Application of fuzzy programming in water-driven oil field development

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Abstract

To get the optimal profit, it is important to design a reasonable development plan for the oil field managers, in which the subject uncertainty (Fuzziness) plays a key role. In this paper, we establish a fuzzy objective resource-based programming model and a fuzzy coefficient type programming model for case study. Differing from the models present in previous papers, we consider the uncertainty in the oilfield development progress and take working load as decision variable. An improved Genetic Algorithm is employed for the numerical solutions of these models. As is shown in the results of case study, we found that almost each indices value of fuzzy optimization results is higher than deterministic optimization results.

Keywords

Fuzzy objective resource-based programming, Fuzzy coefficient type programming.

1. Introduction

At present, most of the oilfield in China is in the middle-late period of development. The recoverable reserves decreases year by year, the development cost presents a tendency of straight climb and the economic benefit gradually glides, which make the oilfield production face a tremendous challenge. As the oilfield gradually develops, it’s an important problem that how to implement a unified planning effectively for oilfield development. Thus, how to get a best programming scheme which accords with the practical oilfield development has attracted more and more attention. Now many researches have concentrated on deterministic programming and random programming. D.A., Rosneft [1] established a multi-criteria workgroup system to study oil field development programming, and improving the economic benefit of Vankorskoye oilfield in a certain degree. Lubin Li [2] analyzed the uncertainty problems of oil field development, and study the random modeling technology, optimization and mathematical statistics etc. method. Yuanyuan Zhang [3] proposed an oilfield development programming for years single target optimization model and case study. YoucefMahboub[4] used the composite inflow performance relationship between oil and gas reservoir systems crossed by a horizontal well to study the HassiMessaoud oilfield, Luis[5]developed a methodology to relate the recoverable oil reserves and ensure maximum economic efficiency and creation of value, T.N.Fructuoso[6] considered that assessment of the original artificial lift systems installed in place to determine better means to produce the existing assets and thus looked for ways to optimize and reduce lifting costs for the operator. The uncertainty emerging in engineering makes programming often contains a lot of uncertainty factors (fuzzy factors), the programming problem which allows objective function and constraint conditions have a certain scale is referred to fuzzy programming. In the process of oil field production optimization, uncertainty is inevitable and cannot be ignored. The uncertainty in the process of optimization is primary due to the limited cognition of oilfield development and inaccurate market forecasting, therefore using the method of fuzzy planning will be better to solve the optimization model which three elements have ambiguity (ambiguity of constraint conditions, vagueness of the objective function; ambiguity of parameter coefficient). The fuzzy optimization model can effectively make up for the disparity of traditional deterministic model and actual planning of oil field development planning, thus it is the supplement and correction to traditional models and methods. By solving these models, we can get a planning scheme which is more suitable for oil field development. Compared with deterministic programming model, by analyzing parameters, fuzzy planning model can reflect inherent characteristics of oilfield, which is different from simple average statistic method used in deterministic programming model. There are many studies about this issue. Antonenko, Park [7] proposed a nonlinear fuzzy programming method, and built multi-objective multi-criteria system to adapt the uncertainty of oilfield development progress. AzatKashapov[8] proposed the way the conventional method of candidate well selection can be optimized with the fuzzy sets theory applied, Mohamed[9] presented the application of using fuzzy logic as an arta of the EOR technologies, Arash[10] gave a new look at conflicting multiple objectives optimization which used fuzzy rules-based system. In this paper, we take the fuzzy uncertainty into consideration, and build a fuzzy objective resource-based programming model and a fuzzy coefficient type programming model for case study, in which the working load is chosen as decision variable. Also, a kind membership is introduced and an improved Genetic Algorithm is employed for the numerical solutions of these models. Finally we perform case study based on real oilfield data and analyze the numerical experimental results.

2. Preliminaries

At first, we list some basic concepts and theorems concerned with the fuzzy programming, which might be utilized in this paper.

Definition2.1 **[11]** Let U denote universe, the mapping $A(x):U\to[0,1]$ determines a fuzzy subset A . $A(x)$ is the membership function of A, it represents the membership degree of x belongs to A . If the value of $A(x)$ is 0 or 1, then fuzzy subset A is classical subset.

In deterministic mathematics, the general form of optimization model can be written as:

$$\begin{aligned} &\min \quad y = f(x) \\ &s.t. \quad g_j(x) \le b_j \quad (j = 1,2,\dots,n) \end{aligned} \tag{1}$$

But in the practical programming, objective function or constraint conditions always have some ambiguities.

If constraints are flexible, this is to say resource limit b_j may take a value from $(b_j - d_j, b_j + d_j)$, where d_j is expansion index and it is determined by decision maker according to practical problems, also $d_j > 0$, then this programming problem is called as fuzzy objective resource-based programming. By blurring the constraint conditions, the general form of the model can be written as:

$$\begin{aligned} &\min \quad y = f(x) \\ &s.t. \quad g_j(x) \lesssim b_j \quad (j = 1,2,\dots,n) \end{aligned} \tag{2}$$

Here, we rewrite the "$\le$"into "$\lesssim$", it represents constraints have some flexibility.

