Research on evaluation model of regional manufacturing capability under digital and intelligent transformation

Jijun Xiao¹, Qiaoli Wang²*, Shu Ou ³

¹,²School of Business, Guilin University of Electronic Technology, Guilin, Guangxi, 541000, China
³Graduate School, Guilin University of Electronic Technology, Guilin, Guangxi, 541000, China

*Corresponding author’s e-mail: wql@gliet.edu.cn

Abstract. With 5G, industrial connectivity and cloud computing going deep into the manufacturing development process, it is particularly important to improve the quality and efficiency of the manufacturing industry. This paper constructs the evaluation index system of manufacturing capacity from four aspects: efficiency creation capability, scientific and technological innovation capability, product distribution capability and information service capability, and constructs the manufacturing capability evaluation model based on AHP-Entropy-TOPSIS to analyze the development of manufacturing capacity in various provinces under digital and intelligent transformation. The results show that since the proposal of "Made in China 2025", the manufacturing capacity of each region has generally increased, and the innovation ability and information ability of the regions with higher grades are obviously ranked higher. We suggest that all provinces should correctly handle the relationship between government and market in the development of science and technology, establish intelligent manufacturing benchmark enterprises in various industries, pay attention to innovation subjects, and promote regional informatization development.

1. Introduction

Facing the opportunities and challenges brought by the deep integration of the new generation of digital communication technology and manufacturing industry, in order to maintain the competitiveness of the existing manufacturing industry and compete for the commanding heights of international competition in the new round of industrial revolution, countries have formulated a series of strategies, such as the "Industrial Internet" of the United States, the "New Industrial France" of France, the "Industry 4.0" of Germany, the "Alliance of Science and technology industry" of Japan, the "Industry 2050 Strategy" of the United Kingdom, and the "Made in China 2025" of China. In recent years, China has been actively promoting intelligent manufacturing, the government has clearly proposed to take intelligent manufacturing as the main direction of the integration of industrialization and industrialization, to realize the transformation of the country from a big manufacturing country to a powerful manufacturing country. However, the transformation of traditional manufacturing industry to intelligent manufacturing is faced with the problems of long duration and uneven regional development. The evaluation of regional manufacturing capacity is of great significance to promote the healthy and sustainable development of regional digital intelligence. The establishment of regional manufacturing capability evaluation model under digital and intelligent transformation is helpful to identify the transformation of
regional manufacturing industry, and provides decision-making reference for the government and enterprises to promote the development of intelligent manufacturing.

Domestic and foreign scholars pay more attention to the research on intelligent technology and application, but the research of evaluation index system and digital development level of manufacturing industry is less [1-3]. Some scholars set up evaluation models to measure enterprises' manufacturing transformation capacity from the perspective of enterprises [4-6], while others set up evaluation models to measure the current manufacturing capacity from the perspective of the whole industry [7-9]. The development of Intelligent Manufacturing in China is still in its infancy. Based on the comprehensive consideration of subjective and objective factors to determine the index weight, this paper constructs the evaluation model of regional manufacturing capacity, and analyzes the situation of manufacturing capacity under the digital intelligence of provinces from both vertical and horizontal aspects. The evaluation results can provide a valuable reference for the government to promote the release of policies related to intelligent manufacturing, and enable provinces and cities to promote the transformation and upgrading of their manufacturing industry in a direction and focus.

2. Constructing the evaluation index system of regional manufacturing capacity

2.1. Evaluation index selection of regional manufacturing capacity

There are many categories under the manufacturing industry. For the selection of evaluation indexes, we should fully consider the current economic development and innovation level of each region, and ensure the universality and guidance of evaluation indexes. Through literature research, research on the development characteristics of regional manufacturing industry and empirical analysis on the influencing factors of enterprise digital intelligence transformation, it can be known that the evaluation of regional manufacturing capacity should include the evaluation of the benefit creation ability, innovation ability, logistics ability and networking ability in the transformation process of traditional manufacturing industry. This paper adheres to the established indicators to cover all aspects of manufacturing enterprise digital and intelligent transformation as far as possible, and uses SMART principles (specific, measurable, attainable, relevant and time-bound) to select the evaluation indexes, and build the evaluation model of regional manufacturing capability from four aspects: benefit creation capability, scientific and technological innovation capability, product circulation capability and information service capability. For the selection of the evaluation object, considering the main application scope of intelligent manufacturing and the availability of research data, the research object of this paper is the industrial enterprises with the main business income of 20 million yuan and above. The selection of evaluation indexes mainly comes from the following four aspects:

(1) Benefit creation capability. The development of digitalization and intelligence of manufacturing industry needs the input of talents, equipment, technology and other elements, and these inputs must be based on enterprise existing capital ability, so this paper mainly selects "the proportion of total industrial profit in GDP of the province" as the index to measure its economic benefits and creativity. In addition, today's manufacturing industry must take the road of sustainable development, so "comprehensive utilization rate of industrial solid waste" is selected as the measurement index of its social benefits.

(2) Scientific and technological innovation capability. Compared with the traditional manufacturing mode, the manufacturing industry under the digital intelligence transformation focuses on improving the intelligence of products and technologies, so the enterprises must have strong innovation strength to adapt to the changes of the market. Enterprise innovation ability mainly reflected by R & D, patents, market mastery ability and the flow of main personnel, therefore, this paper uses four secondary indicators of R & D investment intensity, the number of valid invention patents, the proportion of new product sales revenue in the main business revenue and the number of R & D personnel to reflect the innovation ability.

(3) Product circulation capability. The circulation of products can explain the development of enterprises to a certain extent. The development of intelligent manufacturing is to seek the future
development prospects while pursuing the existing economic value. In the era of intelligent manufacturing, the manufacturing industry is not limited to the development of a certain industry but should pay attention to the overall development of the industrial chain. Therefore, it is necessary to have a strong logistics supply chain system to ensure the circulation of raw materials and products. In this paper, four secondary indicators are set to measure this indicator, including the volume of freight transport, cargo turnover, mileage of grade highways, and number of trucks in operation.

(4) Information service capability. Under the transformation of digitization and intelligence, manufacturing focuses on digitization and intelligence. In order to realize digital intelligence, it is necessary to achieve free sharing of data and free interaction of information. These interactions are inseparable from the application of new technologies such as big data, cloud computing, and Internet of things, and the realization and popularization of these technologies are inseparable from the existence and support of information service enterprises. Therefore, this paper chooses four secondary indicators to measure the ability of information interconnection: numerical control rate of typical enterprises in key industries, the number of websites owned by enterprises, proportion of digital software applications, and proportion of enterprises with e-commerce activities.

2.2. Construction of evaluation index system of regional manufacturing capacity

Based on the analysis of the above evaluation indexes, this paper selects 4 first-class indexes and 14 second-class indexes as the indexes to evaluate the manufacturing capacity in various regions. The details shown in Table 1.

Table 1. Evaluation index of regional manufacturing capacity.

| First level indicators | Secondary indicators                                      | Code  |
|------------------------|----------------------------------------------------------|-------|
| Benefit creation capability (X₁) | Proportion of total industrial profit in GDP of the province | X₁₁   |
|                        | Comprehensive utilization rate of industrial solid waste | X₁₂   |
| Scientific and technological innovation capability (X₂) | R & D investment intensity | X₂₁   |
|                        | Number of valid invention patents | X₂₂   |
|                        | Proportion of new product sales revenue in main business revenue | X₂₃   |
|                        | Number of R & D personnel owned | X₂₄   |
| Product circulation capability (X₃) | the volume of freight transport | X₃₁   |
|                        | Cargo turnover | X₃₂   |
|                        | Have the mileage of grade highways | X₃₃   |
|                        | Number of trucks in operation | X₃₄   |
| Information service capability (X₄) | Numerical control rate of equipment in typical enterprises in key industries | X₄₁   |
|                        | Number of websites owned by enterprises | X₄₂   |
|                        | Application proportion of digital software | X₄₃   |
|                        | Proportion of enterprises with e-commerce activities | X₄₄   |

3. Constructing the evaluation model of regional manufacturing capability

3.1. Determination of evaluation grade

According to the five-level hierarchical framework of CMM and combined with the research and analysis of manufacturing capability under logarithmic intelligence transformation, this paper divides the regional manufacturing capacity into five levels: very high (I), high (II), medium (III), low (IV) and very low (V). The grades in this paper are based on AHP-Entropy-TOPSIS ranking results according to a certain proportion.

