Multidimensional Analysis Model of Perforation Optimizing Design Platform

Runzhou Li¹, Mingfei Li², Caili Song¹, Yihua Dou², Xiaoying Yan¹
School of Computer, Xi'an Shiyou University, Xi'an 710065, China¹
School of Mechanical Engineering, Xi'an Shiyou University, Xi'an 710065, China²
runrunli@xsyu.edu.cn

Abstract. The PODP is designed to optimize the perforation scheme and is characterized for specific oilfield. Many factors such as drilling, geology, fluid, perforation, and string mechanics are involved in the design process, and the parameter attributes are numerous, multidisciplinary and cross related. So, the PODP multi-dimensional analysis model is constructed to shield the high-dimensionality and the cross-correlation of the attributes to provide support for the evaluation of the perforation schemas, acquisition of perforation optimizing design knowledge and more characteristic improvement of algorithms. The application examples show that the model can provide multi-angle, multi-objective and multi-granularity analysis of perforation optimizing design parameters and conclusions.

1. Introduction
Perforation is an important part of well testing and completion. For scientific design, many oil and gas field development research institutions, enterprises, universities, etc. have introduced some perforation optimization design software and tools[1-3]. However, these software and tools use universal models and algorithms, which are not targeted.

The Perforation Optimization Design Platform (PODP) first comprehensively evaluates the reservoir based on the data about geology, fluid and drilling, etc. With the evaluation conclusions, the perforating fluid and perforating technology are screened, the number of perforation interval and perforation position are designed optimally. With these works and API[4] (American Petroleum Institute) perforation experimental data, the reservoir perforation diameter and penetration penetration requirements are assessed and the matched perforators are screened out, hence the first level of screening of the perforators for applicability. Next, the safety of the perforated string and the residual strength of the perforated casing need to be estimated. The safest perforators are retained to ensure that the perforation is carried out safely. Then, the second level of optimization based on perforation safety is achieved. After that, the fluid skin factor, flow efficiency and productivity of the reservoir are analyzed, and the perforator that can get highest production is recommended, that is the third level of optimization based on efficient productivity. Finally, an optimizing design report is formed.

The core of the PODP is composed of dozens of submodules, each of which constitutes an algorithm based on physics/experience model in various domains and is characterized for specific oil and gas field[5]. The attribute parameters involved in are numerous, multidisciplinary and cross related. In order to effectively use these data to evaluate the perforation schemas, acquire the knowledge of
perforation optimizing design and improve the algorithms, a multi-dimensional cube classification model\[^{[6-7]}\] for perforation optimization design is constructed to achieve multi-granularity validity analysis of algorithms validity and customized multi-dimensional association analysis of optimized design scheme. The paper gives the model and its application examples.

2. **PODP multidimensional analysis model**

According to the acquisition methods, the PODP data is divided into two types: basic data obtained by means of experiments, measurements, tests, and calculation data output by models and algorithms. According to the described objects, PODP data can be divided into engineering-experimental data, well-reservoir attribute data and reservoir perforation data.

2.1. **Perforation optimizing design information cube classification model**

A cube classification model usually consists of multiple data dimensions, each representing a type of data\[^{[8]}\]. Firstly, the reservoir attribute dimension, perforation design dimension, and well attribute dimension are designed in the cube classification model of perforation optimization design. The large number and wide variety of basic data that don’t relate to reservoir / perforation designs are mapped to various dimensions in an associated manner and are hierarchically classified together with other data. Then, from the perspective of perforation design, a reservoir positioning dimension is formed by introducing the typical perforation characteristics parameters. A three-dimensional (visual) mapping structure of the model is shown in Fig. 1:

![Fig. 1 A three dimension map of the perforation optimizing design information cube classification model](image)

(1) **Reservoir Attribute Dimension.** It contains a root classification tree consisting of sub-trees and leaf nodes with a reservoir as root. The leaf nodes are the attribute sets from the data set of PODP, which are independent of each other, have clear semantics and are relatively complete. Every leaf node is an abstraction of certain sub-attributes of reservoirs, or an abstraction of certain sub-attributes of engineering-experiment data introduced in an associated manner. The abstraction, covering 1 to n attributes, is the smallest query granularity. The root, subtree, and leaf nodes form a hierarchical
(2) Perforation design dimension. The classification model on the perforation design dimension is a pseudo-three-dimensional structure composed of the design data classification plane and the perforator dimension, as shown in Fig. 1. The design data classification plane contains a root classification tree rooted at the perforator. It is a hierarchical classification structure for perforation design data and engineering-experiment data that can be associated with it. Perforator dimension that forms a stratification of full-sequence mode of the perforation-category enables perforator-based positioning and screening in a query.

