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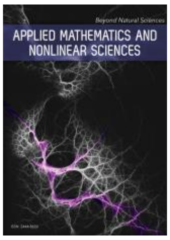

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Design of IPR evaluation system based on linear regression model

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Abstract

This paper first defines the conceptual scope of intellectual property, and the intellectual property evaluation system analyzes the special characteristics of enterprise intellectual property evaluation and compares the differences between several intellectual property management models. Secondly, an open adaptive enterprise IPR evaluation system is constructed based on a linear regression model, and the system structure and the relationship between subsystems are analyzed in depth. Finally, based on the theory of adaptive evaluation management, the adaptive IPR evaluation system is constructed. The adaptive enterprise IPR evaluation model based on linear regression was constructed mainly from three dimensions, and the method to determine the development coordination index and early warning degree of the three dimensions was deduced. The results show that the average efficiency of the typical enterprise IPR evaluation system calculated based on the linear regression model is 0.86, which is 21.3% more efficient than the traditional model. Four of the decision units' DEA is effective, 63% of the inputs are effective, and 37% of the input resources are wasted, which aligns with the actual enterprise. The adaptive IPR evaluation system based on the linear regression model proposed in this paper has theoretical innovation value and practical significance for enterprises to realize the transformation of IPR achievements.

Keywords: Intellectual property evaluation; Linear regression model; Adaptivity; Coordination index; Early warning degree
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1 Introduction

In the era of the knowledge economy, knowledge is an important asset for enterprises to improve their core competitiveness. With the development of science and technology, intellectual property rights, i.e., the exclusive rights of the right holder in terms of the results of his intellectual labor achieved in social practice for a limited period, have gradually become a key factor for enterprises to achieve technological innovation and differentiated competition [1]-[3]. When knowledge is only a factor of production, it is non-exclusive, and when it is freely traded in the market as a commodity and the carrier of intellectual property rights [4]-[5]. Enterprises increasingly value the valuation of intellectual property rights, and it has a huge use and potential value [6]-[7].

Research on the evaluation of IP capabilities is relatively well-developed and has been conducted for different research objects, such as enterprises, universities, industries, and regions [8]. The literature [9] proposed that IP capability can be considered a basic capability element to establish and maintain a competitive position and market share in the international market and that a strong IP capability must be established to become a leading world-class enterprise with independent intellectual property rights. By analyzing the relationship between IP capability and industrial innovation, the literature [10] argues that the improvement of IP capability is inextricably linked to the four aspects of regional IP creation, protection, application, and management environment, and the relevant institutional construction should be strengthened from these four aspects at the same time. The literature [11] makes an evaluation and comparative analysis of the level of intellectual property capability of Xi'an high-tech industry, taking into account the theory of intellectual property capability evaluation and the reality of Xi'an.

At present, relevant studies on IPR cooperation can be analyzed from two perspectives, macro and micro [12]. Among them, the literature [13] considers the construction of an IP talent team as the key and foundation for the successful realization of IP cooperation in the Pan-PRD economic construction. Based on the institutional equilibrium perspective of institutional economics, the literature [14] analyzed the shortcomings of the IPR system in international science and technology cooperation and constructed an innovative framework for its system. The literature [15] showed that issues related to intellectual property rights are the core problems in cooperative R&D between enterprises and universities, among which the negotiation of intellectual property rights between them is particularly complicated. The literature [16] constructed a system of factors influencing IP risk in collaborative innovation and analyzed its application. The literature [17] analyzed the optimal institutional arrangement for university-enterprise collaborative R&D, and its research effectively promotes the transformation of scientific and technological achievements in public research institutions.

In the first part of this paper, by analyzing the current situation of enterprise IPR evaluation and management, we establish a system to improve the evaluation system, pay sufficient attention to strategic management, and build an enterprise IPR management evaluation system. The second part concludes through analysis that the enterprise IP management evaluation system to be constructed should be a complex adaptive system that should conform to the principles of development, adaptability, and synergy. A linear regression model is proposed to construct an enterprise IP management evaluation system. The value evaluation and coordinated development subsystem divide the system's operation mechanism into an external dynamic adaptation, internal synergy, and evolution mechanism. The third part reconstructs the relationship of the three modules based on the error transmission mechanism of the value development module, value operation module and value protection module of the IP evaluation system. The coordinated development of the three modules within the IP evaluation system is evaluated based on the view that the coordination of the three modules directly governs the development of the whole system.

2 IPR evaluation system construction

To obtain a more objective synergistic development of the IP capability system, it is necessary to construct a corresponding evaluation system and assess the level of synergistic development of the regional IP capability system based on the actual situation. Therefore, based on the existing IP evaluation research results, this paper studies the synergistic connotation of the IP capability system. This paper considers IP capability a complete system consisting of three subsystems: IP creation capability, application capability, and protection service capability. By evaluating the synergy degree among the subsystems of IP capability and the synergy degree of the subsystems themselves, the research on the synergy evaluation of the IP capability system is carried out.

2.1 Design of evaluation index system

2.1.1 Evaluation index system design principles

System evaluation involves various aspects such as environment, performance, function, technical conditions, and benefits. Therefore, the following principles shall be followed to design and form a set of scientific and reasonable evaluation index systems.

1) Principle of wholeness: The index system should comprehensively reflect the comprehensive situation of system implementation, including the degree of realization of basic system functions, system performance status, system infrastructure, and technology application, and the system implementation environment.

2) The principle of conciseness: the index system must be clear and concise, and the number of levels should be appropriate. The lower-level indicators should be able to reflect better an important aspect of the corresponding indicators of the upper level, while the upper-level indicators should be able to correctly and reasonably abstract and summarize some relevant indicators of the lower level.

3) Principle of practicality: In addition to the indicators involved in evaluating the general management information system, the index system should also reflect the content of some specific indicators covered by the actual operation of the system.