3.2. Determination of the weight of the evaluation index system

3.2.1. Weight determination of AHP-entropy weight method. AHP-entropy weight method is used to determine the comprehensive weight of the index by combining the weight of the index. Firstly, the problem is organized and hierarchical to construct the model of analytic hierarchy process structure, as shown in Table 1. Then, based on the 9-percentile ratio table, the judgment matrix is obtained by expert scoring, and the evaluation index weight is calculated after consistency test.
In the specific use of entropy weight method, according to the degree of variation of each index, the entropy weight of each index is calculated by using information entropy, and then the weight of each index is corrected by entropy weight, and finally a more objective index weight is obtained. In general, if the greater the degree of variation of an indicator, the more information it provides, the greater its role in the evaluation, the greater its weight. On the contrary, the smaller the degree of variation of an indicator, the less information it provides, the smaller its role in evaluation, and the smaller its weight.

The main solving steps of entropy weight method are as follows:

Suppose there are m evaluation objects and n evaluation indexes, X_{ij} is the original data of the j index in the i object.

Step 1: Normalization of indicators (homogenization of heterogeneous indicators). The positive index and negative index were treated according to formula (1):

$$Y_v = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \quad (1 \leq i \leq m, 1 \leq j \leq n)$$

$$Y_v = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} \quad (1 \leq i \leq m, 1 \leq j \leq n)$$

Step 2: Calculate the characteristic specific gravity, entropy value and entropy weight:

$$p_v = \frac{Y_v}{\sum_{i=1}^{m} Y_v}$$

$$e_v = \frac{\sum(p_v \cdot h_p)}{\sum_{j=1}^{n}(1 - e_j)}$$

$$h_i = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)}$$

### 3.2.2. Determination of comprehensive weight.

AHP is the subjective evaluation weight and entropy weight method is the objective evaluation weight. The comprehensive weight obtained by combining the two methods has higher performance, and the data can better reflect the actual situation. Based on the steps above, the subjective weight \(W = (w_1, w_2, ..., w_j)\) is obtained by AHP method, and the objective weight \(H = (h_1, h_2, ..., h_j)\) is obtained by entropy weight method. The comprehensive weight is calculated as formula (3):

$$Z_j = \frac{W_j \cdot h_j}{\sum_{j=1}^{n} W_j \cdot h_j}$$

### 3.3. Construction of TOPSIS evaluation model based on AHP-Entropy

After the weight of each index has been determined, the TOPSIS evaluation model is used for further evaluation. TOPSIS method was proposed by C.P. Hwang et al. in 1981 [10]. The evaluation method has no clear requirements for the evaluation object, evaluation index and data. Its basic idea is to define the positive ideal solution and negative ideal solution of the decision-making problem first, and then find a scheme which is closest to the positive ideal solution and farthest from the negative ideal solution in the feasible scheme set. TOPSIS evaluation model breaks through the traditional evaluation standards and has universal applicability, and has the advantages of both overall evaluation and local evaluation. It can objectively evaluate each scheme of multi-index problem comprehensively, fully reflects the actual situation of each evaluation index of intelligent manufacturing development level, and then fully reflects the overall development level.

