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Original article

Method of Multimodal Comparative Ranking of Project Drilling Points based on the Normalized Geological and Technological Parameters

Aktan Ye. Ibrayev¹, El-Sayed Negim¹, Dinmuhammed K. Zhenis², Aslan Kurmashev³, Adina Sagyndykova³

¹Satbayev University, Almaty, Kazakhstan

²KMG Engineering, Astana, Kazakhstan

³Kazakh-British Technical University, Almaty, Kazakhstan

ABSTRACT

Background: Effective reservoir management require integrating multiple geological and technological parameters to optimize decision-making. Traditional approaches, while useful, often struggle with the complexity and volume of reservoir data, highlighting the need for more advanced analytical methods.

Aim: This article examines various methodologies for data-driven comparative analysis and its application for selection of drilling points for production and water flooding operations.

Materials and methods: Advanced computational techniques, including machine learning applications, are explored for their role in improving evaluation accuracy. Additionally, this study compares different comparative analysis approaches used in the industry, highlighting their strengths, limitations, and adaptability to various geological conditions.

Results: The synthesis of recent research demonstrates the potential of multimodal analysis approaches to enhance predictive accuracy and decision-making efficiency. Comparative evaluations reveal that while traditional methods remain valuable in certain contexts, data-driven techniques provide superior adaptability and scalability. Future advancements are identified in integrating real-time data streams and cross-disciplinary modeling.

Conclusion: Data-driven comparative analysis, particularly when supported by machine learning, shows significant promise in improving reservoir management practices. By enabling more accurate drilling point selection and more effective water flooding operations, these approaches can drive both economic and operational efficiency. The study emphasizes the importance of continuous innovation and integration of computational tools to address the evolving complexity of reservoir systems.

Keywords: multimodal analysis; geological parameters; technological parameters; comparative analysis; well placement optimization; machine learning; reservoir management.

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Оригинальное исследование

Метод мультимодального сравнительного ранжирования проектных точек для бурения на основе нормализованных параметров геологии и разработки

А.Е. Ибраев¹, Э.-С. Негим¹, Д.К. Женис², А. Курмашев³, А. Сагындыкова³

¹КазННТУ им. К.И. Сатпаева, г. Алматы, Казахстан

²КМГ Инжиниринг, г. Астана, Казахстан

³Казахстанско-Британский технический университет, г. Алматы, Казахстан

АННОТАЦИЯ

Обоснование. Эффективная разработка месторождения требует интеграции показателей геологии и разработки для оптимального принятия решений. Традиционные подходы, хотя и полезны, часто сталкиваются с трудностями при работе с большим объёмом и сложностью данных по месторождениям, что подчеркивает необходимость применения более продвинутых методов анализа.

Цель. В данной статье исследуются методологии сравнительного анализа на основе данных и их практическое применение для выбора точек бурения добывающих и нагнетательных скважин.

Материалы и методы. В исследовании рассматриваются передовые вычислительные методы, в частности, использование машинного обучения для повышения точности оценки месторождения. Проведена сравнительная оценка существующих практик в отрасли, включающая анализ их сильных и слабых сторон, а также адаптируемости к различным геологическим условиям.

Результаты. Результаты последних исследований демонстрируют потенциал мультимодальных подходов к анализу для повышения точности прогнозов и эффективности принятия решений. Сравнительные оценки показывают, что, несмотря на ценность традиционных методов в определённых условиях, методы на основе цифровых данных обладают большей адаптивностью и масштабируемостью. Определены перспективные направления развития – использование потоков данных в реальном времени и междисциплинарное моделирование.

Заключение. Сравнительный анализ, основанный на данных и поддерживаемый методами машинного обучения, обладает значительным потенциалом в улучшении практик управления месторождениями. Благодаря более точному выбору точек бурения и повышению эффективности процессов заводнения данные подходы повышают как экономические, так и производственные показатели. В исследовании подчёркивается важность постоянных инноваций и интеграции вычислительных инструментов для решения растущей сложности систем месторождений.

