Decision-Making while Drilling Wells based on the Results of Modeling the Characteristics of Rocks using Probabilistic-Statistical Methods and Fuzzy Logic

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Abstract. The current level of development of technical means and technologies creates favorable conditions for obtaining better information about the drilling process. To do this, it is necessary to analyze the information received, which in turn requires the use of methods that allow making decisions under uncertainty inherent in the drilling process. The operational information obtained in this case is very important and fundamental, which is of particular importance when drilling wells in areas for which there is no information or it is available in insufficient volume. The paper is devoted to increasing the efficiency of studying geological sections and improving the quality of information obtained in the process of drilling wells using probabilistic-statistical methods and fuzzy logic, which in turn contributes to improving the quality of decisions made. In two figures, a comparative analysis of changes in the properties of rocks and the rate of penetration was demonstrated, homogeneous intervals were identified according to the properties of rocks and drillability in general, which makes it possible to trace the intervals of possible complications.

1. Introduction
Making the right technological decisions when drilling oil and gas wells largely depends on the quality of the information received. The low quality of the information received is one of the reasons for making erroneous decisions, which ultimately leads to complications, accidents, and, in general, a decrease in the technical and economic indicators of well drilling. This, as well as the experience of drilling wells and numerous studies show that the data received during the drilling process needs statistical processing in order to obtain information, which in turn requires deep analysis.

Based on this, the proposed paper is devoted to increasing the efficiency of studying geological sections and improving the quality of information obtained in the process of drilling wells using probabilistic-statistical methods and fuzzy logic, which in turn contributes to improving the quality of decisions made.

2. The Value of Complex Information when Making Decisions in Drilling
To date, a large number of studies have been accumulated on the process of interaction of a drill bit with a rock. In these studies, methods and means are proposed for determining the physical and mechanical properties and abrasiveness of rocks. They include experimental studies, studies based on
the analysis of geological and geophysical information, as well as studies based on classification methods.

As a result of these studies, methods have been proposed that allow assessing the properties of rocks both by cores, cuttings, using the results of geophysical studies of wells, and data from geological and technological research during drilling. In general, the analysis of the work performed shows that it is currently possible to achieve an increase in the level of decisions made using integrated geological, geophysical and technological information, which forms the basis of technological decisions. Information of such kind can be obtained in various ways, it contains uncertainties of a different nature, which affects its quality. Therefore, to obtain and use such information, along with this, it is necessary to use modern methods of data processing and information analysis, taking into account the noted uncertainties. In this case, it is very important to take into account the conditions under which the drilling process proceeds, namely: heterogeneity, fuzziness and random nature of factors. For this, the methods of theory of control and decision-making with insufficient information, which have recently been widely developed in various fields of science and technology, can serve as a reliable basis.

3. Modeling the Characteristics of Rocks in the Well Section

As you know, when analyzing information related to measurements, one has to deal with errors and other uncertainties. Such difficulties arise when making decisions in drilling wells due to the difficulties associated with the creation and use of more accurate instruments for measuring drilling performance and reservoir characteristics, operating parameters, etc. It should be noted that when analyzing information, one can notice that in many cases useful information is hidden in each error [1-3]. Error information can be used to create a reliable tool that complements the traditional techniques required by technologists, geologists, and geophysicists to solve forecasting problems.

When analyzing the work of bits, it is advisable to divide the section into homogeneous intervals and, within their limits, to consider the patterns of changes in drilling indicators. For these purposes, various classification methods have been proposed. One of the simple methods that allows this operation to be performed is the method of D.A. Rodionov [4] well-known from geology, which was used in a number of works, in particular [5]. According to the algorithm of the program, which provides for the application of the noted method, the proposed criterion is calculated, and the calculated value of the criterion proposed in [4] is compared with the corresponding tabular value reflected in the literature on mathematical statistics. The intervals corresponding to the excess of the calculated value of the criterion over the tabular value of Pearson's $\chi^2$ are the boundary between two homogeneous packs, which are heterogeneous with each other. The criterion given in [4] was used by us when dividing the geological section into homogeneous intervals according to two signs that characterize the main properties of rocks, which are necessary when making decisions on the choice of technological parameters. They are hardness, which characterizes the rock's resistance to drilling, and abrasiveness, which characterizes the wear capacity of the rock. Indicators of these properties of rocks, in turn, are functions of lithology, porosity and mineralogical composition of the rock [5].