4) Operability principle: In the design of the indicators, we also need to consider the operability of the data collection of each indicator. That is, the data required for each indicator should be easy to collect and can be processed easily.

2.1.2 Systematic evaluation index system

The enterprise intellectual property cooperation management system is a dynamic and open computer network platform. In addition to evaluating the relevant elements within the system, it is also necessary to evaluate the relevant elements of the environment in which the system is located to make a more comprehensive evaluation of the whole system. Based on the above principles, concerning relevant literature and the structure and characteristics of the constructed system, this paper proposes a complete evaluation index system consisting of 6 primary and 29 secondary indicators, and the evaluation index system of enterprise intellectual property system is shown in Table 1.

Table 1 Evaluation index system of enterprise intellectual property cooperation management

Primary Indicators	Secondary Indicators
System Environment	Implementation level of incentive system
	Establishment and Implementation of Intellectual Property Strategy
	Implementation level of intellectual property protection and regulatory system
	The level of trust among cooperative subjects
	Completeness of contractual provisions
	Effectiveness of Knowledge Process
Systems Function	Coordination capacity for IP cooperation
	Knowledge Acquisition and Representation Capability
	Degree of Knowledge Transfer and Sharing
	Level of Knowledge Creation and Application
	Efficiency of Knowledge Feedback and Update
	Level of Control of Intellectual Property Cooperation
System Performance	Maintainability
	Scalability
	System Efficiency
	Security Stability
	Compatibility
	User Interface Friendliness
System Technology	Normative nature of the technology
	Technical Effectiveness and Advancement
	Support Effectiveness of Key Technologies
	Construction status of system software and hardware platform
System Cost	System construction cost
	System Operation and Maintenance Costs
System Benefits	Quality of New Intellectual Property
	Quantity of new IP
	(Expected) benefits of marketability of new IP
	Magnitude of improvement in efficiency of IP cooperation
	Increase in the level of collaborative innovation

1) The smooth and efficient operation of the system cannot be separated from the internal and external environmental conditions in which it is located. Therefore, the support of a good system's internal and external environment is essential for the implementation and operation of the system.

2) System functionality is a key indicator for evaluating the management system, focusing on the main services users can obtain. Generally speaking, the better the system functions are, the better the system can meet the user's application requirements for collaborative innovation-based enterprise IP cooperation management.

3) The technology adopted by the system reflects the advancedness of the system and the construction level of the whole system platform. Therefore, the system technology needs to be included in the evaluation index evaluation system as a first-level indicator.

2.2 Enterprise intellectual property evaluation system construction

2.2.1 Framework of IPR evaluation system construction

Based on the "stimulus-awareness-response" model, which briefly describes the process of strategic adaptation, this paper applies the principle of system theory to build an adaptive enterprise IP evaluation system by integrating the two perspectives of environment-based and organization resource and capability-based evaluation and adaptation.

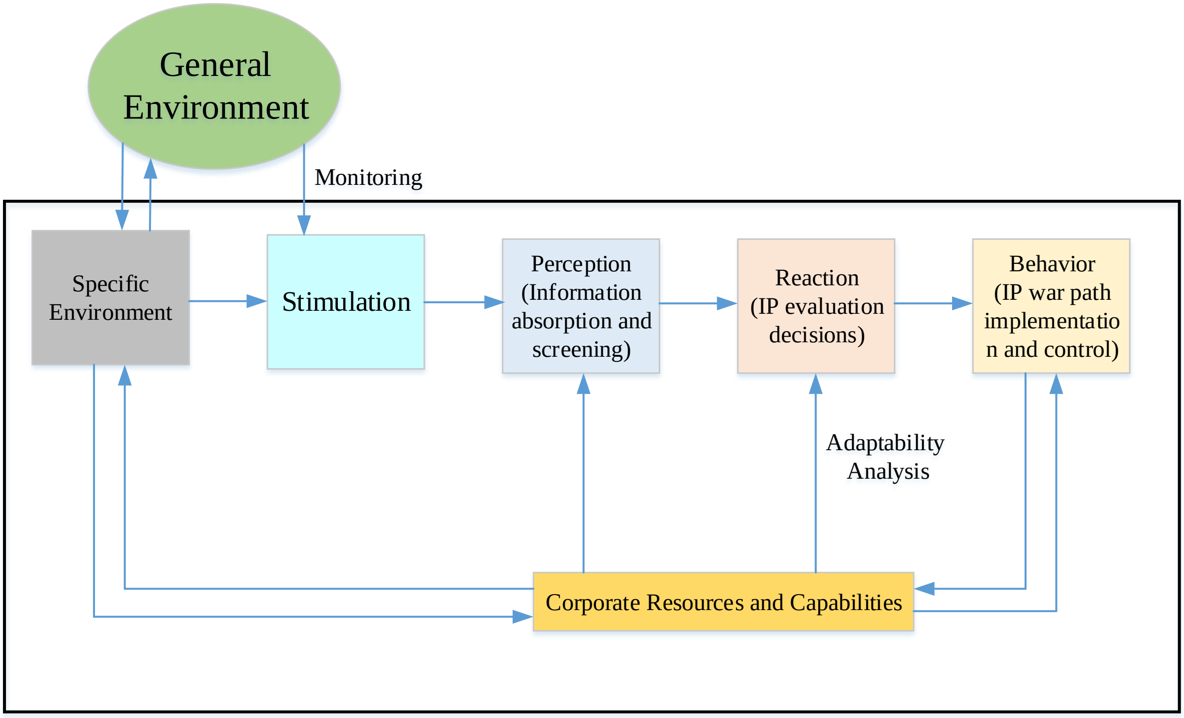

Figure 1 Framework of Intellectual Property Evaluation System for Adaptive Enterprises

Therefore, the operation process of the enterprise IP evaluation system is shown in Figure 2, i.e., monitoring the general environment and the special environment, performing adaptive analysis after sensing information, formulating evaluation planning through IP evaluation decision, implementing evaluation, and controlling the implementation process. When specific actions impact the internal resources and capabilities of the enterprise or the general and special environment, adaptive evaluation continues, and the decision to continue to maintain the development or re-evaluate IPR is determined after the evaluation.