If coefficients are flexible, we call it as fuzzy coefficient type programming model. Simply, we assume that the fuzzy programming model is

$$\begin{aligned} &\min \quad f = \tilde{c}^T x \\ &s.t. \quad Ax \le b \end{aligned} \tag{3}$$

Where $\tilde{c}$ is fuzzy coefficient vector in objective function. There are many others fuzzy forms [12], here it seems verbose to mention.

There are various methods to solve fuzzy programming problems based on the form of fuzzy models. But in general, we can solve fuzzy models by completing the following steps:

1) Fuzzifying the objective function and constraints.

2) Introducing membership function.

3) Converting the fuzzy programming into a new planning problem.

4) Solving the new programming model, which optimal solution is called as the fuzzy optimal solution of original problem.

3. Application of fuzzy programming in water-driven oil field

Oilfield development programming is via analyzing the background of oilfield and coordinating the correlation of various programming objective, determining development target to propose a best scheme which is in accord with actual oilfield. This paper primary aims at studying water-driven oil field, which is divided into old block and new block. We consider n-year program, and take working load (U) of each block as decision variable. Then we take net present value function as objective function. The net present value is the sum of present value by discounting annual project net cash to the initial of a calculation period based on industry benchmark yield.

3.1 Fuzzy objective resource-based programming model

(1)Decision variable: the working load (U),which is denoted as $\left[U_1(i),U_2(i)\right]$, $i=1,2,\ldots,n$ represents the year and the subscript 1of U represents old block and subscript 2 represents new block, the follows are same. In general, most researches use measures, production distribution or others as decision variable, which is too painstaking and have difficulty in implementation. So this paper takes working load as decision variable, which can connect the economic index with development index by incidence relation and realize the whole optimization for economic and development.

(2)Objective function: total net present value (npv) for n years.

$$\max \quad npv=\sum_{i=1}^{n}\begin{pmatrix} P(i)\left(Y_1(i)+Y_2(i)\right)- \\ \left(C_1(i)U_1(i)+C_2(i)U_2(i)\right)\end{pmatrix}(1+r_i)^{-i}$$

Where the subscript1of symbols represents old block and subscript2 represents new block, $i=1,2,\ldots,5$ represents the year. And other symbols represent as:

P: Oil price, ten thousand yuan per ten thousand tons;

Y: Yield, ten thousand tons;

C: Cost, ten thousand yuan;

r: Discount rate.

(3)The constraint conditions:

1) Yield (Y) constraint: total yield of old block and new block is greater than the lower limit of yield ($\underline{Y}$).

$$Y_1(i)+Y_2(i)\geq \underline{Y}(i)$$

2) Investment (I) constraint: total investment of old block and new block is less than upper limit of investment ($\bar{I}$).

$$U_1(i)I_1(i)+U_2(i)I_2(i)\leq \bar{I}(i)$$

3) Cost (C) constraint: total cost of old block and new block is less than upper limit of cost ($\bar{C}$).

$$U_1(i)C_1(i)+U_2(i)C_2(i)\leq \bar{C}(i)$$

4) Annual working load constraint: annual total working load must reach the lower limit ($\underline{U}$) and less than upper limit ($\bar{U}$).

$$\underline{U}(i)\leq U_1(i)+U_2(i)\leq \bar{U}(i)$$

5) Reserve-product balance constraint: the recoverable reserves are not less than total yield.

$$\frac{Q_{\mathrm{re}}}{Y_1(i)+Y_2(i)}\geq 1$$

Where Q_{re} represents recoverable reserves.

6) Internal rate of return constraint: the internal rate of return of project is discount rate when accumulation of annual cash flow is equal to 0 during a calculation period. Only financial internal rate of return is greater than petroleum industry benchmark yield (15%), we think the project is acceptable, so we have:

$$\arg_{r_0}\left\{ npv = \sum_{i=1}^{n} (P(i)Y(i) - C(i)U(i))(1+r_0)^{-i} = 0 \right\} \geq 15\%$$

In this paper, the upper limit of investment is determined by decision maker and may have various values, thus we regard the investment constraint as fuzzy constraint which also makes objective fuzziness.

