# Study on the Method of Fuzzy Comprehensive Evaluation for the Independent Innovation Ability of Construction Enterprises

Chen Fan
Civil Engineering Institution, Hunan University of Science and Technology, Xiangtan, P.R.China, 411201
(E-mail: chenfan3@sina.com)

**Abstract** Based on the connotation of independent innovation ability of construction enterprises, an evaluation index system of independent innovation ability of construction enterprises is set up. Then, entropy method is applied to determine the weight of all indicators, and fuzzy comprehensive evaluation method is used to evaluate independent technical innovation capability of construction enterprises. Finally, an empirical analysis is carried out on a construction enterprise. The results show that the evaluation method proposed in this paper is feasible, and it can be carried out to evaluate the independent innovation ability of construction enterprises correctly.
**Key words** The ability of independent innovation; Fuzzy comprehensive evaluation; Construction enterprises; Entropy method

## 1 Introduction

Independent technological innovation ability is greatly important for construction enterprises to cognize and evaluate. Many scholars have studied the evaluation method of general enterprises and gained some progress. Liu Xisong has researched the evaluation method based on rough sets theory[1]. Wang Ying and Song Jia-sheng have appraised the innovation degree of technology progress in manufacture enterprises by AHP and fuzzy comprehensive method[2]. Qiu Feifei and Pang Zhiqiang have made a summary of the research methods about measuring and evaluating the enterprises' independent innovative capacity in which various model and method were introduced, such as grey theory, artificial neural network and DEA[3].

But to construction enterprises, the technological innovation activities have their own particularities. So, special study is needed to aim at these characteristics. Based on the deeply research on the characteristic of the independent innovation ability of construction enterprise, this paper construct a evaluation index system. Then, entropy method is applied to determine the weight of all indicators, and fuzzy comprehensive evaluation method is used to evaluate it. Finally, an empirical analysis is carried on a construction enterprise.

## 2 Connotation of Independent Innovation Ability of Construction Enterprises

With the rapid growth of national economy, the investment in the fixed assets is enhanced year by year, the proportion of output value of construction industry in GDP is going steady and rising, and its mainstay industry status in national economy is also strengthened day by day. However, for the past years, the labor productivity of Chinese construction industry has not made any great improvement, the technique content in production process is low and the achievements in scientific research are also few[4]. As shown in Table 1, although labor productivity and technical equipment rate of construction enterprises have a tendency of escalation, the scope of escalation is far inferior to that of total output value, moreover, in addition, and their proportion in the total output value presents a declining trend year after year. This illustrates that in present construction enterprises of our country the technique content in production process is partially low and the ability in technical independent innovation is insufficient, which cause the technology advancement lag behind economic growth.

Independent innovation refers to some kinds of innovative activities, namely, construction enterprises make technological breakthrough and overcome technical difficulties through self-exertion and exploration, based on which enterprises apply the new technology in construction depending on their own ability to obtain the anticipated economic benefits and the social benefits. Generally speaking, the independent innovation contains three aspects of contents: First, primitiveness innovation, namely, science discovery or technical invention; Second, the integrated innovation which causes each kind of related technique achievement merge together and forms market competitiveness products and industry; Third, on the basis of widely absorbed global scientific achievements and positively introduction of the advanced overseas technology, assimilation, absorption and re-innovation are fully being carried out. To

construction enterprises, the technological innovation activities have their own particularities. The technological innovation effect is affected by many kinds of factors including natural factors, technical factors and social factors. Therefore, the independent innovation of construction enterprises does not eliminate opening and integration, it can also exist in the integrated technology, the assimilation, absorption and improvement of technology introduction is also a constituent part in the independent innovation. In the independent technological innovation of construction enterprises, independent is the premise, enterprise's own ability is especially important and we must assimilate and absorb the introduction of technology to re-innovate and highlight own intellectual property rights. The core technology, originated from internal technological breakthrough, is what the independent innovation needs and it is tied to enterprise's own strength and obtained through research operations, which is the essential characteristic of independent technological innovation of construction enterprises.