Ключевые слова: мультимодальный анализ, геологические параметры, показатели разработки, сравнительный анализ, оптимизация размещения скважин, машинное обучение, разработка месторождений.

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Түпнұсқа зерттеу

Геология мен игерудің қалыпқа келтірілген параметрлеріне негізделген бұрғылауға арналған жобалау нүктелерін мультимодальды салыстырмалы саралау әдісі

А.Е. Ибраев¹, Э-С. Негим¹, Д.Қ. Жеңіс², А. Құрмашев³, А. Сағындықова³

¹Қ.И. Сәтбаев атындағы ҚазҰТЗУ, Алматы қаласы, Қазақстан

²ҚМГ Инжиниринг, Астана қаласы, Қазақстан

³Қазақстан-Британ техникалық университеті, Алматы қаласы, Қазақстан

АННОТАЦИЯ

Негіздеу. Кен орнын тиімді игеру үшін геология мен игеру көрсеткіштерін біріктіру арқылы оңтайлы шешім қабылдау қажет. Дәстүрлі тәсілдер пайдалы болғанымен, көбінесе кен орындарындағы деректердің үлкен көлемімен және күрделілігімен жұмыс істеуде қиындықтарға тап болады, бұл озық талдау әдістерін қолданудың қажеттілігін көрсетеді.

Мақсаты. Бұл мақалада деректерге негізделген салыстырмалы талдау әдістемелері және өндіруші және айдау ұңғымаларын бұрғылау нүктелерін таңдау үшін олардың практикалық қолданылуы зерттеледі.

Материалдар мен әдістер. Зерттеу барысында алдыңғы қатарлы есептеу әдістері, атап айтқанда кен орнын бағалаудың дәлдігін жақсарту үшін машиналық оқытуды қолдану қарастырылады. Саладағы қолданыста бар тәжірибелерге олардың күшті және әлсіз жақтарын, сондай-ақ әртүрлі геологиялық жағдайларға бейімделуін талдауды қамтитын салыстырмалы бағалау жүргізілді.

Нәтижелері. Соңғы зерттеулердің нәтижелері болжамдардың дәлдігі мен шешім қабылдау тиімділігін арттыру үшін мультимодальды талдау тәсілдерінің потенциалын көрсетеді. Салыстырмалы бағалаулар көрсеткендей, белгілі бір жағдайларда дәстүрлі әдістердің құндылығына қарамастан, сандық деректерге негізделген әдістер бейімделгіштігі мен ауқымдылығының жоғары екендігін көрсетті. Болашақтағы даму бағыттары ретінде нақты уақыт режиміндегі деректер ағындарын пайдалану және пәнаралық модельдеу анықталды.

Қорытынды. Деректерге негізделген және машиналық оқыту әдістерімен қолдау көрсетілетін салыстырмалы талдау кен орындарын басқару тәжірибесін жақсартуда айтарлықтай әлеуетке ие. Бұрғылау нүктелерін дәлірек таңдау және суландыру процестерінің тиімділігін арттыру арқылы бұл тәсілдер экономикалық және өндірістік көрсеткіштерді арттырады. Зерттеу кен орындары жүйелерінің өсіп келе жатқан күрделілігін шешу үшін үздіксіз инновациялар мен есептеу құралдарын біріктірудің маңыздылығын көрсетеді.

Негізгі сөздер: мультимодальды талдау, геологиялық параметрлер, игеру көрсеткіштері, салыстырмалы талдау, ұңғымаларды орналастыруды оңтайландыру, машиналық оқыту, кен орнын игеру.

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Introduction

Optimizing well placement and reservoir management requires integrating geological variability, fluid dynamics, and engineering constraints. Traditional methods, such as static quality maps and empirical ranking techniques, fail to fully capture reservoir heterogeneity and dynamic flow behavior. Advanced machine learning and data-driven approaches enhance decision-making by leveraging real-time monitoring, streamline modeling, and probabilistic simulations, though they lack physical constraints and interpretability.

