Evaluation of a Patent value based on AHP fuzzy comprehensive evaluation method

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Abstract. In order to evaluate the patent value scientifically, objectively and effectively, many factors affecting the patent value are considered in order to make up for the shortcomings of the existing patent evaluation methods. In this paper, the analytic hierarchy process (AHP) (AHP) method is used to establish a comprehensive patent value evaluation index system, and the fuzzy comprehensive evaluation method is used to obtain the final evaluation results, which enriches the existing ideas and methods of patent value evaluation.

1. Introduction

China has gradually entered the era of knowledge economy, meanwhile, the industrial form has gradually shifted to technology-intensive and intellectual-intensive, and intangible assets have played an increasingly important role in the development of enterprises. As part of the intangible assets, the correct assessment of the value of patents will bring huge benefits to enterprises and society. By the end of 2018, the number of patent applications in China had reached 4.323 million. With the development of the knowledge economy, the impact of patent value will become more and more obvious, and the scale of application will continue to expand. Patent valuation plays a very important role in patent property transactions, patent financing, and many other aspects. However, compared with tangible assets, the evaluation of patent value assets has three characteristics, such as timeliness, uncertainty and ambiguity, which leads to the lack of objectivity in patent evaluation in the market. Therefore, it is of great practical significance to seek a more scientific, objective and effective patent asset evaluation method, which is also the need of economic development.

Foreign scholar Pierre (2001) believes that the legislation, economic risk and the present value of future earnings are factors that affect the value of patents[1]; Hou and Lin (2006) believe that the main factors affecting the value of patent rights are market, legislation, technology and technology transfer[2]; for the research of evaluation methods, many domestic scholars, for example, Yuan Jianhong (2000), Luo Exiang and Qian Sengsan (2004) adopt the three basic methods, including cost method, income method and market method[3]; however, Shen Zijia (2008) pointed out that the income present value method which mostly used in the patent trading market is very unobjective, he proposed that the evaluation of patent value should use the fuzzy comprehensive evaluation model to reduce uncertainty and increase objectivity [4]; Zi Zhihong (2017) uses a combination of quantitative and qualitative methods to combine quantitative index evaluation with expert scoring, and separately calculates the value of the quantitative index of the patent and the value of the qualitative index, at last, obtains the value of the patent[5].
In summary, based on the uncertainty and ambiguity of patent value, we should consider all aspects of the evaluation of a patent value and establish a more comprehensive patent value evaluation index system. The three existing basic assessment methods are also flawed, cost method evaluation often lowers the value of patents, which leads to inaccuracy; because the personality of each patent is too clear, it is difficult to find a case comparable to it by market method; if various parameters required by the income method are slightly different, the calculated data are still inaccurate and uncertain. Therefore, the evaluation of patent value can not be calculated only by quantitative methods such as mathematical formulas, but by a combination of quantitative and qualitative methods, then the qualitative evaluation will be converted into quantitative evaluation, next, the data will be calculated and determined. This paper will establish a comprehensive patent value evaluation index system, using the Analytic Hierarchy Process method to obtain the weights of the first-level indicators and the second-level indicators and conduct consistency check, then obtain the group decision conclusions through the group decision matrix method. Next use the fuzzy comprehensive evaluation and establish a single factor fuzzy evaluation matrix to obtain the correction coefficient through fuzzy operation. Lastly, confirm the evaluation value and get the final conclusion.

2. Construction of Patent Value Evaluation Index System

Patent value is an important part of intangible assets. According to the patent characteristics of Shanghai Zhongli Company, the Patent Value is estimated by AHP and fuzzy comprehensive evaluation, and constructs a first-level index system, which includes market value, technical value and legal value.

