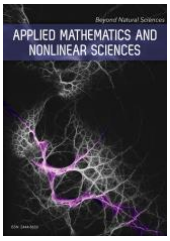
sciendo Applied Mathematics and Nonlinear Sciences, 9(1) (2024) 1-23



Applied Mathematics and Nonlinear Sciences

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Research on Enterprise Management Process Reengineering Strategies for Integrating Innovation Ecosystems in the Age of Artificial Intelligence

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Submission Info

Communicated by Z. Sabir
Received March 15, 2024
Accepted June 8, 2024
Available online July 9, 2024

Abstract

Innovation is the inexhaustible driving force for an enterprise to realize sustainable development, and enterprise management process reengineering within the innovation ecosystem is the key know-how for the growth of enterprise benefits. This paper focuses on the realization of enterprise management process reengineering within the innovation ecosystem. The study starts with the construction of an embedded innovation ecosystem model, and it is then analyzed for threshold effects. The hexadecimal structure of fuzzy Petri nets is used to establish a diagnostic model of enterprise management processes, and problems in enterprise management processes are supervised through fault tree analysis so as to improve and optimize the management processes and process reengineering of the enterprise. The research on enterprise management process reengineering in this paper employs F-cluster analysis and fuzzy C-mean cluster analysis to fully demonstrate the relationship between the activities of every management process in the enterprise. Through the study, it is concluded that the open innovation and shared cognitive capital variables designed in this paper in constructing the embedded innovation ecosystem model have successfully passed the reliability and validity test and play an important role in enterprise innovation. In the case study of enterprise management process reengineering, the management process of enterprise A that implemented process reengineering realized intelligent transformation. The resulting total share of production cost of enterprise A decreased to 91.2%, and the overall cost of energy saving was about 10% or so.

Keywords: Innovation ecosystem; Process reengineering; Cluster analysis; Petri net.
AMS 2010 codes: 68P30

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ISSN 2444-8656
https://doi.org/10.2478/amns-2024-1803

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1 Introduction

Under the new situation, how to better adapt to the market to meet customer demand to maximize the benefits of enterprises has become an important topic for enterprises to think about and explore. The implementation of market-oriented enterprise process re-engineering is imperative. With the gradual implementation of national measures on enterprise system reform and the increasingly fierce competition in the market, it is difficult for enterprises to gain a competitive advantage only through tangible products. The enterprise's central task must be shifted from production-based to "meet and create user demand" as the main enterprise growth has been moved from investment-driven to management-driven [1-3].

How to improve the level of management has become a priority for enterprises [4]. At the same time, many shortcomings of each enterprise are also becoming more and more prominent. First of all, the backwardness of the business philosophy, the heavy power distribution, and neglect of process control leading to the enterprise management function division of labor are too detailed, the business process is long, and many links affect the operational efficiency [5]. Functional management based on specialized division of labor solidified the enterprise management mode. Employees only act according to instructions. Initiative creativity is not enough and is not conducive to the development of individual employees, affecting the vitality of the enterprise and resulting in enterprises facing the potential crisis of brain drain [6-7]. Secondly, the enterprise organizational structure is set up according to the professional departments, each department relies on the superior instructions and regulations to operate, focusing on the power to dominate, affecting the overall effectiveness of the enterprise. More seriously, this functional management determines that the processes of the enterprise are not based on the needs of the market and customers but are produced and operated in the way of organizational and administrative orders [8-10].

Changes in the environment and the pressure of competition force enterprises to face challenges directly [11]. In order to improve market competitiveness, profitability, and rapid market response, enterprises must fundamentally rethink their operation mode and truly establish market-oriented enterprise processes through process reengineering [12].

At the same time, if the enterprise competition is limited to the domestic competition between traditional competitors, the market environment is relatively stable, the enterprise information management is characterized only by information technology as a new means of management to strengthen the internal basic management of the enterprise as the basis for the management of information technology transformation [13-14]. The basic content is the establishment of an enterprise database and enterprise intranet. This is a kind of shallow management informatization, that is to say, the use of advanced productive forces to strengthen and improve the traditional relations of production belonging to the enterprise to realize the basic stage of information management [15]. However, with the development of economic globalization and market integration, especially the Internet and e-commerce, as well as the wide application of information technology, the development of modern enterprises, from the past single reliance on physical capital, evolved into the need to rely on a variety of capital, including information resources, intellectual capital, human capital, research and development, and management innovation, etc. [16].

Enterprises face the rapidly changing globalized market and the realization of information technology competitors and partners. Enterprises must use information technology as an important means to change the original production, operation, and management of enterprises to improve enterprise competitiveness in order to survive and develop in a highly competitive environment [17]. This is a newer sense of enterprise information management. It will be for the enterprise's business content, complete the purchase, allocation, production, storage and transportation, sales, financial settlement,

strategic decision-making, and other aspects of automation and data transformation. Realize the joint flow of information flow, capital flow, and material flow [18].

In the era of e-commerce, the value of modern enterprises is not only related to tangible capital but also to the enterprise's intellectual capital and its supply chain customer relationships and the value of collaborative partners related to the realization [19]. When an enterprise's business activity process involves multiple strategic partners, enterprise business process reengineering is a complex systematic project. Enterprises, through business process reengineering, not only be able to eliminate the non-value-added aspects of the process, but, more importantly, to realize the transformation of enterprise management strategy. Enable enterprises to adapt to the changing needs of customers, improve the value-added capacity of each link in the enterprise value chain, and promote the smooth realization of the enterprise management mode change. The realization of information management is not only to use information technology as a tool for enterprise process reengineering but also to create a new management mode for the enterprise to face the whole supply chain and realize the value. Information management to re-create the new viability and competitiveness of enterprises, so that enterprises can obtain the power of sustainable development [20-21].