In conclusion, the optimization model we have established is as follows, which takes net present value as objective function and investment constraint as fuzzy constraint.

$$\max \quad npv = \sum_{i=1}^{n} \begin{pmatrix} P(i)\left(Y_1(i)+Y_2(i)\right) - \\ \left(C_1(i)U_1(i)+C_2(i)U_2(i)\right) \end{pmatrix} (1+r_i)^{-i} \tag{4}$$

$$s.t. \quad \begin{cases} Y_1(i)+Y_2(i) \geq \underline{Y}(i) \\ U_1(i)I_1(i)+U_2(i)I_2(i) \lesssim \overline{I}(i) \\ U_1(i)C_1(i)+U_2(i)C_2(i) \leq \overline{C}(i) \\ \underline{U}(i) \leq U_1(i)+U_2(i) \leq \overline{U}(i) \\ \dfrac{Q_{\mathrm{re}}}{Y_1(i)+Y_2(i)} \geq 1 \\ \arg_{r_0}\left\{ npv = \sum_{i=1}^{n} (P(i)Y(i) - C(i)U(i))(1+r_0)^{-i} = 0 \right\} \geq 15\% \end{cases}$$

3.2 Fuzzy coefficient type programming model

(1) Decision variable: the working load (U).

(2) Objective function: multiple annual net present value.

(3) The constraint conditions:(as the same as 3.1).

In this section, we take multiple annual net present value as objective function and the constraint conditions are same as 3.1. However in this model we take the oil price as an unknown coefficient, since the oil price is an instability variable and is hard to get as a deterministic value. The fuzzy coefficient type programming model as follows:

$$\max \quad npv = \sum_{i=1}^{n} \begin{pmatrix} \tilde{P}(i)\left(Y_1(i)+Y_2(i)\right) - \\ \left(C_1(i)U_1(i)+C_2(i)U_2(i)\right) \end{pmatrix} (1+r_i)^{-i} \tag{5}$$

$$s.t. \quad \begin{cases} Y_1(i)+Y_2(i) \geq \underline{Y}(i) \\ U_1(i)I_1(i)+U_2(i)I_2(i) \leq \overline{I}(i) \\ U_1(i)C_1(i)+U_2(i)C_2(i) \leq \overline{C}(i) \\ \underline{U}(i) \leq U_1(i)+U_2(i) \leq \overline{U}(i) \\ \dfrac{Q_{\mathrm{re}}}{Y_1(i)+Y_2(i)} \geq 1 \\ \arg_{r_0}\left\{ npv = \sum_{i=1}^{n} (\tilde{P}(i)Y(i) - C(i)U(i))(1+r_0)^{-i} = 0 \right\} \geq 15\% \end{cases}$$

3.3 The solution methods [13]

Solving the fuzzy objective resource-based programming model

From the definition of fuzzy objective resource-based programming, we can get another deterministic programming model:

$$\begin{aligned} &\min \quad y = f(x) \\ &s.t. \quad b_j - d_j \leq g_j(x) \leq b_j + d_j \quad (j = 1, 2, \ldots, n) \end{aligned} \tag{6}$$

The membership function of constraint conditions in fuzzy objective resource-based programming model (2)is defined as:

$$A_j(x)=\begin{cases}0 & ,g_j<b_j-d_j\ or\ g_j>b_j+d_j\\ 1+\dfrac{g_j-b_j}{d_j} & ,b_j-d_j\le g_j<b_j\\ 1 & ,g_j=b_j\\ 1-\dfrac{g_j-b_j}{d_j} & ,b_j<g_j\le b_j+d_j\end{cases}$$

Let the optimal value of model (1) and (6) is f_0, f_1 respectively, then we set $d_0 = f_1 - f_0$. d_0 is expansion index of objective function in model(2) and it also can be determined by decision maker. Next blurring the objective function of model (2), its membership function is defined as:

$$F(x)=\begin{cases}1, & f\le f_0-d_0\\ \dfrac{f_0-f}{d_0}, & f_0-d_0<f\le f_0\\ 0, & f>f_0\end{cases}$$

From the definition of $A_j(x)$ and $F(x)$, we can get two propositions easily.

Proposition2.1 For any $\lambda\in[0,1]$,

$$A_j(x)\ge\lambda\Leftrightarrow\begin{cases}g_j(x)-d_j\lambda\ge b_j-d_j\\ g_j(x)+d_j\lambda\le b_j+d_j\end{cases},(j=1,2,...,n)$$

Proposition2.2 For any $\lambda\in[0,1]$,

$$F(x)\ge\lambda\Leftrightarrow f(x)+d_0\lambda\le f_0$$

According to above propositions, we can obtain

$$\begin{aligned}&\max\quad\lambda\\ &s.t.\begin{cases}f(x)+d_0\lambda\le f_0\\ g_j(x)-d_j\lambda\ge b_j-d_j\\ g_j(x)+d_j\lambda\le b_j+d_j\\ \lambda\ge 0\end{cases}(j=1,2,...,n)\end{aligned}\tag{7}$$

Let the optimal solution of normal programming model (7) is x^*,λ^*, then the fuzzy optimal solution of programming model (2) is x^* and the fuzzy optimal value is $f(x^*)$. Thus solve the fuzzy programming model (2) is equal to solve normal programming model (1), (6), (7).

