Applications of maximum relational subordinate in oil field exploitation plan evaluations

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Abstract. Optimization of oil field exploitation planning is a complicated project with multiple objectives, which depend on a number of factors. This paper addresses the shortcomings of the current evaluation methods by using the maximum subordinate degree principles to establish a new evaluation framework for oil field exploitation plan optimization. A case study illustrated its successful application. We also compare this method with others, confirming that the application of maximum subordinate degree principles for oil field exploitation optimization is reasonable and practical.

Keywords: principle of maximum relational subordinate, oil field exploitation plans, optimization.

1. Introduction

Oil field exploitation is a complicated systematic project. The goodness of the exploitation plan can determine the profits of this oil field in the future. Therefore, before the exploitation, we should analysis the requirements and resources, develop multiple plans. After comparing and optimization, we select the best exploitation plan to practice.

In the processes of optimization, because each plans contain many technical and economic factor, which are interdependent and interconstrained, making the decision making not straightforward. There is a need to quantitatively rank all the plans, classify their strengths and weakness, and finally identify the best plan. However, because of the complexity of geology and the limitation of the research approaches, oil exploitation is impacted by many fuzzy, uncertain and uncharacterized factors. If those uncertainties Dare not handled well, we run the risk of not selecting the optimized plan. This will affect the oil field’s overall economical profit and also cause significant waste of the oil resources.

To address those issues, recently proposed methods include fuzzy comprehensive evaluation, gray correlation analysis, gray comprehensive evaluation, etc. [1]. All those methods degrade the multi-objective problems to single objective problems, which is in the category of linear weighting approach. The weighting factors are assigned artificially, so they are inevitably somewhat arbitrary. However, the maximum subordinate degree principle is one of the multi-objective decision method, which can reflect the complex relationships between evaluation objective and multiple factors. This paper applies this method for optimization of an oil field exploitation planning. This method is reasonable and practical, which can enhance the efficiency and scientific basis of decision making [2].

2. Oil field exploitation plan evaluation factors analysis

2.1 Evaluation factors principles

Industry standard from Ministry of Petrolum, China. If the evaluation factors already exist in the industry standard, then we can directly use them.

Literature review. Some evaluation factors are not in the official industry standards, we explore the literature and identify the standards that are suitable for the corresponding evaluations.

Standards from the field studies. This category covers the contents that are not available in the two types of sources above.

2.2 Selection of the evaluation factors.

There are a number of impacting factors of oil field exploitation, which are interdependent and very complex. Due to the uncertainties associated with different elements, their evaluation results are not very accurate. The evaluation factors for oil field exploitation fall in two types. One the economic factors, which is the large the better. The other type is the cost factors, which is the smaller the better. The two types of factors vary in opposite directions, and they are non-additive. Therefore, it is challenging to establish a perfect and accurate model.

First, we have to identify the evaluation objectives and ranges, find out the factors that impact the exploitation outcome, analyze their importance and impacting ranges, and finally identify the most critical factors.

Second, establish the evaluation factors and standards. This is a very important step that can impact the final conclusions and results. Those factors and the size and type of the project are interdependent. Evaluation cannot be merely based on subjective speculation. We must develop a complete evaluation standard, and combine both modeling and practical experiences.

Third, establish reasonable evaluation criteria, identity the overall basis, weighting factors and evaluation methods. Combining both dynamic and static analysis, macroscopic and microscopic analysis.

To sum up, it is usually reasonable to use the final recovery efficiency (%), annual reduction (%), maximum oil recovery (%), total investment (Billion RMB), net currency value (Billion RMB), investment return period (year), total profit (Billion RMB), internal profit rate (%), average unit cost (RMB/ton) as the evaluation factors.

