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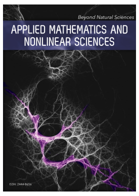

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Identifying the Critical Factors of Sustainable Manufacturing Using the Fuzzy DEMATEL Method

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Abstract

The burgeoning trend of globalization gives rise to the formation of the manufacturing ecosystem. This study aims to identify the critical factors of sustainable manufacturing for countries and regions across the globe finding their unique ecological niches. From the perspective of the ecological niche, we develop an evaluation system of the manufacturing niche. By using the fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, the critical factors, and its causal relationships of the manufacturing niche can be quantified and visualized. The results indicate that: (1) the evaluation system of the manufacturing niche is characterized by complexity and interactivity; (2) technical factors have the strongest impact on the evaluation system, among which R&D investment intensity and the input-output ratio of new products are key indicators; and (3) technical and policy factors are decisive for the system and actively influence economic and ecological factors. Theoretically, it is beneficial to augment the niche theory and industrial economics. Practically, it helps to create a win-win situation to facilitate governments to enact suitable industrial strategies and assist the manufacturing toward a more sustainable trajectory.

Keywords: ecological niche; sustainable manufacturing; evaluation system; influencing factors; fuzzy DEMATEL
AMS 2010 codes: F18941

1 Introduction

The manufacturing has evolved into an enormous industrial ecosystem in which a growing number of areas are embedded [1, 2]. To recognize the sustainable development of manufacturing in the ecosystem, countries, and regions across the globe need to develop unique competitive advantages [3]. Having a competitive advantage

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means the region can occupy a unique niche in the ecosystem. The ecological niche of a region is formulated by the active change and passive influence in its resource environment [4,5]. Similarly, the essence of manufacturing is to meet human needs by transforming natural resources, which is directly manifested as the material exchange between human society and the natural environment [6]. Thus, constructing a manufacturing niche is a dynamic process of utilizing resource endowment to interact with the environment. The country or region which occupies a unique ecological niche can take advantage of its superior resources in the fierce competition of manufacturing and find its advantageous position in the industrial ecosystem [7].

Research on manufacturing competitiveness is mainly based on the theories of comparative advantage and competitive advantage [8,9]. The comparative advantage focuses on the potentiality of industry, while the competitive advantage emphasis the competitiveness of industry [10]. The traditional theory of industrial competitiveness achieves the goal of maximizing individual economic benefits by analyzing the relative and absolute advantages but ignores the symbiotic relationship between industry and environment. The perspective of the ecological niche focuses on the co-evolutionary relationship between the niche subject and the environment, which reflects the situation and trend of the subject and its adaptive degree to the environment. Besides, it is emphasized that industrial development needs to be evaluated within the framework of economic and social sustainability [11]. Based on it, the possible future of sustainable manufacturing is to build a suitable and competitive industrial status from the perspective of the ecological niche.

To construct a manufacturing niche, regions must identify the key factors affecting the niche. The existing research mainly explores the influencing factors through literature analysis [12], an expert investigation [13], factor analysis [14], and fuzzy DEMATEL method [15]. The fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) method is used for mathematical processing and visual analysis of subjective judgment based on literature analysis and expert investigation, which enhances the rationality and objectivity of research. Besides, the fuzzy DEMATEL method can also study the causal relationship between the influencing factors and analyze the internal structure of the influencing indicator system, which is difficult to achieve by other methods mentioned above [16].

Therefore, this paper adopts the fuzzy DEMATEL method to study the impact factors of the manufacturing niche, and it aims to answer the following questions.

Q1: What are the influencing factors of the manufacturing niche? What are the key factors?

Q2: Do the influencing factors of the manufacturing niche interact with each other?

The remainder of this paper proceeds as follows. Firstly, the influencing factors of the manufacturing niche were determined by a detailed literature review. Next, the fuzzy DEMATEL method was used to identify critical factors and their causal relationships. The last part is the discussion and conclusion based on the research results.

The contribution of this article is twofold. Theoretically, this paper addresses the issues of the sustainability of manufacturing which can enrich the theory of ecological niche and industrial competitiveness. Practically, it helps to create a win-win situation that to facilitate countries and regions across the globe to form their unique niches and to assist the global manufacturing industry transforms toward the direction of integrated, ecological, and sustainable.

2 Literature review

The following literature review is summarized from three aspects: ecological niche, manufacturing niche, and the influencing factors of the manufacturing niche. Based on this, the indicators of manufacturing niche are sorted out.

