Applied Mathematics & Information Sciences
*An International Journal*

http://dx.doi.org/10.12785/amis/090459

# Empirical Study on Multilevel Fuzzy Entropy Weight Performance Evaluation Model of the Petroleum Products Export Processing Enterprises in China

*ZUO Hongyan*[1,2,*]

[1] School of Business, Hunan International Economics University, Changsha, China, 410205, P. R. China
[2] Hunan province transnational investment and operations research base, Changsha, China, 410205, P. R. China

Received: 28 Nov. 2014, Revised: 28 Feb. 2015, Accepted: 2 Mar. 2015
Published online: 1 Jul. 2015

**Abstract:** In allusion to the multilevel evaluation index system and the actual situation of subjective assignment weights, a new multilevel evaluation model of the fuzzy entropy weight was established by means of adopting the corresponding membership function to fuzzify the indexes such as extremely large, small and medium-sized and using classification determining the evaluation value of the fuzzy entropy weight, the evaluation matrix of the fuzzy entropy weight and the relative closeness degree of the evaluation index et al. The empirical results show that the new fuzzy entropy multilevel evaluation model can avoid the subjectivity which lies in ascertaining factors' weights and can make the evaluation results more objective. It is of important application and generalization value.

**Keywords:** Fuzzy theory; Entropy weight method; Performance; Empirical research

## 1 Introduction

Among the decision-making evaluation methods currently[1,2], there were two main kinds of weight confirm methods[3]: the subjective method, the objective weighting method[4]. Familiar ones were the delphi method, AHP method, factor Analysis method, entropy value method, comprehensive index, fuzzy comprehensive index, fuzzy comprehensive evaluation[5, 6,7,8,9,10] et al. But there is a big defect that it is hard to get rid of the influence of artificial factors and the randomness of measurement process when using these methods to evaluate, which will lead to the loss of some information and impact the rationality of the evaluation.

Considering that the entropy weight method can determine the entropy weight of evaluation indexes objectively according to the relationship between the different evaluation objects' evaluation index data. But, unfortunately, the entropy weight that measures the same evaluation index of the different evaluation objects were often the same[11,12,13,14], which covers the same evaluation index' difference between different evaluation objects. Thus, entropy weight is a kind of mixed entropy weight actually. Therefore, a new fuzzy entropy weight multi-level evaluation model was established by means of combining fuzzy theory and improving the entropy weight method. The goal that same evaluation index of the different evaluation objects is of the different entropy weight can be realized based on the new fuzzy entropy weight multi-level evaluation model. The effectiveness of the model was proved by empirical research results commendably.

## 2 Multilevel evaluation model based on fuzzy entropy weight

### *2.1 Secondary level evaluation model based on fuzzy entropy weight*

(1) Fuzzification of secondary level evaluation indexes

Suppose there are $m$ evaluation objects, the amount of the first level evaluation indexes is $L$. Moreover, the first level evaluation index ranked $k^{th}$ includes $n$ evaluation indexes classified as the secondary level. For the first level evaluation index ranked $k^{th}$, the evaluation values of the secondary level evaluation indexes about $m$ evaluation

* Corresponding author e-mail: zuohongyan18@126.com

objects composed the matrix $\boldsymbol{T} = (t_{ij})_{m\times n}$ and $t_{ij}$ represent the values of the $j^{th}(j = 1,2,...,n)$ secondary level evaluation indexes under the $k^{th}$ first level evaluation indexes. so, the matrix $\boldsymbol{T}$ made up by the n secondary -level evaluation indexes of the $m$ evaluation objects which under the $k^{th}$ first level evaluation index are expressed as follows:

$$\boldsymbol{T} = \begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1n} \\ t_{21} & t_{22} & \cdots & t_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ t_{m1} & t_{m2} & \cdots & t_{mn} \end{bmatrix} \tag{1}$$

For the secondary evaluation index may exit the different types: (1) Extremely large indexes; (2) Extremely small indexes; (3) The medium-sized indexes, some measurements for fuzzification of secondary level evaluation indexes were expressed as follows.

If the value of the $j^{th}(j = 1,2,...,n)$ secondary level evaluation index is a extremely large index, the calculation formula of its membership degree is as shown in formula (2) :

$$\mu_{ij} = \frac{t_{ij} - \min\limits_{1\le i\le m}(t_{ij})}{\max\limits_{1\le i\le m}(t_{ij}) - \min\limits_{1\le i\le m}(t_{ij})} \tag{2}$$

If the value of the $j^{th}(j = 1,2,...,n)$ secondary level evaluation index is a extremely small index, the calculation formula of its membership degree is as shown in formula (3):

$$\mu_{ij} = \frac{\max\limits_{1\le i\le m}(t_{ij}) - t_{ij}}{\max\limits_{1\le i\le m}(t_{ij}) - \min\limits_{1\le i\le m}(t_{ij})} \tag{3}$$

If the value of the $j^{th}(j = 1,2,...,n)$ secondary level evaluation index is a medium-sized index, the calculation formula of its membership degree is shown as formula (4):

$$\mu_{ij} = \begin{cases} 1 & t_{ij} = u_j \\ 1 - |t_{ij} - u_j| / \max|t_{ij} - u_j| & t_{ij} \neq u_j \end{cases} \tag{4}$$

where, the $u_j$ is the mean value of the $j^{th}(j = 1,2,...,n)$ secondary level medium-sized evaluation index.