This paper centers on the construction of the embedded innovation ecosystem model. It sets the management system entropy of member enterprises in the embedded innovation ecosystem according to the mathematical expressions of enterprise management entropy and management dissipation. The embedded innovation ecosystem model is analyzed in terms of threshold effect, marginal incremental law, systematic effect, and structural effect to fully demonstrate the powerful role of the model in promoting enterprise innovation. We analyze the development stages and management procedures of enterprise management processes, conduct internal and external comprehensive diagnoses of problems in enterprise management through fuzzy Petri nets, and promote enterprises to accelerate the pace of optimization, improvement, and process reengineering by combining the quantitative and qualitative analysis of fault trees. The core technology of enterprise process reengineering adopts F-clustering and fuzzy C-mean clustering algorithms to realize the purpose of simplifying the calculation of process matrix according to the different intensity of information interaction under varying levels of development, and to carry out the reengineering of enterprise management process according to the actual situation.

2 Embedded Innovation Ecosystem Model

2.1 Modeling

The management system entropy of member enterprises in the embedded innovation ecosystem has been established according to the mathematical expression of enterprise management entropy [22] and management dissipation:

$$S_T = S_i + S_c \tag{1}$$

Where: S_T denotes the management system entropy of member enterprises; S_i denotes the management (positive) entropy of member enterprises; S_e denotes the management dissipation (management negentropy) formed by member enterprises accepting platform empowerment, and the management negentropy generated by other internal and external factors is not taken into account for the time being.

The management negentropy generated by member enterprises receiving platform empowerment can be expressed mathematically as follows:

$$S_c = \sum_{i-1}^{5} K_i S_d \tag{2}$$

where: $i(i=1,2,\cdots,5)$ denotes the empowerment dimensions that affect S_e respectively: platform data enablement, connectivity enablement, commercialization enablement, operations enablement, and technology enablement;

The managerial negentropy generated by each dimension of platform enablement on member firms $S_e(i=1,2,\cdots,5)$ further depends on the sub-factors included in each dimension, then:

$$S_a = K_B \sum_{j-1}^{n} P_{ij} \ln P_{ij} \tag{3}$$

Where: K_B denotes the empowerment coefficient of the platform empowerment dimension i, which reflects the average level of empowerment of core firms to member firms in the resource dimension i; $P_{ij}(i=1,2,\cdots,5; j=1,2,\cdots,n)$ denotes the probability that sub-factor j included in the platform empowerment dimension i affects the management negentropy of member firms, $\Sigma n P_{nj} = 1$.

The probability that the sub-factors of each dimension of platform empowerment affect the management negentropy of member firms depends on the empowerment strength of each sub-factor of the dimension and its weight. Denoting the empowerment intensity of subfactor j included in platform empowerment dimension i by $Q_{ij}(i=1,2,\cdots,5; j=1,2,\cdots,n)$ and its corresponding weight by $w_{ij}(i=1,2,\cdots,5; j=1,2,\cdots,n)$ and $\sum_{i-1}^{n} w_{ij} = 1$, there are:

$$P_{ij} = \frac{Q_{ij}/w_{ij}}{\sum_{j-1}^{n} Q_{ij}/w_{ij}} (j=1,2,\cdots,n) \tag{4}$$

$$P_{ij} = \frac{Q_{ij}/w_{ij}}{\sum_{j-1}^{n} Q_{ij}/w_{ij}} (j=1,2,\cdots,n) \tag{5}$$

The function to construct the enterprise resource effectiveness regarding the entropy of the enterprise management system is as follows:

$$Y_T = e^{-S_F} \tag{6}$$

Where: Y_T denotes the resource effectiveness of member firms; S_T denotes the entropy of the management system of member firms. Then, the profitability of member firms E_T can be expressed as follows:

2.2 Model Analysis

2.2.1 Threshold effect

The profitability $\left(E_T\right)$ of the member firms is known to be:

$$E_T = \lambda e^{-s_1 - s^2} - 1 \tag{7}$$

For this study, equation (7) can be rewritten as:

$$E_T = \lambda e^{|s_s| - s_s} - 1 \tag{8}$$

$$\left|S_c\right|^* = S_i - \ln \lambda \tag{9}$$

$$E_T = \frac{\lambda Y_T C_T - C_T}{C_T} = \lambda Y_T - 1 \tag{10}$$

2.2.2 Law of marginal increment

Considering $\left|S_e\right|$ as a whole, the second-order partial derivatives of $\left|S_e\right|$ for both sides of the equality sign of Eq. (8) are obtained:

$$\frac{\partial^2 E_T}{\partial \left|S_e\right|^2} = \lambda e^{|s_.| - \text{å}} > 0\left(S_e < 0\right) \tag{11}$$

Eq. (11) shows that the second-order derivative of E_T with respect to $\left|S_c\right|$ is greater than 0, indicating that E_T is marginally increasing with regard to $\left|S_{\mathrm{e}}\right|$. The embedded innovation ecosystem platform empowerment effect is not linear, as the absolute value of the size of the negentropy generated by the platform empowerment on member enterprises improves, the entropy structure of the management system of member enterprises keeps changing, and the profitability of enterprises accelerates.

2.2.3 Systemic effects

Considering $\left|S_{ei}\right|$ as a whole, the partial derivatives of $\left|S_e\right|\left(i = 1, 2, \cdots, 5\right)$ for each side of the equal sign of Eq. (11) can be obtained:

$$\frac{\partial E_T}{\partial \left|S_e\right|} = K_i \lambda e^{-\sum_{i=1} \kappa_{jl} |s_a| - s_i} > 0 \tag{12}$$

This indicates that for a platform empowerment dimension $l\left(l\text{ò}\{1, 2, 34, 5\}\right)$, the larger the absolute value of management negentropy $\left|S_e\right|$ generated by the dimension for member firms, the stronger the profitability of member firms; the larger the weight Kl of the dimension, the larger the

empowerment level of other dimensions $\left|S_{e|}\right|$ ($i \neq l$ and $i\grave{o}\{1,2,34,5\}$), and the larger the marginal enhancement of member firms' profitability by the empowerment level of the dimension. The same applies to the empowerment of other dimensions.

