Evaluation Method of Design Programs for Intelligent Downhole Tool

Lijun Lin, Jian Li, Yun Liu

School of Mechanical Engineering, Chengdu University, Chengdu 610106, China.

Abstract. Intelligent Downhole Tool dedicates the inevitable development and design direction of completion technique in the future. The property of non-uniqueness of the program will be strengthened during the mapping from function target domain to proposal domain. To select the optimal one and overcome the weakness of uncertain language information which is strong subjective and unsuitable for quantitative analysis, a method called uncertain language multi-attribute decision-making is applied into the design and determination of Intelligent Downhole Tool programs. By building the multi-attribute system that faces the solution set, according to the multi-attribute system oriented to proposal collection, multi-attribute evaluation matrix is obtained based on the language value of different proposals under specific attributes or attributes set. Then, using The Uncertain Expansion Order Weighting Average (UEOWA) operator and the formula of possibility degree to evaluate and sequence the schemes, a comparative reasonable one influenced by the specific property set is finally selected. The method's application was showed through the proposals evaluation of smart downhole valve.

Key words: Intelligent Downhole Tool; design program; program evaluation; smart well.

1. Introduction

Intelligent completion dedicates the direction of completion technique in the future field and will bring a huge advantage and benefit in field developments [1]. As the middle portion of intelligent well completion requirements analysis and tool designs, the Intelligent Downhole Tool design programs determine most of intelligent well completion system's key characteristics as function, structure cost and etc[2]. The programs also determine if the final product can meet the field actual requirement. The designs involved the subjects including mechanical, electronic, computer, fluid mechanics, petroleum and gas, geology and etc. They belong to the complex MEMS (Micro-Electro-Mechanical Systems) products and the production application requirements and complexity of equipment itself make it more difficult to complete. At the same time it also causes the diversity of design programs. Given this, in order to obtain the comprehensive best program we need to evaluate and do decision-making according to various conditions.

Many researchers studied and applied the product designs and decision-making evaluation into the actual life. They applied the fuzzy set theory, grey correlation method, case reasoning technology, form matrix, virtual reality technology and other advanced theories into the design and decision-making of program and achieved great results [3-8]. In petroleum and gas industry, Zhu Xue-ning applied the fuzzy set theory into the design and decision-making of the horizon directional drilling machine among suppliers [9]. Yu Lei came up the idea to build the oilfield project evaluation system based on the fuzzy set theory to obtain the best one [10]. Li Qiao-yun applied the grey correlation method into the decision-making and optimization of layers' restructuring plan [11]. Su Xing applied the fuzzy comprehensive evaluation method into the optimizing of underground gas storage programs [12]. Zhen Yun-chuan applied the fuzzy analytic hierarchy process into the reservoir productivity evaluation [13]. Du Xing-yuan applied the fuzzy comprehensive evaluation method into Tianjin port Nanjiang Oil Supply Base construction scheme comprehensive evaluation [14]. Yong Yu applied the fuzzy comprehensive evaluation method into G petrochemical refining processing scheme comprehensive evaluation [15]. Xian Feng-qiang applied the fuzzy mathematics method to optimize fracturing wells [16].These results have been applied into petroleum and natural gas industry well.

However, there are only few technical articles and reports concentrating on multi-process evaluation and decision-making technology in intelligent well completion aspect. This article is based on the Intelligent Downhole Choke problems that involved in the actual development process.

Through the analysis which caused the diversification of design program to establish the multi-attribute program evaluation system, we can use uncertain linguistic multi-attribute decision-making method to evaluation the designs and provide a more scientific method and design mentality for the advanced intelligent tools .Of course, this method is also suitable to program optimizing .

2. The Diversification and Evaluation System of Intelligent Downhole Tool Design Program

2.1 Causes Analysis of the Diversified Designs

Set the function target of Intelligent Downhole Tool is domain A while $a \in A$. Define the product functional structure is domain B and product design is domain C while $b \in B$, $c \in C$. Through the mapping relationship, we set domain B_a is the corresponding set of element a mapped in domain B, set domain C_a is the corresponding set of element B_a mapped in domain C. The ultimate function aim of the product can be expressed by a mathematical semantic mapping relationship: $A \xrightarrow{X} B \xrightarrow{Y} C$. Based on the fuzzy mathematics theory, the mapping mathematical relationships between the spoken elements and sets are: $\mu_X(a,b) = \mu_{B_a}(b)$ and $\mu_Y(b,c) = \mu_{C_a}(c)$, as shown in figure 1. From the picture, mapping the single element - Intelligent Downhole Tool function target - to the product function structure domain and design domain will obtain more than one corresponding solution then we can obtain a set of solutions which can meet the requirements.

