Evaluating the Collaborative Innovation Performance of Advanced Manufacturing Industry and Modern Service Industry Based on Extension Method

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Abstract. With the increasing convergence of service and manufacturing industry, service industry plays an important role in the value chain of modern manufacturing industry, advancing the transition from traditional manufacturing pattern to the service-manufacturing integration. This paper employed extension method to assess the collaborative innovation performance of advanced manufacturing industry and modern service industry and conducted case study for model demonstration and validation. This study provided a new approach for the decision makings in the collaborative innovation of advanced manufacturing industry and modern service industry.

Keywords: advanced manufacturing industry, Modern service industry, Extension method, Performance evaluation.

1. Introduction
Advanced manufacturing industry and modern service industry are the outcomes of industry development at the senior stage, having the characteristics of knowledge, information and technology intensiveness, less resource consumption and environmental pollution. With the principal symbol of the third industrial revolution, the development of service economy provides an opportunity for the transition of manufacturing industry. The boundary between manufacturing and service industry is becoming dim, and the convergence of the two industry accelerates.

For the convergence of advanced manufacturing industry and modern service industry, existing studies primarily explored the procedure from two perspectives. One perspective is the manufacturing industry servitization. Eichengreen and Gupta regarded technological innovation or technological convergency as the main force for the industry convergency [1]. Esmaeilian et al maintained that converging with service industry is an inevitable trend for the development of manufacturing industry [2]. Lu came up with the approach to construct the two industries’ convergency mechanism [3]. Peng and Kuang used the input-output table to measure the convergency extent of the producer service industry and manufacturing industry in China [4]. Another perspective to analyze the convergency of service and manufacturing industry is the value chain and supply chain. Lundquist and Olander pointed out that the industry convergency is a dynamic process of mutual substitution and mutual complementation between technology and product [5]. Goldhar and Berg analyzed the convergency of media industry and communications industry and concluded that the convergency process consisted of value chain decomposition and reconstitution [6]. Liu et al. maintained that the information
technology-based information service industry would become the new growth point of model service industry [7].

It can be seen that existing studies mainly explored the convergency development of service and manufacturing industry from certain perspective. Comparatively, indicators and evaluation method of the collaborative innovation performance of advanced manufacturing industry and modern service industry are lacking. This is the main motivation of this study.

2. Affecting factors of the collaborative innovation of advanced manufacturing industry and modern service industry

2.1. Policy support
Policy and regulations are indispensable for the collaborative development between industries. In terms of industrial specialization, loose economic policies are more helpful to advance industry development. In this study we used the ratio of Heilongjiang’s fiscal expenditure to GDP to measure policy supports

2.2. Constraints of resources and environment
The rapid development of an industry will create economic wealth. However, the resource consumption and environmental pollution associated with industry growth should be not ignored. The extensive development of economy would result in high consumption of energy and resources, intensive pollutant emissions, and low production efficiency, and will barricade industrial synergic development. This study adopted the ratio of Heilongjiang’s industrial pollution treatment to industrial value-added as the indicator of resources and environmental constraint.

2.3. The ratio of employees in the service and manufacturing industry in Heilongjiang to the province’s total employees
Labor inputs are critical for industrial development. Notably, many rural people migrate to cities and work in manufacturing plants and commercial service industry. But with the scale application of artificial intelligence, the number of manufacturing workers will significantly be decreased, while the commercial service industry will play a critical role in absorbing labors.

2.4. The level of economic development
The collaborative development between industries accelerates the transfer and optimization of production factors. High-level economic development level will advance the convergency of modern service industry and advanced manufacturing industry. In this study we used the per capita gross national product of Heilongjiang to reflect the province’s economy development state.

2.5. The level of capital input
Capital input enables current production, while creates supplies for future production. Serving as the main driving force of social and economic development, investment in fixed assets is the essential means of social reproduction of fixed assets. This study used the investment in fixed assets as the indicator of capital input.

2.6. The level of marketization
The state of marketization determines the flow of production factors between industries, and thus changes industrial scale. This study used the marketization index developed by Fan as the indicator to reflect level of marketization, and we assumed that the increase in marketization helps to promote the convergency of both of industries.
2.7. The level of science and technology input

The level of science and technology input drives industrial development, promoting technology spillover. Thus, it affects the convergency of modern service industry and advanced manufacturing industry. This study used the R&D investment of Heilongjiang as the indicator to reflect the level of science and technology input.

