SOCAR Proceedings

Drilling & Completion

journal home page: http://proceedings.socar.az

MACHINE LEARNING OPTIMIZATION OF CLUSTER PAD STRUCTURE AND WELL DESIGN

Sh. Z. Ismailov, Y. Y. Shmoncheva*, G. V. Jabbarova

Azerbaijan State University of Oil and Industry, Baku, Azerbaijan

A B S T R A C T

The optimization of cluster pad structures and drilling planning is a key factor in enhancing efficiency and reducing costs in oil and gas field development. This study focuses on the application of machine learning algorithms, mathematical modeling, and digital technologies for the rational placement of well clusters. By integrating production wells within a single infrastructure zone, cluster drilling improves resource allocation, minimizes environmental impact, and optimizes field development. The study also explores modern well trajectory control techniques to minimize wellbore intersections and reduce drilling complexity, ensuring operational safety and cost-effectiveness. A major challenge in well clustering is the lack of universal criteria for well grouping. This study proposes a clustering methodology that considers these factors, enabling optimal well placement while reducing infrastructure costs. The research also investigates offshore field development, determining the optimal number of fixed platforms for efficient drilling using machine learning techniques. The results demonstrate that machine learning algorithms significantly enhance the accuracy of optimal well pad placement. Systematic modeling and scenario analysis have reduced the number of required fixed platforms without compromising production efficiency, leading to substantial capital savings. A standardized well grouping methodology has been developed, ensuring a structured approach to well pad design and minimizing drilling risks. These findings contribute to the advancement of modern drilling technologies and provide a framework for improving efficiency in field development. The proposed solutions offer practical applications for reducing costs, optimizing well distribution, and ensuring sustainable oil and gas production.

Keywords: well clustering; modeling; cluster pad; optimization; drilling; machine learning.

Date submitted: 18.10.2024 **Date accepted:** 12.03.2025

© 2025 «OilGasScientificResearchProject» Institute. All rights reserved.

1. Introduction

The modern oil and gas industry requires an efficient approach to field development, cost minimization, and the reduction of environmental risks. Optimization of cluster pad structure and drilling planning significantly enhances productivity, reduces production costs, and ensures the sustainable development of the industry [1-4].

A cluster pad (CP) is an infrastructure facility that integrates multiple production wells within a single zone to optimize drilling and field operations. The key advantages of the cluster method include the following: reduction of infrastructure construction costs, simplification of logistics for materials and equipment, and minimization of environmental impact [5, 6].

The optimal placement of cluster pads is determined by several factors:

1. Geological conditions (field structure, distribution of productive layers);
2. Hydrodynamic characteristics (permeability, pressure, saturation);
3. Technical constraints (capabilities of drilling equipment, drilling technology);
4. Economic factors (costs of construction, production, and transportation);
5. Environmental requirements (landscape preservation, minimization of emissions and waste) [4, 7].

To determine the optimal location and structure of cluster pads, the following methods are used:

1. Geological and geophysical modeling – analysis of field structure to identify the most productive zones;
2. Hydrodynamic modeling – prediction of reservoir behavior during production [8];
3. GIS technologies – digital data processing for cartographic analysis of the area;
4. Machine learning and Big Data analytics – analysis of historical data on production and well construction [9].

Modern digital solutions significantly enhance the accuracy of planning. Modern digital methods incorporate intelligent data analysis for selecting optimal production technologies, including enhanced oil recovery (EOR) methods [10-13]. For this purpose, software packages such as Petrel, Eclipse, and CMG are used for reservoir modeling

**E-mail:* yelena.shmoncheva@asoiu.edu.az

http://dx.doi.org/10.5510/OGP20250101041

and production forecasting. Drones and satellite imaging are employed to assess geographical and environmental conditions, while artificial intelligence (AI) and Big Data analytics optimize well placement [14-17].

Well clustering is one of the key stages in the design and operation of oil and gas fields, aimed at optimizing well placement, reducing drilling costs, and ensuring operational safety. However, the lack of clearly defined clustering criteria can result in inefficient utilization of cluster pad space, increased costs, and complications during well construction [3, 18].

The main existing challenge is the absence of universal clustering criteria. Different fields require different approaches to well clustering due to variations in geological conditions, technological constraints of drilling equipment, and applied drilling methods.