3.3.2Solving the fuzzy coefficient type programming model

Supposing the fuzzy coefficients $\tilde{c}$ of model (3) can be recorded as $(c_M;c_L,c_R)_{LR}$, here $(c_M;c_L,c_R)_{LR}$ is fuzzy number and it represents that the value of c is about c_M . c_L is the left expansion index of c_M, and c_R is right expansion index of c_M .Thus, we can rewrite the fuzzy programming model(3) as

$$\begin{aligned}&\min\quad f=(c_{1M};c_{1L},c_{1R})_{LR}\,x_1+\ldots+(c_{nM};c_{nL},c_{nR})_{LR}\,x_n\\ &s.t.\quad Ax\le b\end{aligned}\tag{8}$$

Where $(c_{1M};c_{1L},c_{1R})_{LR}$ is fuzzy number, and it represents that the value of c_j is about $c_{jM}\ (j=1,2,...,n)$. c_{jL} is the left expansion index of c_{jM} and c_{jR} is right expansion index of c_{jM} .

We might as well set fuzzy objective function as $\min\ f=c_1x_1+c_2x_2+\ldots+c_nx_n$, if c_j is flexible, its membership function is defined as

$$u_j(c_j)=\begin{cases}0 & , c_j < c_{jM}-c_{jL} \ or \ c_j > c_{jM}+c_{jR} \\ 1+\dfrac{c_j-c_{jM}}{c_{jL}} & , c_{jM}-c_{jL} \le c_j < c_{jM} \\ 1 & , c_j = c_{jM} \\ 1-\dfrac{c_j-c_{jM}}{c_{jR}} & , c_{jM} < c_j \le c_{jM}+c_{jR}\end{cases}$$

Where c_{jM} , c_{jL} , c_{jR} are known. c_{jL} , c_{jR} is the left expansion index and right expansion index respectively. Following is the solving method.

1) Solving the following programming model.

$$\begin{aligned} \min \quad & f = c_{1M}x_1 + c_{2M}x_2 + \ldots + c_{nM}x_n \\ s.t. \quad & Ax \le b \end{aligned} \tag{9}$$

Supposing its optimal value is f_0 .

2) Solving secondary programming model.

$$\begin{aligned} \min \quad & f = c_1x_1 + c_2x_2 + \ldots + c_nx_n \\ s.t. \quad & \begin{cases} Ax \le b \\ c_{jM} - c_{jL} \le c_j \le c_{jM} + c_{jR},\ j = 1,2,\ldots,n \end{cases} \end{aligned} \tag{10}$$

Where $c_1, c_2, ..., c_n$ and $x_1, x_2, ..., x_n$ are unknown variables, supposing its optimal value is f_1 .

3) Assuming that the expansion index of objective function is defined as $d_0 = f_1 - f_0 > 0$, and blurring the objective function. Then we can use symmetrical type fuzzy discrimination to convert the fuzzy model into the following normal programming model:

$$\begin{aligned} \min \quad & \lambda \\ s.t. \quad & \begin{cases} Ax \le b \\ c_1x_1 + c_2x_2 + \ldots + c_nx_n + d_0\lambda \le f_0 \\ c_j - c_{jL}\lambda \ge c_{jM} - c_{jL},\ j = 1,2,\ldots,n \\ c_j + c_{jR}\lambda \le c_{jM} + c_{jR},\ j = 1,2,\ldots,n \end{cases} \end{aligned} \tag{11}$$

Where $\lambda, c_1, c_2, ..., c_n$ and $x_1, x_2, ..., x_n$ are unknown variables. We suppose the optimal solution of model (11) is $\lambda^*, c_1^*, c_2^*, ..., c_n^*$ and $x_1^*, x_2^*, ..., x_n^*$, $x_1^*, x_2^*, ..., x_n^*$ are regard as the fuzzy optimal solution of original fuzzy programming model (3).

4. Case study

In this section, we take five-year program as example and we will use genetic algorithm to solve models based on real oilfield data, and draw conclusions by comparing the optimization results of fuzzy models with optimization results of deterministic programming models. We take onshore water drive block as example, the other blocks are similar.

4.1 Genetic algorithm

This paper uses genetic algorithm to solve models, it primary includes several steps as follows:

(1)Setting parameters: first we will design evaluation function based on objective function, next we need to determine the type of choose operator, cross operator and mutation operator, also we need to determine the probability of cross and mutation, then we should determine the maximum iterative step number , termination rules and the scale of population.

(2)Generating initial population: we take all variables as binary code and design decode rules according to the scale of problem and accuracy requirement. Then we will generate initial population randomly.

(3)Genetic manipulation: in this step, we will carry out choose operation, cross operation, and mutation operation respectively based on current population POP(k), and we will get new generation population POP(k+1).

(4)Termination: if the iterative step number reaches maximum or current population satisfies termination rules, then the iteration will be terminated. Next we need to decode and output the optimal solution and optimal value. Otherwise, let k=k+1and return to step (3).