3. Extension assessment method

Extension Method is a frequency or method that solves problem qualitatively and quantitatively. Fundamental logical cells of Extension Method included: subject, character and subject’s character value, which is \( R = (\text{subject}, \text{character}, \text{value}) = (N, C, C(N)) \). Change of three matter elements and subjects’ internal structure lead to change of subject, and matter element become a basic tool to describe subject’s changeability. Combined with the basic idea of extension theory, the model of Advanced Manufacturing Industry and Modern Service Industry Performance evaluation is established.

Determination of Classic Field. Assume that the amount of assessment index are “n”, \( C_1, C_2, \ldots, C_n \); the amount of assessment level are “m”, \( N_1, N_2, \ldots, N_m \); then matter-element subject with the same characteristics can be demonstrated as:

\[
\begin{pmatrix}
N_{11} & N_{12} & \cdots & N_{1m} \\
N_{21} & N_{22} & \cdots & N_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
N_{n1} & N_{n2} & \cdots & N_{nm}
\end{pmatrix}
\]

where \((X_y)_{n \times m}\) is matter-element matrix; \( <a_{ij}, b_{ij}> \) is the value range of index \( N_j \) relative to index \( C_i \).

Determinations of segment field matter elements and assessment-waiting matter elements.

Let \( R_p = (P, C, X_p) = \begin{pmatrix} P & C_1 & X_{p1} \\ & & \vdots \\ & C_n & X_{pn} \end{pmatrix} \)

where \( P \) is the set of type; \( X_p \) is value range of \( P \) relative to \( C_n \) that is segment field \( <a_{pi}, b_{pi}> \). Indicate investigated data by matter elements.

a) Let \( w_j \) represent weighted parameter of index \( C_i \) \( \sum_{i=1}^{n} w_j = 1 \).

b) Calculate position value

\[
D(x_i, X_y, X_{pi}) = \begin{cases} 
\rho(x_i, X_{pi}) - \rho(x_i, X_y) & x_i \in X_{pi} \\
-1 & x_i \in X_y 
\end{cases}
\]

where \( \rho(x_i, X_{pi}) \) represents distance between dot and interval \( X_{pi} \), represents distance between dot and interval \( X_y \).

c) Calculation of Correlation Function
\[ K_j(x_i) = \frac{\rho(x_i, X_j)}{D(x_i, X_j, X_p)} = \begin{cases} \frac{\rho(x_i, X_j)}{\rho(x_i, X_j) - \rho(x_j, X_p)} & D(x_i, X_j, X_p) \neq 0 \\ \frac{\rho(x_i, X_j)}{\rho(x_j, X_p) - 1} & D(x_i, X_j, X_p) = 0 \end{cases} \]

Correlation function \( K_j(x_i) \) represents attribution of assessment-waiting matter’s each index relative to category “j”.

d) Calculate correlation degree of assessment-waiting matter relative to level “j”

\[ K_j(P_0) = \sum_{i=1}^{n} w_i K_j(x_i) \]

If \( K_{j0}(P_0) = \max_{j \in \{1, 2, \ldots, m\}} K_j(P_0) \), then assessment-waiting matter belongs to category \( j_0 \), Let

\[ j^* = \frac{\sum_{j=1}^{m} j \times K_j(P_0)}{\sum_{j=1}^{m} K_j(P_0)} \]

where \( j^* \) is called level variable value of \( P_0 \).

3.1. Extension model for performance evaluation of advanced manufacturing industry and modern service industry

The correct selection of evaluation index is necessary for the further research. On the basis of the existing research results, select evaluation index \( C_1 \) as the Policy support, \( C_2 \) as the Constraints of resources and environment, \( C_3 \) as the ratio of employees in the service and manufacturing industry in Heilongjiang to the province’s total employees, \( C_4 \) as the level of economic development, \( C_5 \) as the level of capital input, \( C_6 \) as the level of marketization, \( C_7 \) as the level of science and technology input. It can be used to evaluate the level range of each influencing factor through expert correspondence, and establish the corresponding classical domain by using the results of statistical processing