Step 1: Calculate the gauge matrix:

$$R = [r_{ij}]_{m \times n}$$

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}}}$$

Step 2: The weighted canonical matrix V is constructed:

$$V_v = Z_j \cdot r_{ij} (1 \leq i \leq m, 1 \leq j \leq n); \quad V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix}$$

$$V = \begin{bmatrix} z_1 \cdot r_{11} & z_1 \cdot r_{12} & \cdots & z_1 \cdot r_{1n} \\ z_2 \cdot r_{21} & z_2 \cdot r_{22} & \cdots & z_2 \cdot r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ z_m \cdot r_{m1} & z_m \cdot r_{m2} & \cdots & z_m \cdot r_{mn} \end{bmatrix}$$
Step 3: The positive ideal solution and negative ideal solution are determined:
Assuming the maximum and minimum values of index $j$ in matrix $V$ be $v_{ij}^+\text{ and } v_{ij}^-$, then:

$$Z^+ = \{v_{ij}^+, v_{i2}^+, \ldots, v_{in}^+\} (j = 1, 2, \ldots, n) \quad Z^- = \{v_{ij}^-, v_{i2}^-, \ldots, v_{in}^-\} (j = 1, 2, \ldots, n)$$

(6)

Step 4: The Euclidean distance from each evaluation object to positive and negative ideal solution is calculated:

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_{ij}^+)^2} (1 \leq i \leq m, 1 \leq j \leq n) \quad D_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_{ij}^-)^2} (1 \leq i \leq m, 1 \leq j \leq n)$$

(7)

Step 5: Calculate the relative closeness:

$$B_i = \frac{D_i^-}{D_i^- + D_i^+} (i = 1, 2, \ldots, m)$$

(8)

4. Empirical research

4.1. Determination of data source and index weight
All the index data in this paper are obtained from China Statistical Yearbook, China Science and Technology Statistical Yearbook and Evaluation Report on the Integration Development Level of China's Informatization and Industrialization. "Made in China 2025" was formally put forward by the State Council in the strategic document issued in 2015. Considering the time of document submission, enterprise response time, data availability and data integrity, we selected 30 provinces and autonomous regions (excluding Hong Kong, Macao, Taiwan and Tibet) from 2015 to 2017 and the latest year of 2019 as the research objects. Due to the limited length of this article, the original data will not be listed one by one here.

According to AHP and formula (1) - (3), we obtained the comprehensive weight of each index from 2015 to 2019, as shown in Table 2.

| Code | Combined weight |
|------|----------------|
| X_{11} | 0.1264 0.1598 0.0523 0.0596 |
| X_{12} | 0.0134 0.0135 0.0387 0.0244 |
| X_{21} | 0.0519 0.0446 0.1337 0.0475 |
| X_{22} | 0.1858 0.1796 0.0212 0.2041 |
| X_{23} | 0.0599 0.0586 0.1202 0.0481 |
| X_{24} | 0.0788 0.0764 0.0173 0.1042 |
| X_{31} | 0.0503 0.0480 0.0619 0.0521 |
| X_{32} | 0.0556 0.0563 0.0151 0.0752 |
| X_{33} | 0.0142 0.0125 0.0107 0.0147 |
| X_{34} | 0.0192 0.0179 0.0227 0.0253 |
| X_{41} | 0.0075 0.0111 0.0976 0.0126 |
| X_{42} | 0.0664 0.0643 0.0831 0.0791 |
| X_{43} | 0.2543 0.2450 0.3160 0.2347 |
| X_{44} | 0.0163 0.0123 0.0095 0.0184 |

4.2. TOPSIS method was used for evaluation
According to the above combination weights, the weighted standardized decision matrix $V$ is obtained according to equations (4) and (5), and then the closeness degree and ranking of each province in different years are calculated according to equations (6) - (8), as shown in Table 3, where $B$ represents the closeness degree, $R$ represents the ranking and $L$ represents the level.
Table 3. The closeness degree of manufacturing capacity of provinces.

