International Journal of Multimedia and Ubiquitous Engineering
Vol.9, No.7 (2014), pp.319-332
http://dx.doi.org/10.14257/ijmue.2014.9.7.27

Research on the Measurement of Enterprise Technological Innovation Capability Model based on Information Axiom

Huaping Zhang

Management and Economics School of North China University of Water Resources and Electric Power
zhanghuaping@ncwu.edu.cn

Abstract

Enterprise technological innovation is featured by multi-level, multi-index, complex with uncertain information. This paper studies the measurement of enterprise technological innovation capability based on measurement index system that can reflect the innovation ability in an objective and systematic way. This index system is constructed according to certain rules and standards and sheds light on the measurement index model based on Euclidean distance and Information axiom. In this model, measurement indicators of different types are standardized and Euclidean distance is established. Then the weight of information content produced by Euclidean distance is calculated to get the comprehensive information content so as to measure the enterprise technological innovation capability. Measurement of three enterprises proves the model to be systematic, scientific and feasible.

Keywords: *Enterprise technological innovation; Capability measurement; Information axiom; Euclidean distance; Model*

1. Introduction

In the era of knowledge-based economy, with the development of science and technology and the rising market competition, enterprise technological innovation has become the driven force of the sustainable development as well as the core factor of competition. Therefore, it is necessary to increase the enterprise's innovation capability to be more competitive in the market [1-4].

Currently, many researchers, home and abroad, have studies the measurement of enterprise technological innovation with fruitful progress [5-9]. However, there is a lack of consensus on measurement analysis principles, the construction of measurement index system, analysis method and the selection of model. So it is hard to reflect the overall quality of the measurement. Some analytical methods and models are not operational or feasible. Thus, this paper proposes a measurement model based on information axiom and previous researches.

2. The Construction of Measurement Analytical Principles and Index System of Enterprise Technological Innovation Capability

2.1. Measurement Analytical Principles of Enterprise Technological Innovation Capability

Measurement analytical principles are the guidance of the index system. Only with scientific principles can the index system be reasonable. Based on previous researches, this paper proposes the following principles.

ISSN: 1975-0080 IJMUE

(1) Systematic principle: The process of technological innovation is summed as innovation accumulation, R and D, manufacturing, sales and reaching economic profits. Therefore, the index system should reflect the actual capability of technological innovation in an all-round way. This is a complicated process of system engineering decision analysis.

(2) Scientific principle: Indicators should not overlap each other. The index system should both address relevant problems of measurement and make sure a clear definition and an objective, accurate and fair measurement and analysis result.

(3) Feasibility principle: The measurement indicators should be feasible and practical, which means the data is acquired effectively, simply and conveniently for effective measurement and analysis.

(4) Purpose principle: Measurement indicators should reflect the level of enterprise technological innovation capability and be able to point out the weaknesses in innovation so as to provide reference and guidance for further improvement.

(5) Layer-clear principle: Measurement indicators of each layer should be distinguished from each other and have clear hierarchy and differences to that they are comparable.

(6) Comprehensive principle: Measurement indicators should reflect the technological innovation in an all-round way. The whole and inner connection of different factors that affect the selection of indicators should be guaranteed. Otherwise, indicators may be incomplete.

(7) Quantitative and qualitative principle: Some indicators and quantitative indicators while others are qualitative ones. Quantitative indicators can produce the accurate quantitative description model. Qualitative indicators can produce fuzzy membership or fuzzy interval description. This ensures the effectiveness of the measurement model of enterprise technological innovation capability.

2.2. The Construction of Measurement Index System of Enterprise Technological Innovation Capability

According to abovementioned principles and after consulting with relevant experts and data, the measurement index system is shown in Table 1 aimed at the manufacturing and sale process of technological innovation while taking into consideration human resources, money, innovation institution and innovation prospect.

