become the core driving force. How to conduct quality measurement and evaluation has special guiding significance for Shanxi's equipment manufacturing industry to overcome the difficulties it is facing.

The 2022 Action Plan for the Transformation and Improvement of Traditional Equipment Manufacturing Industry in Shanxi Province (hereinafter referred to as the "Action Plan") clearly points out that for the five development priorities, green and intelligent development has become the top priority. The equipment manufacturing industry, as one of the strategic industries in Shanxi [2], is becoming increasingly important for research and exploration of green and intelligent development.

Greenization is an important component of the progress and development of human society and is the key to measuring sustainable development [2]. Intelligence is the future of manufacturing technology development, and it is a major trend to improve the efficiency of equipment manufacturing and promote economic development [3].

2   Literature Review

The existing domestic literature on the analysis and research of ways to promote high-quality innovation and development in the manufacturing industry is relatively detailed and rich, mainly focusing on the evaluation and calculation standards of the high-quality development level of the manufacturing industry and the research on the path to improve innovation and development. The research on equipment manufacturing industry is a very important component of the overall evaluation of the manufacturing industry. The relevant literature and materials related to the quality evaluation process of the entire equipment manufacturing industry can mainly be divided into the following categories: firstly, the evaluation of the comprehensive innovation driving capacity indicators of the national equipment manufacturing industry. Qian Xiaojing, Liu Lu, and Sun Yiming constructed an evaluation index system for the high-quality development level of the equipment manufacturing industry from three dimensions. The relevant research on evaluating the equipment manufacturing industry mostly focuses on the individual innovation or development stage of the equipment manufacturing industry, and the existing measurement systems follow the "input-output" analysis[4], without fully considering the intelligent and green development. In addition, some studies have been conducted on high-quality development. For example, Chen Jin and He Ning established an industrial modernization indicator system based on high-quality development [5]. Yan Shigang [6] and Wang Xingwang [7] selected evaluation indicators from four dimensions and quantitatively analyzed China's industrial competitiveness using comprehensive evaluation methods such as Analytic Hierarchy Process and Fuzzy Evaluation. The third is research on the equipment manufacturing industry abroad. Francesca Lotti et al. [8] studied the issue of high and low production efficiency, and the results showed that production efficiency is influenced by many factors. Sajid Anwar[9] explored the various mutual transformation relationships that arise in the ongoing devel-

opment trend of Japan's equipment manufacturing industry, and further studied the sustained higher economic policy investment brought about by the Japanese government's funding. Didik Purwadi[10] takes talent as the research focus and analyzes the importance of talent to the industry.

The research on measuring the development level of equipment manufacturing industry mainly starts from the perspectives of competitiveness and comprehensive development level. Based on constructing an evaluation index system for the demia, and research, increase the industrial concentration of the equipment manufacturing industry, and reshape the boundaries between the market and the government. Based on the maturity model, Wang Yumei and Zhang Xiaowei [11] constructed a three-dimensional indicator system that includes economic capacity, technological innovation capacity, and resource utilization capacity. Principal component and cluster analysis methods were used to measure the intelligent manufacturing capacity of the manufacturing industry in 31 provinces of China. Hu Lina [12] analyzed the necessity of green transformation in the equipment manufacturing industry from four aspects: technological innovation, industrial structure, development mode, and market position, combined with national policies. From the perspective of fiscal policy support, propose strategic considerations for the transformation and upgrading of China's equipment manufacturing industry. At present, there is relatively little research by domestic scholars on the effectiveness of green innovation in equipment manufacturing. Wu Chuanqing et al.[13] calculated the green innovation efficiency of China's equipment manufacturing industry in 30 provinces and found that the overall efficiency of China's equipment manufacturing industry is not high, and most provinces have not reached the optimal configuration level.

The focus is on independently developing core technology breakthroughs in areas such as industrial intelligent control; Highlighting energy conservation and greening, promoting the comprehensive reduction of total energy consumption and improvement of energy efficiency in the high-end traditional equipment manufacturing industry as the development goal; Emphasize service-oriented development and promote the mutual promotion between traditional equipment manufacturing and modern service industries. Starting from the four links of "intelligent manufacturing - production level - green manufacturing - service awareness", this article systematically constructs an evaluation index system for the quality measurement of Shanxi Province's equipment manufacturing industry. Based on this, a combination of Analytic Hierarchy Process and Entropy Method is used to measure and analyze the quality measurement level of Shanxi Province's equipment manufacturing industry from 2011 to 2021.