Figure 1, taken from [5], shows changes in hardness and abrasiveness with depth compared to ROP (rate of penetration) with different bits. The homogeneous intervals drilled with the same types of bits are also identified. The given data were processed by the "moving average" method, which allows to reduce the amplitude of the data scatter and to more clearly identify the trend of the parameter under consideration. It also shows the change in the parameter that comprehensively characterizes the rock drillability and allows one to estimate the intervals of abnormal changes in reservoir pressure (this is evidenced by the deviation of points from a straight line, called a "trend line").
Figure 1. Results of the analysis of information on well drilling in the Karabagly field (Azerbaijan).

It should be noted that in the practical use of the results of well drilling, it is necessary to take into account the presence of noise. In this regard, it becomes necessary to study some random processes against the background of others (impulse noise). We have applied the method of automatic selection [6] to estimate the useful signal in operating parameters. The program that we have applied includes filtering noise when analyzing information and values of the above-mentioned complex drillability parameter, known as the "d-exponent". Changing of the statistics L, which is the main one when applying the method of "automatic selection", makes it possible to judge whether the system under consideration is homogeneous, i.e. the value L calculated for the drilling index can be used to determine homogeneous intervals. The figure above also shows the change in this statistic. The bursts of its values on the graph indicate a breach of the homogeneity of the rocks in terms of drillability.

To date, fuzzy logic is successfully used in the assessment and use of reservoir characteristics [2, 3, 7-9]. In the past, researchers in the field of natural sciences noticed that many seemingly random events are accompanied by certain patterns. It should be noted that earlier, in the eighteenth century, scientists identified a pattern in the change in any observation result around its average value. Such
patterns, or distributions, were closely approximated by continuous curves called "normal distribution curves" and referred to the laws of probability [3, 8, 9]. The normal distribution is completely determined by two parameters: mean and dispersion. In this case, the dispersion depends on hidden, inherent parameters and measurement error. Dispersion around the mean value is one of the main conditions that give rise to the causes of fuzziness, and in this regard, in [3], the authors made an attempt to substantiate why this parameter characterizes fuzziness and requires the use of fuzzy logic exactly.

Thus, the analysis shows that the solution of the problems of modeling technological processes is significantly hampered by the presence of uncertainty associated with both the use of random and fuzzy values. The difference between these values is that random variables convey the fact that the investigated variables can take different values with different probabilities, while fuzzy variables convey approximation in determining the values of these variables themselves. In addition, fuzzy values may be preferable in case of insufficient statistical data and related information necessary for estimates that are more reliable. The study of various relationships that take place during well drilling made it possible to develop a reasonable calculation scheme for assessing the characteristics of a geological section.

In order to outline a unified approach that includes both probabilistic and fuzzy modeling as special cases, values called fuzzy random are considered in the literature [2, 10]. According to the research carried out, a fuzzy random variable is a random variable whose values are not ordinary real numbers, but fuzzy numbers. In the work [5] the application of the noted provisions is considered on the example of predicting the lithology of the rocks of the section of one of the wells drilled in Azerbaijan by a set of attributes (hardness, abrasiveness, lithology indicator, porosity, permeability) obtained as a result of geological-geophysical and technological studies in the process of drilling wells. It should be noted that the choice of features depends on the specific task at hand. The analysis of the distribution showed that for each of the listed features, with the exception of permeability, it obeys the normal law (permeability, as you know, obeys the logarithmically normal law, therefore, their logarithms are taken as its values).

As is known from probability theory, for a normal distribution, the distribution density is expressed in the following way:

$$P(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$  \hspace{1cm} (1)$$

In the above formula, \(P(x)\) expresses the density of the distribution of the feature in conjunction with the arithmetic mean value \(\mu\) and standard deviation \(\sigma\). In this case, as already noted, the features are hardness, abrasiveness, lithology index, porosity, permeability. In accordance with this, \(\mu\) and \(\sigma\) will express the mean value and standard deviation of each of these signs, respectively.

The arithmetic mean and standard deviation for each feature are calculated according to the data obtained from the results of geological and technological studies in the process of drilling wells, core studies and geophysical studies for each lithological type of rock.