Table 1. Measurement Index System

System index	First measurement index	Weight	Second measurement index	Weight
Measurement index system of enterprise technological innovation C	R&D capability C_1	W_1	R&D funds investment ratio C_{11}	W_{11}
			R&D proportion of human resources C_{12}	W_{12}
			Number of patent C_{13}	W_{13}
			R&D cycle C_{14}	W_{14}

			Successful rate of R&D C_{15}	W_{15}
			Capability of cooperation C_{16}	W_{16}
			Overall quality of R&D staff C_{17}	W_{17}
	Implement capability C_2	W_2	Equipment level C_{21}	W_{21}
			Manufacturing cycle C_{22}	W_{22}
			Proportion of professionals C_{23}	W_{23}
			Overall quality of professionals C_{24}	W_{24}
			Training input of professionals C_{25}	W_{25}
	Management capability C_3	W_3	Proportion of management team C_{31}	W_{31}
			Overall quality of management team C_{32}	W_{32}
			Innovation awareness of entrepreneurs C_{33}	W_{33}
			Rationality of organizational structure C_{34}	W_{34}
			Rationality of innovation institution C_{35}	W_{35}
	Production capability C_4	W_4	Ratio of output to input of new products C_{41}	W_{41}
			Output rate of new products C_{42}	W_{42}
			Conversion rate of science achievement C_{43}	W_{43}

	Marketing capability C_5	W_5	Market share of new products C_{51}	W_{51}
			Market research capability C_{52}	W_{52}
			Marketing cost rate C_{53}	W_{53}
			Net profit rate C_{54}	W_{54}

3. Measurement Model of Enterprise Technological Innovation Capability based on Information Axiom

3.1. Analysis of Information Content Based on Information Axiom

Axiom design was first introduced by Profesor Suh N P of MIT in 1990. It was the application of Shannon information theory in the field of design as well as an effective decision method [10-13]. Information axiom is an important design theory. It refers to that under the independent axiom, the system with the maximum information content I is the best one. Information content I is defined as the logarithmic function of the probability that the system meets the given design requirement. There is:

$$I = -\log_2 P = \log_2(1/P) \tag{1}$$

In the expression, P refers to the probability that the system meets the given design requirement.

As the probability function is random, the probability can be expressed as:

$$P = \int_b^a p_s(D)dD = A_C \tag{2}$$

In the expression, $p_s(D)$ refers to the probability distribution function; a refers to the down limit of the design range; b refers to the up limit of the design range; A_C refers to the area enclosure by system range and design range.

3.2. Standardization of Measurement Indicators

In the measurement index system, some indictors are quantitative indicators while others are qualitative indicators that are fuzzy and uncertain and require fuzzy language for description.

Therefore, in order to effectively analyze the measurement, there is a necessity to standardize indicators of different type. Suppose all the indicators value can be expressed in the form of interval value, that is, $c_{ij} = \left[c_{ij}^L, c_{ij}^R\right]$. In particular, when $c_{ij}^L = c_{ij}^R$, $c_{ij} = c_{ij}^L = c_{ij}^R$ is the accurate information at a point.

Standardization is based on whether measurement indicator $c_{ij} = \left[c_{ij}^L, c_{ij}^R\right]$ is a positive or adverse indicator.

①When measurement indicator $c_{ij}=\left[c_{ij}^{L},c_{ij}^{R}\right]$ is a positive indicator, the indicator v_{ij} after standardization is:

$$v_{ij}=\left[v_{ij}^{L},v_{ij}^{R}\right]/\left\|C_{ij}\right\|_{\max} \tag{3}$$

In the expression,

$$\left\|C_{ij}\right\|_{\max}=\max_{1\le j\le n}\left(\max\left(\left|c_{ij}^{L}\right|,\left|c_{ij}^{R}\right|\right),\max\left(\left|c_{ij}^{L}\right|,\left|c_{ij}^{R}\right|\right),\cdots,\max\left(\left|c_{ij}^{L}\right|,\left|c_{ij}^{R}\right|\right)\right) \tag{4}$$

It is the maximum norm of design scheme i about measurement indicator j.