| Province      | 2015   | 2016   | 2017   | 2019   |
|---------------|--------|--------|--------|--------|
| Guangdong     | 0.4769 | 0.5214 | 0.4793 | 0.9109 |
| Beijing       | 0.6012 | 0.6020 | 0.5940 | 0.2218 |
| Jiangsu       | 0.3182 | 0.3162 | 0.3952 | 0.1850 |
| Zhejiang      | 0.2340 | 0.2330 | 0.2230 | 0.1850 |
| Shanghai      | 0.3026 | 0.2870 | 0.2380 | 0.1850 |
| Shandong      | 0.2197 | 0.2230 | 0.2230 | 0.1850 |
| Shanxi        | 0.1480 | 0.1605 | 0.1690 | 0.1739 |
| Sichuan       | 0.1828 | 0.1803 | 0.1803 | 0.1239 |
| Fujian        | 0.1608 | 0.1739 | 0.1739 | 0.1239 |
| Anhui         | 0.1625 | 0.1683 | 0.1739 | 0.1239 |
| Chongqing     | 0.1339 | 0.1344 | 0.1344 | 0.1239 |
| Hubei         | 0.1515 | 0.1586 | 0.1586 | 0.1239 |
| Liaoning      | 0.2405 | 0.2390 | 0.2390 | 0.1239 |
| Tianjin       | 0.1770 | 0.1699 | 0.1699 | 0.1239 |
| Henan         | 0.1544 | 0.1619 | 0.1619 | 0.1239 |
| Hunan         | 0.1279 | 0.1144 | 0.1144 | 0.1239 |
| Hebei         | 0.1200 | 0.1266 | 0.1266 | 0.1239 |
| Jiangxi       | 0.1305 | 0.1463 | 0.1463 | 0.1239 |
| Hainan        | 0.0646 | 0.0987 | 0.0987 | 0.1239 |
| Inner Mongolia| 0.0789 | 0.0878 | 0.0878 | 0.1239 |
| Jilin         | 0.1037 | 0.1068 | 0.1068 | 0.1239 |
| Shanxi        | 0.0447 | 0.0450 | 0.0450 | 0.1239 |
| Guizhou       | 0.0862 | 0.0849 | 0.0849 | 0.1239 |
| Guangxi       | 0.0917 | 0.0902 | 0.0902 | 0.1239 |
| Ningxia       | 0.0482 | 0.0479 | 0.0479 | 0.1239 |
| Yunnan        | 0.0569 | 0.0374 | 0.0374 | 0.1239 |
| Xinjiang      | 0.0531 | 0.0441 | 0.0441 | 0.1239 |
| Gansu         | 0.0286 | 0.0225 | 0.0225 | 0.1239 |
| Heilongjiang  | 0.0629 | 0.0431 | 0.0431 | 0.1239 |
| Qinghai       | 0.0401 | 0.0288 | 0.0288 | 0.1239 |

4.3. Analysis of evaluation results

According to the proportion of each of the five levels accounting for 15%, 20%, 30%, 20% and 15%, the development level of intelligent manufacturing in different years of each province is obtained, as shown in Table 3.