2.2.4 Structural effects

Convert Eq. (3) to:

$$S_{ei} = K_{ki} \sum_{j-1}^{n} \frac{Q_{ij} / w_{ij}}{\sum_{j-1}^{n} Q_{ij} / w_{ij}} \ln \frac{Q_{ij} / w_{ij}}{\sum_{j-1}^{n} Q_{ij} / w_{ij}} \tag{13}$$

Simplify Eq. (13) further as:

$$\left|S_{ij}\right| = K_{Bj} \ln \sum_{j-1}^{n} Q_{ij} / w_{ij} - K_{Bj} \frac{\sum_{j-1}^{n} Q_{ij} / w_{ij} \ln Q_{ij} / w_{ij}}{\sum_{j-1}^{n} Q_{ij} / w_{ij}} \tag{14}$$

The partial derivative of $Q_{ij}\left(j = 1,2,\cdots,n\right)$ for each side of the equal sign of Eq. (14) is obtained:

$$\frac{\partial \left|S_e\right|}{\partial Q_{ij}} = \frac{K_{bi}\left(\sum_{j-1}^{n} Q_{jj} / w_{ij} \ln Q_{jj} / w_{ij} - \ln Q_{jj} / w_{ij} \sum_{j-1}^{n} Q_{jj} / w_{jj}\right)}{w_{jj}\left(\sum_{j-1}^{n} Q_{jj} / w_{ij}\right)^2} \tag{15}$$

3 Enterprise management process diagnosis

3.1 Petri net method

Petri Net is a mesh information flow model [23], which mainly includes two types of nodes, event and condition, according to the triggering rules to make its event-driven state evolve, and the dynamic reflection is the process of system dynamic operation.

3.1.1 Mathematical definition of Petri nets

DEFINITION: A sufficient condition for the quintuple $PN = \left(P, T; F, A, M\right)$ to constitute a net system is:

1) $N=\left(P,T;F\right)$ constitutes a directed net, called the base net of PN.

2) A,M is in turn, the capacity function, the weight function, and the identity on N, and M is the initial identity of the tuple.

Petri nets can also be used to compute final identifications using matrices:

$$M=c\mu_0 \tag{16}$$

Where: C is the mapping matrix and μ is the initial identification:

$$C(s,t)=\begin{cases} -w(s,t)if & f(s,t)\subseteq F \\ wstif & fs\subseteq F \\ 0 & Other \end{cases} \tag{17}$$

Where: $w(s,t)$ is the right of a directed arc from s to t.

$f\left(s,t\right)$ denotes the existence of a directed path from s to t.

Where: $u=\left(u1,u2,\ldots,un\right),n=\left|p\right|$, the logo gives the number of tokens in each repository Pi in the Petri net. The number and distribution of tokens varies with the movement of the Petri net, which operates the system and keeps changing the identifications through the firing of variations.

1) One of the firing rules: for a Petri net $PN=\left(P,T,I,O\right)$ with identity u and variation $t\in T$, it is an authorized firing if the following conditions are satisfied.

$$u(Pi)\geq \#(Pi,I(ti)) \tag{18}$$

$$u(Pi)+\#(Pi,O(t))\leq K(Pi) \tag{19}$$

2) Firing Rule No. 2: When a variation ti fires, a new identifier u' will be generated, and the

$$u'=(Pi)=u(Pi)-\#(Pi,I(ti))+\#(Pi,O(ti)) \tag{20}$$

3.1.2 Fuzzy Petri nets

The fuzzy Petri net is structured as a sextuple of the form: $FPN=\left(P,T,I,O,f,a\right)$, where P is the set of libraries, T is the set of finite variations, I is the input function, O is the output function, $f:T\rightarrow[0,1]$, each variation corresponds to a real number in the range of $[0,1]$, and $a:P\rightarrow[0,1]$ is the mapping between its corresponding libraries and its identity value.

Definition: $FPN\overset{\Delta}{=}(P,T,D,I,O,f,a,\beta)$, where:

1) $P=\left\{p1,p2,\ldots,pm\right\}$, denotes the Kusho set.

2) $T=\{t1,t2,\ldots,tm\}$, denotes the variation set

3) $D=\{t1,t2,\ldots,tm\}$, denotes the variation set, denotes the proposition set, $PTD=\varnothing$, $|P|=|D|$.

4) $I: p\infty \to T$, denotes the input function and $p\infty$ is the set of position multisets.

5) $O: T \to p\infty$, denotes the output function, which determines the output location.

6) $\alpha: P \to [0,1]$, denotes the function of association, which is the navel projection from a variation to a real value between $[0,1]$;

7) $\alpha: P \to [0,1]$, denotes the function of association, which is a mapping from a position to a $[0,1]$ between real values;

8) $\beta: P \to D$, denoting the function of associations, which is a mapping from a position to a proposition.

Fuzzy generative rules are widely used for the relationship between two or more propositions. Let R be the set of fuzzy generative rules, $R:\{R_1,R_2,R_3\}$. The rules are defined as: IFd_j, $THENdk(CF=\mu_i)d_j=d$ are propositions, μ_i is the determinant of the rule, and the range of μ_i is $[0,1]$. If μ_i is closer to 1, then rule R is more plausible. It has the following three types.

Type 1: $R_i: IFd_jTHENd_k(CF=\mu_i)$.