The flow diagram as follows:

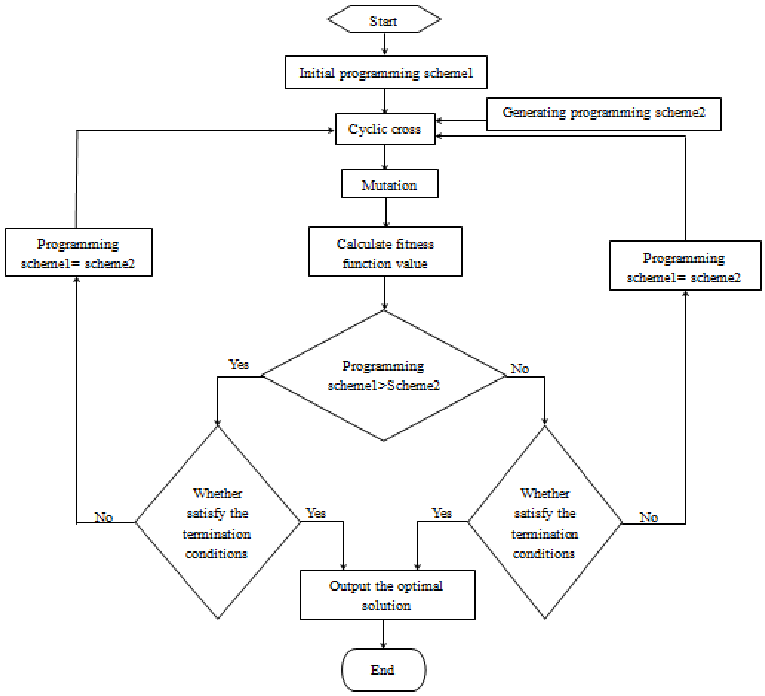

Fig.1 the solving steps of genetic algorithm

4.2 Solving fuzzy objective resource-based programming model

(1)Using genetic algorithm to solve the deterministic programming model, and the given upper limit of investment is 12 billion yuan, the optimization resultsas table1.Limitations of space, here we only list several critical indexes.

From table1, we can get the optimal value $f_0 = 829298.9056$.

Table1 Deterministic programming model optimizationresults

	New well of new block					New well of old block				
Net present value: 829298.9056(ten thousand yuan)	Year 2016	Year 2017	Year 2018	Year 2019	Year 2020	Year 2016	Year 2017	Year 2018	Year 2019	Year 2020
Number of well (port)	735.00	688.00	632.00	823.00	791.00	883.00	958.00	1047.00	743.00	795.00
Total yield (ten thousand tons)	63.86	171.73	244.80	314.18	382.31	60.00	167.41	253.24	306.44	334.23
Total investment (ten thousand yuan)	682376.90	638741.90	586751.30	764076.40	734367.50	517529.10	561486.90	613650.10	435474.70	465952.00
Total cost (ten thousand yuan)	144237.05	315572.91	451660.58	609550.03	761563.06	154010.84	348570.56	542574.68	672209.75	787888.98
Total profit (ten thousand yuan)	57344.14	214253.40	303901.20	365213.50	434863.60	38533.99	174884.90	251849.00	291760.80	272033.60

Table2 Fuzzy programming model optimization results

	New well of new block					New well of old block				
Net present value: 929793.4650(ten thousand yuan)	Year 2016	Year 2017	Year 2018	Year 2019	Year 2020	Year 2016	Year 2017	Year 2018	Year 2019	Year 2020
Number of well (port)	843.0	796.0	740.0	451.0	898.0	883.0	958.0	1047.0	743.0	795.0
Total yield (ten thousand tons)	73.24	197.55	283.02	325.36	372.26	60.00	167.41	253.24	306.44	334.23
Total investment (ten thousand yuan)	782644.49	739009.50	687018.89	418710.16	833706.70	517529.13	561486.87	613650.05	435474.68	465952.04
Total cost (ten thousand yuan)	165431.07	363297.81	522692.55	607659.57	755199.40	154010.84	348570.56	542574.68	672209.75	787888.98
Total profit (ten thousand yuan)	65770.22	246209.36	350910.49	397778.31	413190.83	38533.99	174884.86	251849.02	291760.77	272033.63

(2)Using genetic algorithm to solve the deterministic programming model which under the relaxed constraint conditions, here we give tolerance $d = 1$ billion yuan.

$$\max \quad npv = \sum_{i=1}^{5} \begin{pmatrix} P(i)\left(Y_1(i)+Y_2(i)\right)- \\ \left(C_1(i)U_1(i)+C_2(i)U_2(i)\right) \end{pmatrix} (1+r_i)^{-i} \tag{12}$$

$$s.t. \quad \begin{cases} Y_1(i)+Y_2(i) \geq \underline{Y}(i) \\ U_1(i)I_1(i)+U_2(i)I_2(i) \leq \bar{I}(i)+d \\ U_1(i)C_1(i)+U_2(i)C_2(i) \leq \bar{C}(i) \\ \underline{U}(i) \leq U_1(i)+U_2(i) \leq \bar{U}(i) \\ \dfrac{Q_{\mathrm{re}}}{Y_1(i)+Y_2(i)} \geq 1 \\ \arg\limits_{r_0} \left\{ npv = \sum_{i=1}^{5} (P(i)Y(i)-C(i)U(i))(1+r_i)^{-i} = 0 \right\} \geq 15\% \end{cases}$$

The optimal value $f_1 = 936898.0607$.