Well inclination angle and trajectory profile significantly influence the process. Wells can be deviated or horizontal, requiring different approaches to bottom-hole assembly (BHA) design and drilling process organization. The absence of clear clustering criteria leads to difficulties in determining the necessity of steerable BHAs for trajectory control and non-steerable BHAs for simple profiles.

Optimizing the drilling sequence helps minimize well interference and avoid trajectory intersections. The kick-off point (KOP) depth defines the initial deviation point of the wellbore, which is crucial for trajectory control. Modern well planning methods require the development of mathematical models and algorithms to account for geological and technical conditions, borehole stability requirements, and optimal trajectory profiles [19, 20].

To ensure efficient well clustering, standardized criteria and methodologies must be developed, incorporating:

1. Analysis of well inclination angle and trajectory profile;
2. Selection of the optimal BHA type;
3. Development of drilling sequence determination algorithms;
4. Automated calculations of kick-off point (KOP) depth [21-23].

The development of these criteria will enhance drilling efficiency, reduce technical and economic costs, and improve operational safety in cluster well development.

This study also explores the determination of the optimal number of offshore fixed platforms for efficient reservoir development with a predefined number of wells using machine learning techniques.

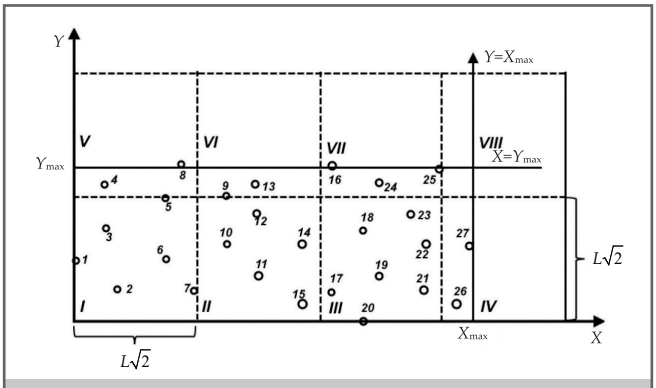

Fig. 1. Field layout covered with a grid of squares

2. Modeling

For modeling, data from a hypothetical field, where the drilling of 27 wells is planned, was used. The objective is to determine the optimal number of fixed platforms and develop a well clustering scheme for the specified wells (fig. 1).

The work is carried out in the following sequence:

1) Based on the given development grid, coordinate systems are selected, passing through the boundary points (well bottom holes). For example, the Y-axis passes through point (bottom hole) 1, while the X-axis passes through point (bottom hole) 20 (fig. 1).

From the coordinates of the given well bottom holes, a matrix of X-values is constructed in ascending order. At the same time, the ordinate values may vary arbitrarily, meaning that: $x_1<x_2<x_3...,x_n$, while the Y-values may follow different relationships:

$$y_j<y_{j+1}$$
$$y_j=y_{j+1}$$
$$y_j>y_{j+1}$$

Thus, the following matrix is obtained:

$$\begin{matrix} x_1 & y_1\ y_2\ y_3\ \dots\ y_m \\ x_2 & \\ x_3 & \\ \vdots & \\ x_n & \end{matrix}$$

2) After constructing the matrix, lines are drawn through the designated well bottom hole coordinates. These lines are used to visualize the clustering structure and determine the optimal distribution of wells across the platforms. Vertical and horizontal lines are drawn based on the X and Y coordinate values.

3) These lines help in grouping wells into clusters and identifying potential intersections.

$$Y=X_{max} \text{ and } X=Y_{max}$$

The clustering process is adjusted to ensure an optimal arrangement of wells within the predefined coordinate grid. This step is crucial for further optimization of well placement and reducing unnecessary platform deployment.

4) According to the maximum deviation L (predefined for the given field), the number of squares covering the specified development grid is determined. The deviation LLL represents the maximum allowable horizontal displacement of a wellbore from the platform. The development grid is divided into squares of side length LLL, ensuring that each well remains within an optimal drilling radius. The number of squares required to cover the grid is calculated based on the total field area and well distribution. This step helps in optimizing the number of platforms while ensuring that all wells are within the acceptable deviation range.

$$\left|\frac{X_{max}}{L\cdot\sqrt{2}}\right|+1=S_x$$

$$\left|\frac{Y_{max}}{L\cdot\sqrt{2}}\right|+1=S_y$$

where: S_x–denotes the number of grid squares along the X-axis; S_y–denotes the number of grid squares along the Y-axis. In this case: S_x=4, S_y=2.