Type 2: $R_i: IFd_iORd_jTHENd_k(CF=\mu_i)$.

Type 2: $R_i: IFd_iANDd_jTHENd_k(CF=\mu_i)$.

3.2 Management Process Diagnosis and Related Technology Analysis

3.2.1 Management Process Development

1) Stages of development of corporate management processes

Establishment of the company's business management system (see Table 1).

Table 1. Establishes the business management system of the enterprise

Establish an enterprise management system	Establish a sound management system	Customer information, technical file management
		The quality management of the whole team is established.
		Market development and management specifications
		Establish crisis management and sign system.
		Cost reduction control system
	Corporate behavior specification	Improve the organizational function mechanism.
		Establish a human resource management system.
		Establish the whole process quality management consciousness.
		Design main business flow

Setting up the operation and profit model of the enterprise

Setting up the core position of financial management is the most important, i.e., the implementation of the financial system, analyzing the overall strategic objectives of the company, forming the business process of each department within the enterprise, and designing the enterprise management process to achieve cost reduction control.

2) The procedure of the enterprise management process

The process of management process can be divided into “planning - research - evaluation - summary - improvement” and five aspects. Researching, summarizing, and improving are all part of the process. However, evaluation is crucial to proving the success of the entire process. Here are the specifics:

In the planning stage, the business strategy of the enterprise is determined through business diagnosis and strategic orientation, and the business structure of the enterprise is gradually formed.

In the subsequent realization phase, capability analysis, creation, and validation are carried out according to the business architecture, and then the application of capabilities is deployed.

In the process of managing the business, assess whether the allocation of resources is reasonable for departmental management and the business capabilities of employees.

In order to get feedback, it is crucial to focus on the management system, strengthen the department’s internal communication, and encourage employees to make bold suggestions.

Continuously improve and expand the performance of the management process application system so that the guarantee system and business operation structure can achieve the desired effect and guarantee.

3.2.2 Enterprise Management Diagnosis

The quality of improvement and optimization is directly affected by the accuracy or otherwise of diagnosis, which is an important tool for effective supervision. The diagnosis classification in Figure 1 indicates that diagnosis can be divided into two categories based on the different diagnosis subjects.

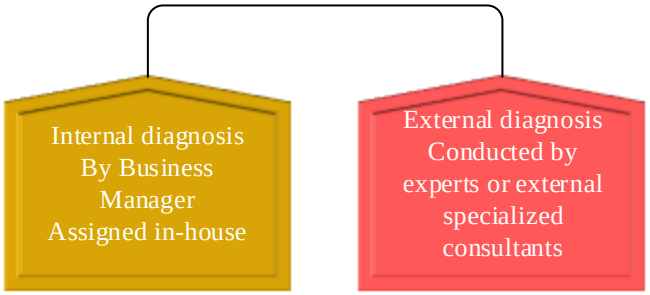

Figure 1. Two types of diagnosis

Fault tree [24]: a special and inverted tree-like logical causal diagram that expresses the causal relationship between various events in a system using event symbols, logic gate symbols, and transfer symbols. Fault tree analysis (it is based on the system's upcoming accidents or the results of accidents that have occurred to find the conditions and related laws related to the occurrence of the event and to identify the sources of accidents in the system that may cause accidents to occur. The reliability of the system can be analyzed using a mathematical method to model the fault tree.

1) Steps to build a fault tree

Select and determine the top event

The least expected fault in the product system is called the top event of the fault tree. When there is more than one least expected fault state of the product system, the most critical fault or several faults can be selected as the top event by analyzing from the perspective of the product function. Therefore, the top event may not be the only one.

Creating a Fault Tree

The steps for constructing a fault tree are as follows:

First, after the top event is determined, it is taken as the root of the fault tree. Then, all possible direct causes leading to the top event are identified as the first-level intermediate events, and the top event and the immediate, intermediate events are connected with appropriate logic gates according to the logical relationship between them; second, various direct causes causing the first level intermediate events are identified, and they are connected with logical relationship gates; and, finally, so on and so forth. The bottom event has been traced back to the top event until all the original causes have been identified.

2) Fault tree qualitative analysis

Qualitative analysis of the fault tree is required to find the top event caused by the occurrence of all the failure modes, from a mathematical point of view, to find out all the fault tree cut sets (minimum). Downward and upward methods are used to find the minimum cut set.

3) Quantitative analysis of fault tree

The probability of occurrence of the top event is the failure probability of the system failure $F(t)$, under the premise of knowing that the likelihood of occurrence of the basic event is known, the probability of occurrence of the top event can be calculated by using the expression of the minimum cut set of the fault tree so that the reliability of the system can be evaluated.

4 Enterprise management process reengineering method based on cluster analysis

4.1 Enterprise management process reengineering method based on F-cluster analysis

4.1.1 Fuzzy relations and their operations

In the Cartesian product (if U and V denote the coordinate axes, then $U \times V$ is the set of plane points):

$$U \times V = \{(u,v) | u \in U, v \in V\} \tag{21}$$

Formally, if some restriction is imposed on the assignment of elements in the domains U and V, this restriction embodies some special relation between U and V, which is said to be a subset of $U \times V$, and accordingly, there:

DEFINITION: A fuzzy subset R of $U \times V$ is a fuzzy relation from U to V, denoted as: $U \xrightarrow{R} V$ Here the fuzzy relation R refers to a binary fuzzy relation, as explained below:

1) R is a fuzzy relation from U to V;

2) When $U = V$, it is often called a fuzzy relation on U;

3) $\mu_R : U \times V \to [0,1]$, $\mu_R(u_0, v_0)$ is called u_0, v_0 has the degree of relationship R, that is, the affiliation function is binary;

4) If the domain of the argument is the direct product of n sets:

$$U_1 \times U_2 \times \cdots \times U_n \tag{22}$$

Then, the domain it corresponds to is the n element fuzzy relation R and its affiliation function is a function of n variables.