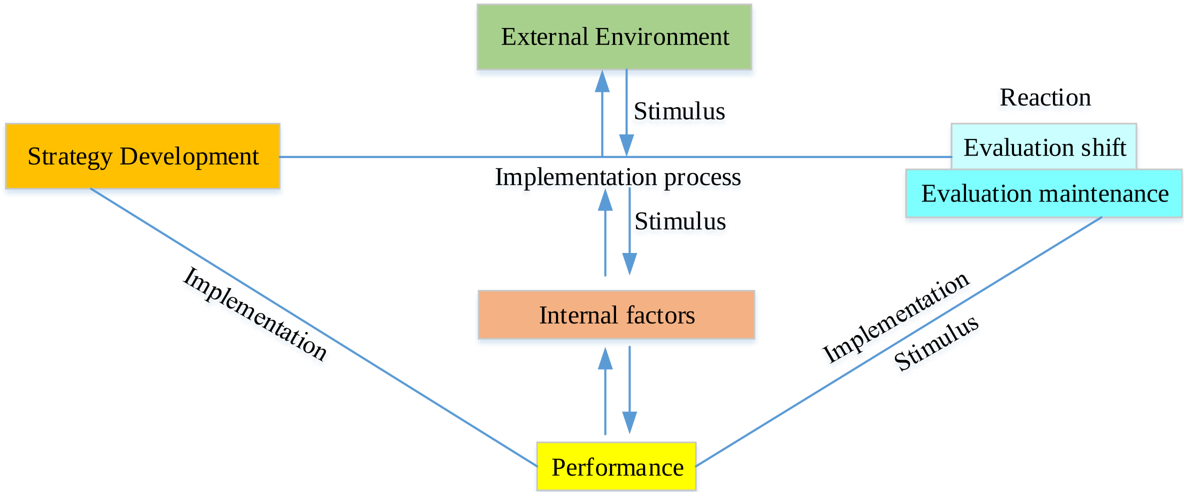

Figure 2 The operation process of the intellectual property strategy subsystem

2.2.2 Corporate IP evaluation dimensions

The TMR model divides the IP strategy into three dimensions: technology development, market development and property rights development, which better reflects the systemic nature and is closer to the actual enterprise management. Figure 3 shows the evaluation planning path of the closeness of each IP work.

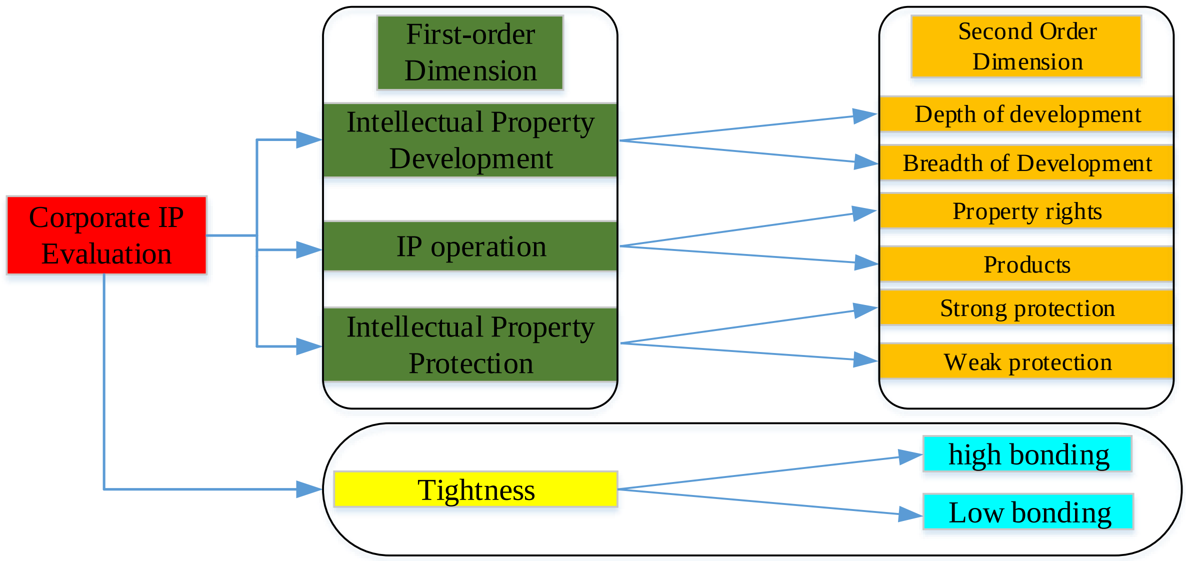

Figure 3 Four dimensions of corporate IP strategy

3 IPR evaluation system based on the linear regression model

There are various methods of IP evaluation, and the common ones are data envelopment analysis (DEA), principal component projection, coupling degree analysis, linear regression analysis, etc. The linear regression analysis method can measure the coordination of the system from the input-output perspective. Therefore, the use of linear regression analysis for IPR evaluation has operability characteristics and can visually reflect the coordinated development process in the system.

3.1 Linear regression model of enterprise intellectual property evaluation model

3.1.1 Linear regression model construction

The three dimensions of IP development, operation, and protection are used to establish the axes, and the IP evaluation decision of an enterprise is the point in space with coordinate (x, y, z). The axis is the development axis. The closer to the origin, the smaller the value, the more the IP development should strengthen the breadth, and the further away from the origin, the more the IP development should strengthen the depth. Axis Y is the operation axis, and the closer the value of y is to the origin, the smaller the value, the more product-oriented operation should be adopted for IPR operation, and the further away from the origin, the more property-oriented operation should be adopted for IPR operation. Axis Z is the property rights protection axis, the closer to the origin, i.e. the smaller the value of z, the weaker the protection intensity of intellectual property rights can be adopted, and the further away from the origin, the stronger the protection intensity should be. The linear regression model of intellectual property rights evaluation is shown in Figure 4.