2.1 Ecological Niche

Niche was first proposed by natural ecologist Johnson in 1910, but the concept of niche has not fully formed. Ecologist Joseph Grinnel (1917) initially defined ecological niche as "the final unit distributed by exactly one species or subspecies," which was later defined as "spatial niche" [17]. Based on the perspective of biological status, Elton (1927) proposed that the niche of an animal was the mutual relationship among animals, food, and predators, which later referred to as the "functional ecological niche" [18]. Hutchinson (1957) established the multi-dimensional super-volume niche model, which defines the niche as the combined total of the living conditions of a biological unit and its relationship with other organisms [19]. This theory has been widely recognized from the view of the organism's demand and adaptation to the resource environment, which is known as a multi-dimensional super-volume niche. The development of the concept of niche has gone through three major stages: "spatial niche," "functional niche" and "multi-dimensional super-volume niche." Since then, many scholars have further studied the connotation and extension of a niche. Most of them have integrated or enriched the concept of niche based on previous studies. Combining "spatial niche" and "functional niche," Woodwell et al. (1975) pointed out that niche refers to the location of a species in a natural ecosystem and its functional relationship with related species [20]. Cao (1995) applied fuzzy mathematics to put forward the concept of fuzzy niche, in an attempt to overcome the limitation of Hutchinson's concept of multi-dimensional super-volume niche [21]. He argues that the boundary of the niche is fuzzy and needs further clarification. Hao (2005) further explores and measures the theory of fuzzy super-volume niche on this basis [22]. Odling-Smee et al. (1996) emphasized the function of the niche and believed that the construction of niche was the self-positioning created by biological units through metabolism, selection, and other biological activities [23]. Zhang and Xie (1997) believed that a "multi-dimensional super-volume niche" could better reflect the essence of the concept of niche and better adapt to the development of ecological theory [24]. Warren et al. (2008) established the ecological niche model, popularly known as the ENM model, and pointed out that the difference in the niche was affected by environmental factors [25]. Laland et al. (2016) suggest that niche is an active choice made by biological units under environmental impact by discussing the concept of niche and related research results, emphasizing the important role of environmental factors [26]. Peng and Wang (2016) identify the development course of relevant studies on niche concepts and considered that the connotative characteristics of niche concepts include spatiotemporal, functional, environmental adaptability and population relationship, etc. [27]. This provides a more comprehensive view of niche theory. Li's (2019) study reveals the functional relationship between species and proposes that the niche has the characteristics of mutual benefit, adaptability, potential energy, etc. [28]. Schirmer et al. (2019) argue that niche is influenced by species activities, emphasizing the functional connotations of niches [29]. Although the foregoing conceptions of a niche are defined from different aspects, the basic ideas of niche theory are predominantly reflected in three aspects. First, it represents the status and function of biological units in the ecosystem. Second, it reflects the degree of acquisition and utilization of resources by biological units in the living environment. Third, it exhibits the competitive relationships among biological units and the impacts of such relationships on ecosystem diversity and order.

2.2 Manufacturing Niche

The application of niche theory in industry-related research involves a wide spectrum of sectors, such as agriculture [30], manufacturing [31], and tourism [32]. The research objectives of the manufacturing niche can be divided into three main categories from macro- to micro-level: manufacturing industry [33–35], manufacturing enterprises [36, 37], and manufacturing enterprise managers or employees [38]. The manufacturing industry is considered as the objective of this study. The manufacturing niche lies in the geographical or functional position of each region in the manufacturing ecosystem. On this basis, the influencing factors of the manufacturing niche are discussed.

2.3 Factors of the Manufacturing Niche

To develop a framework to evaluate the manufacturing niche, we used keywords "manufacturing development," "manufacturing evaluation" and "niche" in Google Scholar, Web of Science, and Scopus to identify pertinent literature that can facilitate our investigation. We set strict criteria to ensure that the documents we retrieved from the databases are up-to-date and of high relevance to our study [39–48]. We select some of the

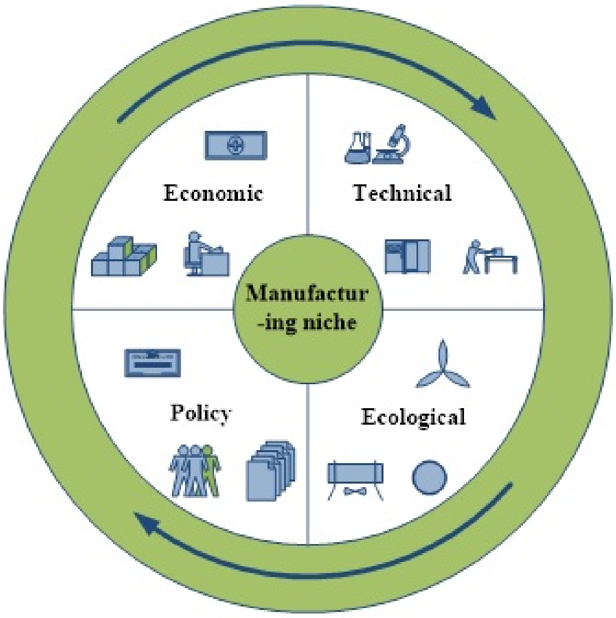

Fig. 1 Factors of manufacturing niche

most frequently occurring factors in the literature and invite experts to confirm the importance of indicators. And then the influencing factors of the manufacturing niche are divided into the economic factors, technical factors, policy factors, and ecological factors (Fig. 1). According to the evaluation principles of scientificity, flexibility, and operability [49], the indicators of each factor are summarized in Table 1.

3 Materials and Methods

To further explore the influencing factors and analyze the structure of the evaluation system of the manufacturing niche, the fuzzy DEMATEL method is used to quantify and visualize the research issues. The DEMATEL method, first proposed by the Battelle Memorial Institute at the Geneva Research Center in 1973 [50], is a comprehensive method that combines matrix and mathematical models to analyze structural relationships. The purpose of this approach is to help decision-makers identify causal relationships between essential criteria and key components of complex systems [51]. DEMATEL, as a valid evaluation technology, refers to the systematic relationships that can be clearly expressed with accurate values. However, it is difficult to realize the ideal state of precise description. Due to the limitations of evaluation criteria, different preferences, and other uncertain factors, it is often difficult to determine the exact value of the relationships. To improve the DEMATEL, many scholars use the fuzzy DEMATEL method to reduce subjective differences and judgment ambiguities [52–54]. According to the level identification, the impact degree is converted to the accurate value by the form of interval value. The operation steps are shown in figure 2.