(3)Thus, we can determine the value of d_0 and convert the fuzzy models into normal programming models as formula (13).

$$\max \quad g = \lambda \tag{13}$$

$$s.t. \quad \begin{cases} Y_1(i)+Y_2(i) \geq \underline{Y}(i) \\ U_1(i)I_1(i)+U_2(i)I_2(i)+d_0\lambda \leq \bar{I}(i)+d_0 \\ U_1(i)C_1(i)+U_2(i)C_2(i) \leq \bar{C}(i) \\ \underline{U}(i) \leq U_1(i)+U_2(i) \leq \bar{U}(i) \\ \dfrac{Q_{re}}{Y_1(i)+Y_2(i)} \geq 1 \\ \arg\limits_{r_0} \left\{ npv = \sum_{i=1}^{5} (P(i)Y(i)-C(i)U(i))(1+r_i)^{-i} = 0 \right\} \geq 15\% \\ npv - d_0\lambda \geq f_0 \\ 0 \leq \lambda \leq 1 \end{cases}$$

Then, we use genetic algorithm to solve this model, the optimization results as table2.

From table1, we can get the maximal net present value of deterministic programming model is about 829299ten thousand yuan, while table2 tell us the maximal net present value of fuzzy programming model is about 929793ten thousand yuan. In order to compare the optimization results more clearly, we draw a histogram as Fig.2 based on the data of table1 and table2. By comparing the optimization results of deterministic programming with fuzzy programming, we can obtain that under the situation of satisfying the constraint conditions, the optimization results of the latter is better.