Thus, the maximum possible number of fixed platforms

required for the development of the given field is initially determined using the following equation:

$$N=S_x \cdot S_y=8$$

5) For eight grid squares, eight subsets are formed. Each subset is sequentially checked to determine whether it is empty, meaning it does not contain any elements of the matrix. Upon verification, it is found that the eighth square does not contain any wells (elements of the constructed matrix), allowing its exclusion.

6) To further identify empty subsets among the remaining seven squares, a discrete displacement of the squares by a length of Δh is applied. It is observed that if Square I is shifted upward by $2\Delta h$ and Square II by Δh, then Squares V and VI are no longer required (fig. 2). Here, Δh is a predefined value exceeding the platform size, ensuring optimal spatial adjustment.

Square III is shifted to the right by a distance of Δh to cover well No. 26. As a result, four squares and well No. 27 remain (fig. 3).

After verifying the possibility of reducing the number of squares, the next step is to identify opportunities for connecting uncovered points – in this case, well No. 27.

To achieve this, the coordinates of the square centers are first determined:

For the first square:

$$\left(\frac{L\cdot\sqrt{2}}{2};\ \frac{L\cdot\sqrt{2}}{2}+2\Delta h\right)$$

For the second square:

$$\left(\frac{3L\cdot\sqrt{2}}{2};\ \frac{L\cdot\sqrt{2}}{2}+\Delta h\right)$$

For the third square:

$$\left(\frac{5L\cdot\sqrt{2}}{2};\ \frac{L\cdot\sqrt{2}}{2}\right)$$

For the fourth square:

$$\left(\frac{7L\cdot\sqrt{2}}{2};\ \frac{L\cdot\sqrt{2}}{2}\right)$$

For the seventh square:

$$\left(\frac{7L\cdot\sqrt{2}}{2};L\cdot\sqrt{2}\right)$$

8) To avoid the intersection of wellbores when drilling two or more wells in the same azimuth, the coordinates of the future platforms are shifted in different directions along the X and Y axes by a distance of Δh.

9) The condition $A \le 2L$ is verified, where A represents the distance between wells 16 and 27. If this condition is satisfied, wells 16, 24, 25, and 27 can be drilled from a single platform. If not, the condition $L_1 \le L$ is checked, and well 27 is assigned to Square III.

10) As a result, a single engineering solution is obtained with the number of platforms equal to 4 (fig. 4).

11) Using tabulated cost data, the total expenditures for platform foundations and well construction are determined as a function of deviation.

12) Next, platforms are relocated in increments of Δh to identify the optimal solution.

Once the engineering solution is established, the optimization task is carried out to minimize the objective function.

$$C=\sum_{r=1}^{M}\sum_{s=1}^{N}C_{rs}+\sum_{r=1}^{M}C_r \qquad (1)$$

where C_{rs} – the cost of well drilling as a function of deviation; M – the number of fixed offshore platforms (FOP); N – the total number of wells in the field; C_r – the total cost of the FOP, depending on sea depth and the wells assigned to it, provided in tabular form.

Knowing the coordinates of the FOP, the number of wells assigned to each platform can be easily determined.

A non-stationary coordinate system is introduced, passing through the coordinates of the FOP:

$$X_r, Y_r \quad r=1,\bar{M}$$

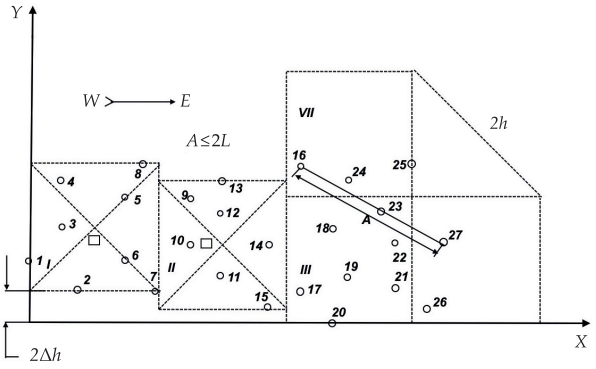

Fig. 2. Well-to-platform assignment for reducing the number of platforms

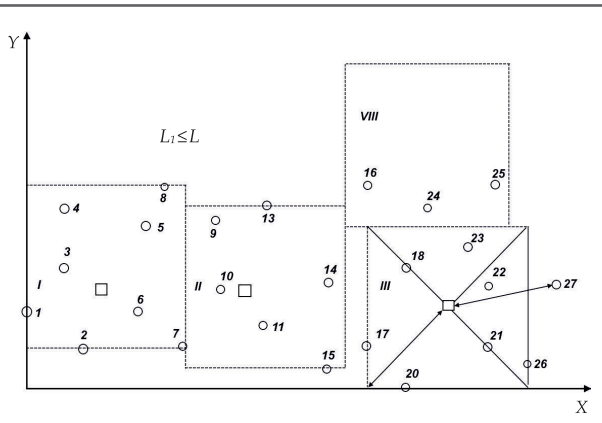

Fig. 3. Selection of the minimum number of platforms by shifting squares

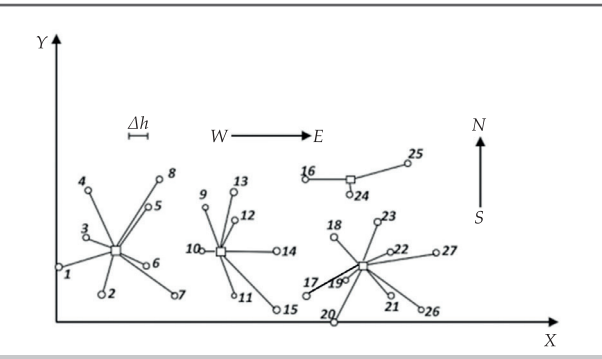

Fig. 4. Well Clustering Solution

3. Calculation of new offshore platform coordinates

The new coordinates of offshore platforms are determined using the following formulas:

$$x_r^\theta = \frac{\sum_{s=1}^{n_{ri}} X_s}{n_i}$$
$$y_r^\theta = \frac{\sum_{s=1}^{n_{ri}} Y_s}{n_i} \quad (2)$$

n_{ri} – the number of wells assigned to each platform,

$$i = 1, \bar{M}_k$$
$$M_k \in M$$
$$\sum_{k=1}^{r} M_k = M$$

The following conditions must be checked:

a) Ensuring all wells n_{ri} belong to the area covered by the squares. To satisfy this condition, squares are approximated by circles with a radius R,
where:

$$R_{\min} < R < R_{\max}$$
$$R = \sqrt{\left(x_2 - x_3\right)^2 + \left(y_2 - y_3\right)^2} \quad (3)$$

$R_{\min}$ and $R_{\max}$ – are the minimum and maximum well deviations for the given field.

b) Ensuring well placement within overlapping circular areas.

The overlap criterion between two circles is calculated as:

$$E = 2R - AB$$
$$AB = \sqrt{\left(x_{r-1}^{\theta'} - x_r^{\theta'}\right)^2 + \left(y_{r-1}^{\theta'} - y_r^{\theta'}\right)^2}$$

If E=0 – the circles touch each other.

If E>0 – the circles overlap.

If E<0 – the circles do not intersect.

The number and coordinates of wells within region E are recorded:

$$x_{r-1}^{\theta'},\ y_{r-1}^{\theta'},\ x_r^{\theta'},\ y_r^{\theta'}$$

These represent the OSP coordinates relative to the fixed coordinate system X, Y where the well coordinates X_s, Y_s are defined.

c) Preventing multiple wells from being drilled in the same azimuth.

To ensure this, the tangents of angles passing through the points are calculated:

$$\left(x_r^\theta, y_r^\theta\right)\ \left(x_{s'_r}, y_{s'_r}\right) s'_r \in s \sum_{r=1}^{M} s'_r = s$$

$$tg\gamma_{s'_r} = \frac{y_r^\theta - y_{s'_r}}{x_r^\theta - x_{s'_r}}$$

$$\left|tg\gamma_{s'_{r-1}} - tg\gamma_{s'_r}\right| \le \varepsilon$$

ε is a predefined value indicating the allowable azimuthal angle between wells drilled from a single offshore platform (OSP). For example, ε=10° can be used as a reference.

d) If the number of wells drilled from a single OSP is limited and equal to M_2, the following condition is verified:

$$\sum_{s=1}^{N} x_{rs} \le M_2 \quad \eta = 1, \bar{M}$$

e) Each well can be drilled from only one offshore platform (OSP). This constraint is verified as follows:

$$\sum_{s=1}^{N} x_{rs} = 1 \quad s = 1, \bar{N}$$

f) All N wells must be drilled from offshore platforms (OSP), with the total number of platforms equal to M. This condition is verified as follows:

$$\sum_{r=1}^{M}\sum_{s=1}^{N} x_{rs} = N$$

In other words, the circles must cover the entire field so that no wells remain outside the designated circles.

g) The condition verifying the assignment of well sss to platform rrr is checked as follows:

$$x_s \le \sqrt{\left(x_r^\theta\right)^2 + \left(y_r^\theta\right)^2}$$

If conditions (a) and (c) are not met, the calculation returns to Equation (2), and new offshore platform (OSP) coordinates are determined.