After being fuzzified, fuzzy membership degree value $\mu_{ij}$ of all the secondary indexes are located in the range 0 and 1. Considering the logarithmic function of fuzzy entropy weight method requires that all the data are not equal to zero, the traditional linear scaling transformation method should be improved based on the idea of efficacy coefficient, namely make $r_{ij} = 0.5\mu_{ij} + 0.5$. In order to ensure the $t_{ij} > 0$, there must have $0.5 \le r_{ij} \le 1$.

So, under the $k^{th}$ first level evaluation indexes, the fuzzy evaluation matrix of the $n$ secondary level evaluation about $m$ evaluation objects indexes $\boldsymbol{R} = (r^{ij})_{m\times n}$ is expressed as follows:

$$\boldsymbol{R} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{5}$$

(2) Determination of the entropy weight of the secondary level evaluation indexes' fuzzy evaluation value

Generally speaking, in comprehensive evaluation, the index value' variation level of one index is greater, the information entropy is smaller, the amount of information provided by the index is lager, the weight of this index should be lager too; On the contrary, the weight of this index should be smaller. Therefore, we can calculate the weight of each index with entropy according to their variation level. So, under the $k^{th}$ first level evaluation indexes, the variable entropy weight value of the $n$ secondary level evaluation indexes' fuzzy value about m evaluation objects can be represented as:

$$e_{ij} = \frac{1 - r_{ij}\ln(r_{ij})}{m - \sum\limits_{i=1}^{m} r_{ij}[\ln(r_{ij})]} \tag{6}$$

(3) Construction of the fuzzy entropy two level evaluation matrix

Because of the different importance about the $n$ secondary level evaluation indexes of the $m$ evaluation objects which under the $k^{th}$ first level evaluation index, we should take the $e_{ij}$ into consideration which represent the entropy weight of the secondary level evaluation indexes, and weight the fuzzy evaluation value about the $n$ secondary level evaluation indexes of the $m$ evaluation objects which under the $k^{th}$ first level evaluation index, and then, the weighted results can be used to constitute fuzzy entropy weight evaluation matrix $V = (v_{ij})_{m\times n}$:

$$V = (v_{ij})_{m\times n} = \begin{bmatrix} r_{11}e_{11} & r_{12}e_{12} & \cdots & r_{1n}e_{1n} \\ r_{21}e_{21} & r_{22}e_{22} & \cdots & r_{2n}e_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1}e_{m1} & r_{m2}e_{m2} & \cdots & r_{mn}e_{mn} \end{bmatrix} \tag{7}$$

(4) Calculation of the secondary evaluation indexes' relative close degree.

The positive ideal solution $v_j^+$ and negative ideal solution $v_j^-$ of the n secondary level evaluation indexes of the m evaluation objects which under the $k_{th}$ first level evaluation indexes can be represented as:

$$v_j^+ = \{(\max_{1\le i\le m} v_{ij} | j = 1,2,...,J_1), (\min_{1\le i\le m} v_{ij} | j = 1,2,...,J_2)\} \tag{8}$$

where, $J_1$ is the benefit type index; $J_2$ is the cost type index, and $J_1 + J_2 = n$.

$$v_j^- = \{(\min_{1\le i\le m} v_{ij} | j = 1,2,...,J_1), (\max_{1\le i\le m} v_{ij} | j = 1,2,...,J_2)\} \tag{9}$$

The distance between the $m$ evaluation objects which under the $k^{th}$ first level evaluation index and positive ideal solution, negative ideal solution respectively are:

$$d_i^+ = [\sum_{j=1}^{n}(v_{ij} - v_j^+)]^{\frac{1}{2}} (i = 1,2,\cdots,m) \tag{10}$$

$$d_i^- = [\sum_{j=1}^{n}(v_{ij} - v_j^-)]^{\frac{1}{2}} (i = 1,2,\cdots,m) \quad (11)$$

The relative close degree between the $m$ evaluation objects which under the $k^{th}$ first level evaluation index and the positive and negative ideal solution is:

$$S_i = \frac{d_i^-}{d_i^+ + d_i^-} (i = 1,2,\cdots,m) \quad (12)$$

According to the size of the relative close degree, we could rank the $m$ evaluation objects under the $k^{th}$ first level evaluation index, namely, if the $S_i$ in the $\boldsymbol{S} = \{S_1,...,S_m\}$ is bigger??the $i^{th}$ evaluated object under the $k^{th}$ first level evaluation index is better.