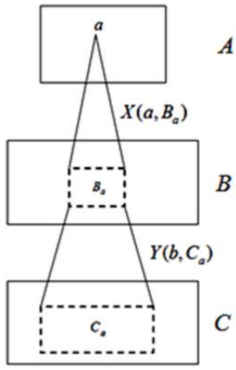

Figure. 1 Mapping relation ship of target A to design program C

During the actual development, the function target of products is usually a combination of multi-objective requirements which can be recorded as the function targets set of products. All the elements in the set have a relationship between "and" and "or" with each other. Assumed α and β are two elements belong to the downhole tool function target set A, their combination in the production function structure domain B will be expressed as below [9]:

$$\alpha \text{ or } \beta: \quad \mu_\alpha \text{ or } \beta(x) = \max(\mu_\alpha(x), \mu_\beta(x));$$

$$\alpha \text{ and } \beta: \quad \mu_\alpha \text{ and } \beta(x) = \min(\mu_\alpha(x), \mu_\beta(x));$$

$$Not \quad \alpha = \overline{\alpha} : \mu_\alpha(x) = 1 - \mu_\alpha(x)$$

The above formulas also can be applied to the relationship between the product function structure domain B to the design domain C. Given this, product function targets set assembly produce different product function structure combinations sets and product design programs sets. This is in line with the actual production. When there are many design sets meeting the same or similar product function targets, we need to compare and evaluate them to finally choose the most suitable one which behaves wonderful under the influences of factors like the cost, research and development difficulty and key technique. To achieve the multi-program decision-making and evaluation, the first step is to construct the evaluation system for the design program.

2.2 The Evaluation System for Intelligent Downhole Tools Design Programs

As it mentioned before, there are diversity programs for Intelligent Tool as the target function and application environment have been settled. Weather the chosen solution is optimal or not will directly determine the future market competitive power of Intelligent Downhole Tool. When optimizing, the difference of research and development difficulty, economic cost, production cycle time, organization, personnel technical level, experimental platform and other related support resource often become the important attribution to evaluate. Different solutions need different enterprise resource, product cost and efficiency. The social benefits like security and environmental protection are also different. Therefore, each main attribute contains more than one sub-attributes, and between the sub-attributes there are mutual restriction and promotion relationships which formed the multi-attributions, as it shown in figure 2.

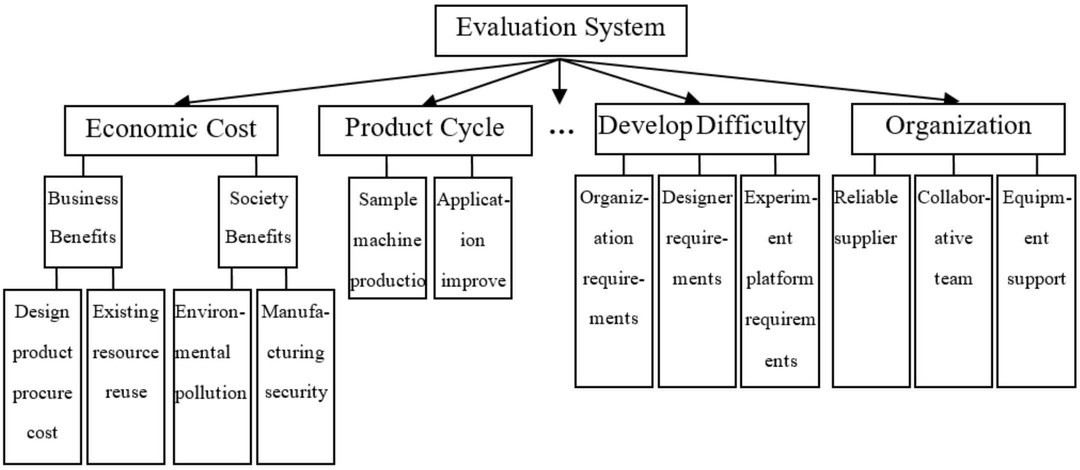

Figure. 2 The multi-attribute system of Intelligent Downhole Tool design program evaluation