3.1 DEMATEL Method

The DEMATEL method can adequately visualize the causal relationship of a complex structure and identify the critical indicators based on graphics. This method is widely applicable to solve comprehensive problems. According to the definition and method of Fontela and Gabus (1976) [55], the steps of using the DEMATEL method are as follows.

Step 1: Determine the influencing factors and define the relationships between factors. Suppose that the system contains a group of elements $E=\{e_1, e_2, \ldots, e_n\}$, and there is a specific pairing relationship (e_i, e_j) among the

Table 1 Indicators of manufacturing niche.

Factors	Indicators	
Economic factor (A_1)	Total asset contribution rate	N_1
	Industrial value-added growth rate	N_2
	Profit margin on output	N_3
	Profit margin on sales	N_4
	Profit margin on cost and expense	N_5
	Fixed assets investment novelty coefficient	N_6
Technical factor (A_2)	R&D investment intensity	N_7
	R&D personnel investment intensity	N_8
	The number of invention patents per capita	N_9
	The input-output ratio of new products	N_{10}
	The proportion of technology market turnover	N_{11}
Policy factor (A_3)	Government R&D expenditure ratio	N_{12}
	The number of government innovation policies	N_{13}
	The rate of introduction of scientific and technological talents	N_{14}
Ecological factor (A_4)	Energy consumption per unit output value	N_{15}
	Completion rate of industrial pollution control	N_{16}
	Air quality ratio	N_{17}

Source: sorted out by authors

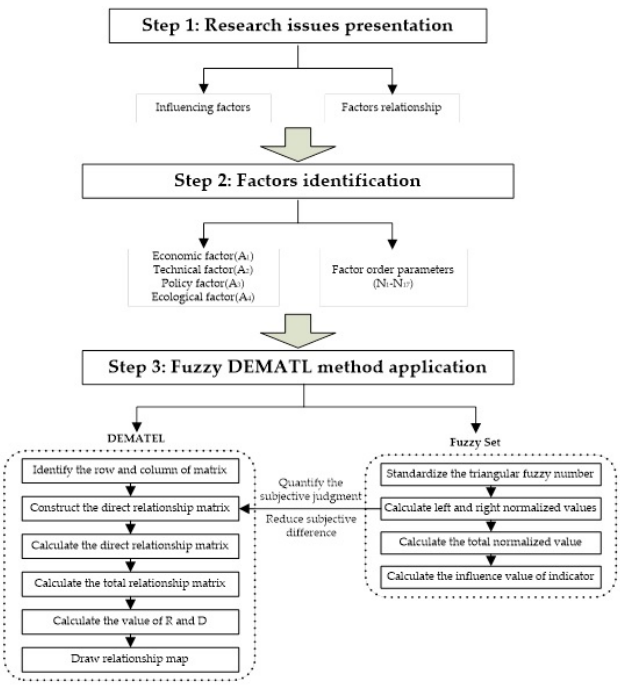

Fig. 2 Steps of fuzzy DEMATEL

factors. Use a_{ij} to express the influence relationship of the element e_i on the element e_j.
Step 2: Construct the direct relation matrix A. The influence intensity between the two factors is divided into five levels of "0-4". 0, 1, 2, 3 and 4 indicate "no influence", "low influence ", "medium influence ", "strong influence" and "very strong influence" respectively. The direct relation matrix A can be expressed as:

$$A = \begin{bmatrix} 0 & a_{12} & \dots & a_{1n} \\ a_{21} & 0 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 0 \end{bmatrix} = [\mathrm{a}_{ij}]_{n\times n} (1 \leq i \leq n, 1 \leq j \leq n, i \neq j) \tag{1}$$

Step 3: Normalization matrix A. The normalized direct relation matrix Z is obtained as follows:

$$s = \frac{1}{\max\limits_{1\leq i\leq n} \sum\limits_{j=1}^{n} a_{ij}} \tag{2}$$

$$Z = s \times A \tag{3}$$

Step 4: Calculate the comprehensive relation matrix T, where I represents the unit matrix.

$$T = \sum_{i=1}^{n} Z_i = \sum_{i=1}^{+\infty} Z_i = Z(I-Z)^{-1} \tag{4}$$

Step 5: Calculate the sum of rows and columns of the matrix T. The index t_{ij} in matrix T indicates the comprehensive influence degree of the element e_i on e_j. The sum of the line i is represented by r_i, which is called the influence degree D. D represents the sum of the effects of the factor e_i on others. The sum of columns j is represented by c_j, which is called the affected degree R. R represents the sum of the extent to which the factor e_j is affected by others. When $i = j$, $(r_i + c_i)$ denotes the impact degree of the index i on the whole system, which is called centrality $(D+R)$. When $i = j$, $(r_i - c_i)$ denotes the impact degree of the index e_i on the whole system, which is called cause degree $(D-R)$. If $(r_i - c_i) > 0$, index e_i denotes causal factor, and if $(r_i - c_i) < 0$, index e_i denotes outcome factor.

$$D = \left[\sum\nolimits_{j-1}^{n} t_{ij}\right]_{n\times 1} \tag{5}$$

$$D = \left[\sum\nolimits_{j-1}^{n} t_{ij}\right]_{n\times 1} \tag{6}$$

Step 6: Draw the elemental influence diagram. The Cartesian coordinate system is established with the central degree $(D+R)$ and the cause degree $(D-R)$ as the horizontal and vertical axes. Mark the positions of elements in the coordinate system and rank the indicators in order of importance.