②When measurement indicator $c_{ij}=\left[c_{ij}^{L},c_{ij}^{R}\right]$ is an adverse indicator, the indicator v_{ij} after standardization is:

$$v_{ij}=\left\|C_{ij}\right\|_{\min}/\left[v_{ij}^{L},v_{ij}^{R}\right] \tag{5}$$

In the expression,

$$\left\|C_{ij}\right\|_{\min}=\min_{1\le j\le n}\left(\min\left(\left|c_{ij}^{L}\right|,\left|c_{ij}^{R}\right|\right),\min\left(\left|c_{ij}^{L}\right|,\left|c_{ij}^{R}\right|\right),\cdots,\min\left(\left|c_{ij}^{L}\right|,\left|c_{ij}^{R}\right|\right)\right) \tag{6}$$

It is the minimum norm of design scheme i about measurement indicator j.

3.3. Calculation Model of Information Content of Measurement Indicator

Through the analysis of measurement indicators, it is clear the probability distribution function in which different indicators should meet the analysis requirement is not available. So, it is necessary to deal with the indicator value. In this paper, Euclidean distance is introduced for this purpose.

As measurement indicators after standardization have unified scale standard, the optimal measurement indicator sequence $\boldsymbol{V}^{\otimes}$ can be constructed.

$$\boldsymbol{V}^{\otimes}=\left(v_{01}^{\otimes},v_{02}^{\otimes},\cdots,v_{0n}^{\otimes}\right)=\left(\left[v_{01}^{a},v_{01}^{b}\right],\left[v_{02}^{a},v_{02}^{b}\right],\cdots,\left[v_{0n}^{a},v_{0n}^{b}\right]\right) \tag{7}$$

In the expression:

$$v_{0j}^{\otimes}=\left[v_{0j}^{a},v_{0j}^{b}\right]=\left[\max_{1\le i\le m}\left(v_{ij}^{a}\right),\max_{1\le i\le m}\left(v_{ij}^{b}\right)\right] \tag{8}$$

The Euclidean distance between measurement indicator j and the optimal indicator sequence $\boldsymbol{V}^{\otimes}$ under measurement analysis scheme i is:

$$D_{\left(v_{ij},v_{0j}^{\otimes}\right)}^{ij}=\sqrt{\frac{\left|v_{ij}^{a}-v_{0j}^{a}\right|^{2}+\left|v_{ij}^{b}-v_{0j}^{b}\right|^{2}}{2}} \tag{9}$$

The closeness degree between measurement indicator j and the optimal indicator sequence $\boldsymbol{V}^{\otimes}$ under measurement analysis scheme i is:

$$\kappa^{ij}_{\left(v_{ij},v^{\otimes}_{0j}\right)} = 1 - D^{ij}_{\left(v_{ij},v^{\otimes}_{0j}\right)} \tag{10}$$

The meaning of expression (10) is: If $\kappa^{ij}_{\left(v_{ij},v^{\otimes}_{0j}\right)} = 1$, measurement indicator j and the optimal indicator sequence $\boldsymbol{V}^{\otimes}$ are overlapped; If $\kappa^{ij}_{\left(v_{ij},v^{\otimes}_{0j}\right)} = 0$, measurement indicator j and the optimal indicator sequence $\boldsymbol{V}^{\otimes}$ are not overlapped; If $0 < \kappa^{ij}_{\left(v_{ij},v^{\otimes}_{0j}\right)} < 1$, measurement indicator j and the optimal indicator sequence $\boldsymbol{V}^{\otimes}$ are partially overlapped.

According to statistical distribution, probability that meets the design requirement is expressed by the exponential distribution density function:

$$P_{ij} = e^{-\left|1-\kappa^{ij}_{\left(v_{ij},v^{\otimes}_{0j}\right)}\right|} \tag{11}$$

The information content I_{ij} between measurement indicator j and the optimal indicator sequence $\boldsymbol{V}^{\otimes}$ under measurement analysis scheme i is:

$$I_{ij} = -\log_2 P_{ij} = \log_2 e^{-\left|1-\kappa^{ij}_{\left(v_{ij},v^{\otimes}_{0j}\right)}\right|} \tag{12}$$

Expression (12) shows that the closer measurement indicator j is to the optimal indicator, the smaller the information content I_{ij} of measurement indicator j will be. Under such circumstance, the measurement analysis scheme is the best one and vice versa.