Typically, a well section is not homogeneous, meaning it consists of several intermittent rock layers. Each of the rock types is characterized by an average value of characteristics, including hardness (as well as other rock characteristics) and its standard deviation, as a result of which there are \(\mu_i\) and \(\sigma_i\) pairs for each rock type \(f_i\). In the case when the value of one or another rock characteristic is of type \(f\), the fuzzy probability of this characteristic \(x\) (which was obtained experimentally and / or based on a complex of geological, technological and geophysical studies) can be calculated using the expression (1), by substituting the distribution characteristics of the mean value \(\mu_i\) and the standard deviation \(\sigma_i\). Similarly, you can also calculate the fuzzy possibilities for all other types of rocks \(f\) and characteristics. Such fuzzy possibilities will only apply to one specific rock type.

For clarity, let us formulate our task once again. In this case, we assume that we have a lot of rock lithotypes, according to the lithological column given in the well design. It is necessary to refine this
column with the help of a complex of features characterizing a particular lithological difference of rocks. For this purpose, we have many features that characterize the type of rock – these are the values of hardness, abrasiveness, lithology index, porosity, permeability. Based on these values, it is necessary to classify the recognized rock as one or another lithological type. It should be noted that different characteristics of rocks can serve as signs, depending on the goal.

It is of interest to consider the relationship between the fuzzy possibility for each rock type and the fuzzy possibility of the mean or most probable value. To do this, first we will denormalize expression (1), i.e. we divide it by the numerator, as it was done in works [3, 9]:

$$P(\mu) = \frac{\frac{(\mu - \mu_f)^2}{2\sigma^2}}{\frac{1}{\sigma^2}} = \frac{1}{\sigma^2}$$

The relative fuzzy possibility $R(x_f)$ that the hardness of $x$ will belong to type $f$ as compared with the fuzzy possibility of measuring the mean value of $\mu_f$ and is calculated as the ratio of expression (1) to expression (2) [3, 9]:

$$R(x_f) = \frac{\frac{(x - \mu_f)^2}{2\sigma^2}}{1}$$

The fuzzy possibility can now be calculated in comparison with all possible rock types. Due to the fact that the same rock in the section of one well may occur several times at different depths, in this case, the relative frequency of this occurrence will be one of the determining factors. By multiplying expression (3) by the square root of the assumed occurrence $n_f$ of a particular rock type $f$, we obtain the formula for determining the fuzzy possibility [3]:

$$F(x_f) = \sqrt{n_f} e^{\frac{-(x - \mu_f)^2}{2\sigma^2}}$$

The fuzzy possibility $F(x_f)$ is based on estimates of the values of each feature obtained using core analysis data and / or on a complex of geological, technological and geophysical studies. The process is repeated alternately for each other feature, for example, porosity, and then for each lithotype of rocks to obtain $F(z_f)$. This step will provide $F(y_f)$, the fuzzy possibility that the measured porosity $y$ is of lithotype $f$. At this stage, we have five fuzzy probabilities ($F(x_f), F(y_f), F(z_f)$...) which are based on fuzzy possibilities available for different characteristics of rocks ($x, y, z$...). They indicate that the lithotype $f$ is the most likely. These fuzzy possibilities are then harmoniously averaged to obtain the aggregate fuzzy possibility [3, 5]:

$$C_f = \frac{1}{\frac{1}{F[x_{por}]} + \frac{1}{F[x_{perm}]} + \frac{1}{F[x_{arb}]} + \frac{1}{F[y_{por}]} + \frac{1}{F[y_{perm}]} + \frac{1}{F[y_{arb}]} + \frac{1}{F[z_{por}]} + \frac{1}{F[z_{perm}]} + \frac{1}{F[z_{arb}]}}$$

The noted calculation process is performed for each lithological type $f$. The lithotype associated with the smallest cumulative fuzzy possibility is taken as the most probable for a given set of features. On the example of the section of the well-considered above, calculations were carried out according to the noted scheme and the results are given in [5]. According to a similar scheme, using the above expressions, calculations were performed for a well, also drilled in one of the fields. Hardness, porosity and carbonate content are taken as features for a comprehensive assessment of rock drillability. In this case, the formula for determining the harmonic mean will take the form:

$$C_f = \frac{1}{\frac{1}{F[x_{por}]} + \frac{1}{F[x_{perm}]} + \frac{1}{F[x_{arb}]} + \frac{1}{F[x_{arb}]} + \frac{1}{F[y_{por}]} + \frac{1}{F[y_{perm}]} + \frac{1}{F[y_{arb}]} + \frac{1}{F[z_{por}]} + \frac{1}{F[z_{perm}]} + \frac{1}{F[z_{arb}]}}$$