Usually, the Analytic Hierarchy Process (AHP) is more subjective in weight allocation, while the Entropy Method requires collecting a large amount of data as the basis for weight allocation. Therefore, this article combines Analytic Hierarchy Process and Entropy Method for comprehensive weighting, which to some extent improves the accuracy of quality measurement in the equipment manufacturing industry and serves as a reference for further decision-making.

3   Determination of Quality Measurement and Evaluation System

3.1   Quality Measurement Logic of Shanxi Equipment Manufacturing Industry

From the perspective of industrial applications, the development of intelligent greening is a continuous process of advancing towards high-quality industrial foundations and modernization. It is a high-level development state in which the entire industrial chain and key links of a high-quality industrial foundation can continue to develop fully and effectively. Shanxi is in a period of transformation and development in transforming its economic structure and growth mode. Taking quality change as the main goal of deepening the supply side structural reform, striving to build Shanxi into a province with strong quality, and improving the quality of the equipment manufacturing industry are important measures to achieve the transformation and development of Shanxi's industrial economy. As a "manufacturing industry" in the manufacturing industry, the equipment manufacturing industry has typical characteristics, mainly covering the four links of "intelligent manufacturing - production level - green manufacturing - service awareness". Its development quality is the result of the positive interaction and feedback mechanism formed by the four links of intelligent manufacturing, production level, green manufacturing, and service awareness[14]. Therefore, this article constructs a quality measurement system for the equipment manufacturing industry in Shanxi Province under the development of intelligent greening from four aspects: "intelligent manufacturing - production level - green manufacturing - service awareness".

3.2   Quality Measurement and Evaluation Index System for Equipment Manufacturing Industry

Based on the quality measurement logic of the equipment manufacturing industry, and fully considering the relationship between data availability and data reliability, this article constructs a quality measurement evaluation index system for the equipment manufacturing industry from four dimensions: intelligent manufacturing, production level, green manufacturing, and service awareness, as shown in Table 1.

Table 1. Evaluation Index System

Primary indicators	Secondary indicators	Explanation of indicators
	Investment level of intelligent equipment	Measured by the import value of intelligent equipment and instruments
Intelligent manufacturing	Total factor productivity of equipment manufacturing industry	Total factor productivity equals the productivity growth rate plus the labor share multiplied by the labor input growth rate plus the capital share multiplied by the capital input growth rate
	Intelligent production capacity	Measured by the operating income of equipment manufacturing owners

	capital productivity	Capital Production Level=Total Capital/Industrial Sales Value
production level	Mass loss	Quality loss rate=Total quality loss/Total industrial output value
	Labor production improvement rate	Labor production improvement level=Total capital/Annual average number of employees
green manufactur-ing	Proportion of green products	Green product proportion=Green product output/Total product output
	Technical transformation expenditure	Technical transformation expenditure
	Unit energy output	Unit Energy Output=Gross Industrial Product/Energy Consumption Value
service conscious-ness	Contribution rate to the improvement of ecological living environment	Measuring the reduction in investment in pollution control
	Contribution rate to innovation ability and competitiveness improvement	Measured by the growth rate of gross domestic product

4 Instance validation

According to the evaluation system in Table 1, with the quality measurement of equipment manufacturing industry as the target layer Q, intelligent manufacturing P1, production level P2, green manufacturing P3, and service awareness P4 as the decision-making layer, intelligent equipment investment level C1, equipment manufacturing total factor productivity C2, intelligent production capacity C3, capital production level C4, labor production improvement level C5, proportion of green products C6, unit energy output C7 The contribution rate C8 to the improvement of ecological living environment and the contribution rate C9 to the improvement of innovation ability and competitiveness are used as the indicator layer. Calculate the weight of each indicator using the Analytic Hierarchy Process.

Obtain the weights of various indicators of Shanxi Equipment Manufacturing Industry Quality Measurement Index based on Analytic Hierarchy Process $\alpha_i = \{0.0451, 0.1111, 0.2741, 0.0149, 0.0270, 0.0489, 0.2319, 0.1279, 0.0704, 0.0121, 0.0364\}$.

In the actual calculation process, due to the large amount of data, this article uses SPSS pro software to analyze the collected data. Calculate the weights of various indicators in the Shanxi Equipment Manufacturing Industry Quality Measurement Index based on the entropy method according to the steps in 4.2 $\beta_i = \{0.0451, 0.1111, 0.2741, 0.0149, 0.0270, 0.0489, 0.2319, 0.1279, 0.0704, 0.0121, 0.0364\}$.