3. Principles of maximum subordinate degree

Let $\underset{\sim}{A}=(\underset{\sim}{A}_1,\underset{\sim}{A}_2,\cdots,\underset{\sim}{A}_n)$ be a fuzzy set on X field, $A_j(j=1,\cdots,n)$ be n fuzzy subset on X field. $X_i\in X(i=1,\cdots,t)$, the subordinate vector of X_i with respect to fuzzy set A is B_i;

$$B_i=(b_{i1},b_{i2},\cdots,b_{in})\quad i=1,\cdots,n \tag{1}$$

Meanwhile, we assume field X has n such elements $x_j^{\,0}(j=1,\cdots,n)$, which renders their subordinate vector $B_j^{\,0}$ to be;

$$B_j^{\,0}=(b_{j1}^{\,0},b_{j2}^{\,0},\cdots,b_{jn}^{\,0})$$

In which $b_{jk}^{\,0}=\begin{cases}1 & \text{or}\, j=k\\ 0 & \text{or}\, j\neq k\end{cases}$

That is to say, the subordinate degree of $X_j^{\,0}$ with respect to fuzzy subset $\underset{\sim}{A}_j$ is 1, and is zero with respect to other fuzzy subsets. Obviously, $X_j^{\,0}$ completely belongs to $\underset{\sim}{A}_j$.

In order to determine the subordination of $x_i^{\,0}(i=1,\cdots,t)$, we must first calculate the correlation degree of subordinate vector $B_i\,(i=1,\cdots,t)$ and $B_j^{\,0}\ (j=1,\cdots,n)$, which is;

$$r_{ij}=\frac{1}{n}\sum_{k=1}^{n}\xi_{ij}(k)\qquad(i=1,\cdots,n) \tag{3}$$

In which

$$\xi_{ij}(k)=\frac{\min_i\min_k\Delta_{ij}(k)+\rho\max_i\max_k\Delta_{ij}(k)}{\Delta_{ij}(k)+\rho\max_i\max_k\Delta_{ij}(k)} \tag{4}$$

$$\Delta_{ij}(k)=\left|b_{jk}-b_{jk}^{0}\right| \tag{5}$$

According to the maximum subordinate principle,

If S϶ {i=1… n}, it satisfies

$$r_{is}=\max\left\{r_{i1},r_{i2},\cdots,r_{in}\right\} \tag{6}$$

Then x_i is subordinate to $\underset{\sim}{A}_s$.

If we consider the importance of various decision making factors, we can add weighting factors to the correlation coefficients, obtaining the weighted correlation factor r_{ijw} , which is

$$r_{ijw} = \sum_{k=1}^{n} a_k \xi_{ij}(k) = (a_1, a_2, \cdots, a_n) \begin{bmatrix} \xi_{ij}(1) \\ \xi_{ij}(2) \\ \cdots \\ \xi_{ij}(n) \end{bmatrix} = A \cdot \sum^T \quad (7)$$

In which $\sum$ is correlation vectors, A is weighting vectors, A= $(a_1, a_2, \cdots, a_n)$ which satisfies

$$\sum_{i=1}^{n} a_i = 1$$

Weighting vector A can be obtained by the AHP method.

Now, if S∈ {i=1…n} that satisfies

$$r_{isw} = \max(r_{i1w}, r_{i2w}, \cdots, r_{inw}) \quad (8)$$

Then x_i is subordinate to $\underset{\sim}{A}_s$.

According to the maximum subordinate principle, if the subordinate vector B_i of x_i has the largest correlation r_{is} or largest weighted correlation r_{isw} with the subordinate vector B_s^0 of x_s^0 , which completely belongs to $\underset{\sim}{A}_s$, then x_i is relatively subordinate to $\underset{\sim}{A}_s$. Compared with the maximum subordinate principle, the maximum relational subordinate principle has the following characteristics

Under the maximum relational subordinate principle, the information from the non-maximum subordinate vector will play a role in the evaluation process. However, under the maximum subordinate principle, once the maximum subordinate vector is obtained, the other vectors would not affect the decision making.

Maximum relational subordinate principles calculate the correlation degree between the subordinate vector B_i of the element x_i , and the subordinate vector B_j^0 $(j = 1, \cdots, n)$ of n reference elements belonging to n different categories, and then obtain the subordinate of x_i . This allows fully use of the information from the different vectors from the element, avoiding biased conclusions.