### *2.2 Comprehensive evaluation model based on fuzzy entropy weight*

(1)Construction of the fuzzy entropy comprehensive evaluation matrix

Constructing the comprehensive evaluation index' fuzzy entropy weight evaluation matrix $W = (w_{ij})_{m\times L}$ with $S_k(k = 1,2,...,L)$ which represent the relative close degree of $m$ evaluation objects under the $L$ first level evaluation, the matrix is as follows:

$$W = (w_{ik})_{m\times L} = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1L} \\ s_{21} & s_{22} & \cdots & s_{2L} \\ \vdots & \vdots & \vdots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mL} \end{bmatrix} \quad (13)$$

(2) Calculation of the comprehensive evaluation indexes' relative close degree.

The positive ideal solution $w_i^+$ and negative ideal solution $w_i^-$ of the m evaluation objects' $L$ first level evaluation indexes can be represented as:

$$w_i^+ = \{(\max_{1\le i\le m} w_{ik} | k = 1,2,...,J_1), (\min_{1\le i\le m} w_{ik} | k = 1,2,...,J_2)\} \quad (14)$$

where, $J_1$ is the benefit type index; $J_2$ is the cost type index, and $J_1 + J_2 = L$.

$$w_i^- = \{(\min_{1\le i\le m} w_{ik} | k = 1,2,...,J_1), (\max_{1\le i\le m} w_{ik} | k = 1,2,...,J_2)\} \quad (15)$$

The distance between the $L$ first level evaluation indexes of the m objects and positive ideal solution, negative ideal solution represented by $D_i^+$, $D_i^-$ can be respectively represented as follows:

$$D_i^+ = [\sum_{k=1}^{L}(w_{ik} - w_i^+)]^{\frac{1}{2}} (i = 1,2,\cdots,m) \quad (16)$$

$$D_i^- = [\sum_{k=1}^{L}(w_{ij} - w_i^-)]^{\frac{1}{2}} (i = 1,2,\cdots,m) \quad (17)$$

The total relative close degree $C_i$ of the $L$ first level evaluation indexes' positive and negative ideal solution about m evaluation objects is expressed as:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} (i = 1,2,\cdots,m) \quad (18)$$

According to the size of the relative close degree $C_i$, $m$ evaluation objects can be ranked. The bigger the $C_i$ is ??the better the $i^{th}$ evaluated object is.

## 3 Application research on fuzzy entropy weight evaluation model

Four China petroleum export processing enterprise respectively represented by enterprise1, enterprise2, enterprise 3 and enterprises 4 were selected and their performance data in 2009 were gotten in order to do the fuzzy entropy weight evaluation research. Under the principles of importance, comprehensiveness, comparability and operability, combining the actual situation of China petroleum export processing enterprises, five first level indexes were selected including the export competitive ability $X_1$, financial profitability $X_2$, assets operation ability $X_3$, debt paying ability $X_4$, development ability $X_5$ and 17 secondary level indexes including export rate of the Output value $X_{11}$, export profit rate $X_{12}$, the international market share $X_{13}$, the return on assets $X_{21}$, the rate of return on equity $X_{22}$, the ratio of profits to cost $X_{23}$, Main business profitability $X_{24}$, rate of stock turnover $X_{31}$, total property cycling rate $X_{32}$, accounts receivable turnover $X_{33}$, asset-liability ratio $X_{41}$, current ratio $X_{42}$, quick ratio $X_{43}$, net profit growth rate $X_{51}$, the main business growth rate $X_{52}$, export growth rate $X_{53}$ and Technical Input Ratio $X_{54}$ to reflect the 4 China petroleum export processing enterprise' performance in 2009, the specific index system and evaluation index data were shown in table 1.

It is well known that the asset-liability ratio $X_{41}$ is the extremely small type index and the other 16 secondary level evaluation indexes are all belong to extremely large type.

### *3.1 Fuzzy entropy weight evaluation of the first level indexes*

Due to table 1, the performance evaluation index system of the petroleum export processing enterprise constituted by two layers including the first level indexes and the secondary level indexes, therefore, the fuzzy entropy weight evaluation to the performance evaluation first level indexes of China's petroleum export processing enterprise was done firstly.

(1) Fuzzy entropy weight evaluation of the export competitive ability index

**Table 1:** Performance evaluation index system and data of the petroleum export processing enterprises / %

| First level indexes | Secondary level indexes | Enterprise1 | Enterprise2 | Enterprise3 | Enterprise4 |
|---|---|---|---|---|---|
| $X_1$ | $X_{11}$/% | 0.3462 | 0.148 | 0.0991 | 0.0159 |
| | $X_{12}$/% | 0.0808 | 0.0421 | 0.104 | 0.036 |
| | $X_{13}$/% | 0.00601 | 0.004961 | 0.002167 | 0.000326 |
| $X_2$ | $X_{21}$/% | 0.106 | 0.055 | 0.136 | 0.047 |
| | $X_{22}$/% | 0.09 | 0.047 | 0.116 | 0.04 |
| | $X_{23}$/% | 0.033 | 0.014 | 0.043 | 0.022 |
| | $X_{24}$/% | 0.159 | 0.217 | 0.219 | 0.257 |
| $X_3$ | $X_{31}$/% | 7.34 | 12.11 | 8.76 | 8.06 |
| | $X_{32}$/% | 3.238 | 3.655 | 3.266 | 2.223 |
| | $X_{33}$/% | 35.04 | 4723.1 | 54.92 | 139499.6 |
| $X_4$ | $X_{41}$/% | 1.203 | 0.393 | 0.487 | 0.465 |
| | $X_{42}$/% | 0.887 | 1.151 | 0.793 | 1.394 |
| | $X_{43}$/% | 0.342 | 0.133 | 0.193 | 0.614 |
| $X_5$ | $X_{51}$/% | -1.146 | -1.067 | -1.293 | -1.092 |
| | $X_{52}$/% | -0.209 | -0.002 | -0.183 | 0 |
| | $X_{53}$/% | -0.223 | 0.64 | 0.582 | -0.398 |
| | $X_{54}$/% | 0.0001 | 0 | 0.0004 | 0.0011 |

