Construction of Evaluation Index System of Technological Innovation Capability of Smes in Manufacturing Industry Based on AHP Method

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Abstract. Small and medium-sized enterprises play an important role in China's economic and social development. At present, with the rising cost of manpower, raw materials and financing, and the severe damage to overseas markets, manufacturing SMEs must obtain competitiveness through technological innovation. This paper takes manufacturing SMEs as the research object, and studies the connotation, process and evaluation criteria of technological innovation from the perspective of evaluation. Based on the analysis of the process of technological innovation, a two-level evaluation index system is established. Finally, the weight of evaluation index is calculated accurately by analytic hierarchy process method.

1. Introduction

At present, small and medium-sized enterprises in China account for more than 99.8% of the total number of enterprises in the country. The value of final products and services created by small and medium-sized enterprises accounts for about 60% of GDP, and the tax paid is about 50% of the total national tax revenue. They provide more than 75% of urban jobs. In China, 65% of patents, 75% of technological innovation and 80% of new product development are completed by small and medium-sized enterprises. It can be seen that SMEs have made great contributions to activate the urban and rural economy, meet diversified needs, provide employment, and increase financial revenue and technological innovation. Therefore, SMEs play an important role in China's social and economic development.

In recent years, due to the slowdown of global economic growth, many manufacturing SMEs face the problem of contraction of overseas markets. At the same time, the rising cost of manpower, raw materials and financing has made many manufacturing SMEs face survival crisis. Therefore, through technological innovation to build competitiveness has become the consensus of manufacturing SMEs. This paper takes SMEs in manufacturing industry as the research object and carries out research from the perspective of technological innovation evaluation, aiming at obtaining the evaluation index system, which can provide some reference for SMEs' transformation and upgrading.

2. Connotation of Technological Innovation Capability of Manufacturing SMEs

The term innovation was first proposed by Austrian-American economist Joseph A. Schumpeter in 1912. He believes that innovation is to establish a new production function, that is, the recombination of production factors [1]. With technological innovation playing a more and more significant role in...
promoting social and economic development, many scholars have carried out a lot of research on technological innovation [2-8].

Based on the research results of these scholars, we can make clear that technological innovation is not only a systematic engineering, but also an economic activity. The most important form of technological innovation is through the development and design of new products or services, including the adoption of new processes and equipment. The ultimate criterion for testing technological innovation is whether the market accepts it or not. Technological innovation that can achieve economic benefits is successful.

3. Principles for Determining Evaluation Index of Technological Innovation Capability of Manufacturing SMEs

3.1. Principle of Purposefulness

The selection and formulation of evaluation criteria need to meet the requirements and purposes. For different research purposes, evaluation indicators can choose spatial criteria, time criteria or planning criteria.

3.2. Principle of Objectivity

Objectivity means that the evaluation criteria should conform to the actual social and economic environment of the enterprise and its own development, so as to ensure that the evaluation does not contain subjective assumptions.

3.3. Principle of Scientificity

Scientificity means that evaluation reflects the objective law of things' development as far as possible. On the one hand, evaluation criteria should have scientific concepts, on the other hand, quantitative indicators suitable for evaluation objects.

3.4. Principle of Implementability

Implementability refers to the specific, quantitative and clear evaluation criteria. The evaluation criteria are easy to implement in the evaluation process, and the evaluation results are accurate, which will not cause the evaluation distortion.

4. Technological Innovation Process of Manufacturing SMEs

Technological innovation is a comprehensive process in which enterprises discover and grasp potential market demand, organize production factors and resources, carry out a series of activities such as R&D, manufacturing and sales, and ultimately obtain commercial benefits. From the point of view of system, technological innovation mainly consists of technological innovation drive, core process, integrated management, support resources and ultimate effectiveness, as shown in Fig.1.
Technological innovation is mainly driven by technological development and customer demand. The core process of technological innovation mainly includes four links: market analysis, R&D and design, production and manufacturing, and marketing. The comprehensive management of technological innovation mainly includes the formulation of innovation decision-making, the construction of innovation team, the management of innovation strategy and the innovation incentive mechanism. Technological innovation resources support includes human resources, R&D funds and infrastructure. Technological innovation performance mainly includes four aspects: new product development, market share promotion, and sales revenue increase and cost reduction.

5. Evaluation Index of Technological Innovation Capability of Manufacturing SMEs

Based on the process analysis of technological innovation, two-level evaluation indicators can be determined. There are four indicators in the first level, namely, Implementing Capability, Integrated Management Capability, Investment Capability and Performance Capability, which are marked as U1, U2, U3 and U4 respectively.

5.1. Implementing Capability of Technological Innovation

The implementation capability of technological innovation refers to the ability to complete a series of core activities of technological innovation, including market research, R&D and design, production, manufacturing and sales. The implementation capability of technological innovation can be evaluated from four aspects.

The first aspect is the enterprise's market analysis capability, which is the enterprise's ability to obtain market demand information in time. Specifically, two secondary indicators can be identified, namely, Market Research and analysis capacity and market data system building capacity, respectively, recorded as U11, U12.