| Index system | Specific meaning |
|--------------|-----------------|
| Legal value  | The legal value of a patent is stipulate the legal users of patents from the legal point of view, effectively circumvent the illegal use of patented technology by others, and protect the legitimate rights and interests of patent inventors. The legal value of patents types includes the stability, exclusiveness, dependence, timeliness, number of patent applications, international coverage, patent licensing status, determinability of patent infringement, the degree of stability of legal status and so on. |
| Technical value | The technological value of a patent refers to the intrinsic value of patent itself, a series of functions and meanings of technological activities and their achievements. The technological value of a patent is embodied in innovation ability, technological content, maturity, technological breadth, degree of substitution, technological renewal cycle, etc. |
| Market value  | The market value of patent refers to the benefits that can be obtained from the commercialization of patents in the market. Market value can be measured by marketability, market demand, market competitiveness, market monopoly, profit sharing rate, market prospects, etc. |

3. The weight analysis of Patent Index System based on AHP.
Complex systems are characterized by a variety of variables, complex structures and a significant role of uncertainties, which are inevitable in the process of patent value evaluation. Different factors have different importance, but as to how to reflect the importance of these factors, it is necessary to estimate the relative importance of each factor. That is to say, they are compared according to the weights of each factor. In this article, we adopt an effective method which combines quantitative analysis with qualitative analysis, that is, analytic hierarchy process (AHP) is used comprehensively to divide the influencing factors in complex systems into hierarchical structures with a certain sequence according to a certain degree of correlation.

3.1 Establishing Hierarchical Analysis Structure and Hierarchical Relationship of Patent Asset Value.

Target level: The index system of patent asset value evaluation model.

Criteria level: It contains three first-level indicators and nineteen second-level indicators. See Table 2 for details.

| The index system of patent asset valuation model | Legal value A1 | Technical value A2 | Market value A3 |
|------------------------------------------------|----------------|--------------------|-----------------|
| ExclusivenessB1                                 | StabilityB2    | Innovation abilityB8|
| StabilityB2                                     | TimelinessB3   | Technical contentB9|
| TimelinessB3                                    | DependenceB4   | MaturityB10        |
| DependenceB4                                    | Patent licensing statusB5 | The degree of substitutionB11 |
| Patent licensing statusB5                        | The decidability of patent infringementB6 | Configuration technology dependencyB12 |
| The decidability of patent infringementB6       | International coverageB7 | Technology renewal cycleB13 |
| International coverageB7                        |                 |                    |
| Market-oriented abilityB14                      | Market demand levelB15 |                    |
| Market demand levelB15                          | Market competitivenessB16 |                    |
| Market competitivenessB16                       | Market monopoly degreeB17 |                    |
| Market monopoly degreeB17                       | Profit sharing rateB18 |                    |
| Profit sharing rateB18                          | Market prospectsB19 |                    |
| Market prospectsB19                             |                    |                    |

3.2 Determination of weight based on Analytic hierarchy process (AHP)

3.2.1 Construct the judgment matrix.

Set A as the goal. \( u_c, u_R \) (\( C, R=1, 2, \cdots, n \)) represent each factor. UCR represent the proportion of the impact of \( u_c \) and \( u_R \) on the upper level of indicators, that is the ratio of \( u_c:u_R \). Then all UCR are used to construct A-U judgement matrix \( P \).

\[
P = \begin{bmatrix}
  u_{11} & u_{12} & \cdots & u_{1n} \\
  u_{21} & u_{22} & \cdots & u_{2n} \\
  \vdots & \vdots & \ddots & \vdots \\
  u_{n1} & u_{n2} & \cdots & u_{nn}
\end{bmatrix}
\]
3.2.2 Computational importance order.
According to the judgement matrix $P$ shown, the maximum eigenvalue ($\lambda_{\text{max}}$) and its corresponding eigenvector ($W$) are obtained by calculating the corresponding formulas. The equation is as follows:

$$P \cdot W = \lambda_{\text{max}} W$$

Then the obtained eigenvector $W$ is normalized, in the other word, ranking the importance of each evaluation factor. The weight mentioned above are the normalized values.