Recent advancements in subsurface characterization and well optimization have been driven by integrating geophysical, geological, and machine learning methodologies. In the Midland Basin, Texas, 3D seismic mapping has significantly enhanced well placement in the Wolfcamp Formation [1]. Using Vibroseis trucks and dynamite charges to generate seismic waves, the data collected through geophones underwent various processing techniques like time migration and seismic inversion to derive key rock properties. These seismic attributes were integrated with core samples, well logs, and geomechanical models, with machine learning algorithms identifying patterns between seismic signals and petrophysical properties. This integration allowed for more accurate reservoir models, reducing geological risks and optimizing horizontal drilling trajectories, ultimately leading to increased well productivity and economic efficiency.

Additionally, machine learning can improve production forecasting and decision-making in horizontal subsurface target identification and geosteering [2–3]. By using Random Forest models, SHAP analysis, and Monte Carlo simulations, production profiles were generated to predict cumulative oil production and identify critical factors like distance to the waterfront at well startup. Multi-criteria decision-making (MCA) approaches in geosteering further optimize well trajectory management by balancing various objectives, such as drilling efficiency and well placement accuracy [4]. Although challenges like high implementation complexity and data requirements remain, these integrated methodologies represent the future of reservoir management, offering more precise and cost-effective operations.

This study proposes a systematic approach for selecting targets in reservoir engineering operations using multimodal comparative analysis, which ranks candidates based on static and dynamic parameters while balancing multiple objectives. This formalized approach reduces subjective errors, improves decision quality, and enables real-time automation, though its implementation requires extensive data, model calibration, and rapid analysis in dynamic conditions.

By comparing conventional static methods with AI-driven and streamline-based techniques, this study highlights their strengths, limitations,

and applicability under varying geological conditions. The findings contribute to improving well placement strategies, reducing reservoir modeling uncertainty, and enhancing hydrocarbon recovery through an integrated, data-driven decision-making framework.

Materials and methods

Comparative method was developed for ranking a large amount of input points with multiple parameters. Whole set of input points consists of n points $(x_1, \dots, x_n)$ with N parameter values $(p_1^i, \dots, p_N^i)$. The main purpose of the methodology is to rank points based only on their input data, without using expert weights for each parameter separately. To solve this problem, it was proposed to use a complex parameter P_i based on the product of the normalized values of the geological and technological attributes of each point.

There are parameters for which a positive effect is of great importance, such as oil reserves or oil saturation. But in some cases, it is necessary to calculate the inverse value of the parameters, for example, for the water cut. Normalized value of parameter is calculated using minimal and maximal values of the set. For parameters with positive effect $p_j^{i.norm.pos}$ can be derived from equation:

$$p_j^{i.norm.pos} = \frac{p_j^i - \min_{1..N} p^i}{\max_{1..N} p^i - \min_{1..N} p^i} \quad (1)$$

For parameters with inversed effect $p_j^{i.norm.inv}$ is calculated from equation (2):

$$p_j^{i.norm.inv} = 1 - \frac{p_j^i - \min_{1..N} p^i}{\max_{1..N} p^i - \min_{1..N} p^i} \quad (2)$$

where:

p_j^i – value of the given parameter;

$\min_{1..N} p^i$ – minimal value for the set of the given parameter;

$\max_{1..N} p^i$ – maximal value for the set of the given parameter.

Complex parameter P_i is a product of the multiplication of positive and inversed normalized values of parameters. If there are N parameters, and M of them are positive and O negative ($N=M+O$), then the complex value will be calculated using the formula (3):

$$P_i = \prod_{j=1}^M p_j^{i.norm.pos} \times \prod_{j=1}^O p_j^{i.norm.inv} \quad (3)$$

Thus, using a complex parameter, it is possible to rank input points within a single structural or geological unit (dome, block, horizon). If the input points have values on other structures, then further comparison can be carried out based on the sums of all complex parameters. Using

normalized values allows you to ensure that points are compared based on comparable parameters on the same dimensions. To avoid using expert weights for the parameters, it is assumed that each parameter makes the same contribution to the final estimate. To improve the accuracy and robustness of the results, it is recommended to exclude abnormal values from the parameter sets before calculations.