**Table1 Related Stat. and Data on Technical Improvement of Construction Enterprises（2000—2006）[5]**

| years | Total value of construction industry （billion） | Growth rate of output value | Labor productivity (Yuan/person) | Growth rate of labor productivity | Technical Equipment rate (Yuan/person) | Growth rate of technical equipment rate |
|---|---|---|---|---|---|---|
| 2000 | 12497.6 | | 15929 | | 6304 | |
| 2001 | 15361.56 | 22.92% | 17621 | 10.62% | 7136 | 13.20% |
| 2002 | 18527.18 | 20.61% | 15715 | -10.82% | 9675 | 35.58% |
| 2003 | 23083.87 | 24.59% | 17476 | 11.21% | 9957 | 2.91% |
| 2004 | 29021.45 | 25.72% | 20887 | 19.52% | 9297 | -6.63% |
| 2005 | 34552.10 | 19.06% | 23427 | 12.16% | 9273 | -0.26% |
| 2006 | 41557.16 | 20.27% | 25741 | 9.88% | 9109 | -1.77% |

Independent technological innovation ability, the measurement whether construction enterprises are to be competent in technological innovation work, determines its success in carrying out the technological innovation for construction enterprises. As for construction enterprises, independent technological innovation ability is the basic safeguard for their survival and development, the economic benefits height brought by the technological innovation is an important mark to measure enterprise's competition and its ability to survive, it is as well as the fundamental factor to determine enterprise's position in the market and its growth potential. In building industry field, technological innovation activities have universality. In order to survive and develop, enterprises must try to adapt themselves to market changes and project demands, speed up the steps with unceasingly renovated knowledge and craft and promote the independent innovation level and ability. At present the independent innovation of construction enterprises in our country is insufficient, to a great extent this is caused by lower independent technological innovation ability of construction enterprises. Therefore, it is greatly important for construction enterprises to cognize and evaluate independent technological innovation ability of their own.

## 3 Index System for Independent Innovation Ability Evaluation

To establish an evaluation index system for independent innovation ability of construction enterprises aims not only at carrying out the evaluation for independent innovation ability, but also controlling the enterprise independent innovation process and the actual state, finding problems, analyzing reasons, bringing about the promotion of technological innovation effect and improving management through evaluation index system, thus we can further strengthen the independent technological innovation ability of construction enterprises. Therefore, three aspects of functions that this index system should contain are evaluation, supervision and guidance.

According to the characteristics of the independent innovation ability of construction enterprises, we divide the evaluation index system for independent innovation ability of construction enterprises into three levels, namely, target hierarchy, rule hierarchy and index hierarchy. "independent innovation ability of construction enterprises" is the target hierarchy, under which we establish five constituent factors of "investment ability of innovative resources", "innovative management capacity", "research and development ability", "output ability" and "innovation effect", the five factors make up rule hierarchy, under each of which three to five factors are set up to form index hierarchy. In order to enhance the scientific nature and the rationality of this index system, this article is on the pretext of Expert Conference Law and Delphi Law and we tabular the preliminary establishment of evaluation index system, list some partial factors and factor in the questionnaire, and leave some blanks to allow

experts to carry out the index replacement and fluctuation. Through sending out the questionnaire to experts and conference discussion, we synthesize some opinions from experts, and then fix factors and the factor of each level through statistics and analysis, thus the evaluation index system for independent innovation ability of construction enterprises is established, as shown in Figure 1.