The comprehensive weight of the quality measurement of equipment manufacturing industry in Shanxi Province can be obtained $\omega_i = \{0.0392, 0.1221, 0.2589, 0.0169, 0.0280, 0.0449, 0.1153, 0.1283, 0.1962, 0.0111, 0.0256\}$, the results are shown in Table 2.

Table 2. Comprehensive Weights of Quality Measurement Index System for Equipment Manufacturing Industry

index	Analytic Hierarchy Process Weights	Entropy method weight	comprehensive weight
C1	0.0451	0.0392	0.0435
C2	0.1111	0.1221	0.1205
C3	0.2741	0.2589	0.2757
C4	0.0149	0.0169	0.0164

C5	0.0270	0.0280	0.0285
C6	0.0489	0.0449	0.0485
C7	0.2319	0.1153	0.1692
C8	0.1279	0.1283	0.1326
C9	0.0704	0.1962	0.1216
C10	0.0121	0.0111	0.0120
C11	0.0364	0.0256	0.0316

According to the weight results of the indicator system and after standardizing the data, the quality measurement score formula for Shanxi's equipment manufacturing industry is obtained, as shown in(1)

$$Y=\sum_{i=1}^{n} T_i Q_I, i=1,2,3,...,n \tag{1}$$

Y is the evaluation score for the quality measurement of various industries in the equipment manufacturing industry, O_i is the actual value of the standardized raw data of each evaluation indicator, T_i is the corresponding weight of indicator O_i.

5   Quality Measurement Analysis of Shanxi Equipment Manufacturing Industry

To analyze the influencing factors of quality measurement accurately and effectively in Shanxi's equipment manufacturing industry, this article further calculates the quality measurement index of the equipment manufacturing industry based on the established evaluation system and weight calculation and considers the impact of adding different indicators on quality measurement. Firstly, based on the established quality measurement evaluation system, the quality measurement index of Shanxi's equipment manufacturing industry is calculated, and the results are shown in Table 3.

Table 3. Quality Measurement Index of Shanxi Equipment Manufacturing Industry

Years	Intelligent manufacturing	production level	green manufacturing	service consciousness
2011	0.3475	0.3921	0.5452	0.4664
2012	0.3681	0.4035	0.564	0.4833
2013	0.4554	0.3984	0.5848	0.4977
2014	0.5191	0.4289	0.6113	0.5252
2015	0.5767	0.4376	0.6337	0.5441
2016	0.6379	0.463	0.6566	0.5677
2017	0.6971	0.4907	0.6686	0.5836
2018	0.7658	0.4983	0.7011	0.6099
2019	0.8122	0.5064	0.7238	0.6290
2020	0.8091	0.5011	0.7284	0.6247
2021	0.8327	0.5226	0.7589	0.6477

Based on the data in Table 3, two dimensions of production level and service awareness were added as the basis, and two dimensions of intelligent manufacturing and green manufacturing were added for calculation and analysis. The results are shown in Table 4 and Fig. 1.

Table 4. Dimension Quality Measurement Index

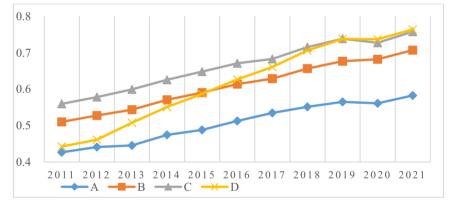| Years	Measure index			
	A:Production level and service awareness	B:Production level and service awareness and green manufacturing	C:Production level and service awareness and intelligent manufacturing	D:Production level, service awareness, green manufacturing, and intelligent manufacturing
2011	0.4293	0.5128	0.3644	0.4424
2012	0.4434	0.5301	0.3831	0.4612
2013	0.4481	0.5460	0.4489	0.5079
2014	0.4771	0.5733	0.5041	0.5508
2015	0.4909	0.5930	0.5503	0.5870
2016	0.5154	0.6164	0.6024	0.6266
2017	0.5372	0.6314	0.6528	0.6605
2018	0.5541	0.6592	0.7077	0.7060
2019	0.5677	0.6791	0.7454	0.7374
2020	0.5629	0.6813	0.7411	0.7370
2021	0.5852	0.7097	0.7650	0.7637