3.2 Fuzzy Set Method

In actual decision-making situations, evaluation on a pair of objects is not an accurate score, but a linguistic expression based on the experience and expertise of experts. The ambiguity of evaluation increases the difficulty of calculating evaluation results. To measure and quantify the subjective judgments or fuzzy concepts of the expert panel, this paper introduces the fuzzy set theory. It uses Triangular Fuzzy Number (TFN) to convert the judgment statements numerically. In fuzzy logic, each number between 0 and 1 represents a partial actual value, corresponding to binary logic [0, 1]. According to the research and application of fuzzy set theory by Cerioli (1990) [56] and Chen et al. (2006) [57], the following definitions are given.
Definition 1: Define the fuzzy number $\tilde{A}$ on the real number set R. Define the membership function $u_{\tilde{A}}(x)$. $u_{\tilde{A}}(x)$ is the degree of membership of x to u. For any $x \in \tilde{A}$, there is a number $u_{\tilde{A}}(x) \in [0,1]$ corresponding to it.

Definition 2: $\tilde{A}$ is defined as a triple (l,m,r) according to Triangular Fuzzy Number (TFN), where l, m, r are real numbers and $l \leq m \leq r$. The lower and upper limits of the fuzzy number are l and r respectively. The membership function can be expressed as:

$$u_{\tilde{A}}(x) = \begin{cases} 0, x \leq l \\ \frac{x-l}{m-l}, l < x \leq m \\ \frac{r-x}{r-m}, m < x \leq r \\ 0, x > r \end{cases} \tag{7}$$

Converting the fuzzy language judgments into specific scores is the core of the fuzzy set method. According to the Converting Fuzzy Data into Crisp Scores (CFCS) method proposed by Opricovic and Tzeng(2004) [58], the total normalized value is calculated by the left and right normalized values, and the quantification process of the fuzzy data is completed by weighting the total score. Assuming that there are K experts who are invited to express their judgments on the impact of the factor e_i on the factor e_j by k_{ij}, the specific steps of applying the CFCS method are as follows.

Step 1: Standardize the triangular fuzzy number.

$$xl_{ij}^k = \frac{l_{ij}^k - \min l_{ij}^k}{\Delta_{\min}^{\max}} \tag{8}$$

$$xm_{ij}^k = \frac{m_{ij}^k - \min m_{ij}^k}{\Delta_{\min}^{\max}} \tag{9}$$

$$xr_{ij}^k = \frac{r_{ij}^k - \min r_{ij}^k}{\Delta_{\min}^{\max}} \tag{10}$$

Where, $\Delta_{\min}^{\max} = \max r_{ij}^k - \min l_{ij}^k$.

Step 2: Calculate left and right normalized values.

$$xls_{ij}^k = \frac{xm_{ij}^k}{1 + xm_{ij}^k - xl_{ij}^k} \tag{11}$$

$$xrs_{ij}^k = \frac{xr_{ij}^k}{1 + xr_{ij}^k - xm_{ij}^k} \tag{12}$$

Step 3: Calculate the total normalized value.

$$x_{ij}^k = \frac{xls_{ij}^k(1 - xls_{ij}^k) + xrs_{ij}^k xrs_{ij}^k}{1 - xls_{ij}^k + xrs_{ij}^k} \tag{13}$$

Step 4: Calculate the influence value of factor e_i evaluated by the expert k on factor e_j.

$$w_{ij}^k = \min l_{ij}^k + x_{ij}^k \Delta_{\min}^{\max} \tag{14}$$

Step 5: Calculate the influence value of factor e_i evaluated on the factor e_j by expert panel K.

$$w_{ij} = \frac{1}{K} \sum_{k=1}^{K} w_{ij}^k \tag{15}$$

4 Results

The fuzzy DEMATEL method was used to identify the key influencing factors and analyze the relationships between factors of the manufacturing niche. The specific steps are as follows.
Step 1: Invite an expert panel to assess the relationships between factors. According to the evaluation system determined above, the primary impact factors of manufacturing niche include economic factor (A_1), technical factor (A_2), policy factor (A_3), and ecological factor (A_4). The four factors contain a total of 17 order parameter components (N_1-N_{17}). Seven experts in the field of industrial management were invited to determine the degree of interaction between factors based on knowledge reserves and practical experience by questionnaire. The expert panel is composed of three scholars specialized in industrial management, two government officials from the industrial development sector, and two senior managers from manufacturing enterprises. All the experts have been working in the field of manufacturing for more than ten years. The composition of the expert panel represents perspectives from various stakeholders including researchers, policymakers, and practitioners, which ensures the reliability of our analysis. The influence degree of factors were divided into five levels: with no influence as "0," low influence as "1," medium influence as "2," strong influence as "3" and very strong influence as "4." The direct relationship matrix A was constructed according to formula (1).
Step 2: According to the Fuzzy Semantic Scale (Table 2) and the CFCS method, the experts' judgments were converted into fuzzy triangular numbers. The direct relation matrix $\tilde{A}$ was calculated by using formula (8)-(13).

Table 2 The Fuzzy Linguistic Scale.

Linguistic terns	Influence score	Triangular fuzzy numbers(TFN)
No influence	0	(0,0.1,0.3)
Low influence	1	(0.1,0.3,0.5)
Medium influence	2	(0.3,0.5,0.7)
Strong influence	3	(0.5,0.7,0.9)
Very strong influence	4	(0.7,0.9,1)

Source: proposed by Wang and Chang [59].