3. Program Evaluation Method

Uncertainty expression language is always throughout the product design program evaluation process. The remarkable performance is the fuzzy semantic expression of evaluation, such as "the design of program 1 has difficulty in research and development", "scheme 2 has better behavior of market prospect than program" etc. Uncertainty information can be divided into random information and fuzzy information [17], but in this paper we don't strictly distinguish "fuzzy" and "not sure". For each attribute, the relevant personnel can hardly give a precise numerical model evaluation and often offer an empirical uncertainty language evaluation. The definition of uncertainty language variables as below:

Def 1[18]: Set $\tilde{\mu}=[s_a, s_b], s_a, s_b \in \bar{S}$ while $\bar{S}$ is the uncertain linguistic variables set in the specified scope, S_a and S_b separately represents the floor level and upper limit and $\tilde{\mu}$ is the uncertain linguistic variable.

Take an example, $S=\{s_{-2}, s_{-1}, s_0, s_1, s_2\}$ equals to {bad, a bit poor, generally, slightly better, better}and it is the uncertain linguistic evaluation set according to the economic cost of a program at the same time it's the original basis of the program evaluation and decision-making.

Using the uncertain linguistic to evaluate multi-attribute decision-making method, first of all is to choose the language aggregation operator. Commonly used operators include: Uncertain Language Hybrid Aggregate (ULHA), Uncertain Expansion Weighting Arithmetic Average (UEWAA), Uncertain Expansion Order Weighting Average (UEOWA) and etc. Among them, ULHA and UEWAA often applied to the group decision-making. In this paper, we used UEOWA to optimize the programs. It defined as below:

Def 2[18] Set μ as the uncertain language variable, ν as the same definition as Def1, $l_{ab}=b-a, l_{cd}=d-c$ and the possibility degree of $\mu \geq \nu$ will be described as:

$$P(\mu \geq \nu) = \max\left\{ 1 - \max\left(\frac{d-a}{l_{ab} + l_{cd}}, 0\right), 0 \right\} \quad (1)$$

In this formula, l_{ab} and l_{cd} are the calculation method to assess the scale range of the linguistic, the bigger numerical they are, the stronger uncertainty they show.

Steps of program decision-making method based on UEOWA operator are as follows:

Step 1 Set X as the programs set, U as the attributes set. Decision-makers give the language assessment value r_{ij} of program $x_i \in X$ under the condition of attribute $u_j \in U$ and get the evaluation matrix $R = (r_{ij})_{n\times m}$ while $r_{ij} \in S$;

Step 2 Decision-makers according to experience give the value of w and applied UEOWA operator to gather language evaluation information to evaluate the i line in matrix R .After this we can gain the comprehensive evaluation value of attribute $z_i(w)(i \in N)$ of program x_i : $z_i(w) = UEOWA_W(r_{i1}, r_{i2}, \cdots, r_{im})$.

Step 3 Calculate the possibility degree between the comprehensive evaluation value $z_i(w)(i \in N)$ of each program, according to $p_{ij} = P(z_i(w) \geq z_j(w))(i, j \in N)$, and build possibility degree matrix $\tilde{p} = (p_{ij})_{n\times n}$;

Step 4 Use the following sort formula (2) to obtain the sequencing vector $\tilde{v} = (v_1, v_2, \cdots, v_n)$ of the degree matrix:

$$v_i = \frac{1}{n(n-1)}\left(\sum_{j=1}^{n} p_{ij} + \frac{n}{2} - 1\right), \quad i \in N \quad (2)$$

Step 5 Sort programs by each component size to get the optimal program under the multi-attribute relative conditions.

The weighted vector w in Step2 of this method is up to the experience of decision-makers. Although it reflects the algorithm flexibility, the inability to analysis the importance of each attribute quantitatively makes the defects obviously because of the strong subjectivity. The attributes of rough set are important because the calculation method provides an effect solution to solve this problem.