Fig. 1. Comparison of Dimension Quality Measurement Indices

By calculating the quality measurement index of the equipment manufacturing industry in Shanxi Province, it can be found that from 2011 to 2019, the quality measurement index of the equipment manufacturing industry increased from 0.4424 to 0.7374, showing a significant upward trend. However, this index decreased in 2020, dropping to 0.7340, and then rapidly increased to 0.7637 in 2021. Based on the data in Table 4, the measurement indices of production level and service awareness as the basis have increased from 0.4293 to 0.5852, while the quality measurement indices considered for all four dimensions have increased from 0.4424 to 0.7637. The former is significantly lower than the latter. Therefore, the contribution of intelligent manufacturing and green manufacturing to the quality measurement of the equipment manufacturing industry has maintained a high level, and the index is showing a stable and continuous upward

trend; Looking at the development and changes in the past 11 years, intelligent manufacturing and green manufacturing have become the most important forces in the development of equipment manufacturing industry in Shanxi Province.

Green manufacturing is the only way to significantly improve resource and energy utilization efficiency and achieve green development and is an inherent prerequisite for building a strong manufacturing country. Green manufacturing is the process of innovating traditional manufacturing technologies, design concepts, and production methods, achieving efficient and clean utilization of resources and energy, and minimizing environmental impacts. According to the data in Table 4 and Fig. 1, considering the three dimensions of production level, green manufacturing, and service awareness, the quality measurement index has increased from 0.5128 to 0.7097. Despite the comprehensive promotion of green manufacturing, the trend is clear, but challenges still exist. Low investment in green manufacturing technology research and development, prominent shortcomings in key core technologies, and weak willingness of enterprises to actively invest in implementing green manufacturing have also become obstacles to accelerating the green transformation of the equipment manufacturing industry.

Intelligence is the prospect of manufacturing technology development and the direction of future manufacturing technology development. According to data comparison, considering the three dimensions of intelligent manufacturing, production level, and service awareness, the quality measurement index is relatively large, increasing from 0.3644 to 0.7650. This is because intelligence has become stable in recent years, and various sub industries in the equipment manufacturing industry will maintain a certain level of investment to maintain intelligent manufacturing and will increasingly rely on the level of intelligence in future development.

According to the data in Figure 1, from 2011 to 2021, the quality measurement index of Shanxi's equipment manufacturing industry increased from 0.4424 to 0.7637, showing a significant upward trend. The index only decreased in 2020. From the perspective of four links, intelligent manufacturing has become the most influential link from the smallest impact in 2011 to 2021, indicating that intelligent manufacturing has become an important part of the development of the equipment manufacturing industry.

6   Conclusion

On the basis of existing research and based on the development characteristics of the equipment manufacturing industry in Shanxi Province, this article selects evaluation indicators suitable for measuring the quality of the equipment manufacturing industry in Shanxi Province, constructs an indicator evaluation system for the four stages of "intelligent manufacturing production level green manufacturing service awareness", and uses a combination of Analytic Hierarchy Process and Entropy Method to give corresponding comprehensive weights to each indicator, and conducts corresponding measurement and calculation, From 2011 to 2021, the quality measurement index of the equipment manufacturing industry in Shanxi Province increased from 0.5568 to 0.7609, showing a significant upward trend. Through comparative experiments, it can

be concluded that intelligent manufacturing has played a promoting role in the calculation of the quality measurement index of Shanxi's equipment manufacturing industry; Green manufacturing plays a constraining role in the calculation process. The two links of intelligent manufacturing and green manufacturing have made significant contributions to the quality measurement process of the equipment manufacturing industry.

The intelligent and green development of equipment manufacturing industry is an important lever for Shanxi to transform its industrial growth mode and activate the driving force of China's industrial development during the 14th Five Year Plan period. During the 14th Five Year Plan period, further promoting the improvement of quality measurement in Shanxi's equipment manufacturing industry and providing decision-making support for formulating economic development strategies and macroeconomic regulation for Shanxi's equipment manufacturing industry are:

Firstly, strengthen the level of intelligent manufacturing in the equipment manufacturing industry, and promote the development of the equipment manufacturing industry with the level of intelligent manufacturing.

Secondly, continue to promote high-end development. Quality is the foundation of development and directly affects a company's reputation and market position.

Thirdly, strengthen technology, accelerate the promotion of green and low carbon upgrading and transformation, and support the development of the equipment manufacturing industry with green development.

Fourthly, actively explore and integrate market related information, improve market response speed, and level, and achieve coordinated development of informatization, intelligence, and industrialization.

Fund projects

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