(3) Well attribute dimension and reservoir location dimension. The basic well parameters constitute the well attribute dimension. The reservoir location dimension is composed of typical reservoir perforation attributes such as spatial properties, oil and gas reservoir type, reservoir temperature and reservoir pressure, etc. These attributes are categorized side by side, hierarchized according to database pattern, and can be applied to the cube classification model individually or together to achieve the generalization (scroll up) positioning or refinement (drill down) positioning of the reservoir. Fig. 1 is a three-dimensional mapping structure with only selected spatial properties as positioning dimensions.

2.2. Analysis (query) mapping
The query based on the perforation optimizing information cube classification model is a process defined on the view of the classification model, decomposed to the root classification trees, mapped to the database schema, and then be merged into a property set according to the attribute association pattern. Hence, a query mapping method based on the classification model must be defined.

Definition 1: In the perforation design information classification cube model, for any classification tree, if D indicates the set of attributes represented by a leaf nodes, the constraint of the root classification tree is:

\[ D_i \cap D_j = \emptyset \quad (i \neq j) \]

Definition 2: The query defined on the cube classification model can be represented as a quadruple: \( W = \langle F(n), P(n), R, L \rangle \). \( n \) indicates the number of the root classification trees covered by the query. \( P(n) \) is a query attribute set defined by the user on the view of the classification model. \( P(n) \) also is a union of the nodes to be queried on the \( n \) root classification trees. \( F(n) \) is a set of roots involved in a query and \( R \) is the association relationship among the roots. \( L \) is the reservoir positioning mode defined by the user through the reservoir positioning dimension.

The mapping of \( F(n) \) and \( L \) is relatively fixed, and the mapping method is mainly included in the mapping of \( P(n) \) and \( R \). The mapping of \( P(n) \) and \( R \) includes the mapping of different hierarchical nodes (combination) to leaf node attributes, the mapping of leaf node attributes to database fields, and the complete relationship generated in the mapping process among database fields.

In the perforation optimizing information cube classification model domain, let \( P \) denote the complete root classification trees nodes set, and \( D \) denote the complete set of attributes represented by leaf nodes. \( P_i \) indicates that node \( P_i \) is a descendant of node \( P_j \). \( D_j \) indicates \( P_j \) is a leaf node, and \( D_j \) is the attribute set represented by \( P_j \). Then the leaf node set is defined as: \( F = \{ P_k | P_k \in P \cup \exists D_k(D_k \in D \cap D_k \leq P_k) \} \), the branch node set is defined as: \( L = P - F \).

The query defined on the leaf node is represented as: \( R_L = \{ < w, D_k > | D_k \in D \cap P_k \in P \cap D_k \leq P_k \} \). The mapping to the attribute set is described as follows:

\[ R_L = \{ < w, D_k > | D_k \in D \cap P_k \in P \cap D_k \leq P_k \} \]

The query defined on the branch node is represented as: \( R_B = \{ < w, P_j > | P_j \in L \} \). The mapping to the attribute set is described as follows:

\[ R_B = \{ < w, \bigcup_{k=1}^{n} D_k > | \forall D_k(\exists P_k(P_k < P_j \cap D_k \leq P_k)) \cap D_k \in D \cap P_k, P_j \in P \} \]

The combined query defined on the leaf node and the branch node is represented as:

\[ R_z = \{ < w, P_j > \cup < w, D_k > | P_j \in L \cap D_k \in D \} \]
When a leaf node is a child or grandchild of a branch node, the mapping to the attribute set is:

\[ R_z = \{ <w, D_i > \mid \forall D_l (\exists P_l (P_l < P_j \land D_l \leq P_l)) \land D_i \in D \land P_i, P_j \in P \} \]

otherwise:

\[ R_z = \{ <w, \bigcup_{l=1}^{n} D_l \land D_k > \mid D_i, D_k \in D \land \forall D_l (\exists P_l (P_l < P_j \land D_l \leq P_l)) \land P_i, P_j \in P \} \]