Since a fuzzy relation is a special form of fuzzy set, the same properties of operations for fuzzy sets hold for fuzzy relations. Since the affiliation function $\mu_R(u,v)$ of the fuzzy relation R from U to V can be represented by matrix R, the operation of fuzzy relation can be realized by matrix operation completely.

Let $M_{m \times n}$ denote the fuzzy relation matrix of all m rows and n columns, which can be defined for any R, $S \in M_{m \times n}$:

Intersection matrix $R \cap S = (r_{ij} \wedge s_{ij})$

The concatenation matrix $R \cup S = (r_{ij} \vee s_{ij})$

Cosine matrix $\overline{R} = (1 - r_{ij})$, in the above definition $i = 1, 2, \cdots, m$; $j = 1, 2, \cdots, n$

From the fuzzy relationship:

$$R \cup S = r_j \cup s_j \quad i = 1,2,\cdots,m,\ j = 1,2,\cdots,n \tag{23}$$

The process structure matrix formed by fuzzy relationship synthesis can comprehensively reflect the dependency relationship between process activities and recognize the structure of the whole process and the dependency relationship and dependency strength of each activity. Thus, process optimization and reengineering can be carried out more effectively.

4.1.2 Process structure matrix based on λ-level intercepts

Definition: set $R = \left(r_{ij}\right)_{m\times n}$, $\forall \lambda \in [0,1]$, notation:

$$\begin{aligned} R_\lambda &= \left(r_{ij}(\lambda)\right)_{m\times n} \\ r_{ij}(\lambda) &= \begin{cases} 1 & r_{ij} \geq \lambda \\ 0 & r_{ij} < \lambda \end{cases} \end{aligned} \tag{24}$$

Then R_λ is said to be a λ-truncated matrix of R.

$$\begin{aligned} R_\lambda &= \left(r_j(\lambda)\right)_{m\times m} \\ r_{ij}(\lambda) &= \begin{cases} 1 & r_{ij} > \lambda \\ 0 & r_j \leq \lambda \end{cases} \end{aligned} \tag{25}$$

Then R_λ is said to be a λ-strong truncated matrix of R.

The λ-intercept matrix R_λ represents the λ-intercept relationship, i.e. $\forall(u,v) = 1 \Leftrightarrow R(u,v) \geq \lambda \quad \forall \lambda \in [0,1]$, the intercept matrix must be a Boolean matrix.

For the mode-intercept relation matrix R, different levels of $\lambda \in [0,1]$ are chosen and the λ-intercept set R_λ of R is taken, such that the mode-intercept relation matrix characterizing the relationship between the units of the system is transformed into a 0-1 matrix R_λ describing whether or not the units of the system are correlated at a certain intensity:

$$R_\lambda = \begin{bmatrix} r_{11}(\lambda) & r_{12}(\lambda) & \cdots & r_{1n}(\lambda) \\ r_{21}(\lambda) & r_{22}(\lambda) & \cdots & r_{2n}(\lambda) \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1}(\lambda) & r_{m2}(\lambda) & \cdots & r_{mn}(\lambda) \end{bmatrix} \tag{26}$$

Where $r_j(\lambda)$ takes the value of:

$$r_{ij}(\lambda) = \begin{cases} 1 & r_{ij} > \lambda\ time \\ 0 & r_{ij} \leq \lambda\ time \end{cases} \tag{27}$$

For example, the process structure matrix based on the information space relationship-building style is R:

$$R=\begin{bmatrix} 1 & 0.9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.7 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.3 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.7 & 0 & 1 & 0 & 0.8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.3 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7 & 1 \end{bmatrix} \tag{28}$$

The process structure matrix based on the money flow space building equation is S:

$$S=\begin{bmatrix} 1 & 0.4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.8 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.4 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.3 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0 & 1 & 0 & 0.6 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.2 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7 & 1 \end{bmatrix} \tag{29}$$

From the previous equation:

$$M = R \cup S = r_{ij} \cup s_{ij} \tag{30}$$

4.2 Fuzzy clustering-based process reengineering approach

Theorem 1: Let $R \in U_{m\times n}$ be a fuzzy equivalence matrix, then for λ, $\mu \in [0,1]$, and each class in the classification determined by $\lambda < \mu$, R_{μ} is a subclass of some class in the classification determined by R_{λ}.

Theorem 2: Let $R \in u_{m\times n}$, R_{λ} denote the classes classified by λ. Then $R_{\lambda} \supseteq R_{\mu}\left(\lambda, \mu \in [0,1]\right)$ when $\lambda < \mu$.

When λ is gradually reduced from 1 to 0, the elements contained in the classification determined by the F-equivalence relationship R become more and less, and are steadily merged and finally become a class. This process forms a dynamic clustering diagram. Thus, it can realize the purpose of simplifying the calculation of the process structure matrix under different development levels

according to the different intensity of information interaction and manage it according to the specific actual situation.

Let $\lambda_1 = 0.2$, then there are:

$$M_{\lambda=02} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix} \tag{31}$$

When $\lambda_1 = 0.2$, there is an informational dependency between activity $A_1, A_2, A_3, A_4, A_5, A_7, A_5, A_9$ and no informational dependency between activity A_6 and the other activities.

When $\lambda_2 = 0.3$ is set, there are:

$$M_{\lambda=0.3} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix} \tag{32}$$

When $\lambda_1 = 0.3$, there is an informational dependency between activity $A_1, A_2, A_3, A_4, A_5, A_7, A_8, A_9$ and no informational dependency between activity A_6 and the other activities. It follows that when $\lambda_1 = 0.3$, there is no change in the matrix.