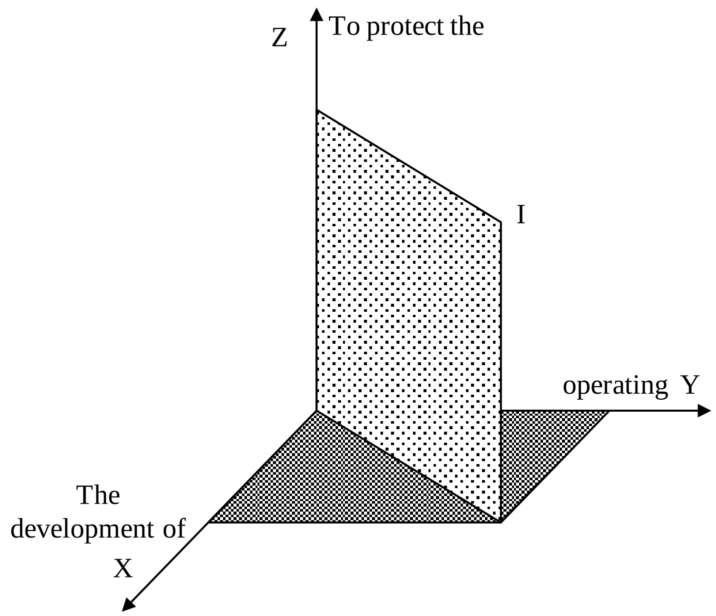

Figure 4 Linear regression model of enterprise IPR evaluation

3.1.2 Indicator identification

The quantitative selection of the enterprise intellectual property strategy model is firstly based on the enterprise's situation, and the indicators are selected using the indicator evaluation table, and the intellectual property evaluation selection indicator system is constructed, and the indicator evaluation table is shown in Table 2.

Table 2 Evaluation table of enterprise intellectual property evaluation selection index

Selected indicators	Number of weights	Number of scores	Weighted score
Finger 1	K_1	X_1	K_1X_1
Finger 2	K_2	X_2	K_2X_2
Finger 3	K_3	X_3	K_3X_3
…	…	…	…
Finger n	K_m	X_m	K_mX_m
Combined weighting Total weights of rating values	1	1	Internal/External Indicators Comprehensive weighted evaluation value

3.1.3 Determining weights

Different indicators have different degrees of influence on the enterprise IP strategy model selection, and there are various methods to determine the weights in terms of weights. In this paper, the judgment matrix of the importance of indicators is shown in Table 3, and the weights range from 0 to 1.0, with the sum of weights equal to 1.

Table 3 Index weights of enterprise intellectual property strategy selection

Indicators	A_1	A_2	…	A_i	…	A_n	Score	Weighting
A_1	1	a_{12}	…	a_{i1}	…	a_{n1}	m_1	$k_1 = m_1 / M$
A_2	a_{21}	1	…	a_{i2}	…	a_{n2}	m_2	$k_2 = m_2 / M$
…	…	…	…	…	…	…	…	…
A_i	a_{i1}	a_{i2}	…	1	…	a_{ni}	m_i	$k_i = m_i / M$
…	…	…	…	…	…	…	…	…
A_n	a_{n1}	a_{n2}	…	a_{in}	…	1	m_n	$k_n = m_n / M$
Total							M	1

Element 1 of the judgment matrix indicates the relative importance of A_i to A_j, and the scale can be used as follows: $a_{ij}, (a_{ij} > 0)$ means A_i is equally important as A_j, 3 means A_i is slightly more important than A_j, 5 means A_i is significantly more important than A_j, 7 means A_i is strongly important than A_j, 9 means A_i is extremely important than A_j, and 2,4,6,8 is in the middle of the above two adjacent scales. The final scores and total scores of each indicator are:

$$m_i = \sum_{j=1}^{n} a_{ij} \tag{1}$$

$$M = \sum_{i=1}^{m} m_i \tag{2}$$

The weight of the indicator is $k_i = m_l/M$, and if r experts participate in the scoring, the final weight is:

$$\bar{k}_t = \frac{1}{r}\sum_{r=1}^{r} k_i \tag{3}$$

3.1.4 Evaluation options

If a company chooses an IP evaluation model that has a composite weighted score of $A(6,6,6)$ point, in most cases it will get a point between two points. In this way, the IP strategy model closest to the ideal solution can be selected by calculating the distance of the composite weighted score $I_i(x_i, y_i, z_i)$ of any one IP strategy from the ideal solution, and the closeness to the ideal solution, then the formula is:

$$S_i = \sqrt{(x_i - 6)^2 + (y_i - 6)^2 + (z_i - 6)^2} \tag{4}$$

$i(i = 1,2, \ldots \ldots .8)$ represents each of the eight IP strategy models in the previous section.

3.2 Early warning of enterprise intellectual property evaluation based on linear regression

3.2.1 Early warning degree evaluation

The linear regression analysis method is a relatively new multivariate data quantitative decision-making method used to evaluate the degree of early warning. This method uses linear regression models to formalize the safety level and early warning object description. It also uses a topological set and correlation function to establish early warning criteria and security level correlations and establishes a comprehensive multi-indicator early warning model to characterize the security status. The evaluation process is as follows:

1) The domain warning object of patent pre

With m patent pre-warning security level $N_1, N_2, \ldots, N_m$, establish the corresponding objects as:

$$R_j = \left((N_j, c_i, v_{ji})\right) = \begin{bmatrix} N_j & c_1, & v_{j1}, \\ & c_2, & v_{j2}, \\ & \vdots & \vdots \\ & c_n, & v_{jn}, \end{bmatrix} = \begin{bmatrix} N_j & c_1, & < a_{j1}, b_{j1} > \\ & c_2, & < a_{j2}, b_{j2} > \\ \vdots & \vdots & \\ & c_n, & < a_{jn}, b_{jn} > \end{bmatrix} \tag{5}$$

Where N_j denotes the j patent warning levels classified $(j = 1,2, \ldots m), c_i(i = 1,2 \ldots n)$ denotes the characteristics of the warning level N_j, i.e. the secondary indicators in the evaluation indexes of this paper. v_{ji} respectively, the range of quantitative values specified by N_j regarding c_i, i.e., the range of values taken by each patent warning level regarding the corresponding index, and it is called R_j the classical domain of patent warning [18].