Results

The proposed multimodal comparative ranking method integrates static geological mapping, dynamic reservoir simulation, and machine learning to optimize well placement through a structured ranking framework. This approach was used in [5] for ranking project points for drilling injector wells. It evaluates well locations based on key factors such as residual oil reserves, drainage radius, injection-production efficiency, and reservoir variability, using a normalized scoring equation. This approach ensures a balanced, adaptive, and computationally efficient solution, prioritizing well locations with high remaining hydrocarbons, optimal spacing, and minimal production inefficiencies.

$$Score_i = (V_{oil}^{res})_i^{norm} \times (1 - (R_{avg}^{opt})_i^{norm}) \times (1 - (K_{cum}^{opt})_i^{norm}) \times (1 - (V_{ratio})_i^{norm}) \quad (4)$$

where:

$(V_{oil}^{res})_i^{norm}$ – normalized residual oil reserves, accounting for remaining hydrocarbons in place;
 $(R_{avg}^{opt})_i^{norm}$ – normalized drainage radius measuring the deviation from the optimal well spacing;
 $(K_{cum}^{opt})_i^{norm}$ – normalized cumulative compensation, indicating injection and production efficiency;
 $(V_{ratio})_i^{norm}$ – normalized deviation of mobile reserves from project values, assessing reservoir variability.

The average drainage radius, adjusted to the project value, is calculated using equation:

$$R_{avg}^{opt} = |R_{avg} - R_{opt}| \quad (5)$$

where R_{opt} is the drainage radius of wells, determined based on the designed well spacing density.

The cumulative compensation, adjusted to the project value, is calculated using equation:

$$K_{cum}^{opt} = |K_{cum} - K_{opt}| \quad (6)$$

where K_{opt} is the target project cumulative compensation.

Another place of application of the proposed approach is the algorithm for selecting drilling points for producing wells. Once all relevant parameters are calculated, project points are ranked based on their likelihood of achieving the highest pro-

duction, considering all associated operational units. The rank of each candidate $score_j^i$ at a specific horizon j is determined using normalized values of cumulative oil production Q_i^{oil} , water injection Q_i^{inj} , and pseudo oil flow rate $q_i^{pseudo_oil}$. These parameters are normalized within the bounds of a single operational unit, with inverse normalization applied to both cumulative oil production and water injection.

$$score_i^j = q_i^{norm} \times Q_i^{oil_norm} \times Q_i^{inj_norm} \quad (7)$$

$$q_i^{norm} = \frac{q_i^{pseudo_oil} - \min\{q_i^{pseudo_oil}\}_i^N}{\max\{q_i^{pseudo_oil}\}_i^N - \min\{q_i^{pseudo_oil}\}_i^N} \quad (8)$$

$$Q_i^{oil_norm} = 1 - \frac{Q_i^{oil} - \min\{Q_i^{oil}\}_{i=1}^N}{\max\{Q_i^{oil}\}_i^N - \min\{Q_i^{oil}\}_i^N} \quad (9)$$

$$Q_i^{inj_norm} = 1 - \frac{Q_i^{inj} - \min\{Q_i^{inj}\}_i^N}{\max\{Q_i^{inj}\}_i^N - \min\{Q_i^{inj}\}_i^N} \quad (10)$$

The overall score of a project point is the sum of its scores across all operational units accessible through drilling at that location. Consequently, candidates linked to a greater number of operational units have a higher chance of oil discovery and receive a higher final evaluation. Based on the ranking results, 19 project points were approved for drilling. During 2024, production wells were drilled at the approved project points. 16 out of 19 wells operate with oil flow rates equal to or exceeding the planned values. The percentage of achieving planned targets for points selected using the software package was 84%.

Alongside the wells selected using the developed algorithm, 129 wells were drilled based on expert analysis of geological and field data. Meanwhile, the percentage of achieving planned targets for wells selected by expert analysis was 79%. Thus, the method of project point placement and ranking proposed in this study demonstrates comparable efficiency to manual selection performed by specialists.