3.1 Uncertain Language Multi-Attribute Decision-Making Embedded Rough Sets

The main method of rough sets to describe information system is gathering. The definition and calculation of attributes importance is described in Reference 12. For a knowledge representation system, the importance of each property is different. The calculation of attributes importance can contribute to removing the redundant attributes and making quantitative analysis of the non-redundant attributes. Embedding the rough attribute importance calculation into the uncertain language multi-attribute decision-making method can make a decision based on the certain data of each attribute's importance, help to reduce the negative influence brought by the subjective factors and improve the reliability and accuracy of the algorithm. The process of uncertain language multi-attribute decision-making method embedded rough sets design process is as below:

(1) Build the evaluation attributes set aimed at the evaluation program set;

(2) Build the uncertain language evaluation scale;

(3) Settle the uncertain language aggregation operator, get language assessment value r_{ij} and construct the evaluation matrix $\tilde{R} = (\tilde{r}_{ij})_{n\times m}$;

(4) The attribute importance judgment;

① List the condition attributes and decision attributes and get the attributes value list;

② Introduce the indiscernible relation $U \mid R_i (i \in (1,n))$ of each attribute $R_i (i \in (1,n))$ aimed at program set U . Get the equivalent relationship of U related to program set R and the related positive field $Pos_p(S)$;

③ Omit each attribute R_i in turn, list the indiscernible relationship $U \mid Ind(P - R_i)$ aimed at the rest attributes and calculate the related positive field $Pos_{P-\{R_i\}}(S)$;

④ Calculate $r_P(S)$, the dependence degree of decision attributes related to condition attributes, according to change of the related positive field and formula $r_p(S) = \frac{Card(Pos_p(S))}{Card(U)}$;

⑤ Obtain the importance of each attribute w according to the formula $w = r_P(S) - Pos_{P-\{P'\}}(S)$;

(5) Calculate each compressive attribute value $\tilde{z}_i(w)(i \in N)$ of program x_i based on w;

(6) Calculate the possibility degree between each program compressive attribute value $\tilde{z}_i(w)(i \in N)$ and establish the possibility degree complementary matrix $P = (p_{ij})_{n \times n}$;

(7) Use sort formula (2) to get the order vector $v = (v_1, v_2, \cdots, v_n)$ of possibility degree matrix P and the order list of programs.

4. Case Study and Analysis

Our institute plan to develop an Intelligent Stepless Variable Choke system which can adjust the diameter of choke and change the fit of the flow areas in real-time according to the actual environment to catch the goal of choking and depress pressure. The system is designed for the harsh conditions, complicated constrain relationships and involved widely, moreover, it applied in professional and particular industries. The function demands expression is complicated, including a large number of specific industries and cross-disciplinary habitual descriptions. The uncertain semantic is obviously.

Using the spoken uncertain language multi-attribute decision-making method to evaluate each design program of Intelligent Downhole Choke can be operated as below:

(1) According to the function target requirements and technical indicators of Intelligent Downhole Choke, the project team puts forward a variety of solutions, as Table1 shows.

Table. 1 Intelligent Downhole Choke design program example

	Signal transmission	Dynamic institution	Actuator	…	DCS system
program1(x_1)	A electrical cable	F motor	cone valve	…	DSP
program2(x_2)	B relay	D electromagnetic valve	wedge valve	…	SCM
program3(x_3)	C transmission	E hydraulic cylinder	sliding sleeve	…	PLC

(2) According to the function requirements of Intelligent Choke, we select design and development difficulty, personnel organization, technical level, market prospects, production cost and etc. 4 main aspects as evaluation decision-making set.

(3) Establish a fuzzy language assessment scale $S = \{S_{-5}, S_{-4}, S_{-3} \cdots S_3, S_4, S_5\}$= {range, very poor, poor, a bit poor, general, a bit good, good, very good, excellent}.

(4) Evaluate 3 design programs of Intelligent Choke according to UEOWA operator and four main attributes of Step(2) to get the evaluation matrix $R = (r_{ij})_{n \times m}$ as Table2.