\[
R = \begin{bmatrix}
N & N_1 & N_2 & N_3 \\
C_{n1} & <0.3,0.5> & <0.5,0.7> & <0.7,0.9> \\
C_2 & <0.7,1> & <0.4,0.7> & <0.1,0.4> \\
C_3 & <0.1,0.1> & <0.1,0.3> & <0.3,0.5> \\
C_4 & <0.3,0.3> & <0.3,0.6> & <0.6,0.9> \\
C_5 & <0.4,0.4> & <0.4,0.7> & <0.7,1> \\
C_6 & <0.4,0.4> & <0.4,0.8> & <0.8,1> \\
C_7 & <0.3,0.3> & <0.3,0.7> & <0.7,0.9> \\
\end{bmatrix}
\]

Then segment field is: \( R_p = \begin{bmatrix}
P & C_1 & <0.3,0.9> \\
C_2 & <0.1,1> \\
C_3 & <0.0,5> \\
C_4 & <0.0,9> \\
C_5 & <0.1> \\
C_6 & <0.1> \\
C_7 & <0.0,9> \\
\end{bmatrix} \)

where \( P \) is the entirety of levels for performance evaluation, which in this study is categorized as three levels: low, medium and high.

Select five collaborative innovation projects and establish the matter element to be evaluated:
Weight coefficient plays an important role in superiority assessment. In order to determine the weight coefficient as reasonably as possible, this paper uses AHP method to determine the weight coefficient of the evaluation index of collaborative innovation projects to be evaluated (Tab.1).

Put data and weight coefficient of R0 into formula (1),(2),(3),(4) Figure out correlation degree of assessment-waiting project relative to each assessment level; Figure out value of level variable (j*). Assessment results are shown in table 2.

According to evaluation results in table 2, the first collaborative innovation project belongs to the first level with low performance for participants; the third and fifth projects belong to the second level with medium performance; the second and fourth projects belong to the third level with high performance, and the performance of the third project belonging to the second level is higher than that of the fifth project, and the performance of the fourth project belonging to the third level is lower than that of the second project.

**Table 1.** Weight factor and assessment index.

<table>
<thead>
<tr>
<th>Assessment index</th>
<th>C₁</th>
<th>C₂</th>
<th>C₃</th>
<th>C₄</th>
<th>C₅</th>
<th>C₆</th>
<th>C₇</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight factor</td>
<td>0.10</td>
<td>0.11</td>
<td>0.11</td>
<td>0.14</td>
<td>0.20</td>
<td>0.16</td>
<td>0.18</td>
</tr>
</tbody>
</table>

**Table 2.** Correlation and assessment result.

<table>
<thead>
<tr>
<th>Project</th>
<th>N₁(low)</th>
<th>N₂(medium)</th>
<th>N₃(high)</th>
<th>j</th>
<th>j*</th>
<th>Assessment result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.35</td>
<td>0.26</td>
<td>0.25</td>
<td>1</td>
<td>1.03</td>
<td>low</td>
</tr>
<tr>
<td>2</td>
<td>0.45</td>
<td>0.59</td>
<td>0.61</td>
<td>3</td>
<td>2.72</td>
<td>high</td>
</tr>
<tr>
<td>3</td>
<td>0.33</td>
<td>0.46</td>
<td>0.56</td>
<td>2</td>
<td>2.06</td>
<td>medium</td>
</tr>
<tr>
<td>4</td>
<td>0.21</td>
<td>0.55</td>
<td>0.65</td>
<td>3</td>
<td>2.61</td>
<td>high</td>
</tr>
<tr>
<td>5</td>
<td>0.34</td>
<td>0.43</td>
<td>0.47</td>
<td>2</td>
<td>1.89</td>
<td>medium</td>
</tr>
</tbody>
</table>

4. Summary

Matter element is an effective formal tool with wide-range of application which is capable of directly reflecting the quality and quantity of matter and vividly depicting its changing process. This study establishes multi-indices matter element model for Performance of Advanced Manufacturing Industry and Modern Service Industry by applying extension method and provides quantitative evaluation results. In generic, this study deepens current research on qualitative analysis on Performance of Advanced Manufacturing Industry and Modern Service Industry and illustrates a quantitative evaluation approach, which undoubtedly provides significant references for the decision making of collaborative innovation.

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