If the value of measurement indicator j is acquired, calculate the information content in the same way as addressed above, the information content sequence I^2_i of measurement indicator j of the second index is:

$$I^2_i = \left(I^2_{i1}, I^2_{i2}, \cdots, I^2_{in}\right) \tag{13}$$

The overall information content I^2_i of second index under measurement analysis scheme i is:

$$I_i^2 = \sum_{j=1}^{n_s} \left(W_{ij} \times I_{ij} \right) \tag{14}$$

the information content sequence I_i^1 of the second index under measurement analysis scheme i is:

$$I_i^1 = \left(I_{i1}^1, I_{i2}^1, \cdots, I_{in}^1 \right) \tag{15}$$

The overall information content I_i of the second index under measurement analysis scheme i is:

$$I_i = \sum_{j=1}^{n_k} \left(W_j \times I_{ij}^1 \right) \tag{16}$$

The information sequence I of all measurement analysis scheme i is:

$$I = \left(I_1, I_2, \cdots, I_m \right) \tag{17}$$

According to the optimal principle based on information axiom, if

$$I_i = \min\left(I_1, I_2, \cdots, I_m \right) \tag{18}$$

Then the measurement analysis scheme i is the optimal measurement scheme which means this scheme has the best technological innovation capability.

4. Case Study and Model Test

This paper takes the technological innovation capability of three enterprises as samples and tests the algorithm and model. Measurement indicator values are acquired after survey, statistics, analysis and expert consultation. Results are shown in Table 2.

Table 2. Measurement Indicator Values of Enterprise Technological Innovation Capability

First measurement index	Weight	Second measurement index	Weight	Measurement indicator value		
				Scheme 1	Scheme 2	Scheme 3
R and D capability C_1	0.27	R and D funds investment ratio C_{11}	0.15	8.05	5.83	7.64
		R&D proportion of	0.14	8.85	6.26	7.75

		human resources C_{12}				
		Number of patent C_{13}	0.13	15	22	18
		R&D cycle C_{14}	0.15	8.5-9.0	7.2-8.0	8.3-8.5
		Successful rate of R&D C_{15}	0.15	6.72	5.83	6.56
		Capability of cooperation C_{16}	0.14	0.65	0.72	0.58
		Overall quality of R&D staff C_{17}	0.14	0.75-0.80	0.80-0.85	0.75-0.80
Implement capability C_2	0.23	Equipment level C_{21}	0.20	0.72	0.81	0.65
		Manufacturing cycle C_{22}	0.22	3.0-3.5	2.6-2.8	2.2-2.5
		Proportion of professionals C_{23}	0.19	0.21	0.25	0.18
		Overall quality of professionals C_{24}	0.19	0.75-0.80	0.75-0.80	0.80-0.85
		Training input of professionals C_{25}	0.20	0.65	0.72	0.43
Management capability C_3	0.18	Proportion of management team C_{31}	0.16	0.11	0.08	0.15

		Overall quality of management team C_{32}	0.20	0.80-0.85	0.75-0.80	0.75-0.80
		Innovation awareness of entrepreneurs C_{33}	0.24	0.75-0.80	0.75-0.80	0.80-0.85
		Rationality of organizational structure C_{34}	0.20	0.80-0.85	0.80-0.85	0.75-0.80
		Rationality of innovation institution C_{35}	0.20	0.80-0.85	0.75-0.80	0.75-0.80
Output capability C_4	0.16	Ratio of output to input of new products C_{41}	0.30	0.72	0.65	0.75
		Output rate of new products C_{42}	0.35	0.68	0.73	0.65
		Conversion rate of science achievement C_{43}	0.35	0.23	0.15	0.18
Marketing capability C_5	0.16	Market share of new products C_{51}	0.25	0.35	0.28	0.41
		Market research capability C_{52}	0.22	0.75-0.80	0.75-0.80	0.80-0.85
		Marketing cost rate C_{53}	0.25	0.25	0.32	0.18
		Net profit	0.28	0.45	0.35	0.62

		rate C_{54}				

Standardize measurement indicators of different types as is shown in Table 3.