Taking the export competitive ability index as an example, the fuzzy entropy weight evaluation to the performance evaluation first level indexes of China's petroleum export processing enterprise was done. After doing the fuzzy processing to the evaluation index through formula (2), the results shown as table 2 were gotten. The variable entropy weight value of these 4 enterprises' export competitiveness index fuzzy value can be calculated with formula (6), and the results were shown in table 3.

**Table 2:** Fuzzy results of the export competitive ability index

| Enterprise | $r_{11}$ | $r_{12}$ | $r_{13}$ |
|---|---|---|---|
| 1 | 1 | 0.8294 | 1 |
| 2 | 0.7 | 0.5449 | 0.9077 |
| 3 | 0.6259 | 1 | 0.6619 |
| 4 | 0.5 | 0.5 | 0.5 |

**Table 3:** Variable entropy weight value of the export competitive ability index

| Enterprise | $e_{11}$ | $e_{12}$ | $e_{13}$ |
|---|---|---|---|
| 1 | 0.2045 | 0.239 | 0.2124 |
| 2 | 0.2556 | 0.2754 | 0.2311 |
| 3 | 0.2645 | 0.2069 | 0.2704 |
| 4 | 0.2754 | 0.2786 | 0.286 |

The fuzzy entropy weight evaluation value of the export competitive ability index could be calculated through formula (7). The calculation results were shown in table 4.

Then it turned to determine the positive ideal solutions and negative ideal solutions of the export competitive ability index. Because of indexes in this article are all benefit type, so, the positive ideal solutions and negative ideal solutions can be gotten according to formula (8) and formula (9) and the results were shown in table 5.

By using of formula (10) $\sim$ (12) to calculate the distance and the relative close degree of the export competitive ability indexes, the results were shown in table 6.

**Table 4:** Fuzzy entropy weight evaluation value of the export competitive ability index

| Enterprise | $v_{11}$ | $v_{12}$ | $v_{13}$ |
|---|---|---|---|
| 1 | 0.2045 | 0.1982 | 0.2124 |
| 2 | 0.1789 | 0.1501 | 0.2098 |
| 3 | 0.1656 | 0.2069 | 0.179 |
| 4 | 0.1377 | 0.1393 | 0.143 |

**Table 5:** Positive ideal solutions and negative ideal solutions of the export competitive ability index

| – | $X_{11}$ | $X_{12}$ | $X_{13}$ |
|---|---|---|---|
| $v_1^+$ | 0.2045 | 0.2069 | 0.2124 |
| $v_1^-$ | 0.1377 | 0.1393 | 0.143 |

(2)Fuzzy entropy weight evaluation of the financial profitability index

After doing the fuzzy processing to the evaluation index by using formula (2), the results shown in table 7 can be gotten. The variable entropy weight value of these 4 enterprises' financial profitability index fuzzy value can

**Table 6:** Distance and the relative close degree of the export competitive ability index

| Enterprise | $d_1^+$ | $d_1^-$ | $S_1$ |
|---|---|---|---|
| 1 | 0.0087 | 0.1129 | 0.9285 |
| 2 | 0.0624 | 0.0792 | 0.5596 |
| 3 | 0.0513 | 0.0815 | 0.6139 |
| 4 | 0.1177 | 0 | 0 |

be calculated with formula (5), and the results were shown in table 8.

The fuzzy entropy weight evaluation value of the financial profitability index could be calculated through formula (7). The calculation results were shown in table 9.

**Table 7:** Fuzzy results of the financial profitability index

| Enterprise | $r_{21}$ | $r_{22}$ | $r_{23}$ |
|---|---|---|---|
| 1 | 0.8315 | 0.8289 | 0.7619 |
| 2 | 0.5449 | 0.5461 | 0.3095 |
| 3 | 1 | 1 | 1 |
| 4 | 0.5 | 0.5 | 0.5 |

**Table 8:** Variable entropy weight value of the financial profitability index

| Enterprise | $e_{21}$ | $e_{22}$ | $e_{23}$ | $e_{24}$ |
|---|---|---|---|---|
| 1 | 0.2388 | 0.2391 | 0.2455 | 0.2864 |
| 2 | 0.2755 | 0.2753 | 0.2772 | 0.2513 |
| 3 | 0.207 | 0.2069 | 0.2034 | 0.2496 |
| 4 | 0.2787 | 0.2787 | 0.2739 | 0.2127 |

Then it turned to determine the positive ideal solutions and negative ideal solutions of the financial profitability index. Because of all indexes in this article are all benefit type, so, the positive ideal solutions and negative ideal solutions can be gotten according to formula (8) and formula (9), the results were shown in table 10.