3.2.3 Consistency test
Above all, we use one-time test to analyze the rationality of weight allocation. Meanwhile, the random consistency ratio is expressed by CR and the general consistency index is expressed by CI. The test formulas are as follows:

$$CR = \frac{CI}{RI}$$

Among them, CI is given by the following formula:

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1}$$

In addition, RI can be used to represent the average random consistency index, including the first to ninth order, the specific RI values for each order can be referred to in the table below

| $n$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----|---|---|---|---|---|---|---|---|---|
| RI  | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 |

When CR of judgment matrix $P$ is less than 0.1 or $\lambda_{\text{max}} = n$, CR=0, it can be considered that matrix $P$ has an acceptable consistency standard, otherwise, it doesn’t have an acceptable consistency standard. It is necessary to modify the factors in $P$ to meet the standard.

3.3 Conclusion of Group Decision Making.

3.3.1 Group Decision Matrix Method.
Through the corresponding position of the matrix corrected by the experts, the geometric average is obtained. Then the final group conclusion is calculated on the basis of the group matrix.

3.3.2 Expert data.

| Table 5. Weight table. |
|------------------------|
| **First-level indicators** | **Second-level indicators** | **Conclusion value** | **Global weight** | **Peer weight** |
| A1 | B1 | 0.1255 | 0.2509 |
| A1 | B2 | 0.1048 | 0.2095 |
| A1 | B3 | 0.0896 | 0.1792 |
| A1 | B4 | 0.0717 | 0.1434 |
| A1 | B5 | 0.0538 | 0.1075 |
| A1 | B6 | 0.0368 | 0.0736 |
| A1 | B7 | 0.0179 | 0.0358 |
| A1 | B8 | 0.0952 | 0.2857 |
| A1 | B9 | 0.0794 | 0.2381 |
| A1 | B10 | 0.0635 | 0.1905 |
| A1 | B11 | 0.0317 | 0.0952 |
| A1 | B12 | 0.0476 | 0.1429 |

The index system of patent asset valuation model 0.0002
Index system of evaluation model: $\lambda_{\text{max}}=3$; $\text{CR}=0$; $\text{CI}=0$

| A1 | A2 | A3 | Weight ($w_i$) |
|----|----|----|----------------|
| 1  | 1.5| 3  | 0.5            |
| 0.6667 | 1  | 2  | 0.3333        |
| 1/3 | 1/2| 1  | 0.1667        |

Legal value: $\lambda_{\text{max}}=7.0034$; $\text{CR}=0.0004$; $\text{CI}=0.0006$

| B1  | B2    | B3    | B4    | B5    | B6    | B7    | Weight ($w_i$) |
|-----|-------|-------|-------|-------|-------|-------|----------------|
| 1   | 1.1667| 1.4   | 1.75  | 2.3333| 3.5   | 7     | 0.2509        |
| 0.8571| 1    | 1.2   | 1.5   | 2     | 2.5   | 6     | 0.2095        |
| 0.7143| 0.8333| 1    | 1.25  | 1.6667| 2.5   | 5     | 0.1792        |
| 0.5714| 0.6667| 0.8  | 1     | 1.3333| 2     | 4     | 0.1434        |
| 0.4286| 1/2   | 0.6   | 0.75  | 1     | 1.5   | 3     | 0.1075        |
| 0.2857| 0.4   | 0.4   | 1/2   | 0.6667| 1     | 2     | 0.0736        |
| 1/7 | 1/6   | 1/5   | 1/4   | 1/3   | 1/2   | 1     | 0.0358        |

Market value: $\lambda_{\text{max}}=6$; $\text{CR}=0$; $\text{CI}=0$

| B8  | B9    | B10   | B11   | B12   | B13   | Weight ($w_i$) |
|-----|-------|-------|-------|-------|-------|----------------|
| 1   | 1.2   | 1.5   | 2     | 3     | 6     | 0.2857        |
| 0.8333| 1    | 1.25  | 1.6667| 2.5   | 5     | 0.2381        |
| 0.6667| 0.8  | 1     | 1.3333| 2     | 4     | 0.1905        |
| 1/2 | 0.6   | 0.75  | 1     | 1.5   | 3     | 0.1429        |
| 1/3 | 0.4   | 1/2   | 0.6667| 1     | 2     | 0.0952        |
| 1/6 | 1/5   | 1/4   | 1/3   | 1/2   | 1     | 0.0476        |

Table 6. Evaluation model index system weight table.