Table 3. Measurement Indicator Value of Enterprise Technological Innovation Capability

Second measurement index	Measurement indicator value		
	Scheme 1	Scheme 2	Scheme 3
R and D funds investment ratio C_{11}	1.000	0.724	0.949
R and D proportion of human resources C_{12}	1.000	0.707	0.876
Number of patent C_{13}	0.682	1.000	0.818
R and D cycle C_{14}	0.800-0.847	0.900-1.000	0.847-0.867
Successful rate of R and D C_{15}	1.000	0.868	0.976
Capability of cooperation C_{16}	0.903	1.000	0.806
Overall quality of R and D staff C_{17}	0.882-0.941	0.941-1.000	0.882-0.941
Equipment level C_{21}	0.889	1.000	0.802
Manufacturing cycle C_{22}	0.629-0.733	0.786-0.846	0.880-1.000
Proportion of professionals C_{23}	0.840	1.000	0.720
Overall quality of professionals C_{24}	0.882-0.941	0.882-0.941	0.941-1.000
Training input of	0.903	1.000	0.597

professionals C_{25}			
Proportion of management team C_{31}	0.733	0.533	1.000
Overall quality of management team C_{32}	0.941-1.000	0.882-0.941	0.882-0.941
Innovation awareness of entrepreneurs C_{33}	0.882-0.941	0.882-0.941	0.941-1.000
Rationality of organizational structure C_{34}	0.941-1.000	0.941-1.000	0.882-0.941
Rationality of innovation institution C_{35}	0.941-1.000	0.882-0.941	0.882-0.941
Ratio of output to input of new products C_{41}	0.960	0.867	1.000
Output rate of new products C_{42}	0.932	1.000	0.890
Conversion rate of science achievement C_{43}	1.000	0.652	0.783
Market share of new products C_{51}	0.854	0.683	1.000
Market research capability C_{52}	0.882-0.941	0.882-0.941	0.941-1.000
Marketing cost rate C_{53}	0.720	0.563	1.000
Net profit rate C_{54}	0.726	0.565	1.000

Euclidean distance is acquired as is shown in Table 4.

Table 4. Euclidean Distance of Measurement Indicators

Second measurement index	Measurement indicator value		
	Scheme 1	Scheme 2	Scheme 3
R and D funds investment ratio C_{11}	0.000	0.276	0.051
R and D proportion of human resources C_{12}	0.000	0.293	0.124
Number of patent C_{13}	0.318	0.000	0.182
R and D cycle C_{14}	0.129	0. 000	0.101
Successful rate of R and D C_{15}	0.000	0.132	0.024
Capability of cooperation C_{16}	0.097	0.000	0.194
Overall quality of R and D staff C_{17}	0.059	0.000	0.059
Equipment level C_{21}	0.111	0.000	0.192
Manufacturing cycle C_{22}	0.259	0.128	0. 000
Proportion of professionals C_{23}	0.160	0.000	0.280
Overall quality of professionals C_{24}	0.059	0.059	0.000
Training input of professionals C_{25}	0.097	0.000	0.403
Proportion of management team C_{31}	0.267	0.467	0.000
Overall quality of	0.000	0.059	0.059

management team C_{32}			
Innovation awareness of entrepreneurs C_{33}	0.059	0.059	0.000
Rationality of organizational structure C_{34}	0.000	0. 000	0.059
Rationality of innovation institution C_{35}	0.000	0.059	0.059
Ratio of output to input of new products C_{41}	0.040	0.133	0.000
Output rate of new products C_{42}	0.068	0.000	0.110
Conversion rate of science achievement C_{43}	0.000	0.348	0.217
Market share of new products C_{51}	0.146	0.317	0.000
Market research capability C_{52}	0.059	0.059	0.000
Marketing cost rate C_{53}	0.280	0.437	0.000
Net profit rate C_{54}	0.274	0.435	0.000

Considering the weight of indicators, the information content sequence of three enterprises is: $I=(0.089, 0.136, 0.103)$. According to the optimal principle based on information axiom, enterprise 1 has the least information content under the measurement index system and the best technological innovation capability.