**Table 9:** Fuzzy entropy weight evaluation value of the financial profitability index

| Enterprise | $v_{21}$ | $v_{22}$ | $v_{23}$ | $v_{24}$ |
|---|---|---|---|---|
| 1 | 0.1986 | 0.1982 | 0.187 | 0.1432 |
| 2 | 0.1501 | 0.1503 | 0.0858 | 0.2 |
| 3 | 0.207 | 0.2069 | 0.2034 | 0.2012 |
| 4 | 0.1394 | 0.1394 | 0.1369 | 0.2127 |

**Table 10:** Positive ideal solutions and negative ideal solutions of the financial profitability index

| — | $X_{21}$ | $X_{22}$ | $X_{23}$ | $X_{24}$ |
|---|---|---|---|---|
| $v_2^+$ | 0.207 | 0.2069 | 0.2034 | 0.2127 |
| $v_2^-$ | 0.1394 | 0.1394 | 0.0858 | 0.1432 |

By using of formula (10)∼(12) to calculate the distance and the relative close degree of the financial profitability indexes, the result were shown in table 11.

**Table 11:** Distance and the relative close degree of the financial profitability index

| Enterprise | $d_2^+$ | $d_2^-$ | $S_2$ |
|---|---|---|---|
| 1 | 0.0724 | 0.1312 | 0.6443 |
| 2 | 0.1429 | 0.0588 | 0.2915 |
| 3 | 0.0115 | 0.1622 | 0.9338 |
| 4 | 0.1164 | 0.0863 | 0.4257 |

(3) Fuzzy entropy weight evaluation of the assets operation ability index

After doing the fuzzy processing to the evaluation index through formula (2), the results shown in table 12 can be gotten. The variable entropy weight value of these 4 enterprises' assets operation ability index fuzzy value can be calculated with formula (6), and the results were shown in table 13.

**Table 12:** Fuzzy results of the assets operation ability index

| Enterprise | $r_{31}$ | $r_{32}$ | $r_{33}$ |
|---|---|---|---|
| 1 | 0.5 | 0.8544 | 0.5 |
| 2 | 1 | 1 | 0.5168 |
| 3 | 0.6488 | 0.8642 | 0.5001 |
| 4 | 0.5755 | 0.5 | 1 |

**Table 13:** Variable entropy weight value of the assets operation ability index

| Enterprise | $e_{31}$ | $e_{32}$ | $e_{33}$ |
|---|---|---|---|
| 1 | 0.2723 | 0.2462 | 0.2675 |
| 2 | 0.2022 | 0.2171 | 0.2664 |
| 3 | 0.259 | 0.2444 | 0.2675 |
| 4 | 0.2665 | 0.2923 | 0.1986 |

The fuzzy entropy weight evaluation value of the assets operation ability index could be calculated through formula (7). The calculation results are as shown in table 14.

**Table 14:** Fuzzy entropy weight evaluation value of the assets operation ability index

| Enterprise | $v_{31}$ | $v_{32}$ | $v_{33}$ |
|---|---|---|---|
| 1 | 0.1361 | 0.2104 | 0.1338 |
| 2 | 0.2022 | 0.2171 | 0.1377 |
| 3 | 0.168 | 0.2112 | 0.1338 |
| 4 | 0.1534 | 0.1462 | 0.1986 |

Then it turned to determine the positive ideal solutions and negative ideal solutions of the assets operation ability index. Because of the indexes in this article are all benefit type, so, the positive ideal solutions and negative ideal solutions can be gotten according to formula (7) and formula (8) the results were shown in table 15.

**Table 15:** Positive ideal solutions and negative ideal solutions of the assets operation ability index

| – | $X_{31}$ | $X_{32}$ | $X_{33}$ |
|---|---|---|---|
| $v_3^+$ | 0.2022 | 0.2171 | 0.1986 |
| $v_3^-$ | 0.1361 | 0.1462 | 0.1338 |

By using of formula (10)∼(12) to calculate the distance and the relative close degree of the assets operation ability index, the results were shown in table 16.

(4) Fuzzy entropy weight evaluation of the debt paying ability index

After doing the fuzzy processing to the debt paying ability X41 through formula (3), and to the current ratio $X_{42}$, quick ratio $X_{43}$ through formula (2), the results can be gotten and shown in table 17. The variable entropy weights value of these 4 enterprises' debt paying ability index fuzzy value were shown in table 18.

**Table 16:** Distance and the relative close degree of the assets operation ability index

| Enterprise | $d_3^+$ | $d_3^-$ | $S_3$ |
|---|---|---|---|
| 1 | 0.0928 | 0.0642 | 0.4089 |
| 2 | 0.0609 | 0.097 | 0.6143 |
| 3 | 0.0735 | 0.0724 | 0.4962 |
| 4 | 0.0861 | 0.0671 | 0.438 |

The fuzzy entropy weight evaluation value of the assets operation ability index could be calculated through formula (7). The calculation results are as shown in table 19.