Step 3: Normalize matrix $\tilde{A}$ according to formula (2)-(3) and calculate comprehensive relation matrix T according to formula (4). The total relation matrix T of the influencing factors is shown in table 3.
Step 4: Calculate the influence degree (D), affected degree (R), center degree (D + R), and cause degree (D-R) of each factor according to formula (5)-(6) which is shown in table 4.
Step 5: Draw an impact diagram (Fig. 3). Centrality is used as the horizontal axis to measure the importance of the factors. The greater the centrality (D+R) of the factor, the more important it is in the system. The causal degree is used as the vertical axis to judge the causal group. If the causality (D-R) of the factor is greater than 0, it indicates that the factor is the causal factor and vice versa is the outcome factor.

Based on the calculation results and the visualization diagram, the components of the evaluation index system of the manufacturing niche are classified and the following results are obtained.

In general, the evaluation system consists of 4 influencing factors and 17-factor order parameters, which is characterized by complexity and interactivity.

In terms of the importance of factors, the centrality value (D + R) of technical factor (A_2) is the largest, followed by the economic factor (A_1) and policy factor (A_3). The centrality value of the ecological factor (A_4) is the smallest. It shows that the technical factor has the most significant impact on other factors and the whole evaluation system. It is the most important factor in the evaluation system, while the ecological factor is the least. Specifically, to the five order parameter components (N_7-N_{11}) of the technical factor (A_2), the centrality values (D+R) ranked in the top five of the evaluation system. Among them, R&D investment intensity (N_7) ranks first and the input-output ratio of new products (N_{10}) ranks second, with little difference in centrality value. It shows that R&D investment intensity (N_7) and the input-output ratio of new products (N_{10}) are the key

Table 3 The total relation matrix T

Factors		N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	N_9	N_{10}	N_{11}	N_{12}	N_{13}	N_{14}	N_{15}	N_{16}	N_{17}
		A_1						A_2					A_3			A_4		
A_1	N_1	0.310	0.330	0.337	0.319	0.325	0.260	0.315	0.298	0.301	0.329	0.307	0.272	0.251	0.272	0.301	0.270	0.242
	N_2	0.369	0.379	0.392	0.372	0.379	0.301	0.369	0.349	0.353	0.385	0.359	0.320	0.294	0.318	0.352	0.317	0.285
	N_3	0.372	0.387	0.387	0.375	0.381	0.303	0.370	0.350	0.354	0.389	0.362	0.319	0.295	0.318	0.354	0.319	0.285
	N_4	0.320	0.333	0.341	0.316	0.329	0.261	0.318	0.301	0.305	0.333	0.310	0.274	0.254	0.273	0.303	0.273	0.245
	N_5	0.331	0.347	0.354	0.335	0.335	0.272	0.331	0.313	0.317	0.346	0.322	0.285	0.264	0.283	0.317	0.285	0.254
	N_6	0.337	0.352	0.358	0.340	0.348	0.271	0.337	0.319	0.321	0.353	0.327	0.290	0.267	0.287	0.321	0.290	0.258
A_2	N_7	0.435	0.455	0.461	0.437	0.446	0.354	0.427	0.413	0.417	0.455	0.425	0.376	0.346	0.374	0.413	0.374	0.334
	N_8	0.437	0.459	0.464	0.440	0.450	0.357	0.440	0.408	0.421	0.459	0.428	0.379	0.349	0.377	0.417	0.377	0.337
	N_9	0.421	0.442	0.446	0.424	0.433	0.344	0.424	0.403	0.398	0.443	0.413	0.366	0.338	0.364	0.402	0.363	0.324
	N_{10}	0.416	0.436	0.442	0.420	0.428	0.341	0.417	0.395	0.399	0.428	0.407	0.360	0.333	0.359	0.397	0.357	0.319
	N_{11}	0.416	0.436	0.443	0.421	0.428	0.341	0.418	0.396	0.401	0.436	0.400	0.362	0.334	0.360	0.397	0.358	0.320
A_3	N_{12}	0.440	0.459	0.466	0.442	0.452	0.360	0.442	0.419	0.424	0.461	0.430	0.375	0.353	0.381	0.420	0.379	0.340
	N_{13}	0.423	0.442	0.449	0.427	0.435	0.347	0.426	0.404	0.408	0.443	0.415	0.371	0.334	0.369	0.405	0.366	0.328
	N_{14}	0.413	0.433	0.437	0.414	0.423	0.336	0.413	0.394	0.398	0.432	0.404	0.359	0.332	0.350	0.394	0.356	0.318
A_4	N_{15}	0.365	0.381	0.386	0.368	0.375	0.297	0.363	0.344	0.346	0.379	0.353	0.314	0.290	0.313	0.342	0.318	0.286
	N_{16}	0.331	0.347	0.352	0.335	0.342	0.271	0.332	0.314	0.318	0.347	0.323	0.288	0.266	0.287	0.322	0.283	0.263
	N_{17}	0.267	0.281	0.285	0.271	0.277	0.220	0.269	0.255	0.257	0.281	0.261	0.234	0.216	0.233	0.261	0.238	0.206

Source: calculated by authors.

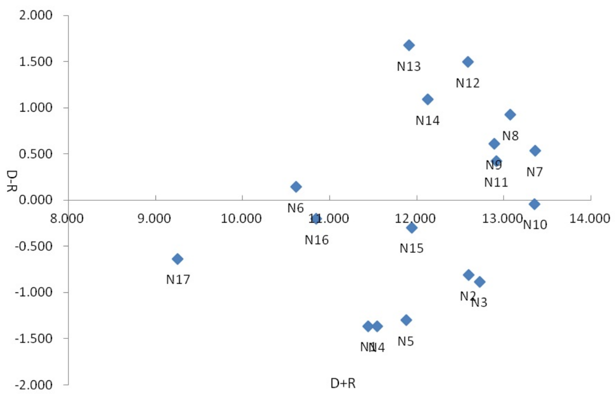

Fig. 3 Cause-effect group diagram.

indicators affecting the manufacturing niche.