The second aspect is the R&D and design capability of enterprises, which can determine two secondary indicators, namely, the number of patent grants per year.

The number of innovative projects set up annually is U13 and U14, respectively.

The third aspect is the production and manufacturing capability of enterprises. Two secondary indicators can be determined, i.e. one-time pass rate of products and preparation period of new product input, which are recorded as U15 and U16 respectively.
The fourth aspect is the marketing capability of enterprises. Two secondary indicators, namely, the marketing intensity of new products and the ability of marketing network construction, can be determined concretely. They are marked as U17 and U18, respectively.

5.2. Integrated Management Capability of Technological Innovation
The comprehensive management capability of technological innovation refers to the management ability around the process of technological development, which includes the innovative consciousness and decision-making ability of the leadership, team cooperation and the construction of relevant incentive system.

The comprehensive management capability of technological innovation can be evaluated by the following five indicators. They are leadership innovation consciousness and courage, technological innovation decision-making ability, technological innovation team building ability, technological innovation strategic management ability, innovation incentive mechanism, respectively marked as U21, U22, U23, U24, and U25.

5.3. Investment Capability of Technological Innovation
Technological innovation investment capacity refers to the reserve and application capacity of various resources, including personnel, funds and infrastructure.

The investment capacity of technological innovation can be evaluated by the following five indicators: R&D investment intensity, R&D personnel investment intensity, R&D investment proportion, R&D personnel total number proportion, and infrastructure investment intensity, which are marked as U31, U32, U33, U34, U35, respectively.

5.4. Performance Capability of Technological Innovation
Technological innovation performance capability refers to the ability to achieve various results in the end, which is mainly reflected in the success rate of new product research and development, market share and profit increase.

The performance of technological innovation can be evaluated by four indicators, namely, the success rate of new product development, the sales revenue ratio of new products, the cost reduction ratio and the market share promotion ratio, which are marked as U41, U42, U43 and U44, respectively.

6. Determining the Weight of Evaluation Index Based on AHP Method

6.1. Principle of Analytic Hierarchy Process
Analytic Hierarchy Process (AHP) was proposed by T. L. Saaty, an American operations researcher and professor at the University of Pittsburgh in the early 1970s. This method has the advantages of systematicness, flexibility and conciseness [9]. It decomposes complex problems into various constituent factors, which are grouped into hierarchical results according to dominant relations. The relative importance of many factors in the hierarchy is determined by comparing them. Then, the relative importance of alternatives is determined by synthesizing the judgments of relevant personnel.

When using analytic hierarchy process to evaluate, it can be divided into four steps as follows:

The first step is to analyze the relationship between the basic elements in the evaluation system and establish the hierarchical structure of the system.

The second step is to compare the importance of each element at the same level with respect to a certain criterion at the upper level. The comparison result of index I and index J is recorded as \( a_{ij} \). From this, the judgment matrix A is constructed, and then the consistency test is carried out to calculate CI and CR indices.

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]
\[ \lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} W_i \]  

\[ CR = \frac{CI}{RI} \]  

RI is an average random consistency index. When CR is less than 0.1, it passes the consistency test.

The third step is to calculate the relative weight of the compared elements to the criterion by judgment matrix A.

\[ W_i = \left( \prod_{j=1}^{n} a_{ij} \right)^{1/n} \]

\[ W_i^n = \frac{W_i}{\sum_i W_i} \]

The fourth step calculates the total weights of each layer of elements for the purpose of the system, and ranks the alternatives.

6.2. Determining the Weight of Evaluation Index Based on AHP

Delphi method is used to compare the indicators in two ways, and the ratio is determined according to the importance of the indicators. For example, when the two indicators are equally important, the ratio is 1; when the index A is more important than the index B, the ratio is 3; when the index A is significantly important than the index B, the ratio is 5; otherwise, the reciprocal.

According to the expert opinions collected, tables 1-5 can be obtained after sorting out and calculating. The overall weight of all indicators is marked as \( w_i \).

**Table 1. First-level Evaluation Index of Technological Innovation Capability**

| Evaluating Indicator                                      | \( U_1 \) | \( U_2 \) | \( U_3 \) | \( U_4 \) | \( w_i \) |
|----------------------------------------------------------|-----------|-----------|-----------|-----------|-----------|
| Implementing Capability of Technological Innovation U1   | 1         | 2         | 2         | 2         | 0.4000    |
| Innovation and Integrated Management Capability U2      | 1/2       | 1         | 1         | 1         | 0.2000    |
| Technological Innovation Investment Capability U3       | 1/2       | 1         | 1         | 1         | 0.2000    |
| Performance Capability of Technological Innovation U4   | 1/2       | 1         | 1         | 1         | 0.2000    |