Table 7. Table of weights of legal value.

Table 8. Table of weights of technical value. Technical value: $\lambda_{\text{max}}=6$; $\text{CR}=0$; $\text{CI}=0$

| B8  | B9    | B10   | B11   | B12   | B13   | Weight ($w_i$) |
|-----|-------|-------|-------|-------|-------|----------------|
| 1   | 1.2   | 1.5   | 2     | 3     | 6     | 0.2857        |
| 0.8333| 1    | 1.25  | 1.6667| 2.5   | 5     | 0.2381        |
| 0.6667| 0.8  | 1     | 1.3333| 2     | 4     | 0.1905        |
| 1/2 | 0.6   | 0.75  | 1     | 1.5   | 3     | 0.1429        |
| 1/3 | 0.4   | 1/2   | 0.6667| 1     | 2     | 0.0952        |
| 1/6 | 1/5   | 1/4   | 1/3   | 1/2   | 1     | 0.0476        |

Table 9. Table of weights of market value.
3.4 Group Decision Data.

4. Patent Value Analysis Based on Fuzzy Comprehensive Evaluation

Fuzzy comprehensive evaluation method is based on membership degree theory of fuzzy mathematics, it also a comprehensive method which uses mathematical methods to transform the nature of evaluation from qualitative to quantitative. In other words, many factors are taken into account by means of fuzzy mathematics. It is a more comprehensive and objective evaluation method for things and objects.

4.1 Mathematical Model of Fuzzy Comprehensive Evaluation

The mathematical model is a comprehensive evaluation of matters considered by using the fuzzy transformation theorem. It includes two steps, one is the evaluation of a single factor, one is the comprehensive evaluation of all factors.

4.1.1 Establishment of evaluation index items

Factor set (U) is a set of factors (ui) that affect the object of evaluation.

\[ U = \{ u_1, u_2, \ldots, u_n \} \]

4.1.2 Establishment of evaluation index weight.

Generally speaking, various factors have varying degrees of influence on the transaction itself under consideration. To clarify the importance of each factor, it is necessary to assign a corresponding weight \( \omega_i \) to each factor \( u_i \). Then the weight set \( W \) can be expressed as:

\[ W = (\omega_1, \omega_2, \ldots, \omega_n) \]

4.1.3 Establishment of evaluation conclusions (alternative sets)

The alternative set (V) is a set of elements (vi) consisting of all kinds of general evaluation results that the evaluator may make to the object of evaluation, that is:

\[ V = \{ v_1, v_2, \ldots, v_m \} \]

4.1.4 One-factor Fuzzy Evaluation

This evaluation step requires the corresponding evaluation of each single factor \( u_i \) in factor set U. Thus, the membership degree of each element in the alternative set V can be determined by \( r_{ij} \), this is the process of single factor fuzzy evaluation. Specifically, a fuzzy set is used to represent the result of \( u_j \) judgment of the first factor.

\[ R_i = \frac{r_{i1}}{v_1} + \frac{r_{i2}}{v_2} + \cdots + \frac{r_{im}}{v_m} \]
In the formula, $R_i$ represents a set of single-factor judgements, which can be simply expressed as $\{r_{i1}, r_{i2}, ..., r_{im}\}$

### 4.1.5 Fuzzy comprehensive evaluation

The single factor fuzzy evaluation only evaluates the single factor, but does not take other factors into account, which is not comprehensive and objective enough. We should also use the weights $\omega_i$, of each factor in the weight set $W$ to take various factors into account, so as to make the results more scientific and objective. Therefore, on the premise that the weight set $W$ and the single factor evaluation matrix $R$ are known, the comprehensive evaluation can be carried out by using the method of fuzzy transformation.