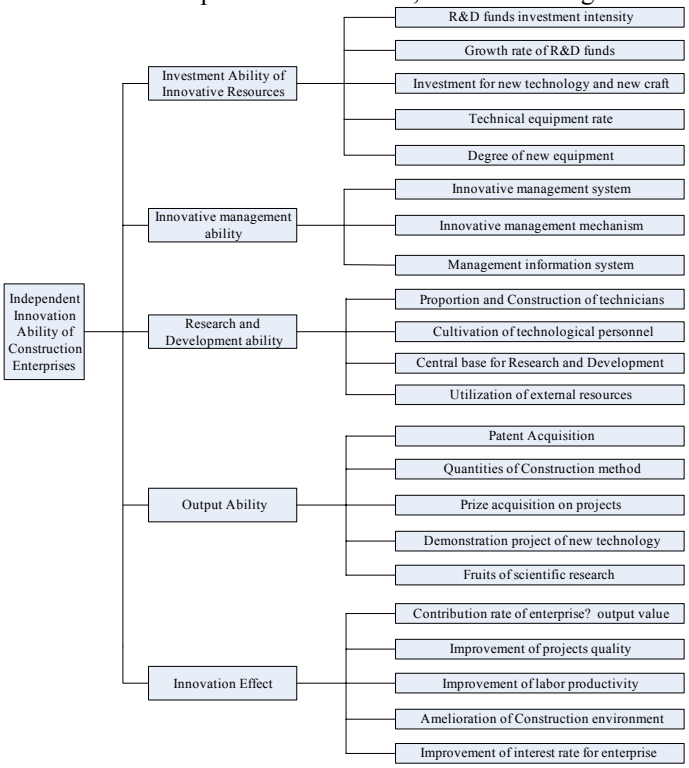


**Figure 1 Index System for Independent Innovation Ability Evaluation of Construction Enterprises**

The concrete computational methods of related indexes are shown as follows:

⑴R&D funds investment intensity =R&D funds/ the turnover of enterprise. In the formula, the turnover of enterprise includes project cost income and other business income of enterprise.

⑵Growth rate of R&D funds = (funds investment this year –funds investment in previous year)/ funds investment in previous year.

⑶The investment for introduction and application of new technology and new craft: Technology introduction and (or) expense disbursement for technological transformations = technology introduction funds + technological transformations funds.

⑷Technical equipment rate = net worth of innate mechanical device at the end of the year / complete number of staff at the end of the year.

⑸Degree of new equipment = net value of assets on construction and production equipment / original value of property.

⑹Proportion and construction of engineers and technicians = $\sum_{i=1}^{4} \omega_i r_i$ / work force of enterprise. In the formula, i denotes the title rank of technical personnel. The primary R&D personnel are taken as the 1st level, the intermediate R&D personnel are on the 2nd level, the high-level R&D personnel and the outstanding contributions experts are attached to the 3rd level and the 4th level respectively. $r_i$ signifies the quantity of R&D personnel on $i_{th}$ level, $\omega_i$ signifies the quality weight of R&D personnel on $i_{th}$ level, $\omega_1$=0.1, $\omega_2$=0.2, $\omega_3$=0.3, $\omega_4$=0.4.

⑺The patent acquisition is signified by $\sum_{i=1}^{3} \omega_i r_i$. In the formula, i signifies the rank of acquired patent, the 1st level indicates the patent of invention, the 2nd level indicates the use of new patent, the 3rd level indicates outer design patent. $r_i$ signifies the patent quantity on $i_{th}$ level. $\omega_i$ signifies the patent weight on $i_{th}$ level, $\omega_1$=0.5, $\omega_2$=0.3, $\omega_3$=0.2.

⑻The construction method is signified by $\sum_{i=1}^{3}\omega_i r_i$, i indicates the rank of construction method, the 1st level indicates construction method on state-level, the 2nd level indicates construction method on provincial level, the 3rd level indicates construction method on municipal level. $r_i$ signifies the quantity of construction method on $i_{th}$ level. $\omega_i$ signifies the construction method weight on $i_{th}$ level, $\omega_1$=0.5, $\omega_2$=0.3, $\omega_3$=0.2.

⑼Labor productivity enhancement = (labor productivity this year - labor productivity in previous year)/ labor productivity in previous year, thereinto, labor productivity of the entire number of work force = growth value on construction industry / the average number of people of complete staff.

Others like prizes acquisition on projects, the fruits of scientific research, the application and demonstration project of new technical, Improvement of projects quality for technological innovation, environment, output value, interest rate etc, the index computation of all of which are in accordance with all above mentioned theory. As space is limited, unnecessary detail will no longer be given.