For each value of indicator c_i with classical domain $v_{ji} = \langle a_{ji}, b_{ji} \rangle$, nodal domain $v_{pi} = \langle 0,1 \rangle$, and $v_{pi} \supset v_{ji}$, where p is the patent warning level all, for the object to be warned, the warning indicator information is expressed in terms of object elements as :

$$\mathrm{R_o} = (\mathrm{P_0}, \mathrm{c_i}, \mathrm{v_i}) = \begin{bmatrix} \mathrm{P_o} & \mathrm{c_1}, & \mathrm{v_1} \\ & \mathrm{c_2}, & \mathrm{v_2} \\ & \vdots & \vdots \\ & c_n, & \mathrm{v_n} \end{bmatrix} \tag{6}$$

where $\mathrm{P_o}$ denotes the name of the warning object and v_i is the value of $\mathrm{P_o}$ with respect to c_i.

The patent warning is positioned at four warning levels, when $j = 1,2,3,4$ when n_j are {safe} {low danger} medium danger} {high danger} respectively, when $j = 1,2,3,4$, for each indicator c_i value, for each indicator to be gauged, and its classical domain is judged by experts as $v_{ji} = \langle a_{ji}, b_{ji} \rangle$ respectively $\langle 0,0.2 \rangle, \langle 0.2,0.5 \rangle, \langle 0.5,0.7 \rangle, \langle 0.7,1 \rangle$.

2) Calculation and determination of the correlation degree

The correlation function is used to determine the correlation degree of each warning level, and the correlation function of the $i(i = 1,2, \ldots, n)$st index value domain belonging to the $j(j = 1,2, \ldots, m)$nd warning level is:

$$K_j(v_i) = \begin{cases} \frac{\rho(v_i, v_{ij})}{\rho(v_i, v_{ip}) - \rho(v_i, v_{ij})}, \rho(v_i, V_{ip}) - \rho(v_i, V_{ij}) \neq 0 \\ -\rho(v_i, V_{ij}) - 1, \rho(v_i, V_{ip}) - \rho(v_i, V_{ij}) = 0 \end{cases} \tag{7}$$

Where v_i is the actual value of the evaluation index, $k_j(v_i)$is the correlation between each index and the patent warning level, $\rho(v_i, v_{ij})$is the distance between point v_i and the finite interval $v_{ij} =< a_{ij}$ and $b_{ij} >$, and $\rho(v_i, v_{ip})$ is the distance between point v_i and the finite interval$v_{ip} =< a_{ip}, b_{ip} >$. Where:

$$\rho(\mathrm{x}, < a, b >) = \left| \mathrm{x} - \frac{\mathrm{a+b}}{2} \right| - \frac{\mathrm{b-a}}{2} \tag{8}$$

The degree of association $k_j(v_i)$ indicates the degree of attribution of each warning indicator of the patent warning object about the evaluation level j, and if $k_j(v_i) = max k_j(v_i), j \in (1,2, \ldots, m)$, then the pre-indicator v_i belongs to the level j.

3) Early warning level assessment

The value of association function $K(x)$ indicates the degree of affiliation of the early warning object to the early warning level. The correlation degree of the early warning object R_0 on the early warning level j is:

$$K_j(R_o) = \sum_{i=1}^{n} \omega_i K_j(v_i) \tag{9}$$

If$K_{jo} = \max_{j \in \{1,2,\cdots,m\}} K_j(R_o)$, then R_o is rated as patent warning levelj_o. When$K_j(R_o) > 0$, it means that the warning object meets the requirements of a certain warning level, and the larger the value is, the better the degree of compliance.

3.2.2 Coordination index of enterprise intellectual property value evaluation system

The coordinated development of the enterprise IP value subsystem depends on the development of each module itself and the level of mutual coordination. The development level of the value development, operation, and protection modules can be expressed in I_D, I_M and $I_P$respectively, i.e. the development degree. Obviously, the determination of I_D, I_M and I_P will be based on the evaluation index groups of each module.

Since the IP value development module, operation module, and protection module are non-linear, their evolution equations can be described as:

$$\frac{dI_{xi}(t)}{dt} = f\left(I_{x1}, I_{x2}, \cdots, I_{xp}\right) \tag{10}$$

$i = 1,2, \dots, p, f$ is a nonlinear function of I_x. Expand it near the origin by Taylor series:

$$f(I_x) = f(0) + W_{x1}I_{x1} + W_{x2}I_{x2} + \cdots W_{xp}I_{xp} + \varepsilon\left(I_{x11}, I_{x2}, \dots, I_{xp}\right) \tag{11}$$

$$W_{xp} = \frac{\partial f(0)}{I_{xp}} \tag{12}$$

Where $\varepsilon\left(I_{x1}, I_{x2}, \cdots, I_{xp}\right)_{\hat{1}} I_{xp}$ is no less than a quadratic analytic function. Based on the fact that the stability of the motion of the nonlinear system depends on the nature of the characteristic roots of the primary approximation system, the stability of the motion can be maintained by omitting the higher order term$\left(I_{x1}, I_x, \cdots, I_{xp}\right)$, and the approximate linear system is:

$$\frac{dI_u(t)}{dt} = \sum_{i=1}^{p} W_{xi}I_{up}, i = 1,2, \cdots, p \tag{13}$$

According to this idea, a general model of enterprise IP value subsystem can be established as:

$$I_x = \sum_{i=1}^{p} f_{ui}(I_{xi})W_x \tag{14}$$

Where, X is the module synergy code, which represents the value development module, operation module, and protection module, respectively; P represents k and m, respectively, and $n; W_{xi}$ is the weight of I_{xi} . and $\sum_{i=1}^{p} W_{xi} = 1; f_{xi}(I_{xi})$ is a measure to evaluate the size of the combined contribution of index I_{xi} to each module X, i.e., the efficacy coefficient, and to satisfy $0 \le f_x(I_x) \le 1$.