Then it turned to determine the positive ideal solutions and negative ideal solutions of the debt paying ability index. Because of indexes in this article are all benefit type, so, the positive ideal solutions and negative ideal solutions can be gotten according to formula (8) and formula (9),the results were shown in table 20.

**Table 17:** Fuzzy results of the debt paying ability index

| Enterprise | $r_{41}$ | $r_{42}$ | $r_{43}$ |
|---|---|---|---|
| 1 | 0.5 | 0.5782 | 0.7173 |
| 2 | 1 | 0.7978 | 0.5 |
| 3 | 0.942 | 0.5 | 0.5624 |
| 4 | 0.9556 | 1 | 1 |

**Table 18:** Variable entropy weight value of the debt paying ability index

| Enterprise | $e_{41}$ | $e_{42}$ | $e_{43}$ |
|---|---|---|---|
| 1 | 0.3029 | 0.2719 | 0.2523 |
| 2 | 0.2249 | 0.2437 | 0.2743 |
| 3 | 0.2376 | 0.278 | 0.2697 |
| 4 | 0.2347 | 0.2065 | 0.2037 |

**Table 19:** Fuzzy entropy weight evaluation value of the debt paying ability index

| Enterprise | $v_{41}$ | $v_{42}$ | $v_{43}$ |
|---|---|---|---|
| 1 | 0.1515 | 0.1572 | 0.181 |
| 2 | 0.2249 | 0.1944 | 0.1371 |
| 3 | 0.2238 | 0.139 | 0.1517 |
| 4 | 0.2243 | 0.2065 | 0.2037 |

By using of formula (10) ∼ (12) to calculate the distance and the relative close degree of the debt paying ability index, the results were shown in table 21.

(5)Fuzzy entropy weight evaluation of the development ability index

After doing the fuzzy processing to the development ability evaluation index through formula (2), the results can be gotten and shown in table 22. The variable entropy weight value of these 4 enterprises' export competitiveness index fuzzy value can be calculated with formula (6), and the results were shown in table 23.

**Table 20:** Positive ideal solutions and negative ideal solutions of the debt paying ability index

| – | $X_{41}$ | $X_{42}$ | $X_43$ |
|---|---|---|---|
| $v_4^+$ | 0.2249 | 0.2065 | 0.2037 |
| $v_4^-$ | 0.1515 | 0.139 | 0.1371 |

Therefore, the fuzzy entropy weight evaluation value of the development ability index can be shown in table 24. The fuzzy entropy weight evaluation value of the development ability index could be calculated through

**Table 21:** Distance and the relative close degree of the debt paying ability index

| Enterprise | $d_4^+$ | $d_4^-$ | $S_4$ |
|---|---|---|---|
| 1 | 0.0913 | 0.0475 | 0.3424 |
| 2 | 0.0677 | 0.092 | 0.576 |
| 3 | 0.0852 | 0.0738 | 0.464 |
| 4 | 0.0006 | 0.1195 | 0.995 |

**Table 22:** Fuzzy results of the development ability index

| Enterprise | $r_{51}$ | $r_{52}$ | $r_{53}$ | $r_{54}$ |
|---|---|---|---|---|
| 1 | 0.8252 | 0.5 | 0.5843 | 0.5455 |
| 2 | 1 | 0.9952 | 1 | 0.5 |
| 3 | 0.5 | 0.5622 | 0.9721 | 0.6818 |
| 4 | 0.9447 | 1 | 0.5 | 1 |

**Table 23:** Variable entropy weight value of the development ability index

| Enterprise | $e_{51}$ | $e_{52}$ | $e_{53}$ | $e_{54}$ |
|---|---|---|---|---|
| 1 | 0.2541 | 0.288 | 0.2803 | 0.2694 |
| 2 | 0.2194 | 0.2149 | 0.2133 | 0.2727 |
| 3 | 0.2954 | 0.2832 | 0.2192 | 0.2554 |
| 4 | 0.2311 | 0.2139 | 0.2872 | 0.2025 |

formula (7). The calculation results were shown in table 24.

**Table 24:** Fuzzy entropy weight evaluation value of the development ability index

| Enterprise | $v_{51}$ | $v_{52}$ | $v_{53}$ | $v_{54}$ |
|---|---|---|---|---|
| 1 | 0.2097 | 0.144 | 0.1638 | 0.147 |
| 2 | 0.2194 | 0.2139 | 0.2133 | 0.1364 |
| 3 | 0.1477 | 0.1592 | 0.2131 | 0.1741 |
| 4 | 0.2183 | 0.2139 | 0.1436 | 0.2025 |

Then it turned to determine the positive ideal solutions and negative ideal solutions of the development ability index. Because of indexes in this article are all benefit type, so, the positive ideal solutions and negative ideal solutions can be gotten according to formula (8) and formula (9), the results were shown in table 25.