By introducing the weighting correlation degree, this approach can meet the needs of various applications.

4. Case Study

An oil field is controlled by both geological formation and rock properties. There are many thin oil layers, with higher initial pressure and low permeability. According to the field survey results, experts proposed eight exploitation plans, with the specific evaluation factors listed below.

In practice, the original data should be standardized.

The oil field exploitation evaluation factors fall into two categories, which are profit and cost factors. In order to enable additivity, we should transfer the values to be the same category. Here, we transform them into profit type factors, then the larger the overall factor, the better the plan. Transformation method is illustrated below that allow

For profit factors:

Xij =xij/xmaxj (9)

For cost factors:

Xij =xminj/xij (10)

Xmaxj, xminj denote the jth factor’s maximum and minimum.

Processed data is shown in Table 2.

Table 1 Oil field properties

Plan	Final recovery efficiency (%)	Annual reduction (%)	Maximum oil recovery (%)	total investment (Billion)	net currency value (Billion)	Dynamic investment return period (year)	total profit (Billion RMB)	Internal profit rate (%)	average unit cost (RMB/ton)
1	39.7	4.24	2.00	0.344	0.0654	8.5	0.750	20.6	101
2	34.9	7.76	2.79	0.345	0.179	4.8	0.867	32.0	96.6
3	34.3	8.63	2.97	0.382	0.224	4.1	0.969	38.8	96.5
4	47.6	5.60	2.64	0.382	0.195	4.8	0.926	34.4	94.2
5	34,8	11.17	3.26	0.419	0.260	3.7	0.945	47.3	95.8
6	35.5	4.69	1.89	0.366	0.0137	13.2	0.686	16.1	107
7	33.5	7.33	2.59	0.329	0.183	4.8	0.864	34.2	94.3
8	36.7	7.06	2.68	0.384	0.135	5.8	0.822	27.1	100

Table 2 Processed data of the oil field.

Plan	Final recovery efficiency (%)	Annual reduction (%)	Maximum oil recovery (%)	total investment (Billion)	net currency value (Billion)	Dynamic investment return period (year)	total profit (Billion RMB)	Internal profit rate (%)	average unit cost (RMB/ton)
A1	0.83	1	0.61	0.96	0.25	0.43	0.77	0.44	0.93
A2	0.73	0.55	0.86	0.95	0.68	0.77	0.89	0.68	0.98
A3	0.72	0.49	0.91	0.86	0.86	0.90	1.00	0.82	0.98
A4	1	0.76	0.81	0.86	0.75	0.77	0.96	0.73	1.00
A5	0.73	0.38	1	0.78	1	1	0.98	1.00	0.98
A6	0.75	0.90	0.57	0.90	0.05	0.28	0.71	0.34	0.88
A7	0.70	0.58	0.79	1	0.70	0.77	0.89	0.72	1.00
A8	0.77	0.60	0.82	0.87	0.52	0.64	0.85	0.57	0.94

Using the maximum relational subordinate principle, we rank the goodness of those plans and compare among all of the optimization approaches. (Shown in Table 3).

Table 3: Ranking Results of the different plans using different methods.

	1	2	3	4	5	6	7	8
Maximum relational subordinate principles	A4	A7	A2	A3	A5	A1	A8	A6
Fuzzy comprehensive evaluation	A4	A7	A3	A2	A5	A8	A1	A6
Grey matter element method	A4	A7	A5	A3	A2	A8	A1	A6

It is seen that the results obtained here is close to those obtained from fuzzy comprehensive evaluation method. Although the fuzzy methods is not necessarily the perfect ranking, the consistence obtained here illustrated the practical values of the approach proposed here.

5. Conclusions

We apply the maximum relational subordinate principles to solve the optimization problem of oil field exploitation. This method avoids the subjective biased of decision making when various factors has similar subordinate degrees.

The comparison results illustrated that the maximum relational subordinate principle is of practical values in oil field exploitation optimization.

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