The vertical comparison of provinces shows that during 2015-2019, nearly half of the provinces have no change in their grades, and the provinces with a change in grades have no change in grade progression and no obvious change between adjacent years. Dynamic analysis of the manufacturing capacity of the three regions from 2015 to 2019 is shown in Figure 1. The eastern region has always been in a leading position and shows a continuous upward trend, and the central and western regions also show an upward trend through one-year adjustment. Connecting with the development of manufacturing industry under digital and intelligent transformation, we can see that the development of digital intelligence needs the support of equipment, technology and talents. It takes a process from the beginning of transformation and development of digital intelligence to enterprises' achieving certain results through digital intelligence manufacturing, that is, there is a delay period from the development of digital intelligence manufacturing to income. During the delay period from investment to gain, the eastern and central regions with better manufacturing development can quickly change the development mode and improve the manufacturing capacity in a relatively short time, while the western regions need a longer delay period. Sichuan has been exploring the development of intelligent manufacturing through model factories since the early stage of intelligent manufacturing development. It has been simultaneously deepening strategic cooperation with various scientific research institutions, improving factor supply and functional support, and building a cascade incubation system, which ensure that the level of Intelligent Manufacturing in Sichuan has been relatively high.
Horizontal comparison of the closeness degree of the first level indicators of five provinces randomly selected in 2017 is shown in Table 4. The score and ranking of the four indicators of benefit creation capability, scientific and technological innovation capability, product circulation capability and information service capability are not completely consistent with the comprehensive ranking of the province's manufacturing capacity, and some indicators are in great contrast. For example, Guangdong Province ranks first in 2017, its manufacturing capacity is mainly supported by scientific and technological innovation ability, product circulation ability and information service ability under digital intelligence. This is because Guangdong Province has a superior geographical location, and its private economy has been booming for many years, and its high-tech industry has developed rapidly and stably, but its benefit creation ability is not superior to other dimensions, this shows that Guangdong province wants to further improve its manufacturing capacity, and then can focus on benefit creation on the premise of ensuring that the existing advantages do not decline; Henan is in grade III in the comprehensive evaluation, and the closeness degree of indicators at all levels needs to be improved, especially the closeness degree of its informatization ability is only 0.0411. This is because Henan Province, as a large agricultural province, is still in the low-end link of the global value chain in the process of transformation, and the proportion of low output and labor-intensive industries is relatively high, in order to improve the manufacturing capability maturity in Henan Province, we can focus on the methods of accelerating the informatization capability while developing all aspects. Through in-depth interpretation of each dimension, we can determine where the weaknesses of digital and intelligent development of regional manufacturing industry are, and make efforts to complement the weaknesses in subsequent development to achieve the effect of getting twice the result with half the effort.

Table 4. First level closeness degree of some provinces in 2017.

| Provinces | X1     | X2     | X3     | X4     |
|-----------|--------|--------|--------|--------|
|           | B      | R      | B      | R      | B      | R      |
| Shanghai  | 0.7891 | 1      | 0.2414 | 6      | 0.6329 | 2      | 0.2601 | 6      |
| Henan     | 0.6451 | 5      | 0.1863 | 11     | 0.3787 | 8      | 0.0411 | 25     |
| Guangdong | 0.6484 | 4      | 0.9476 | 1      | 0.8491 | 1      | 0.8054 | 1      |
| Guangxi   | 0.4765 | 13     | 0.0834 | 22     | 0.1844 | 19     | 0.0821 | 20     |
| Xinjiang  | 0.3370 | 23     | 0.0296 | 27     | 0.1580 | 21     | 0.0171 | 29     |

5. Conclusion

In this paper, an evaluation system of regional manufacturing capacity under digital intelligence is constructed and an improved TOPSIS evaluation model based on the weight of evaluation indicators is established. Then an empirical analysis is conducted to provide guidance for the development direction of regional manufacturing industry, and to promote its quality and efficiency to improve the development level of manufacturing industry. Therefore, this paper puts forward the following suggestions for the provinces with relatively low manufacturing capacity development level: First, correctly handle the relationship between the government and the market in technological development. The government should do a good job in macro-control, introduce policies, create a good innovation environment for innovation creators, provide basic conditions for the market, and innovate the
transformation mechanism of scientific and technological achievements, only when the innovative achievements can be transformed into market profits can the government and enterprises have the confidence to continue to invest. Second, create benchmarking enterprises for digital intelligent manufacturing in various industries. Referring to the development process of benchmark enterprises, they can avoid detours and improve the overall development speed of regional manufacturing industry. Third, we should focus on the main body of innovation and promote the in-depth development of Industry-University-Research Collaboration. It is necessary not only to effectively enhance innovation capacity and promote the deep integration of Industry-University-Research Collaboration, but also to strengthen the training of innovative talents to reserve the impetus for subsequent innovation. Fourth, promote the digitalization and informatization of regional manufacturing capacity. At present, cloud economy has become a new bright spot in economic development. 5G, big data, artificial intelligence and so on have accelerated the development of informatization. The manufacturing industry should also keep up with the development of informatization to realize the efficient transformation of enterprises, and drive the construction of a new manufacturing and service system with full factors, full industrial chain, full value chain and comprehensive connection.

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