Fuzzy comprehensive evaluation set can be represented by $B$, available bj (j = 1, 2... M) to express the index of fuzzy comprehensive evaluation. Specifically, as follows:

$$B = W \cdot R = (\omega_1, \omega_2, ..., \omega_n) \cdot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} = b_1, b_2, ..., b_m$$

But:

$$b_j = \bigvee_{i=1}^{n} (w_i \wedge r_{ij})$$

### 4.1.6 Evaluation Index Assessment

Taking BJ as the weight, the weighted average of each alternative element $V_J$ is carried out.

$$v = \sum_{j=1}^{m} b_j v_j \div \sum_{j=1}^{m} b_j$$

### 4.2 Fuzzy Comprehensive Evaluation Computation

#### 4.2.1 Weight Set of Evaluation Indicators $W$

| Serial number | index                                      | weight |
|---------------|--------------------------------------------|--------|
| 1             | Exclusivity                                | 0.1255 |
| 2             | Stability                                  | 0.1048 |
| 3             | Timeliness                                 | 0.0896 |
| 4             | Dependence                                 | 0.0717 |
| 5             | Patent licensing status                    | 0.0538 |
| 6             | Determinability of patent infringement     | 0.0368 |
| 7             | International coverage                     | 0.0179 |
| 8             | Innovation ability                         | 0.0952 |
| 9             | Technical content                          | 0.0794 |
| 10            | Maturity                                   | 0.0635 |
| 11            | Replaceability                             | 0.0317 |
| 12            | Dependence on Supporting Technology        | 0.0476 |
| 13            | Technology Renewal Cycle                   | 0.0159 |
| 14            | Market Prospect                            | 0.0476 |
| 15            | Market-oriented ability                    | 0.0397 |
| 16            | Profit Sharing Rate                        | 0.0317 |
17 Market Demand Level 0.0159
18 Market Monopoly Degree 0.0238
19 Market Competitiveness 0.0079

4.2.2 Assessment Concluding Set

Table 11. Evaluation conclusion set table.

| Serial number | Conclusion  | Score |
|---------------|-------------|-------|
| 1             | Very high   | 1.60  |
| 2             | Higher      | 1.20  |
| 3             | Reasonable  | 1     |
| 4             | Lower       | 0.8   |
| 5             | Very low    | 0.6   |

4.3 Evaluation Object

4.3.1 Statistics of Single Factor Indicators

Table 12. Single factor index statistical table.

| index                           | Very high | Higher | Reasonable | Lower | Very low |
|---------------------------------|-----------|--------|------------|-------|----------|
| Exclusivity                     | 1.60      | 0      | 0          | 0     | 0        |
| Stability                       | 0         | 1.2    | 0          | 0     | 0        |
| Timeliness                      | 0         | 1.1    | 0          | 0     | 0        |
| Dependence                      | 0         | 1.05   | 0          | 0     | 0        |
| Patent licensing status         | 0         | 0      | 1          | 0     | 0        |
| Determinability of patent       | 0         | 0      | 0          | 0.8   | 0        |
| Exclusivity                     | 0         | 0      | 0          | 0     | 0.7      |
| Stability                       | 1.6       | 0      | 0          | 0     | 0        |
| Technical content               | 0         | 1.3    | 0          | 0     | 0        |
| Maturity                        | 0         | 1.2    | 0          | 0     | 0        |
| Replaceability                  | 0         | 1.1    | 0          | 0     | 0        |
| Dependence on Supporting        | 0         | 0      | 1          | 0     | 0        |
| Technology Renewal Cycle        | 0         | 0      | 0          | 0.9   | 0        |
| Market Prospect                 | 1.6       | 0      | 0          | 0     | 0        |
| Market-oriented ability         | 0         | 1.4    | 0          | 0     | 0        |
| Profit Sharing Rate             | 0         | 1.3    | 0          | 0     | 0        |
| Market Demand Level             | 0         | 1.2    | 0          | 0     | 0        |
| Market Monopoly Degree          | 0         | 1.1    | 0          | 0     | 0        |
| Market Competitiveness          | 0         | 0      | 0          | 1     | 0        |

4.3.2 Statistical Weight R of Single Factor Index

Table 13. Single factor index statistical weight table.