Setting $\lambda_2 = 0.5$, there is:

$$M_{\lambda=0.5}=\begin{bmatrix}1&1&0&0&0&0&0&0&0\\1&1&0&0&0&0&0&0&0\\0&1&1&0&0&0&0&0&0\\0&0&0&1&0&0&0&0&0\\0&0&1&0&1&0&1&0&0\\0&0&0&0&0&1&0&0&0\\0&0&0&0&0&0&1&0&0\\0&0&0&0&0&0&0&1&0\\0&0&0&0&0&0&0&1&1\end{bmatrix} \tag{33}$$

When $\lambda_2=0.5$, there is an informational dependency between activity $A_1,A_2,A_3,A_5,A_7,A_8,A_9$ and no informational dependency between activities A_4, A_6 and other activities.

Since there is no change in the matrix at $\lambda=0.6$ and $\lambda=0.7$, they are omitted.

Setting $\lambda_3=0.8$, there is:

$$M_{\lambda=0.8}=\begin{bmatrix}1&1&0&0&0&0&0&0&0\\1&1&0&0&0&0&0&0&0\\0&0&1&0&0&0&0&0&0\\0&0&0&1&0&0&0&0&0\\0&0&0&0&1&0&1&0&0\\0&0&0&0&0&1&0&0&0\\0&0&0&0&0&0&1&0&0\\0&0&0&0&0&0&0&1&0\\0&0&0&0&0&0&0&0&1\end{bmatrix} \tag{34}$$

When $\lambda_3=0.8$, there is information dependence between activity A_1,A_2,A_5,A_7, and there is no information dependence between activity A_3,A_4,A_6,A_8,A_9 and other activities.

From the previous equation, there are still information dependencies between activity A_1 and activity A_2, and between activity A_5 and activity A_7, which shows that activity A_1 and activity A_2, and activity A_5 and activity A_7 have the greatest information dependency.

5 Analysis of the impact of innovation ecology on business management

5.1 Measurement of variables

5.1.1 Moderating variables

1) Open innovation strategy. The moderator variable, open innovation strategy, includes both open innovation breadth and open innovation depth. Among them, open innovation breadth focuses on measuring the number of business dealings with different open innovation entities in the past three years, while open innovation depth focuses on measuring the depth of interaction with open innovation entities in the past three years.

2) Shared cognitive capital. The moderating variables are shared cognitive capital, shared values, and shared vision. Among them, shared values encompass the fact that the firm and its key partners share common values and culture and that the firm and its key partners share a common understanding of the same concepts (e.g., good, fast, cost, and quality).

5.1.2 Control variables

This paper selects and controls for three control variables, which are (1) Firm age (measured by the number of business offices). (2) Firm size (measured by the number of employees). (3) Firm type (measured by a dummy variable for high-tech firms, where high-tech firms are coded as 0 and traditional firms are coded as 1).

5.2 Data probing

5.2.1 Open innovation

The CITC value and Cronbach's <unk> coefficient of the open innovation variable were analyzed to test its reliability, and the results are shown in Table 2. Open Innovation Reliability Test Results. The minimum value of the overall correlation coefficient CITC is 0.682, which is above the threshold of 0.35. The Cronbach's α correlation coefficient value for the measure of open innovation is 0.927, which is greater than the threshold value of 0.7. The α value becomes smaller when any of the measured items are removed. To sum up, the open innovation variables are consistent internally.

Table 2. Reliability test results of open innovation

Subterm	CICT	Cronbachale's α	Factor load
Incubator	0.706	0.927	0.853
Mature enterprise	0.713		0.882
Venture capital	0.682		0.803
University	0.783		0.817
Institute	0.772		0.784
Leading user	0.684		0.836
Suppliers	0.728		0.855
Rival	0.737		0.896
Trade association	0.694		0.705
Service intermediary organization	0.701		0.811
Trade meeting	0.751		0.829
Government science and technology project	0.748		0.741

5.2.2 Sharing Cognitive Capital

The study conducted a reliability test for shared cognitive capital. First, the CITC value and Cronbach's α correlation coefficient of the shared values variable were analyzed, and the results of the analysis are shown in Table 3. The CITC value and Cronbach's α correlation coefficient for this variable were 0.828 and 0.814, respectively, which were placed above their respective baseline values. The α values become smaller when either measure is removed. In summary, shared values have good internal consistency. Immediately following, the shared vision variable was subjected to a reliability test, and the results of the analysis are shown in Table 3. The CITC value of this variable is 0.806, which is placed above the baseline value of 0.35, and the Cronbach's α correlation coefficient value of the scale is 0.857, which is higher than the threshold value of 0.7. α values become smaller when any of the measurement items are removed. In summary, the shared vision also has good internal consistency.

Table 3. Reliability test results of shared cognitive capital

Variable	CICT	Cronbachale's α	Factor load
Shared values	0.828	0.814	0.896
Shared vision	0.806	0.857	0.849

5.3 Reliability test

5.3.1 Reliability tests

The work of analyzing the reliability of the variables has been completed in the previous subsection. The results of the tests are shown in Tables 2 and 3, and the results of the reliability tests are now described and analyzed in general. The CITC values for open innovation ranged from 0.682 to 0.783, and for shared cognitive capital ranged from 0.806 to 0.828, which are greater than the baseline value of 0.35. The Cronbach's α correlation coefficients for open innovation, shared values, and shared vision were respectively 0.927, 0.896, and 0.849, all of which are higher than their threshold requirement of 0.7, and the α coefficients within this scale become smaller when any of the measurement items are removed. Open innovation and shared cognitive capital were found to pass the reliability test and demonstrate good internal consistency.