Since the system condition is directly reflected in the system coordination condition, relying on the above theoretical reasoning of the composite system development degree and carrying capacity. Drawing on the capacity coupling concept and coefficients in physics, it is extended to obtain the conceptualized calculation equation of the coordination index of multiple systems (or modules) interacting with each other as:

$$D_n = \left[I_1 \cdot I_2 \cdot \cdots I_k \left(\frac{I_1 + I_2 + \cdots + I_k}{k}\right) - k\right]^k \tag{15}$$

Taking the IP development-operation module as an example, the development module and the operation module are interactively coupled to form the development-operation or module. Combined with the above linear regression model theory, the coordination index calculation equation between the development module and operation module can be obtained as follows:

$$D_{DM} = \left[I_D \cdot I_M \cdot \left(\frac{I_D + I_M}{2}\right) - 2\right]^2 \tag{16}$$

Similarly, it is possible to know the equations for development conservation, operation- conservation and the calculation of the coordination index of the system.

4 Results and analysis of the application of the intellectual property value evaluation system

The previous paper proposed that the IP value evaluation system's internal development degree and coordination degree could be evaluated using a linear regression-based model, but due to the confidentiality of individual enterprise data. It is operationally infeasible to select a certain enterprise to obtain time series data for calculation and analyze the coordinated development of this enterprise's IP value subsystem in recent years. Therefore, this method has no practical application to evaluate the coordination of enterprise IP value subsystems. However, since regional IP data are aggregated and can be obtained by looking up the relevant yearbooks, it is possible to evaluate the development degree and coordination degree of regional IP management systems for a certain region.

4.1 Regional IP Value Evaluation Calculation

4.1.1 Evaluation Results of IPR Value Development Degree in Heilongjiang Province

Based on the meaning of coordination of IPR value evaluation system, based on the aforementioned linear regression model will get the IPR development, operation, and protection block development in Heilongjiang Province in the past 16 years I_D, I_M, I_P and based on equation (12) to find out the IPR value subsystem coordination index D_{DM}, D_{DP}, D_{MP} *and* D_{DMP} the specific calculation data are shown in Table 4.

Table 4 Coordination index of intellectual property value evaluation system

Annual	Development			Coordination Index			
	I_D	I_M	I_P	D_{DM}	D_{DP}	D_{MP}	D_{DMP}
2005	0.0025	0.0934	0.0731	0.0077	0.1631	0.1020	0.0114
2006	0.0079	0.2230	0.1290	0.1105	0.1765	0.1055	0.0692
2007	0.0318	0.2731	0.2171	0.1130	0.2624	0.1221	0.0944
2008	0.0810	0.3078	0.3205	0.1417	0.2775	0.1558	0.2568
2009	0.1589	0.3488	0.4472	0.1844	0.2969	0.3436	0.3188
2010	0.1602	0.4378	0.4480	0.2490	0.3149	0.3892	0.3691
2011	0.2423	0.4619	0.4707	0.2536	0.3283	0.4322	0.4194
2012	0.3325	0.4764	0.5605	0.2849	0.3453	0.5117	0.5092
2013	0.4782	0.5277	0.6036	0.3332	0.5799	0.5338	0.5433
2014	0.5264	0.6363	0.6973	0.3497	0.7373	0.5433	0.6240
2015	0.5492	0.7902	0.7743	0.3550	0.7474	0.5594	0.6247
2016	0.6958	0.7955	0.7759	0.6664	0.7490	0.5745	0.6793
2017	0.7957	0.8076	0.8439	0.8264	0.7826	0.6759	0.8099
2018	0.8421	0.8625	0.8551	0.8946	0.9030	0.7227	0.8453
2019	0.8428	0.8706	0.8679	0.9191	0.9175	0.7878	0.8529
2020	0.9324	0.9440	0.9337	0.9591	0.9306	0.8407	0.9032

To reflect the dynamic changes as accurately as possible, the time-series evolution curves of the above data are reflected in the graphs based on the time-series distribution characteristics of the corresponding values mapped to the coordinate system, and the evolution curves of I_D, I_M and I_P in Heilongjiang Province are shown in Figure 5. The graph shows that except for the development degree of IP value operation, which has a "V" shape during 2005-2010 and 2015-2020, the other I_D, I_M and I_P are all on an upward trend. The best performer is I_D, which has steadily improved over the past 16 years, almost in a straight line, mainly due to the increase in innovation investment in Heilongjiang Province from 2005 to 2020. Each indicator's average annual growth rate is above 10%, and the share of R&D in GDP has increased from 0.34% in 2005 to 4.21% in 2020. The evolutionary path has seen two major troughs mainly from the number of patent and trademark as well as copyright infringement disputes filed in 2006 and 2009-2012 had a big growth nature. With the increase in popularity of IPR education, the establishment of a patent technology transfer information dissemination mechanism, and the increased emphasis on the transformation of technological achievements. After 2014 I_M curve shows an upward trend year by year. Small fluctuation upward trend among which the development was relatively flat during 2013-2016, and after 2018 there was substantial growth and increase year by year.