By using of formula (10) $\sim$ (12) to calculate the distance and the relative close degree of the development ability index, the result were shown in table 26.

The fuzzy entropy weight evaluation results of the petroleum export processing enterprise performance' first level indexes such as the export competitive ability, Financial profitability, assets operation ability, debt paying ability, development ability were shown in table 27.

According to the table 27, some results can be gotten as follows:

**Table 25:** Positive ideal solutions and negative ideal solutions of the development ability indexes

| – | $X_{51}$ | $X_{52}$ | $X_{53}$ | $X_{54}$ |
|---|---|---|---|---|
| $v_5^+$ | 0.2194 | 0.2139 | 0.2133 | 0.2025 |
| $v_5^-$ | 0.1477 | 0.144 | 0.1436 | 0.1364 |

**Table 26:** Distance and the relative close degree of the development ability indexes

| Enterprise | $d_5^+$ | $d_5^-$ | $S_5$ |
|---|---|---|---|
| 1 | 0.1025 | 0.0661 | 0.3919 |
| 2 | 0.0661 | 0.122 | 0.6486 |
| 3 | 0.0945 | 0.0805 | 0.4599 |
| 4 | 0.0697 | 0.1193 | 0.6312 |

**Table 27:** Fuzzy entropy weight evaluation results of the first level indexes

| Enterprise | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ |
|---|---|---|---|---|---|
| 1 | 0.9285 | 0.6443 | 0.4089 | 0.3424 | 0.3919 |
| 2 | 0.5596 | 0.2915 | 0.6143 | 0.576 | 0.6486 |
| 3 | 0.6139 | 0.9338 | 0.4962 | 0.464 | 0.4599 |
| 4 | 0 | 0.4257 | 0.438 | 0.995 | 0.6312 |

(l)As for the export competitive ability, the enterprise 1 was the highest one, enterprise 3 is NO.2, enterprises 2 was NO.3 and enterprise 4 was at the bottom. The reason is that enterprise 1 was the highest in indexes like export rate of the output value, export profit rate and the international market share, and its weights were biggest, enterprises 3 is only next to enterprise 1, enterprises 2 ranks third. And on these indexes, all these of the enterprise 4 were the lowest one.

(2)As for the financial profitability, enterprise 3 was far ahead of the others because of that the enterprise 3 was better than the others on all the indexes including return on assets, the rate of return on equity and the ratio of profits to cost, except only less than enterprise 4 in main business profitability. Except the rate of return on equity was a little higher than enterprise 4, all other indexes of enterprise 2 were much less than the other enterprises for its conservative operation.

(3)As for the assets operation ability, enterprise 2 ranks first with its excellent rate of stock turnover and total property cycling rate. Enterprise 3 was ranked as second because of its rate of stock turnover and total property cycling rate is next only to enterprise 2. Enterprise 4 was ranked as the lowest for its weakest rate of stock turnover and total property cycling rate.

(4)As for debt paying ability, enterprise 4 was ranked as first with its excellent current ratio, quick ratio and the small asset-liability ratio. Enterprise 2 is NO.2 in debt paying ability, and enterprise 3 is NO.3, the ranking of

enterprise 4 was the lowest for its high asset-liability ratio and the relatively very small current ratio.

(5)As for development ability, enterprise 2 was ranked as first for its excellent net profit growth rate, export growth rate and the main business growth rate ranking second. Enterprise 4 and enterprise 3 were ranked as second to third respectively, the ranking of enterprise 1 was at the bottom for its lowest net profit growth rate, export growth rate and the main business growth rate.

### *3.2 Fuzzy entropy weight comprehensive evaluation of the petroleum export processing enterprise' comprehensive performance*

Because of all indexes in this article are benefit type, so, the positive ideal solutions and negative ideal solutions can be gotten according formula (4) and formula (15), the results were shown in table 28.

**Table 28:** Positive ideal solutions and negative ideal solutions of the comprehensive performance index

| – | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ |
|---|---|---|---|---|---|
| $w_i^+$ | 0.9285 | 0.9338 | 0.6143 | 0.995 | 0.6486 |
| $w_i^-$ | 0 | 0.2915 | 0.4089 | 0.3424 | 0.3919 |

By using of formula (16) $\sim$ (18) to calculate the distance and the relative close degree of the comprehensive performance index, the result were shown in table 29.

**Table 29:** Distance and the total relative close degree of the comprehensive performance index

| Enterprise | $D_i^+$ | $D_i^-$ | $C_i$ |
|---|---|---|---|
| 1 | 0.786 | 0.9933 | 0.5582 |
| 2 | 0.851 | 0.6898 | 0.4477 |
| 3 | 0.6561 | 0.9036 | 0.5793 |
| 4 | 1.0732 | 0.7085 | 0.3977 |

As shown in the table 29, in the fuzzy entropy weight evaluation of the petroleum export processing enterprise' comprehensive performance, the enterprise 3 was ranked as first, enterprise 1 was ranked as second, enterprise 2 was ranked as third, enterprise 4 was ranked as fourth. To find out their causes, the enterprise 3 was of overwhelming superiority in the financial profitability and was of great advantage in both the export competitive ability and the assets operation ability. But the export competitive ability of enterprise 4 was zero. From these it can be seen that the first level indexes such as the financial profitability, the export competitive ability, the assets operation ability play the decisive role in the fuzzy entropy weight evaluation of the petroleum export processing enterprises' comprehensive performance. Meanwhile, the debt paying ability was not so important to lead to the enterprise 4 being ranked as fourth in comprehensive ranking. So, in order to improve the comprehensive performance, the export rate of the output value, the export profit rate and the international market share can be improved for enterprises 4.