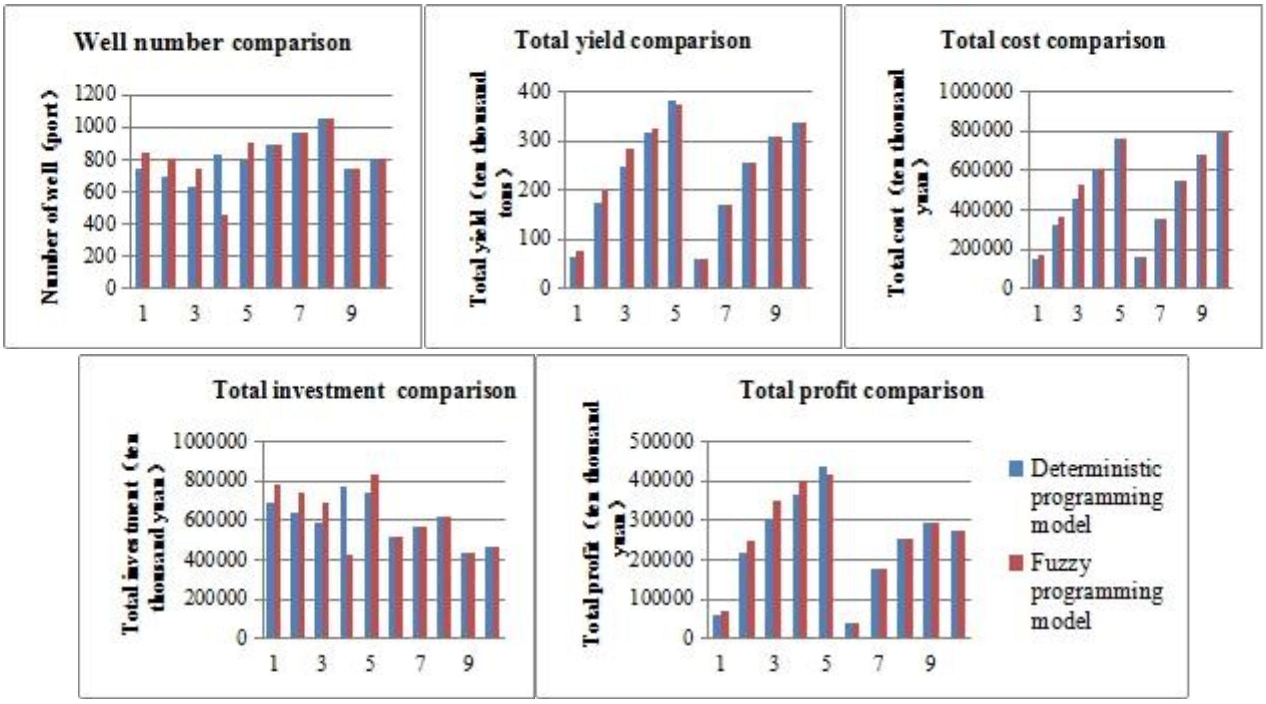

Fig.2 Contrast figure of the optimization results

Table3 Deterministic programming model optimization results

	New well of new block					New well of old block				
Net present value: 268701.7243 (ten thousand yuan)	Year 2016	Year 2017	Year 2018	Year 2019	Year 2020	Year 2016	Year 2017	Year 2018	Year 2019	Year 2020
Number of well (port)	735.0	688.0	374.0	389.0	791.0	883.0	958.0	1047.0	743.0	795.0
Total yield (ten thousand tons)	63.86	171.73	224.11	243.70	292.86	60.00	167.41	253.24	306.44	334.23
Total investment (ten thousand yuan)	682376.87	638741.88	347223.06	361149.12	734367.48	517529.13	561486.87	613650.05	435474.68	465952.04
Total cost (ten thousand yuan)	144237.05	315572.91	401052.26	461058.08	599241.31	154010.84	348570.56	542574.68	672209.75	787888.98
Total profit (ten thousand yuan)	52974.17	202501.04	273195.87	276358.45	300701.42	34428.05	163428.17	234518.64	270789.79	248600.76

4.3 Solving fuzzy coefficient type programming model

Here we take the dollar-yuan exchange rate is 6.5287 and the average specific gravity of oil is 1ton=7.35barrel. On the other hand, we take oil price is 60~80 dollars per barrel which is denoted as [70; 10, 10]since the oil price is difficult to be predicted. So converting oil price from dollar to RMB, and the oil price P=6.5287*7.35*[70; 10, 10] =[3359; 480,480]

yuan per ton.

(1)Taking average oil price as the value of P and the upper limit of investment is 12 billion yuan. Then we solve the deterministic programming models, the optimization resultsas table3.

From table3, we can get $f_0 = 268701.7243$.

(2)Let P as unknown variable, and then using genetic algorithm to solve the following deterministic programming model which under the relaxed constraint conditions.

Table4 Fuzzy programming model optimization results

	New well of new block					New well of old block				
Net present value: 928704.5484(ten thousand yuan)	Year 2016	Year 2017	Year 2018	Year 2019	Year 2020	Year 2016	Year 2017	Year 2018	Year 2019	Year 2020
Number of well (port)	615.0	531.0	465.0	440.0	583.0	883.0	958.0	1047.0	942.0	1125.0
Total yield (ten thousand tons)	53.43	139.97	193.04	229.23	267.89	60.00	167.41	253.24	316.31	366.00
Total investment (ten thousand yuan)	570968 .40	492982 .47	431707 .81	408497 .72	541259 .47	517529 .13	561486 .87	613650 .05	552109 .21	659366 .10
Total cost (ten thousand yuan)	120688 .15	255285 .78	354426 .39	435950 .39	538133 .38	154010 .84	348570 .56	542574 .68	706742 .83	885761 .00
Total profit (ten thousand yuan)	56198. 22	197731 .73	270769 .56	309013 .06	343794 .56	47760. 28	200628 .74	290791 .39	339083 .59	335192 .70