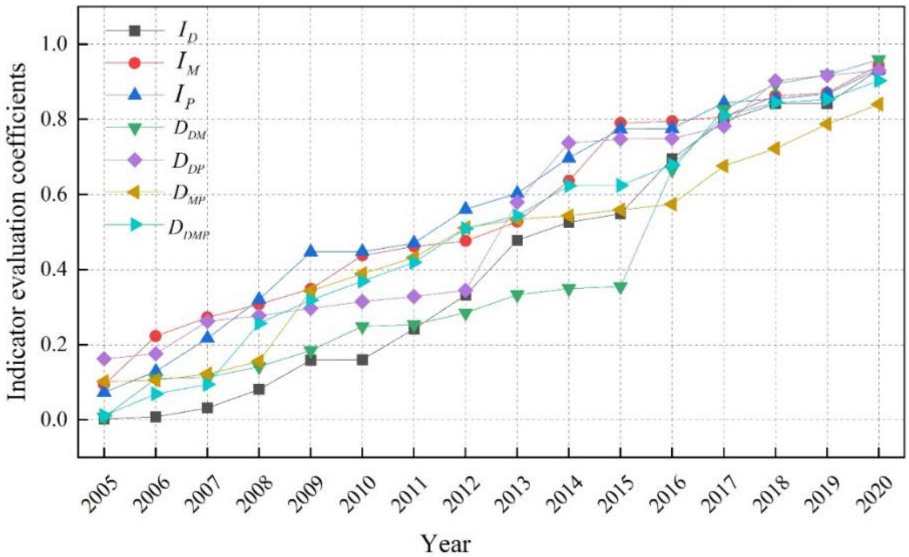

Figure 5 I_D, I_M, I_P evolution curve of Heilongjiang Province

4.1.2 Evaluation Results of the Coordination of Intellectual Property Value Development in Heilongjiang Province

The values of the development coordination degree E_{DM}, E_{DP}, E_{MP} *and* E_{DMP} of the IP value evaluation system were derived according to the linear regression model1, and the specific calculation results are shown in Table 5.

Table 5 Coordination of the development of intellectual property value evaluation system

Annual	Development Coordination				Development Ratio		
	E_{DM}	E_{DP}	E_{MP}	E_{DMP}	I_D / I_M	I_D / I_P	I_M / I_P
2005	0.0067	0.0797	0.0388	0.0038	0.0217	0.0287	0.0069
2006	0.0854	0.2464	0.0476	0.0072	0.0693	0.0782	0.0695
2007	0.1721	0.2868	0.0527	0.0239	0.1078	0.0906	0.0930
2008	0.2385	0.3512	0.1298	0.1447	0.1721	0.2124	0.1502
2009	0.3570	0.4740	0.1299	0.2657	0.2000	0.3804	0.3258
2010	0.5062	0.4860	0.2981	0.3080	0.2506	0.4131	0.4071
2011	0.5328	0.4883	0.5193	0.3466	0.2979	0.4650	0.4284
2012	0.5664	0.5329	0.5543	0.3609	0.5156	0.5198	0.5142
2013	0.5819	0.5431	0.6273	0.3616	0.6028	0.5240	0.5425
2014	0.5977	0.5797	0.6748	0.4621	0.6830	0.5319	0.5916
2015	0.6179	0.6034	0.6886	0.5999	0.7320	0.6461	0.6898
2016	0.7905	0.6122	0.8769	0.6747	0.7636	0.7230	0.7041
2017	0.8158	0.6649	0.9003	0.6898	0.9189	0.7419	0.7044
2018	0.8229	0.7634	0.9352	0.8634	0.9232	0.8687	0.7430
2019	0.8457	0.8078	0.9534	0.8969	0.9290	0.8800	0.8151
2020	0.8647	0.9433	0.9613	0.9305	0.9369	0.9775	0.9386

The time-series evolution curves of the above data are reflected graphically according to the time-series distribution characteristics of the corresponding values mapped to the coordinate system, and the evolution curves of development coordination degree $E_{DM}, E_{DP}, E_{MP}\ and\ E_{DMP}$ in Heilongjiang province are shown in Figure 6. As seen from the figure, the dynamic evolution of the development coordination degree of the value subsystem of intellectual property management in Heilongjiang Province can be divided into two periods the first period is from 2005 to 2010, with an “M” fluctuation and a trough of coordinated development. The second period is from 2010 to 2020 when the degree of coordinated development returns to balance and grows in a linear upward trend. With the improvement of the structure and function of the IP management system, it can be determined that there are six basic types of coordinated development of the value subsystem of IP management in Heilongjiang Province along the interval sequence, which is distributed in different periods. With the development of time, from the unified severe dysfunctional decline type in 2005 to the well coordinated development X or Y lagging type in 2010 and 2020. This indicates that Heilongjiang Province has excelled year by year in developing, operating and protecting intellectual property value and has been effective in intellectual property engineering.

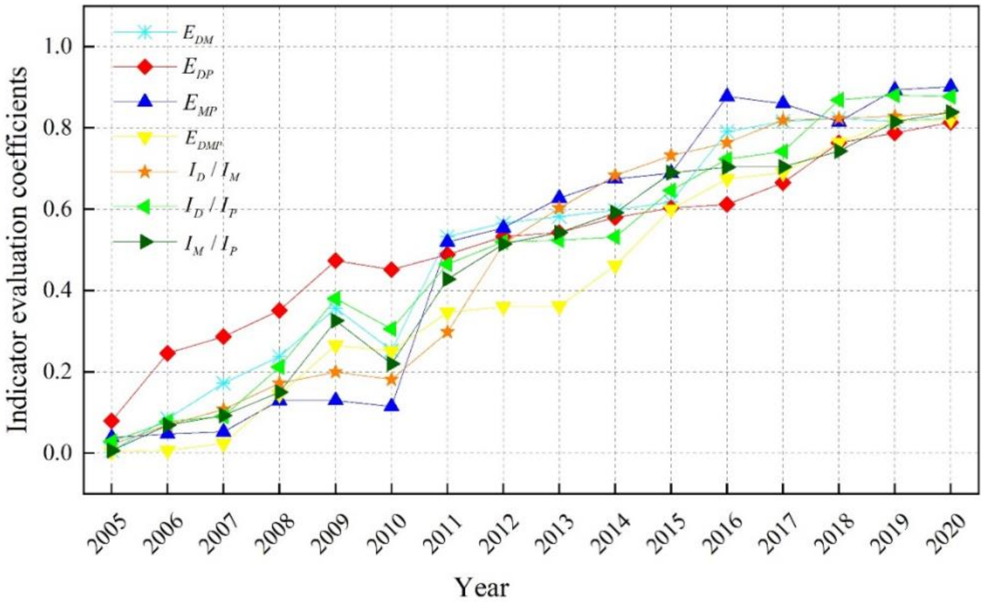

Figure 6 $E_{DM}, E_{DP}, E_{MP}, E_{DMP}$ evolution curve of Heilongjiang Province