Table. 2 evaluation matrix of intelligent choke programes

	u_1	u_2	u_3	u_4
x_1	$[s_0,s_1]$	$[s_{-2},s_0]$	$[s_3,s_5]$	$[s_3,s_4]$
x_2	$[s_{-5},s_{-3}]$	$[s_{-4},s_{-3}]$	$[s_4,s_5]$	$[s_3,s_5]$
x_3	$[s_0,s_1]$	$[s_{-2},s_0]$	$[s_2,s_4]$	$[s_2,s_3]$

(5)Using possibility degree formula (1) to establish program degree matrix:

$$P = \begin{bmatrix} P^{(1)} & P^{(2)} & P^{(3)} \end{bmatrix} =$$

$$\begin{bmatrix} 0.5 & 1 & 0 & 0 & 0.5 & 0.333 & 0 & 0 & 0.5 & 1 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0.667 & 0.5 & 0 & 0 & 0 & 0.5 & 0 & 0 \\ 1 & 1 & 0.5 & 0.667 & 1 & 1 & 0.5 & 0.667 & 1 & 1 & 0.5 & 0.667 \\ 1 & 1 & 0.333 & 0.5 & 1 & 1 & 0.333 & 0.5 & 1 & 1 & 0.333 & 0.5 \end{bmatrix}$$

(6) According to the actual situation, designers settled the order vector of UEOWA operator and the value here is $w = (0.25, 0.3, 0.2, 0.25)$. Use the components of the vector $v^{(i)}(i = 1,2,3)$ respectively to arrange the uncertain language data $r_{ij}(j = 1,2,3)$ in table (2) at line i in a descending order, use UEOWA operator to gather the data and calculate the comprehensive attributes evaluation values $z_i(w)(i \in N)$ of program x_i:

$$z_1(w) = UEOWA_w(r_{11}, r_{12}, r_{13}, r_{14}) = 0.25 \times [s_3, s_5] \oplus 0.3 \times [s_3, s_4] \oplus 0.2 \times [s_0, s_1] \oplus 0.25 \times [s_{-2}, s_0] = [s_{1.35}, s_{2.65}]$$

$$z_2(w) = UEOWA_w(r_{21}, r_{22}, r_{23}, r_{24}) = 0.25 \times [s_4, s_5] \oplus 0.3 \times [s_3, s_5] \oplus 0.2 \times [s_{-4}, s_{-3}] \oplus 0.25 \times [s_{-5}, s_{-3}] = [s_{-0.15}, s_{1.4}]$$

$$z_3(w) = UEOWA_w(r_{31}, r_{32}, r_{33}, r_{34}) = 0.25 \times [s_2, s_4] \oplus 0.3 \times [s_2, s_3] \oplus 0.2 \times [s_0, s_1] \oplus 0.25 \times [s_{-2}, s_0] = [s_{0.6}, s_{2.1}]$$

(7) Calculate the possibility degree $\tilde{p}_{ij} = p(z_i(w) \geq z_j(w)), (i, j = 1,2,3)$ between each comprehensive attribute value $z_i(w)(i = 1,2,3)$ according to the possibility degree operator (1) and establish the possibility degree complementary matrix:

$$\tilde{p} = \begin{bmatrix} 0.5 & 0.9825 & 0.7231 \\ 0.0175 & 0.5 & 0.2623 \\ 0.2679 & 0.7377 & 0.5 \end{bmatrix}$$

(8) Obtain the order vector of possibility degree matrix $\tilde{p}$ by the order formula (2):

$$\tilde{v} = \begin{pmatrix} 0.4524, & 0.2104, & 0.3343 \end{pmatrix}$$

Given this we can get the order of programs: $x_1 > x_3 > x_2$.In other words, compared all these programs aimed at Intelligent Downhole Choke, program1 is the best by the judgment of the multi-attribute decision-making method mentioned here. According to the actual situation, the repeater taken in program 2 is difficult to develop, costs high, has low fine degree of electromagnetic valve control and etc. These problems will reflect the market prospects as well. Program3 costs more, gets lower system flexibility and higher cost on production and site maintenance compared with program1 because of the use of hydraulic power. In contrast from comprehensive aspects, program1is the optimal one. It proves the multi-attribute evaluation and decision-making method adopted in the essay can solve the multi-program problems of Intelligent Downhole Choke.