Figure 2, which is the result of these calculations, shows two lithological columns – given in the well design and refined according to the marked design scheme. In this case, the cumulative fuzzy possibility will be the harmonic mean of three features. A comparison of the identified lithological
types of rocks with the values of fuzzy probabilities is shown. The above calculation algorithm was implemented when analyzing information about wells drilled in one of the fields in Azerbaijan. For one of these wells, as an example, the results are shown in Figure 2. The harmonic mean allows for the identification of rocks by lithology.

![Figure 2. Calculation results and clarified lithological column of one of the wells drilled in Azerbaijan.](image)

Figure 2 also shows the geological characteristics of the section, which is divided into homogeneous intervals using the criterion noted above; here the values of the homogeneity criterion corresponding to the boundaries between homogeneous intervals are shown; the predicted lithological characteristics are given in comparison with the design ones, as well as the well design, justified and built using the noted forecasts and forecasts of reservoir pressures and fracture pressures. Here, as can be seen from the figure, hardness, porosity and carbonate content of rocks are taken as indicators for predicting rock types. The figure shows the changes in these features, as well as the harmonic mean of their fuzzy possibilities.

4. Conclusion
Thus, decision-making while drilling wells is based on comprehensive information obtained during the drilling process. The quality of the decisions made depends on the quality of this information. Modern technical means, methods, software and technologies make it possible to obtain the necessary information and make decisions in an expeditious manner based on data received during the drilling process. The studies presented in this paper make it possible to assess the properties of rocks, the knowledge of which is necessary for drilling, by integrating information received from the results of geophysical well logging, mud logging and experimental studies. This allows you to obtain more complete information about the section of the well being drilled and, as a result, using statistical
methods, it is possible to divide the section into homogeneous intervals, to estimate the intervals of possible complications, while fuzzy logic helps to identify rocks by lithology. This is illustrated in Figures 1 and 2.

References

[1] Khismetov T V, Efendiyev G M, Kirisenko O G, Mammadov T N, Aliyev M S 2006 Drilling performance evaluation and decision-making based on integrated mud logging data Neftyanoe khozyaystvo (Oil Industry) 10 42–4

[2] Zadeh L 1965 Fuzzy Sets Information and Control 8 338–53

[3] Cuddy S J and Glover P W J 2002 The Application of Fuzzy Logic and Genetic Algorithms to Reservoir Characterization and Modeling Soft Computing for Reservoir Characterization and Modeling 1 219–41

[4] Rodionov D A 1981 Statistical Decisions in Geology (Moscow: Nedra Publishing House) p 231

[5] Efendiyev G M, Mammadov P Z, Piriverdiyev I A 2019 Modeling and Evaluation of Rock Properties Based on Integrated Logging While Drilling with the Use of Statistical Methods and Fuzzy Logic Advances in Intelligent Systems and Computing book series vol 1095 10th International Conference on Theory and Application of Soft Computing, Computing with Words and Perceptions – ICSCCW-2019 (Prague, Czech Republic) Springer Nature Switzerland AG pp 503–11

[6] Aghayev S G 1989 A system approach to improved hole drilling efficiency (Baku: Doctor’s thesis) p 52

[7] Fang J H and Chen H C 1997 Fuzzy modeling and the prediction of porosity and permeability from the compositional and textural attributes of sandstone J. of Petroleum Geology 20(2) 185–204

[8] Freund J E and Walpole R E 1980 Mathematical Statistics (New Jersey: Prentice Hall International) p 206

[9] Brown D F, Cuddy S J, Garmendia-Doval A B, McCall J A W 2000 The Prediction of Permeability in Oil-Bearing Strata using Genetic Algorithms Third International IASTED International Conference Artificial Intelligence and Soft Computing

[10] Shvedov A S 2013 On Fuzzy Random Variables (Moscow, National Research University Higher School of Economics: HSE Publishing House) p 28