3. Application analysis

Take the well X1713 and reservoir J2x1 as an example. Consider its combination analysis of well properties, pipe casing properties, rock properties and perforation interval planning, optimization of perforation fluid and perforation technology: \( W_a = \langle F_a(n), P_a(n), R_a, L_a \rangle \). In order to avoid too many returned parameters, when setting \( P_a(n) \), try to select the leaf nodes, such as \( P_a(n) = \{ \text{well-basic information-wellbore}, \text{well-well structure-casing-basic parameters}, \text{reservoir-geology-rock-basic parameters}, \text{reservoir-calculation parameters-perforation position-vertical well}, \text{reservoir-calculation parameters-perforation fluid recommendation}, \text{reservoir-calculation parameters-perforation technology recommendation} \} \). From \( P_a(n) \), confirm \( n=3 \), \( F_a(n) = \{ \text{reservoir location, well property, reservoir property} \} \), and location \( L_a = \{ \text{well and horizon} \} \). \( P_a(n) \) is mapped to the database fields by the analysis engine based on the analysis model metadata and database schema metadata. \( R_a \) is mapped and completed from roots to database fields simultaneously. For instance, the "Depth of the top" and the "Thickness" of the reservoir positioning dimension are matched with the "Hanging depth" and the "Downing Depth" of the "wellbore structure-casing" of the well attribute dimension to get the type of the production casing, etc. The analysis result of the \( W_a \) is shown in Table 1.

![Table 1](image)

**Table 1** A combination analysis of the optimization of perforation position, perforation fluid and perforation technology of X1713-Jx21

| Wellbore | Well structure-casing | Reservoir-location | Rock  |
|----------|-----------------------|--------------------|-------|
| Type     | Depth (m)             | Specification      | Outer diameter (mm) | Wall thickness (mm) | Depth of the top (m) | Thickness (m) | Type | Permeability (%) | Saturation (%) |
| Vertical well | 2662 | 7″×10.36 BG110-3Cr | 139.7 | 7.37 | 2660 | 2 | Fine sandstone | 0.008 | 85 |

Perforation position | Perforation technology | Perforation fluid

Distance to reservoir top (m) | Distance to reservoir bottom (m) | Recommended formula

| 0.720 | 0.280 | TCP balance pressure perforation | 2% sulfonated phenolic resin (SMP-II) + 1% carboxymethyl cellulose (HEC) + 3% KCl + 2% Na2SO3 + 1% ultrafine calcium carbonate powder (JQYZ) + 0.05% surfactant (FC-3B) +4% corrosion inhibitor (KCI) + weighting agent ZnBr2.

\( W_a \) is a horizontal combination analysis. The analysis can also be performed to longitudinal compare between reservoirs. For example, for the same perforator SDP89-16-90-105-dq-003 screened by XX6884-02 reservoir and X1713-Jx21 reservoir, the skin factors and their some relative attributes are compared in query \( W_b \). When setting \( P_b \), the attributes related to the output needs to be carefully selected to make the analysis meaningful. A maybe result of \( W_b \) is show in table 2. Of course, more parameters can be selected to make the engineering meaning of the output of \( W_b \) clearer, in the case that the number of parameters will not interfere with the analysis. From this, we can see that the customization and implementation of queries based on multi-dimensional classification model can be completely and easily based on the user's application needs and objective.
Table 2 Comparative analysis of the skin factors of XX6028-3 and X1713-Jx21 with perforator SDP89-16-90-105-dq-003

|                      | well reservoir | permeability (%) | reservoir thickness (m) | length of perforation interval (m) | corrected perforation diameter (mm) | total skin factor | oil well damage skin factor | plane flow factor | vertical skin factor | compaction pseudo-skin factor | wellbore factor | pressure sensitive skin factor |
|----------------------|----------------|------------------|--------------------------|------------------------------------|-------------------------------------|------------------|----------------------------|------------------|------------------|-------------------------------|----------------|-------------------------------|
| X1713-Jx21           | 0.008          | 2                | 1                        | 0.18                               | 0.189                               | 0.396            | -1.508                    | 0.243            | 0.751            | 0.001                      | 0.306          |                                |
| XX6884-2             | 0.141          | 6                | 3                        | 0.99                               | 0.990                               | 0.447            | -1.310                    | 0.460            | 0.748            | 0.006                      | 0.640          |                                |

Meanwhile, to simplify the application, the multidimensional analysis module of PODP also includes pre-defined algorithm-oriented analysis that can be directly called, as shown in Fig. 2. However, the targeted analysis of specific parameters still needs a customized query.

Fig. 2 The analysis of perforated casing residual strength of X1713-Jx21

4. Conclusion
In the example test, the PODP system has been applied to the perforation scheme design of multiple oil and gas wells. Its multidimensional analysis model has the following characteristics:

1. Effectively classify perforation optimization data with high dimension, multi-domain and cross-correlation, and provide algorithm-oriented and custom multi-dimensional analysis evaluation methods;
2. It can effectively shield the complexity of parameters and realize multi-angle, multi-objective and multi-granularity rapid customized analysis. It can be used for the evaluation of perforation scheme, the acquisition of perforation design knowledge, and the characterization of algorithms.
3. In the current design, most of the algorithm-oriented analysis and evaluation is graphical, but the customized multi-dimensional analysis conclusions are mainly presented in text form. In the future, the visualization needs to be further studied.

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