5.3.2 Validity tests

Next, the variables will be tested for validity and principal component analysis, and the results are shown in Table 4. The first step is to test the validity of open innovation. The unidimensionality and reliability were evaluated by exploratory factor analysis, and the results showed that the KMO value of the moderating variable open innovation was 0.826, which was greater than the benchmark value of 0.7. The probability value of the Bartlett test is 0.000, which is less than the benchmark value of 0.05. The variable had a CR value of 0.991 and an AVE value of 0.774, which were above the benchmark values. It shows that the moderating variable 'open innovation' has sufficient convergence and credibility. Therefore, in-depth factor analysis can be carried out. Subsequently, according to the requirement that the eigenroot value is greater than 1, the principal component factor analysis method is used to analyze the variables of open innovation. The results show that the value of $\chi 2/df$ of open innovation is 2.581, which is less than the threshold value of 3, the value of CFI is 0.996, the value of NFI is 0.957, both of which are greater than the threshold value of 0.900. The RMSEA coefficient is 0.032, which is placed below the standard threshold of 0.080, indicating that the adaptability of this variable is good.

Table 4. Validity test results of open innovation

Variable	Subterm	KMO	CR	AVE	χ^2/df	CFI	NFI	RMSEA
Open innovation	Incubator	0.826	0.991	0.774	2.581	0.996	0.957	0.032
	Mature enterprise							
	Venture capital							
	University							
	Institute							
	Leading user							
	Suppliers							
	Rival							
	Trade association							
	Service intermediary organization							
	Trade meeting							
	Government science and technology project							

Immediately after that, the results of the validity test for the variables shared value values and shared vision are shown in Table 5. The table shows that the CR values for these two variables are 0.852 and 0.856, and the AVE values are 0.747 and 0.799, which are higher than their benchmark values. It indicates that both the moderating variables, shared values and shared vision, have sufficient convergence and credibility. In addition, a validation factor analysis was conducted on shared values and shared vision. The results showed that the values of the fit indicator χ^2/df for the two variables were 2.039 and 2.130, which were less than the threshold value of 3.000, and the CFI values, NFI values, were 0.968, 0.989 and 0.984 and 0.973, both greater than the threshold value of 0.900; the values of RMSEA are 0.001 and 0.012, respectively, which are placed below its standardized threshold value of 0.080. It indicates that the variable is well-fitted.

Table 5. Validity test results of shared cognition capital

Variable	KMO	CR	AVE	χ^2/df	CFI	NFI	RMSEA
Shared values	0.891	0.852	0.747	2.039	0.968	0.989	0.001
Shared vision	0.893	0.856	0.799	2.138	0.984	0.973	0.012

6 Analysis of enterprise management process reengineering based on F clustering analysis

6.1 Analysis of the management process of the reorganized enterprise

Enterprise A has reengineered the existing management process using F-cluster analysis as a base method. A process with higher performance compared to the previous one was constructed. Enterprise A's production and operation data are clustered using the fuzzy C-mean clustering algorithm. The clusters obtained, and the results of the subsequent analysis are shown in Figure 2. The figure shows that, from the process point of view, the process reengineering before and after the general framework has not changed much. The business operated by the enterprise is still the sales department, production department, production planning department, warehousing, and logistics management department, etc. to execute the circular flow between. The management costs of process reengineering after the four departments at the core of the production and planning department reached 90,000 and 80,000 U.S. dollars. However the entire system has undergone a very significant change in the mode

of operation and management. In fact, the whole process has broken the original inter-departmental management system and has transformed it into a new management system built around intelligent management. The entire system is designed to enhance the management process, increase customer satisfaction, and improve production performance. The concept of process reengineering is also aligned with this goal.

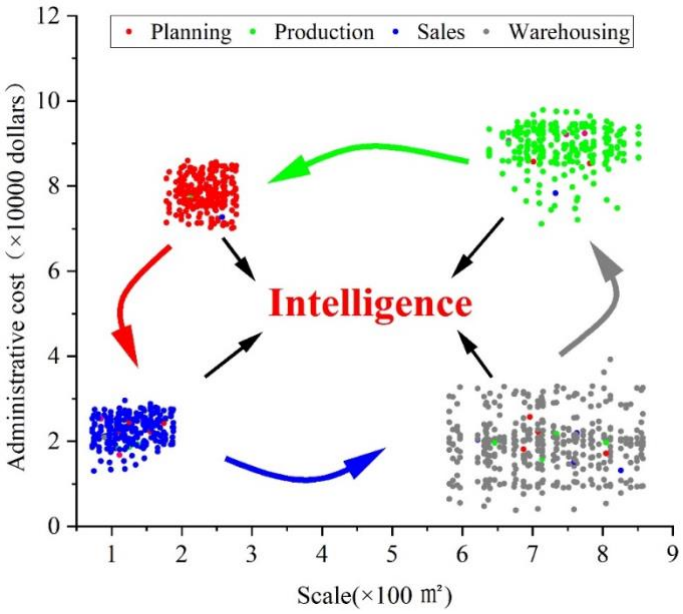

Figure 2. Result of cluster analysis of A enterprise

Secondly, in the relevant data processing mode, changes have also occurred. The efficiency of management is effectively improved through the unified processing of data through the unified database system. At the same time, the new system adopts the relevant tools. The use of these tools has greatly improved the operational efficiency of the enterprise. In addition, the use of new tools and methods has greatly changed the original production management mode. The difference between before and after the implementation of process transformation in enterprise A is shown in Table 6. From the table, it can be concluded that Enterprise A has achieved good results after process transformation, specifically: (1) centralized data entry and audit to ensure the unique accuracy of data. The efficiency and accuracy of data processing have been greatly improved by the centralized data entry management mode and networked data sharing in enterprise Y. (2) The system standardizes the operation process of enterprise management. It makes enterprise management reach a higher level. A large number of intelligent process specifications and data verification in the system make the operation of the enterprise very standardized, and the overall efficiency has greatly improved. (3) The core algorithm of fuzzy C-mean clustering realizes high-efficiency optimization and, at the same time, adopts the pairing scheme, which not only improves the utilization rate of the original production materials but also increases the orderliness of the site.