In terms of the correlations between factors, the causal factors are mainly distributed in technical factors (A_2) and policy factors (A_3). In contrast, the outcome factors are mainly distributed in economic factors (A_1) and ecological factors (A_4). Indicators with a (D-R) value greater than 0 are the causal factors, including fixed assets investment novelty coefficient (N_6), R&D investment intensity (N_7), R&D personnel investment intensity

Table 4 The centrality of factors and cause-effect group.

		D	R	(R+D)	(R-D)
A_1	N_1	5.040	6.403	11.443	-1.363
	N_2	5.890	6.700	12.591	-0.810
	N_3	5.919	6.800	12.718	-0.881
	N_4	5.090	6.455	11.545	-1.365
	N_5	5.289	6.587	11.876	-1.298
	N_6	5.378	5.234	10.612	0.143
A_2	N_7	6.944	6.411	13.356	0.533
	N_8	6.999	6.075	13.074	0.923
	N_9	6.748	6.139	12.886	0.609
	N_{10}	6.656	6.697	13.354	-0.041
	N_{11}	6.666	6.246	12.911	0.420
A_3	N_{12}	7.042	5.544	12.586	1.499
	N_{13}	6.792	5.118	11.910	1.675
	N_{14}	6.608	5.518	12.126	1.090
A_4	N_{15}	5.823	6.120	11.943	-0.297
	N_{16}	5.323	5.524	10.846	-0.201
	N_{17}	4.312	4.946	9.257	-0.634

Source: calculated by authors.

(N_8), the number of invention patents per capita (N_9), the proportion of technology market turnover (N_{11}), government R&D expenditure ratio (N_{12}), the number of government innovation policies (N_{13}), rate of introduction of scientific and technological talents (N_{14}). They belong to the technical factor (A_2) and the policy factor (A_3). Indicators with a (D-R) value less than 0 are the outcome factors, including total asset contribution rate (N_1), industrial value-added growth rate (N_2), the profit margin on output (N_3), the profit margin on sales (N_4), the profit margin on cost and expense (N_5), the input-output ratio of new products (N_{10}), energy consumption per unit output value (N_{15}), the completion rate of industrial pollution control (N_{16}) and air quality ratio (N_{17}). They are economic factors (A_1) and ecological factors (A_4). The distribution of the factors indicates that technical and policy factors play a decisive role in the evaluation system, actively affecting economic and ecological factors. Economic and ecological indicators are the embodiment of output.

5 Discussion

This study provides insights into the influencing factors and the evaluation structure of the manufacturing niche. Countries and regions can identify the strengths and weaknesses of the manufacturing niche, which supports the development and implementation of rational industrial strategies. The results indicate that technical factors and policy factors are decisive for the evaluation system of the manufacturing niche. It shows that strengthening innovation activities and policy supports can increase the economic output and environmental friendliness of the manufacturing. It can also enhance competitive advantage and sustainability. Dynamic strategies can be enacted to be adapted to local conditions. As for the role of technical factor, there has been a consensus on its crucial function [60]. The lack of technical capacity is the bottleneck hindering the improvement of national economics and the development of the manufacturing industry. With the advance of science and technology, the weights of technical factors are increasing. However, the emphasis on economic and policy factors is different. Most of the existing studies have focused on the role of economic factors. These studies demonstrate that the market is the driving force to enhance industrial competitiveness [61]. While the policy factors tend to be treated lightly or to be limited to the scope of policy research [62]. As for ecological factors, more attention has been paid with the popularization of ecological concepts in recent years.

Thus, the results of this paper confirm the salient role of technical factors. The development and enhancement of innovation activities can significantly increase the competitive advantage of manufacturing. A series of arrangements for technological innovation has accelerated the flow of technology from advanced countries to developing countries. This kind of technological innovation activity is mainly manifested in the process of digestion, absorption, and re-innovation of technology in the developing countries to play the diffusion effect of technology, which leads to the rapid development of a series of related industries.

Meanwhile, the results of this paper underline the role of policy factors. It is considered that the strengthening of policy is the reason for improving market efficiency and green development of the manufacturing industry. The formulation and implementation of a series of industrial policies can accelerate the flow and allocation of industrial resources such as capital, technology, and talents. It also guides the manufacturing toward the direction of low energy consumption and low pollution.

6 Conclusions

This paper develops a system to evaluate the manufacturing niche and analyze the key factors and their causal relationships. It can provide the basis for scientific decision-making by the governments and industrial organizations, contributes to build a more sustainable manufacturing ecosystem and to promote the manufacturing toward the direction of integration, dynamics, and ecology.

The fuzzy DEMATEL method is used in this paper to quantify and visualize the critical factors and system structure of the manufacturing niche. This method can reduce the subjective biases and vague judgments. It facilitates policymakers, practitioners, and researches to identify the causal relationships between important standards and examine the key components of complex systems.

According to the results, the evaluation system of the manufacturing niche is characterized by complexity and interactivity. Technical factors have the strongest impact on the system among which R&D investment intensity and the input-output ratio of new products are the key indicators affecting the manufacturing niche. Technical and policy factors are decisive for the system and affect the economic and ecological factors actively.

In this paper, the number of experts interviewed is limited and the results lack the verification of empirical data. In terms of further research perspectives, we may dig into the niche of specific manufacturing industries and extend the comparisons to different countries and regions.