## 4 Determination of Index Weight

Through analysis and comparison, this article makes a use of entropy value method to determinate various indexes weight in evaluation system, applies multiple fuzzy evaluation methods to carrying out the comprehensive evaluation for independent innovation ability of construction enterprises. The entropy value method is objectively authorized, the index weight is determined by analyzing the degree of relations between various indexes and the information amount offered by various indexes, the use of data in the evaluation is originated from the primary information of the sample, which can to a certain extent avoid the deviation caused by subjective factor.

### 4.1 The basic principle of entropy value method

"Entropy" weighs the disorder of information in the information theory. In the information theory the formula of information entropy is

$$H(X) = -k\sum_{j=1}^{m} P(x_i)InP(x_i) \tag{1}$$

In the formula: H(X) is the information entropy, k is the paulzema constant, $P(x_i)$ is the probability of event $x_i$. The above equation shows a system X= ($x_i$, i=1,2,…, m) disorder. The bigger the information entropy H(X) is, the higher disorder of the system is, and then the utility value of information is even smaller. Otherwise, the smaller the information entropy is, the higher system's degree of order is, and then the utility value of information is even bigger. The entropy value method precisely applies the above principle to measuring and calculating the divergence degree of various indexes, and then calculates each index weight objectively.

Suppose multi objective evaluation questions are set up and there are m evaluation objects, n evaluation index and the primitive index data matrix $X=(x_{ij})_{m\times n}$. First of all, standardize it to obtain the standardized matrix of index data $Y=(y_{ij})_{m\times n}$, thereinto, $y_{ij} = x_{ij} / \sum_{j=1}^{m} x_{ij}$, then the entropy value of indexes is

$$e_j = -k\sum_{j=1}^{m} y_{ij}Iny_{ij}, k = (Inm)^{-1} \tag{2}$$

The divergence coefficient of various indexes is $h_j=1-e_j$, weight of indexes is $a_j = h_j / \sum_{j=1}^{m} h_j$ .

### 4.2 Computation of index weight

The computational process of the evaluation index weight of independent innovation ability of construction enterprises is: First, according to the above methods, the weight of basal evaluation index in system can be counted. Then according to formula (3) we can calculate the evaluation value of upper layer classified index of various samples.

$$S_h = \sum_{j=1}^{m} a_j y_{ij} / \sum_{i=1}^{m}\sum_{j=1}^{m} a_j y_{ij} \tag{3}$$

In the formula, $S_h$ is the comprehensive evaluation value of previous index(h=1,2,…,5), $a_j$ is the weight of basal evaluation index, $y_{ij}$ is the standardized value of basal evaluation index, n is the integer of basal evaluation index, m is the sample number selected from synthetic evaluation. Finally, we take $S_h$ as its basic evaluation data and calculate the weight of first-level index according to the entropy value method. The result is shown in Table 2.

**Table 2 Weight of Indexes**

| Target | Rule hierarchy | weight | Index hierarchy | weight |
|---|---|---|---|---|
| Independent Innovation Ability of Construction Enterprises | Investment Ability of Innovative Resources | 0.29 | R&D funds investment intensity | 0.31 |
| | | | Growth rate of R&D funds | 0.24 |
| | | | Investment for new technology and new | 0.12 |
| | | | Technical equipment rate | 0.18 |
| | | | Degree of new equipment | 0.15 |
| | Innovative management ability | 0.16 | Innovative management system | 0.33 |
| | | | Innovative management mechanism | 0.48 |
| | | | Management information system | 0.19 |
| | Research and Development ability | 0.23 | Proportion and Construction of | 0.32 |
| | | | Cultivation of technological personnel | 0.28 |
| | | | Central base for Research and | 0.21 |
| | | | Utilization of external resources | 0.19 |
| | Output Ability | 0.17 | Patent Acquisition | 0.17 |
| | | | Quantities of Construction method | 0.23 |
| | | | Prize acquisition on projects | 0.18 |
| | | | Demonstration project of new technology | 0.15 |
| | | | Fruits of scientific research | 0.27 |
| | Innovation Effect | 0.15 | Contribution rate of enterprise's output | 0.14 |
| | | | Improvement of projects quality | 0.20 |
| | | | Improvement of labor productivity | 0.28 |
| | | | Amelioration of Construction | 0.11 |
| | | | Improvement of interest rate for | 0.27 |