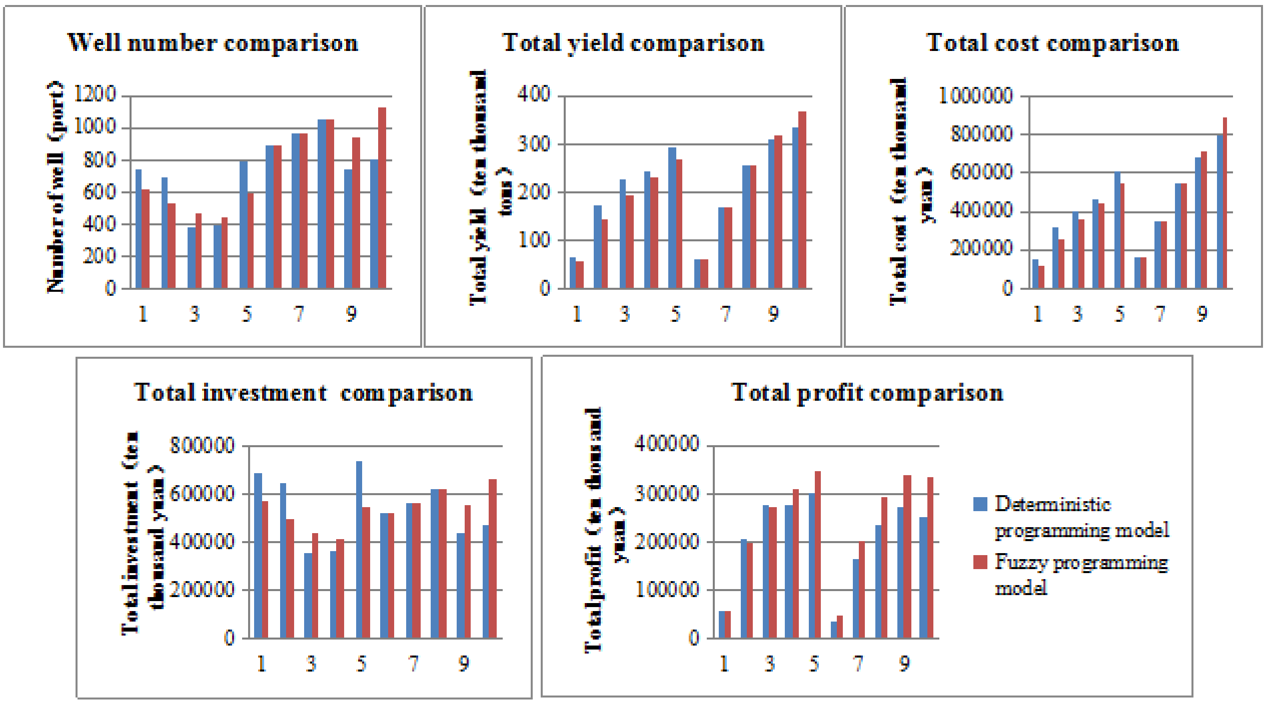

Fig.3 Contrast figure

$$\max \quad npv=\sum_{i=1}^{5}\begin{pmatrix} P(i)\left(Y_1(i)+Y_2(i)\right)- \\ \left(C_1(i)U_1(i)+C_2(i)U_2(i)\right)\end{pmatrix}(1+r_i)^{-i} \tag{14}$$

$$s.t.\begin{cases} Y_1(i)+Y_2(i)\geq \underline{Y}(i) \\ U_1(i)I_1(i)+U_2(i)I_2(i)\leq \overline{I}(i) \\ U_1(i)C_1(i)+U_2(i)C_2(i)\leq \overline{C}(i) \\ \underline{U}(i)\leq U_1(i)+U_2(i)\leq \overline{U}(i) \\ \dfrac{Q_{re}}{Y_1(i)+Y_2(i)}\geq 1 \\ \arg_{r_0}\left\{npv=\sum_{i=1}^{5}(P(i)Y(i)-C(i)U(i))(1+r_i)^{-i}=0\right\}\geq 15\% \\ 70-10\leq P\leq 70+10 \end{cases}$$

The optimization value $f_1=1819110.6818$. Thus, $d_0=f_1-f_0=1550408.9575$.

(3)Blurring the objective function, and then using symmetrical type fuzzy discrimination to convert the fuzzy model into the following normal programming model:

$$\max \quad g = \lambda \tag{15}$$

$$s.t. \quad \begin{cases} Y_1(i) + Y_2(i) \geq \underline{Y}(i) \\ U_1(i)I_1(i) + U_2(i)I_2(i) \leq \overline{I}(i) \\ U_1(i)C_1(i) + U_2(i)C_2(i) \leq \overline{C}(i) \\ \underline{U}(i) \leq U_1(i) + U_2(i) \leq \overline{U}(i) \\ \dfrac{Q_{re}}{Y_1(i) + Y_2(i)} \geq 1 \\ \arg_{r_0}\left\{ npv = \sum_{i=1}^{5} (P(i)Y(i) - C(i)U(i))(1+r_0)^{-i} = 0 \right\} \geq 15\% \\ npv - d_0\lambda \geq f_0 \\ 3359 - 480 \leq P - 480\lambda \leq 3359 + 480 \\ 0 \leq \lambda \leq 1 \end{cases}$$

The optimization results as table4.

From table3, we can get the maximal net present value of deterministic programming model is about 268702ten thousand yuan, while table4 tell us the maximal net present value of fuzzy programming model is about 928705ten thousand yuan. Fig.3 is the contrast figure of optimization results, which is drew based on the data of table3 and table4. By comparing the optimization results of deterministic programming with fuzzy programming, we can find the total yield of table4 is a little less than table3, but the total investment and total cost of table4 are also less than table3, and the total profit of table4 is higher, also we can obtain that under the situation of satisfying the constraint conditions, the optimization results of the latter is better.

5. Conclusion

In the above case, fuzzy programming model has a bigger optimal net present value than deterministic programming model. Comparing the deterministic programming model optimization resultswith fuzzy programming model optimization results, we can find that almost each index of the latter is better.

In this paper, we take the fuzzy uncertainly into consideration, and using genetic algorithm to solve the established models. The case study indicates that we can obtain a better optimization scheme when we consider the fuzzy factors, since the deterministic programming ignoring the actual oilfield situation while fuzzy programming is more suitable for oilfield.

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