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References

[1] Maltsev, A., C. Mercier-Suissa, and A. Mordvinova, Interpretation of the term "Reindustrialization" in the conditions of globalization. Economy of region, 2017. 1(4): pp. 1044-1054.

[2] Baas, L., *Cleaner production and industrial ecology: a dire need for 21st century manufacturing*, in *Handbook of Performability Engineering*. 2008, Springer. pp. 139-156.

[3] Blázquez, L., C. Díaz-Mora, and B. González-Díaz, The role of services content for manufacturing competitiveness: A network analysis. Plos one, 2020. 15(1): pp. e0226411.

[4] McInerny, G.J. and R.S. Etienne, Pitch the niche–taking responsibility for the concepts we use in ecology and species distribution modelling. Journal of Biogeography, 2012. 39(12): pp. 2112-2118.

[5] Schlichtman, J.J., The niche city idea: How a declining manufacturing center exploited the opportunities of globalization. International Journal of Urban and Regional Research, 2009. 33(1): pp. 105-125.

[6] Li, P.; Wang, Q.; HE, J.; WU, B., The Construction of the Index System of Sustainable Development of China's Manufacturing Sector and Forecast. China Industrial Economics, 2010(5): pp. 5-15.

[7] McCarthy, I. and Y. Tan, Manufacturing competitiveness and fitness landscape theory. Journal of Materials Processing Technology, 2000. 107(1-3): pp. 347-352.

[8] Eaton, J. and S. Kortum, Technology, geography, and trade. Econometrica, 2002. 70(5): pp. 1741-1779.
[9] Porter, M.E., The five competitive forces that shape strategy. Harvard business review, 2008. 86(1): pp. 25-40.
[10] Lin, Y. and Y. Li, Between comparative advantage, competitive advantage and economic growth in developing countries. Management World, 2003. 7.
[11] Yu, C.,; Fuji, X.; Xiaoyu, Y.; You J, Determinants and path selection of niche evolutionary of strategic emerging industries. Journal of Systems & Management 2018. 27: pp. 414-421, 451.
[12] Swuste, P., et al., Process safety indicators, a review of literature. Journal of Loss Prevention in the Process Industries, 2016. 40: pp. 162-173.
[13] Holm, H., et al., Indicators of expert judgement and their significance: an empirical investigation in the area of cyber security. Expert Systems, 2014. 31(4): pp. 299-318.
[14] Chen, C. K., Construct model of the knowledge-based economy indicators. Transformations in Business & Economics, 2008. 7(2): pp. 21-31.
[15] Lin, R. J., Using fuzzy DEMATEL to evaluate the green supply chain management practices. Journal of Cleaner Production, 2013. 40: pp. 32-39.
[16] Büyüközkan, G. and G. Çifçi, A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. Expert Systems with Applications, 2012. 39(3): pp. 3000-3011.
[17] Grinnell, J., The niche-relationships of the California Thrasher. The Auk, 1917. 34(4): pp. 427-433.
[18] Elton, C., Animal ecology: London. Sidgwick and Jackson, Ltd, 1927.
[19] Hutchinson, G.E., Cold spring harbor symposium on quantitative biology. Concluding remarks, 1957. 22: pp. 415-427.
[20] Woodwell, G., R. Whittaker, and R. Houghton, Nutrient concentrations in plants in the Brookhaven oak-pine forest. Ecology, 1975. 56(2): pp. 318-332.
[21] Cao, G., The definition of the niche by fuzzy set theory. Ecological Modelling, 1995. 77(1): pp. 65-71.
[22] Feng, H., Study and application on the theory of fuzzy hypervolume niche. 2005, Jiangsu University: Zhenjiang, China.
[23] Odling-Smee, F.J., K.N. Laland, and M.W. Feldman, Niche construction. The American Naturalist, 1996. 147(4): pp. 641-648.
[24] Zhang, G. and S. Xie, Developement of Niche Concept and Its Perspectives: A Review. [J]. Chinese Journal of Ecology, 1997. 16(46-51).
[25] Warren, D.L., R.E. Glor, and M. Turelli, Environmental niche equivalency versus conservatism: quantitative approaches to niche evolution. Evolution: International Journal of Organic Evolution, 2008. 62(11): pp. 2868-2883.
[26] Laland, K., B. Matthews, and M.W. Feldman, An introduction to niche construction theory. Evolutionary ecology, 2016. 30(2): pp. 191-202.
[27] Peng, W. and X. Wang, Concept and connotation development of niche and its ecological orientation. Chinese Journal of Applied Ecology, 2016. 27(1): pp. 327-334.
[28] Li, D., Several thoughts on niche and niche ethics. Academic Exchange 2019. 4: pp. 87-95.
[29] Schirmer, A., et al., Individuals in space: personality-dependent space use, movement and microhabitat use facilitate individual spatial niche specialization. Oecologia, 2019. 189(3): pp. 647-660.
[30] Bleed, P. and A. Matsui, Why Didn't Agriculture Develop in Japan? A Consideration of Jomon Ecological Style, Niche Construction, and the Origins of Domestication. Journal of Archaeological Method and Theory, 2010. 17(4): pp. 356-370.
[31] Ward, P.T., D.J. Bickford, and G.K. Leong, Configurations of manufacturing strategy, business strategy, environment and structure. Journal of management, 1996. 22(4): pp. 597-626.
[32] Navickas, V. and A. Malakauskaitė, The possibilities for the identification and evaluation of tourism sector competitiveness factors. Inžinerinė ekonomika, 2009(1): pp. 37-44.
[33] Peng, B., et al., The cultivation mechanism of green technology innovation in manufacturing industry: From the perspective of ecological niche. Journal of Cleaner Production, 2020. 252: pp. 119711.
[34] Tian, H. and Z. Wang, Chinese green process innovation in automotive painting: the strategic niche management perspective. International Journal of Environmental Science and Technology, 2020. 17(2): pp. 993-1010.
[35] Spillan, J.E., et al., Strategic capabilities, niche strategy orientation and performance: a four-nation assessment. International Journal of Business Performance Management, 2018. 19(4): pp. 427-449.
[36] Zhao, Z.-y., W.-j. Ling, and G. Zillante, An evaluation of Chinese Wind Turbine Manufacturers using the enterprise niche theory. Renewable and Sustainable Energy Reviews, 2012. 16(1): pp. 725-734.
[37] Xiaodi, X. and W. Zilong, The Kr Selecting Strategy of Enterprise Niche. Management Review, 2006. 10: pp. 35-40.
[38] Li, Z. J., A. M. Yan, and J. Wei, The Niche Structure and Measurement of the Senior Managers in Equipment Manufacturing Industry. Systems Engineering, 2012. 12: pp. 77-83.
[39] Rusinko, C., Green manufacturing: an evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes. IEEE Transactions on Engineering Management, 2007. 54(3): pp. 445-454.
[40] Apergis, N., C. Economidou, and I. Filippidis, Innovation, technology transfer and labor productivity linkages: evidence from a panel of manufacturing industries. Review of World Economics, 2008. 144(3): pp. 491-508.