## 4 Conclusions

As for the evaluation index system including first and secondary indexes, according to the actual conditions that there may exist three different types of the secondary evaluation index: extremely large, small indicator and the medium-sized index, therefore, the corresponding membership function should be used to fuzzily them. And then a new multilevel evaluation model of the fuzzy entropy weight was established by means of classification to determine the fuzzy entropy weight evaluation value, the fuzzy entropy weight evaluation matrix and the relative closeness degree of the evaluation index. The empirical results show that the model is a new synthetical and quantitative integration evaluation method. The mathematical and physics concepts of the model are clear, which could avoid the subjectivity which lies in ascertaining multi-factors' weights, and could make the evaluation results be more objective, and possesses the value to applied and disseminated.

## Acknowledgement

The authors would like to acknowledge Project(13JD31) supported Social Science Foundation of Hunan Province and the Project(201305) supported by Major Science Foundation of Hunan International Economics University.

## References

[1] Chunhua Wang, Zhaoping Zhong, Rui Li, Jiaqiang E, Recognition of the flow regimes in the spouted bed based on fuzzy c-means clustering[J]. Powder Technology, 205(1-3): 201-207(2011).

[2] Jiaqiang E, Yuqiang Li, Jinke Gong, Function chain neural network prediction on heat transfer performance of oscillating heat pipe based on grey relational analysis[J]. Journal of Central South University of Technology, 18(5): 1733-1737(2011).

[3] Jiaqiang E, Intelligent fault diagnosis and its application [M]. Changsha: Hunan University Press, 2006. (in Chinese)

[4] Jiaqiang E, Cheng Qian, Teng Liu, Research on the vibration characteristics of the new type of passive super static vibratory platform based on the Multi-objective parameter optimization[J]. Advances in Mechanical Engineering, 2014: 1-8(2014).

[5] Aihua LIU, Shiliang Shi, Chao Wu, Application of the Fuzzy Recognition Based Fuzzy Synthetic Assessment to High Building Fire Risk Assessment[J]. China Safety Science Journal, 15(11): 107-111(2005). (in Chinese)
[6] S. I. Ropers, B. A. Greenaway, UK Perspective on the development of marine ecosystem indicators [J]. Marine Pollution Bulletin, 50(1): 9-19(2005).
[7] B. A. Wilcox, Ecosystem health in practice; emerging areas of application in environment and human health[J]. Ecosystem Health, 7(4): 317-325(2002).
[8] A. H. Joneso, N. Voulvoulisn, J. N. Ixster, Potential ecological and human health risks associated with the presence of pharmaceutically active compounds in the aquatic environment[J].Critical Reviews in Toxicology, 34(4): 335-350(2004).
[9] M. S. Jerry, B. Mariano, Y. Annalee, E. Molina, M. Conception, P. Mas, Developing ecosystem health indicators in centro habana: A community-based approach[J]. Ecosystem Health, 7(1): 15-26(2001).
[10] Zhouquan Luo, Hongyan Zuo, Yiwei Wang, Fuzzy entropy evaluation method of the safety for man-machine-environment system[J]. Fuzzy Systems and Mathematics, 25(6): 169-174(2011). (in Chinese)
[11] Zhaohong Wang, Wei Zhan, Dynamic Engineering Multi-criteria Decision Making Model Optimized by Entropy Weight for Evaluating Bid[J]. Systems Engineering Procedia, 5: 49-54(2012).
[12] Xiaoliang Zhao, Qingjie Qi, Ruifeng Li, The establishment and application of fuzzy comprehensive model with weight based on entropy technology for air quality assessment[J]. Procedia Engineering, 7: 217-222(2010).
[13] Jun Ye, Multi-criteria fuzzy decision-making method using entropy weights-based correlation coefficients of interval-valued intuitionistic fuzzy sets[J]. Applied Mathematical Modelling, 34(12): 3864-3870(2010).
[14] Zhengyuan Jia, Chunmei Wang, Zhiwei Huang, Gang Zhang, Evaluation Research of Regional Power Grid Companies' Operation Capacity based on Entropy Weight Fuzzy Comprehensive Model[J]. Procedia Engineering, 15: 4626-4630(2011).

**Hongyan Zuo** received the PhD degree in Safety management Engineering at Central South University. her research interests include intelligent information fusion algorithm and its application on complex economic system; safety management and early warning on the economic system. She has published some research articles in international journals such as Mathematical problems in engineering,Journal of Central South University,Journal of Information & Computational Science and International Journal of Mining Science and Technology.