| index                           | Very high | Higher | Reasonable | Lower | Very low |
|---------------------------------|-----------|--------|------------|-------|----------|
| Exclusivity                     | 1         | 0      | 0          | 0     | 0        |
| Stability                       | 0         | 1      | 0          | 0     | 0        |
| Technical content               | 0         | 1      | 0          | 0     | 0        |
| Maturity                        | 0         | 1      | 0          | 0     | 0        |
| Dependence                      | 0         | 1      | 0          | 0     | 0        |
| Patent licensing status         | 0         | 0      | 1          | 0     | 0        |
| Determinability of patent       | 0         | 0      | 0          | 1     | 0        |
infringement
International coverage 0 0 0 0 1
Innovation ability 1 0 0 0 0
Technical content 0 1 0 0 0
Maturity 0 1 0 0 0
Replaceability 0 1 0 0 0
Dependence on Supporting Technology 0 0 1 0 0
Technology Renewal Cycle 0 0 0 1 0
Market Prospect 1 0 0 0 0
Market-oriented ability 0 1 0 0 0
Profit Sharing Rate 0 1 0 0 0
Market Demand Level 0 1 0 0 0
Market Monopoly Degree 0 1 0 0 0
Market Competitiveness 0 0 1 0 0

4.3.3 Membership matrix B

Table 14. Membership matrix table.

| Conclusion              | Subordination Degree |
|-------------------------|----------------------|
| Very high               | 0.2683               |
| Higher                  | 0.5518               |
| Reasonable              | 0.1093               |
| Lower                   | 0.0527               |
| Very low                | 0.0179               |

According to calculation, it is concluded that comprehensive score=1.25364

4.4 Conclusion B of Fuzzy Comprehensive Evaluation

\[ B = W \cdot R = (0.2683, 0.5518, 0.1093, 0.0527, 0.0179) \]

4.5 Fuzzy comprehensive score v:(correction coefficient)

\[ v = B \cdot V C^T = 0.2683 \times 1.6 + 0.5518 \times 1.2 + 0.1093 \times 1 + 0.0527 \times 0.8 + 0.0179 \times 0.6 = 1.25364 \]

5. Case analysis

Shanghai Zhongli Company is a medium-sized private high-tech enterprise which integrates R & D technology, supporting production and independent marketing. It is mainly engaged in the research of automobile engine and chassis shock absorber series, other industrial rubber and plastic products. As of the evaluation reference date, the company has the ownership of the valid valuation patent and its ancillary rights, unlicensed use, and on July 13, 2015, the company wants to evaluate the value of the B patent assets and entrusts an asset evaluation body.

This patented technology can be used in the production of many automobile spare parts and can be based on the historical sales data to determine the expected income; combined with the patent protection period and market prospect of the product, the return period of 10 years and 5 months can be determined; the discount rate of assets can be determined by WACC (weighted average cost of capital) backward method, and the share rate can be determined by comparing the company law. Through comprehensive operation, it is concluded that the evaluation value of B patent assets and June 30, 2015 is 7.9 million yuan.

It is known that the deviation correction coefficient obtained by fuzzy comprehensive hierarchy method is 1.25364. By using this method, the corresponding patent value of B patent assets can be obtained, which is 9.904 million yuan.
790*1.25364=9.904 (million yuan)

From the above calculation, it can be seen that if only the income method is used to calculate the value of the patent, the income of the patent will be underestimated, which will lead to the reduction of the contribution of the patent to the enterprise. However, if the fuzzy comprehensive evaluation method is used to eliminate the influence of some accidental factors, the evaluation value of the patent can be evaluated more accurately.

6. Conclusion
According to the characteristics of the case, this paper sorts the first and second level indexes, establishes the index system of AHP, calculates the proportion of each factor through AHP analytic hierarchy process, modifies it by using fuzzy comprehensive evaluation method, obtains the deviation correction coefficient, effectively reduces the deviation of patent value evaluation, correctly evaluates the enterprise patent, ensures the maximization of enterprise interests, and obtains a more accurate patent evaluation value.

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