[41] Huang, Q. and J. He, The core capability, function and strategy of Chinese manufacturing industry: Comment on" Chinese manufacturing 2025". China Industrial Economics, 2015. 6: pp. 5-17.
[42] Li, L., Z. Cheng, and J. Liu, The "new pattern" of Chinese manufacturing industry and its evaluation research. China Industrial Economics, 2015. 2: pp. 63-75.
[43] Amato, L.H. and C.H. Amato, The effects of global competition on total factor productivity in US manufacturing. Review of Industrial Organization, 2001. 19(4): pp. 405-421.
[44] Mohanty, R. and S. Deshmukh, Evaluating manufacturing strategy for a learning organization: a case. International Journal of Operations & Production Management, 1999.
[45] Lutter-Günther, M., et al. *Economic and ecological evaluation of hybrid additive manufacturing technologies based on the combination of laser metal deposition and CNC machining*. in *Applied mechanics and materials*. 2015. Trans Tech Publ.
[46] Correia da Silva Andrade, L.P., et al., Evaluation of Technological Trends and Demands of the Manufacturing Industry to a Center of R & D & I. Journal of technology management & innovation, 2015. 10(3): pp. 104-119.
[47] Huang, L.C. and Zhang H. C., Evaluation of Efficiency of Technology Innovation in Beijing's Manufacture Industry R&D Management, 2006. 3: pp. 279-282.
[48] Chen, H.; Yin, X.; Chen, J.; Wang, L., Research on scientific and technological innovation niche based on holistic innovation theory. Science of Science and Management of S.& T., 2019. 40: pp. 3-16.
[49] Qi, E. S. and Wang H. M., Evaluation Systems for Manufacturing Informatization. Industrial Engineering Journal 2004. 7(5): pp. 1-4.
[50] Gabus, A. and E. Fontela, World problems, an invitation to further thought within the framework of DEMATEL. 1973: Battelle Geneva Research Centre, Geneva.
[51] Chang, B., Chang C. W., and Wu C. H., Fuzzy DEMATEL method for developing supplier selection criteria. Expert systems with Applications, 2011. 38(3): pp. 1850-1858.
[52] Akyuz, E. and E. Celik, A fuzzy DEMATEL method to evaluate critical operational hazards during gas freeing process in crude oil tankers. Journal of Loss Prevention in the Process Industries, 2015. 38: pp. 243-253.
[53] Wu, W.-W. and Y.-T. Lee, Developing global managers' competencies using the fuzzy DEMATEL method. Expert systems with applications, 2007. 32(2): pp. 499-507.
[54] Lin, K. P., M. L. Tseng, and P. F. Pai, Sustainable supply chain management using approximate fuzzy DEMATEL method. Resources, Conservation and Recycling, 2018. 128: pp. 134-142.
[55] Fontela, E. and A. Gabus, The DEMATEL observer, DEMATEL 1976 report. Battelle Geneva Research Center, Geneva, 1976.
[56] Cerioli, A. and S. Zani, *A fuzzy approach to the measurement of poverty*, in *Income and wealth distribution, inequality and poverty*. 1990, Springer. pp. 272-284.
[57] Chen, C. T., C. T. Lin, and S. F. Huang, A fuzzy approach for supplier evaluation and selection in supply chain management. International journal of production economics, 2006. 102(2): pp. 289-301.
[58] Opricovic, S. and G.-H. Tzeng, Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. European journal of operational research, 2004. 156(2): pp. 445-455.
[59] Wang, M. J.J. and T. C. Chang, Tool steel materials selection under fuzzy environment. Fuzzy Sets and Systems, 1995. 72(3): pp. 263-270.
[60] Kirner, E., S. Kinkel, and A. Jaeger, Innovation paths and the innovation performance of low-technology firms—An empirical analysis of German industry. Research Policy, 2009. 38(3): pp. 447-458.
[61] Filieri, R., From market-driving to market-driven. Marketing Intelligence & Planning, 2015. 33(3): pp. 238-257.
[62] Reischauer, G., Industry 4.0 as policy-driven discourse to institutionalize innovation systems in manufacturing. Technological Forecasting and Social Change, 2018. 132: pp. 26-33.