5. Conclusion and Prospect

Intelligent Downhole Tool is part of Intelligent Well Completion technique. It connects the intelligent well analysis system and the terminal task actuators. It is an advanced product produced by various subjects, professional techniques overlapping and comprehensive application with not only one design program. The attributes are different in each program related to technique difficulty, human resource distribution, products cost and market prospect so the program design and decision-making become a process of multi-attribute decision-making evaluation. Because of the uncertain language evaluation involved in the decision-making process, this essay introduces UEOWA operator to value the uncertain language multi-attribute, applies the possibility degree matrix to sort the uncertain language variables so as to get the optimal sort in the particular attributes set. Case studies show that the method can provide a scientific and objective idea for the process of Intelligent Downhole Tool design programs and decision-making.

Acknowledgments

Supported by Sichuan Science and Technology Program (20186120285).

Reference

[1]. Abdullatif A, AL Omair. Economic evaluation of smart well technology [D]. Texas: Texas A&M University, 2007.

[2]. Han Dan-xiu, Li Xiang-fang, Fu Li-xia. Adaptability Study of Intelligent Well Systems in East China Sea Oil Field [J]. International Journal of Plant Engineering and Management, 2008, 13(4):205-213.

[3]. TIMOTHY J R, Fuzzy logic with engineering applications [M]. John Wiley & Sons Ltd, the Atrium, Southern Gate, Chichester, West Sussex, England, 2004.

[4]. GU Ying-kui, YANG Zhen-yu, Fuzzy multi-criteria decisioin-making model for conceptual design candidates' evaluation [J]. Computer Integrated Manufacturing Systems, 2007, 13(8): 1504-1510.

[5]. Lu Da-gang, Wang Li, Zhang Peng, et al. Grey relation degree approach to fuzzy multiple attribute decision-making for structural scheme design [J]. Journal of Harbin Institute of Technology, 2007, 39(6): 841-844.

[6]. HU Liang-ming, XU Cheng, FANG Jun, Case-based reasoning and its application in scheme design of small arms expert system [J]. Journal of System Simulation, 2007, 19(4): 772-775.

[7]. Chen Yong, Feng Peien, He Bin, et al. Automated conceptual design of mechanisms using improved morphological matrix [J]. Journal of Mechanical Design, Transactions of the ASME, 2006, 128(3): 516-526.

[8]. YE J, CAMPBELL R I, PAGE T, et al. An investigation into the implementation of virtual reality technologies in support of conceptual design [J]. Design Studies, 2006, 27(1): 77-97.

[9]. Chu Xue-ning, ZHANG Zai-fang, LIU Hang, Outline schemes decision-making for supplier involved horizontal directional drilling development [J]. Computer Integrated Manufacturing Systems, 2007, 13(6): 1047-1053.

[10]. [Yu Lei. Evaluation analysis on Development Planning of Liaohe oilfield based on fuzzy theory [J]. Silicon Valley, 2012, 31(5):28.

[11]. Li Qiaoyun, Zhang Jiqun, Deng Baorong, et al. Grey decision-making theory in the optimization of strata series recombination programs of high water-cut oilfields [J]. Petroleum Exploration and Development, 2011, 38(4):463-468.

[12]. Su Xin, Zhao Hongtao, Yuan Zongming, et al. Optimum method for underground gas storage projects based on fuzzy comprehensive evaluation [J]. Acta Petrolei Sinica, 2006, 27(2):125-128.

[13]. Zheng Yunchuan1, She Jun2, Qing Qing3, et al. Fuzzy method to evaluate reservior deliverability of sulige gasfield[J]. Natural Gas Exploration and Development, 2011, 34(4):22-25.

[14]. Du Xingyuan. Comprehensive Evaluation of Tianjin Port Supply Oil Base Construction Scheme [D].Tianjin: Tianjin University, 2009.

[15]. Yong Yu. Model Constructing and Applying for Refinery Configuration Schemes Selecting of GPC [D].Guangzhou: South China University of Technology, 2009.

[16]. Xie Fengqiang. Appling Fuzzy Evaluation Decision Mode to Select Fracture Well [J]. Science Technology and Engineering, 2010, 10(7):1768-1771.

[17]. Zhong Shisheng. Fuzzy Theory and Technique for engineering proposal design [M]. Harbin: Harbin institute of technology press, 2000.

[18]. Xu Zeshui. Uncertain Multiple Attribute Decision Making: Methods and Applications [M]. Beijing: Tsinghua University Press, 2004.