Table 6. Production Mode Comparison

Production management mode before process reconstruction	Production management mode after process reconstruction
The number of items and the number of products in the work list is the management object.	The physical shelf is a management object. A physical shelf corresponds to a production process card with the same processing process.
The work order will enter multiple shelves after the classification, and the quantity and specifications of each shelf will be produced according to the production process of the production process.	The contents of each shelf are determined in the plan, and the process must be placed in the order of the plan.
When the production process is optimized, it will be optimized for the same order and will not be mixed with his order. The production data utilization is general.	The production process will use the same type of material in all orders The order is optimized together, and the shelves are placed in the order of pre-set shelves, and the material utilization is higher.
The follow-up process only gets the work list sent by the previous process. The received shelf to be able to know exactly what your job is.	The task of the follow-up process is allocated in the planning phase and can be checked in real time and can be adjusted in the system.
After the production of each shelf, the various procedures will be recorded manually. After the end of the working class, the unified delivery will be submitted to the production statistics department.	After each shelf is completed, the production process card is scanned by the on-site terminal, and the production feedback is made.
The situation of breakage or quality inspection will be recorded by the quality inspection department after the end of the work class.	The condition of damage or inspection is immediately returned to the system, which can be directly entered into the supplementary process without the end of the work class.
When the interlayer or hollow pairing, the shelf pairing is multiple and the match is difficult.	The pairing is more efficient when the sandwich or the hollow match.

6.2 Analysis of economic benefits of enterprise process reengineering

After process reengineering, Enterprise A conducted a period of operation tracking and is still satisfied with the benefits brought to enterprise management by system-based process reengineering. Since Enterprise A's orders are non-standard orders and the condition of each order varies greatly, it is difficult to compare them by visualizing the orders. Still, by comparing them with the previous data, it is found that the overall cost can be saved by about 10%. This is already a very significant improvement for a manufacturing company. The change of system benefits after process reengineering in Enterprise A is shown in Figure 3. From the figure, it can be seen that the production cost share of enterprise A has decreased by 8.8%. At the same time, other conditions remain unchanged, in which the material cost, production cost, management cost, logistics cost, and other costs have decreased to a share of 47.9%, 13.6%, 14.8%, 5.1% and 9.8%, respectively. The reduction in operating expenses of the enterprise after process reengineering means that Enterprise A will generate higher revenues than before.

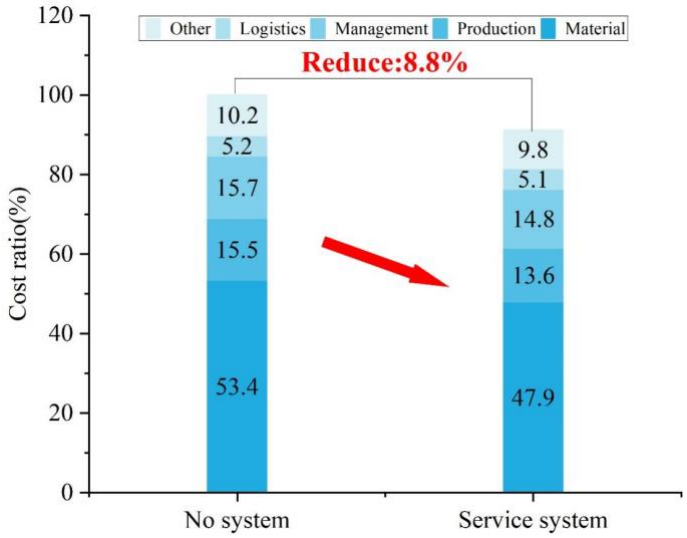

Figure 3. System Benefits Analyze

7 Conclusion

To analyze embedded innovation ecosystems, this paper concentrates on constructing the moderating variables of open innovation and shared cognitive capital. It is detected that the overall correlation coefficient CICT of the open innovation variable in the reliability test has a minimum value of 0.682, and the value of Cronbach's α correlation coefficient is 0.927, which are both greater than the corresponding standard values, indicating that the open innovation variable successfully passes the reliability test. The validity test also suggests that the variable open innovation has good validity and convergence. The relevant test values for shared cognitive capital reliability testing are higher than their benchmark values. The validation factor analysis of the variables shows that the values of the fit indicator χ^2/df for the variables are 2.039 and 2.130, which are both less than the threshold value of 3.000. The CFI values NFI values are 0.968, 0.989, and 0.984, 0.973, respectively, which all indicate that the variable passes the reliability test and has a good fit.

The cluster analysis method is utilized in this paper to analyze Enterprise A's production and operation data in order to explore the effects and benefits of enterprise process reengineering. The results show that although the overall structure of Enterprise A has not changed, its overall operation and management methods have undergone significant changes. After process reengineering, Enterprise A adopts intelligent management methods with artificial intelligence technology as the core, which greatly improves the productivity and customer satisfaction of the enterprise. At the same time, process reengineering for enterprise A had brought about an overall cost of about 10% energy saving, in which the cost of materials, production, management, and other expenses compared to the process before the transformation accounted for a decline of about 5.5%, 1.9%, 0.9%, 0.1%, and 0.4% respectively. Process reengineering effectively reduces production and management costs for enterprise A, thus promoting the sufficient growth of its production and operational efficiency.

Fund Project:

This article is a collaborative education project between industry and academia of the Ministry of Education. The project name is "Research on the Construction and Teacher Training of Business Administration Professional Training Base in Universities Based on Virtual Reality Technology" (Project number: 231107235130532).

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