Conclusion

Well placement optimization methods continue to evolve, yet none of the existing approaches fully integrates geological, technological, and dynamic production parameters. Static ranking methods, such as quality maps, remain effective tools for initial assessment but fail to account for changes in drainage volumes and fluid dynamics. Numerical flow simulations provide accurate predictions of pressure distribution and fluid movement. However, this approach is computationally demanding and highly sensitive to input uncertainties. Meanwhile, machine learning-based approaches enable rapid processing of large datasets but may generate geologically infeasible recommendations and require continuous model retraining.

To enhance the efficiency and adaptability of well placement optimization, a multimodal comparative ranking has been proposed, integrating static geological properties, dynamic reservoir modelling, and AI-driven predictive analytics. This approach enables a systematic ranking of key parameters, including residual oil reserves, drainage radius, cumulative compensation, and deviations in mobile reserves from project values. The formation of an integrated well ranking system ensures not only the assessment of reservoir potential but also the optimization of spatial well distribution considering well interactions. Main advantage

of the proposed method is usage of a normalization of the parameter values instead of expert weights. This allows to constant updates of results and minimizes a human factor in decision making processes. Case studies of combined geological modelling, hydrodynamic simulation, and AI-based methods demonstrate that multimodal analysis can significantly improve well placement accuracy and reservoir drainage efficiency. Research findings presented in global scientific literature confirm the flexibility and adaptability of this approach, allowing it to be applied across various reservoir types and evolving field conditions.

ADDITIONAL INFORMATION

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Authors' contribution. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work. The greatest contribution is distributed as follows: Aktan Ye. Ibrayev – methodology development, data interpretation validation and critical revision of the manuscript; El-Sayed Negim – scientific supervision, refinement of research design; Dinmuhammed K. Zhenis – execution of computational experiments and manuscript writing; Aslan Kurmashev – literature review, preparation of tables and figures, and manuscript formatting; Adina Sagyndykova – geological parameter analysis, comparison of industry practices, and interpretation of findings.

ДОПОЛНИТЕЛЬНО

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Конфликт интересов. Автор декларирует отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

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AUTHORS' INFO***Aktan Ye. Ibrayev**ORCID [0009-0005-1731-7092](https://orcid.org/0009-0005-1731-7092)e-mail: ibrayev.a@su.edu.kz.**El-Sayed Negim**ORCID [0000-0002-4370-8995](https://orcid.org/0000-0002-4370-8995)e-mail: m.elsaid@satbayev.university.**Dinmukhammed K. Zhenis**ORCID [0009-0003-4934-7347](https://orcid.org/0009-0003-4934-7347)e-mail: dimashzhenis.pe@gmail.com.**Aslan Kurmashev**ORCID: [0009-0001-8807-4252](https://orcid.org/0009-0001-8807-4252)e-mail: a_kurmashev@kbtu.kz.**Adina Sagyndykova**ORCID: [0009-0008-3352-3744](https://orcid.org/0009-0008-3352-3744)e-mail: a_sagyndykova@kbtu.kz.**ИНФОРМАЦИЯ ОБ АВТОРАХ*****Ибраев Актан Ермакович**ORCID [0009-0005-1731-7092](https://orcid.org/0009-0005-1731-7092)e-mail: ibrayev.a@su.edu.kz.**Негим Эль-Саид**ORCID [0000-0002-4370-8995](https://orcid.org/0000-0002-4370-8995)e-mail: m.elsaid@satbayev.university.**Женис Динмухаммед Канатулы**ORCID [0009-0003-4934-7347](https://orcid.org/0009-0003-4934-7347)e-mail: dimashzhenis.pe@gmail.com.**Курмасhev Аслан**ORCID: [0009-0001-8807-4252](https://orcid.org/0009-0001-8807-4252)e-mail: a_kurmashev@kbtu.kz.**Сагындыкова Адина**ORCID: [0009-0008-3352-3744](https://orcid.org/0009-0008-3352-3744)e-mail: a_sagyndykova@kbtu.kz.

*Автор, ответственный за переписку / Corresponding Author