5. Conclusion

This paper proposes a measurement model of enterprise technological innovation capability while addressing the problems in the measurement analysis. This model realizes the standardization of measurement indicators of different types by establishing a measurement index system. it also calculate the Euclidean distance and proposes an improved calculation model of information content which makes it possible to measure the enterprise technological innovation capability. By practical test, the model is proved to be effective and feasible. It has a simple physical definition and calculation method with high accuracy and reliability. It can provide a good support for the computed-based intelligence technological innovation. It also serves as guidance to the development of enterprise technological innovation so as to increase the competitiveness of the enterprise.

Acknowledgments

This paper is supported by Scientific Research Foundation of Henan Province Education Department (No. 12A630078) and Decision Research Bidding Project of People's Government of Henan Province (No. 2012B382).

References

[1] C. Prescott and L. H. Ensign, "Competing explanations for knowledge exchange: Technology sharing within the globally dispersed R&D of the multinational enterprise [J]", Journal of High Technology Management Research, vol. 20, (**2009**), pp. 75–85.
[2] M. H. Bala Subrahmanya, "Pattern of technological innovations in small enterprises: comparative perspective of Bangalore (India) and Northeast England (UK) [J]", Technovation, vol. 25, no. 3, (**2005**), pp. 269-280.
[3] W. Dejin, "Research on technology innovation evaluation of enterprises [J]", Science and Technology Management Research, vol. 7, (**2010**), pp. 12-13+52.
[4] T. Wei, J. Rifu and L. Meng, "Research on technological innovation evaluation of enterprises [J]", Science and Technology Progressed and Policy, vol. 24, no. 5, (**2007**), pp. 195-200.
[5] Z. Yongyue, M. Zhiqiang and C. Yongqing, "Multi-level fuzzy comprehensive evaluation on enterprise's green technology innovation environment [J]", Science and Technology Progressed and Policy, vol. 27, no. 9, (**2010**), pp. 102-105.
[6] K. Ke and W. Chunxiu, "Selection model of enterprise's investment project based on multi-level fuzzy evaluation method [J]", Industry Technology and Economy, vol. 27, no. 6, (**2008**), pp. 148–150.
[7] K. Cormican and D. O'Sullivan, "Auditing best practice for effective product innovation management [J]", Technovation, vol. 24, (**2004**), pp. 819-829.
[8] R. Adams, J. Bessant and R. Phelps, "Innovation management measurement: A review [J]", International Journal of Management Reviews, vol. 8, (**2006**), pp. 21-47.
[9] T. Yilin, "Research on evaluation index model of enterprise technological innovation [J]", Science and Technology Management Research, vol. 7, (**2009**), pp. 173-175.
[10] M. Ogot, "Conceptual design using axiomatic design in a TRIZ framework [J]", Procedia Engineering, vol. 9, (**2011**), pp. 736-744.
[11] D. Tang, G. Zhang and S. Dai, "Design as integration of axiomatic design and design structure matrix [J]", Robotics and Computer-Integrated Manufacturing, vol. 25, no. 3, (**2009**), pp. 610-619.
[12] W. Tichun, C. Bingfa and B. Liangfeng, "Multi-attribute Optimal Selection Model of Large-Scale Hydraulic Turbine Scheme Design Based on Information Axiom [J]", Journal of Nanjing University of Aeronautics and Astronautics, vol. 43, no. 6, (**2011**), pp. 822-826.
[13] A. M. Gonçalves-Coelho and A. J. F. Mourão, "Axiomatic design as support for decision-making in a design for manufacturing context: A case study [J]", International Journal of Production Economics, (**2007**), vol. 109, nos. 1-2, pp. 81-89.