# 5 Fuzzy Comprehensive Evaluations for Independent Innovation Ability

## 5.1 Evaluation method

⑴Determination of comment set. Suppose that V= ($v_1$, $v_2$,⋯, $v_m$) is the comment set, thereinto, m is the comment number. In this paper, according to the characteristic of comprehensive evaluation for independent innovation ability of construction enterprises, we presume m=5, then define the comment set as V= ($v_1$, $v_2$, $v_3$, $v_4$, $v_5$) = (good, better, general, worse, bad).

⑵Weight. The rule hierarchy set is noted as U=($U_1$, $U_2$, ⋯, $U_s$), thereinto, s is the total of factors and s=5 in this article, its weight is noted as A= ($a_1$, $a_2$, ⋯, $a_s$) and $U_i$ = ($U_{i1}$,$U_{i2}$,⋯,$U_{ini}$), i=1, 2, ⋯, s is for the index hierarchy set, the $U_{ini}$ signifies the factor set which $i_{th}$ factor in rule hierarchy corresponds to and the index hierarchy weight is noted as $A_i$=($a_{i1}$, $a_{i2}$,⋯, $a_{ini}$), in which $n_i$ is the total factor that the $i_{th}$ factor corresponds to, however, it is 3~5 respectively in this article.

⑶Fuzzy evaluation of single factor. To carry out the fuzzy evaluation of single factor on the $n_i$ factor in each $U_i$, and then we get the fuzzy evaluation matrix of single factor in each index, as follows:

$$R_i = \begin{bmatrix} r_{i11} & \cdots & r_{i1k} & \cdots & r_{i1m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{ij1} & \cdots & r_{ijk} & \cdots & r_{ijm} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{in1} & \cdots & r_{ink} & \cdots & r_{inm} \end{bmatrix} \qquad i=1, 2, \cdots, \ s \tag{4}$$

$R_i$ is the fuzzy evaluation matrix which signifies a mapping from the index hierarchy to comment set. In this, the $r_{ijk}$ indicates the possible degree of the $k_{th}$ kind of evaluation from the $j_{th}$ factor of index hierarchy to the $i_{th}$ factor of rule hierarchy, namely looking from the $j_{th}$ factor, the attachment degree of fuzzy set of evaluation for subordination to the $k_{th}$ kind for a project, then we can make a result that the judgment vector of index hierarchy $U_i$ is $B_i = A_i \circ R_i = (b_{i1}, b_{i2}, \cdots, b_{im})$, in the formula i=1, 2,⋯, s.

⑷Comprehensive evaluation. In the entire evaluation index system, U is also the rule hierarchy of index hierarchy $U_i$, therefore, the fuzzy evaluation matrix of U is

$$R = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_s \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ b_{s1} & b_{s2} & \cdots & b_{sm} \end{bmatrix} \tag{5}$$

Finally, the judgment vector of index hierarchy $U_i$ is $B = A \circ R = (b_1, b_2, \cdots, b_m)$, suppose $b_k$=Max($b_1$, $b_2$, ⋯, $b_m$), then we can get a fuzzy comprehensive evaluation result $v_k$.

**5.2 Empirical analysis**

We will take a construction enterprise as our evaluation object and use the above methods to carry out the evaluation for its independent innovation ability. Firstly, we invite experts to evaluate each index from $U_1$~$U_5$ according to comment set V, from which we obtain the evaluation matrix of single factor, that is:

$$R_1=\begin{bmatrix}0.25 & 0.55 & 0.15 & 0.05 & 0\\ 0.20 & 0.45 & 0.20 & 0.10 & 0.05\\ 0 & 0.15 & 0.50 & 0.25 & 0.10\\ 0.05 & 0.20 & 0.40 & 0.20 & 0.15\\ 0.05 & 0.05 & 0.30 & 0.35 & 0.25\end{bmatrix} \quad R_4=\begin{bmatrix}0 & 0 & 0.25 & 0.65 & 0.10\\ 0.15 & 0.80 & 0.05 & 0 & 0\\ 0.20 & 0.45 & 0.35 & 0 & 0\\ 0.15 & 0.50 & 0.20 & 0.10 & 0.05\\ 0.15 & 0.30 & 0.40 & 0.10 & 0.05\end{bmatrix} \quad R_5=\begin{bmatrix}0.25 & 0.30 & 0.30 & 0.15 & 0\\ 0.15 & 0.20 & 0.25 & 0.25 & 0.15\\ 0.20 & 0.60 & 0.15 & 0.05 & 0\\ 0.25 & 0.45 & 0.15 & 0.15 & 0\\ 0.15 & 0.40 & 0.25 & 0.10 & 0.10\end{bmatrix}$$

$$R_2=\begin{bmatrix}0.20 & 0.55 & 0.15 & 0.10 & 0\\ 0.10 & 0.15 & 0.50 & 0.20 & 0.05\\ 0 & 0 & 0.20 & 0.65 & 0.15\end{bmatrix} \quad R_3=\begin{bmatrix}0.15 & 0.15 & 0.65 & 0.05 & 0\\ 0 & 0.10 & 0.20 & 0.50 & 0.20\\ 0 & 0.05 & 0.20 & 0.60 & 0.15\\ 0.15 & 0.60 & 0.20 & 0.05 & 0\end{bmatrix}$$

Index weight A= (0.29, 0.16, 0.23, 0.17, 0.15）, $A_1$= (0.31, 0.24, 0.12, 0.18, 0.15), $A_2$= (0.33, 0.48, 0.19), $A_3$= (0.32, 0.28, 0.21, 0.19), $A_4$= (0.17, 0.23, 0.18, 0.15, 0.27), $A_5$= (0.14, 0.20, 0.28, 0.11, 0.27)。

Through the evaluation of single factor, we get it as follows:

$$B_1=A_1\circ R_1=(0.142 \quad 0.34 \quad 0.2715 \quad 0.158 \quad 0.0885)$$
$$B_2=A_2\circ R_2=(0.114 \quad 0.2535 \quad 0.3275 \quad 0.2525 \quad 0.0525)$$
$$B_3=A_3\circ R_3=(0.0765 \quad 0.2005 \quad 0.344 \quad 0.2915 \quad 0.0875)$$
$$B_4=A_4\circ R_4=(0.1335 \quad 0.421 \quad 0.255 \quad 0.1525 \quad 0.038)$$
$$B_5=A_5\circ R_5=(0.189 \quad 0.4075 \quad 0.218 \quad 0.1285 \quad 0.057)$$

Through comprehensive evaluation, we get it as follows:

$$B=A\circ R=A\circ\begin{bmatrix}B_1 & B_2 & B_3 & B_4 & B_5\end{bmatrix}^T=(0.12806 \quad 0.31797 \quad 0.286305 \quad 0.198465 \quad 0.0692)$$

$b_k$= Max($b_1$, $b_2$, …, $b_5$)=Max (0.12806, 0.31797, 0.286305, 0.198465, 0.0692)=0.31797=$b_2$, according to the attachment degree maximum theory, the independent innovation ability of this enterprise is $v_2$, that means better.

## 6 Conclusion

In a new era of knowledge economy with Information networking and economic globalization, independent innovation ability is regarded as the foundation for construction enterprises to survive and develop. By use of Expert Conference and Delphi Law for reference to establish the index system, this paper enhances the scientific nature and rationality of the evaluation index system, and the entropy value method used to determinate indexes weight can avoid the deviation caused by subjective factor effectively. The process of empirical analysis indicates that the multiple fuzzy comprehensive evaluation method is feasible to evaluate the independent innovation ability of construction enterprises, and the results are basically reasonable. By applying this method, it is advantageous in grasping the actual state of independent innovation ability of construction enterprises and discovering the primary factor that affects the ability. Of course, the perfection of this method need compare with other methods such as DEA, rough set, neural network or grey theory which have been proved useful in other field. It should be studied as another subject for further progress.

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