CI=0, CR=0, Consistency test passed

**Table 2. Secondary Evaluation Index of Technological Innovation Implementing Capability**

| Evaluating Indicator                                       | \( U_{11} \) | \( U_{12} \) | \( U_{13} \) | \( U_{14} \) | \( U_{15} \) | \( U_{16} \) | \( U_{17} \) | \( U_{18} \) | \( W_i \) | \( w_i \) |
|-----------------------------------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|-----------|-----------|
| Market Research and Analysis Capability U_{11}            | 1            | 1            | 3            | 1            | 3            | 3            | 3            | 1            | 0.1885    | 0.0754    |
| Construction of Market Big Data System U_{12}             | 1            | 1            | 3            | 1            | 3            | 3            | 3            | 1            | 0.1885    | 0.0754    |
| Number of patent authorizations per year U_{13}           | 1/3          | 1/3          | 1            | 1/3          | 1            | 1            | 1            | 1/3          | 0.0628    | 0.0251    |
| Number of innovative projects set up annually U_{14}     | 1/3          | 1/3          | 1            | 1/3          | 1            | 1            | 1            | 1/3          | 0.1885    | 0.0754    |
| One-time pass rate of products U_{15}                     | 1/3          | 1/3          | 1            | 1/3          | 1            | 1/2          | 1/2          | 1            | 0.0661    | 0.0264    |
| New Product Input Preparedness Cycle U_{16}               | 1/3          | 1/3          | 1            | 1/3          | 2            | 1            | 1/2          | 1/2          | 0.0690    | 0.0276    |
| Marketing Intensity of New Products U_{17}                | 1/3          | 1/3          | 1            | 1/3          | 2            | 2            | 1            | 1/2          | 0.0823    | 0.0329    |
| Marketing Network Building Capability U_{18}              | 1            | 1            | 3            | 1            | 1            | 2            | 2            | 1            | 0.1543    | 0.0617    |

CI=0.0396, CR= 0.0281, Consistency test passed
Table 3. Secondary Evaluation Index of Comprehensive Management Capability of Technological Innovation

| Evaluating Indicator | U_21 | U_22 | U_23 | U_24 | U_25 | W_i | w_i |
|----------------------|------|------|------|------|------|-----|-----|
| Leadership Innovation Awareness | 1    | 1    | 3    | 3    | 3    | 0.3305 | 0.0661 |
| Decision-making Capability of Technological Innovation | 1    | 1    | 3    | 3    | 3    | 0.3305 | 0.0661 |
| Technological Innovation Team Building Capability | 1/3   | 1/3   | 1    | 2    | 1    | 0.1269 | 0.0254 |
| Strategic Management Capability of Technological Innovation | 1/3   | 1/3   | 1/2  | 1    | 1/2  | 0.0852 | 0.0170 |
| Innovation incentive mechanism | 1/3   | 1/3   | 1    | 2    | 1    | 0.1269 | 0.0254 |

CI=0.0194, CR=0.0173, Consistency test passed

Table 4. Secondary Evaluation Index of Technological Innovation Resource Input Capability

| Evaluating Indicator | U_31 | U_32 | U_33 | U_34 | U_35 | W_i | w_i |
|----------------------|------|------|------|------|------|-----|-----|
| Investment intensity of R&D funds | 1    | 1    | 3    | 3    | 3    | 0.3305 | 0.0661 |
| R&D personnel investment intensity | 1    | 1    | 3    | 3    | 3    | 0.3305 | 0.0661 |
| Ratio of R&D expenditure to total expenditure | 1/3   | 1/3   | 1    | 1    | 1/2  | 0.0956 | 0.0191 |
| Ratio of R&D personnel to total staff | 1/3   | 1/3   | 1    | 1    | 1/2  | 0.0956 | 0.0191 |
| Input intensity of basic equipment | 1/3   | 1/3   | 2    | 2    | 1    | 0.1478 | 0.0296 |

CI=0.0194, CR=0.0173, Consistency test passed

Table 5. Secondary Evaluation Index of Technological Innovation Performance Capability

| Evaluating Indicator | U_41 | U_42 | U_43 | U_44 | W_i | w_i |
|----------------------|------|------|------|------|-----|-----|
| Success rate of new product development | 1    | 1    | 3    | 3    | 0.3750 | 0.7500 |
| New Product Sales Revenue Ratio | 1    | 1    | 3    | 3    | 0.3750 | 0.7500 |
| Cost reduction ratio | 1/3   | 1/3   | 1    | 1    | 0.1250 | 0.2500 |
| Promotion of market share | 1/3   | 1/3   | 1    | 1    | 0.1250 | 0.2500 |

CI=-1.4803e-16, CR=-1.6633e-16, Consistency test passed

7. Conclusion
This paper takes manufacturing SMEs as the research object, and studies the connotation, process and evaluation criteria of technological innovation from the perspective of evaluation.

Based on the analysis of the process of technological innovation, a two-level evaluation index system is established from four aspects: the implementation capability, the comprehensive management capability, the investment capability and the performance capability of technological innovation. Finally, the weight of evaluation index is calculated accurately by analytic hierarchy process.

Evaluating technological innovation capability can help SMEs to understand their own development situation more clearly and help them find problems and solve them in time. In addition, based on the evaluation results, the government can also formulate reasonable policies to support SMEs.

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