4.2 Evaluation system operation effect analysis

4.2.1 Analysis of IPR evaluation system development modules

The correlation coefficients of input-output indicators are shown in Table 6, and it can be seen that the correlation coefficient tables of the input-output indicators of the IP value subsystem development modules are all less than 0.95, and no adjustment of the indicators is required. The average technical efficiency (ATE) of the six typical enterprises' IP value subsystem development modules is 0.92 using the linear regression model, with a variance of 0.8, two DEA valid, and four decision units non-valid. The average efficiency is high, and the variance is small, indicating that most enterprises attach more importance to the development of IPR value, and the effect of IPR development management work has been reflected. This situation should be related to the advantages of enterprises in IPR development. Compared with most private enterprises, SOEs have stronger investment ability and risk tolerance, have gathered a large number of scientific and creative talents with stable teams, and have the innovation ability of system integration, which can carry out many major projects.

Table 6 IPR evaluation system development module input-output indicators

	x_1	x_2	x_3	x_4	x_5	x_6	y_1	y_2	y_3
x_1	1	0.308	0.169	0.457	0.343	0.171	0.135	0.088	0.466
x_2	0.590	1	0.105	0.321	0.071	0.499	0.205	-0.371	0.450
x_3	0.328	0.151	1	0.088	0.038	0.373	0.103	0.004	0.221
x_4	0.061	0.342	0.367	1	0.242	0.466	0.591	0.239	0.015
x_5	0.149	0.147	0.291	0.068	1	0.037	0.199	0.187	0.158
x_6	0.267	0.178	0.595	0.010	0.231	1	0.655	0.006	0.047
y_1	0.484	0.146	0.141	0.141	0.485	0.264	1	0.300	0.319
y_2	0.560	0.463	0.167	0.294	0.241	0.320	0.564	1	0.215
y_3	0.518	0.176	0.617	0.284	0.225	0.311	0.030	0.328	1

4.2.2 IPR Evaluation System Operation Module Analysis

The correlation coefficients of the input-output indicators of the operation module of the IPR evaluation system are shown in Table 7, which shows that the correlation coefficients of the input-output indicators of the operation module are all less than 0.92, and no adjustment of the indicators is needed. Using the linear regression model, the average technical efficiency (ATE) of the operation module of the IPR value subsystem of six typical enterprises was calculated to be 0.72, with a variance of 0.52, two decision units DEA valid, and four decision units non-valid. The average efficiency value is very low, and most of the enterprises' efficiency values are lower than the average efficiency, and the variance is large, and there is a big gap between each sample enterprise in IPR operation. The efficiency values of enterprises C, E, and F are all low, and the lowest technical efficiency value of the enterprise F decision unit is 0.42, and most of its inputs are ineffective. It indicates that the effect of enterprise IP operation is generally very poor except for the outstanding enterprises, and there is a large gap between the enterprises with excellent performance and the ordinary enterprises. Moreover, the efficiency performance of each input index of non-effective enterprises is poor, indicating that most enterprises have great problems in IPR management, whether in terms of the system and personnel of IPR operation or terms of IPR industrialization and licensing and transfer.

Table 7 Comparison of IPR Evaluation System Operation Modules

DMU	Indicator	Actual value	Projected value	Difference value	Difference percentage
A (0.85)	x_1	0.526	1.211	0.550	46.74%
	x_2	2.845	0.399	-1.028	32.35%
	x_3	2.825	1.490	-0.810	30.87%
	x_4	2.678	1.074	-0.103	44.70%
	x_5	2.799	1.215	0.306	41.31%
	y_1	1.446	0.384	-0.834	40.86%
	y_2	2.676	0.899	0.365	5.32%
C (0.58)	x_1	1.572	0.404	0.398	47.78%
	x_2	0.930	1.659	-0.547	53.86%
	x_3	1.116	1.754	-1.018	0.55%
	x_4	0.529	1.341	1.550	30.99%
	x_5	1.522	0.477	1.505	44.53%
	y_1	1.135	1.362	1.178	20.65%
	y_2	2.173	0.936	-1.212	7.58%

5 Conclusion

Only by effectively conducting IP management evaluation can an enterprise fully expand its market and technology space and occupy the initiative of competition. In this paper, an adaptive IPR evaluation system based on a linear regression model is constructed by applying IPR management theory, system theory, technology innovation theory, and other related theories. The conclusions are summarized as follows:

1) The average technical efficiency (ATE) of the development module of the intellectual property evaluation system of the six enterprises was calculated using a linear regression model as 0.91, with a variance of 0.09. This situation should be related to the advantages of enterprises in

intellectual property development. Compared with most private enterprises, state-owned enterprises have stronger investment capacity and risk tolerance, and the defense system gathers a large number of scientific and creative talents with a stable team and with the innovative ability of system integration. They can carry out many major projects.

2) In this paper, a linear regression model is used to construct an enterprise IP management evaluation system containing a strategic, value, and coordination subsystem. The operation mechanism of the system is divided into an external dynamic adaptation mechanism, an internal synergy mechanism, and an evolution mechanism. The joint action of these mechanisms can enhance the effectiveness of the enterprise IP management system and promote its harmonious development.

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