The distance L from the bottom hole of a well located within region E to the OSP is computed, and the well is assigned to the platform that minimizes the objective functional (1).

If condition (g) is not satisfied, the well located outside the designated circle is reassigned to other circles while ensuring compliance with inequality (3). If condition (3) is also not met, the calculation returns to Equation (2), adjusting the OSP coordinates to a new position.

Initially, a sufficiently large value of c_i is chosen. If all conditions are met, c_{i+1} is calculated using Equation (1), and the condition $c_i - c_{i+1} > 0$ is verified. If this inequality holds, c_{i+1} replaces c_i for the next iteration.

If, during platform relocation, it is found that no wells are assigned to platform r, that offshore platform (OSP) is excluded from further consideration.

Thus, as the OSPs are repositioned, their total number decreases.

The following information is printed as the final output:

- Number of foundations (OSPs);
- Number of wells assigned to each foundation;
- Coordinates of foundations and assigned wells;
- Final value of the objective functional (1).

Conclusions

1. The use of machine learning algorithms has significantly increased the accuracy of determining optimal locations for well pads.
2. Systematic modeling and analysis of alternative placement schemes has reduced the number of required fixed platforms without loss of productivity, which has led to a significant reduction in capital expenditures.
3. A unified well grouping methodology has been created based on machine learning algorithms, providing a standardized approach to well pad design and minimizing drilling risks.

References

1. Kapustin, A. I., Mokrev, A. A., Shakshin, V. P. (2022). Optimization of well pad drilling using dynamic programming ideas /In: Actual problems of the oil and gas industry. Collection of reports from three scientific-practical conferences of the Oil Industry Journal. *Moscow*.

2. Shatrovskiy, A. G., Chinarov, A. S., Salikhov, M. R. (2020). The grouping of planned wells for well pads location by multi-layer field. PROneft. *Professionally about Oil*, 3(17), 44-49.

3. Abramov, A. (2019). Optimization of well pad design and drilling – well clustering. *Petroleum Exploration and Development*, 46(3), 614–620.

4. Wang, G., Huang, W., Gao, D. (2024). Optimization design method of «well factory» platform planning and wellhead layout for oil and gas development. *SPE Journal*, 29, 5875–5895.

5. Karsakov, V. A., Tretyakov, S. V., Devyatyarov, S. S., Pasynkov, A. G. (2013). Well construction capital investment optimization during field development conceptual engineering. *Oil Industry*, 12, 33–35.

6. Mozhchil, A. F., Tretyakov, S. V., Dmitriev, D. E., et al. (2016). Technical and economic optimization of well padding in the integrated conceptual design. *Oil Industry*, 4, 126-129.

7. Zhang, J., Hu, N., Li, W. (2022). Rapid site selection of shale gas multi-well pad drilling based on digital elevation model. *Processes*, 10(5), 854.

8. Nwachukwu, A., Jeong, H., Sun, A., et al. (2018). Machine learning-based optimization of well locations and WAG parameters under geologic uncertainty. In: SPE Improved Oil Recovery Conference, Tulsa, Oklahoma, USA. *Society of Petroleum Engineers.*

9. Li, H., Wan, B., Chu, D., et al. (2023). Progressive geological modeling and uncertainty analysis using machine learning. *ISPRS International Journal of Geo-Information*, 12(3), 97.

10. Suleimanov, B. A., Ismailov, F. S., Dyshin, O. A., Veliyev, E. F. (2016). Selection methodology for screening evaluation of EOR methods. *Petroleum Science and Technology*, 34(10), 961-970.

11. Suleimanov, B. A., Ismailov, F. S., Dyshin, O. A., Veliyev, E. F. (2016). Screening evaluation of EOR methods based on fuzzy logic and Bayesian inference mechanisms. In: *SPE Russian Petroleum Technology Conference and Exhibition, Moscow, Russia. Society of Petroleum Engineers*.

12. Suleimanov, B. A., Feyzullayev, Kh. A., Abbasov, E. M. (2019). Numerical simulation of water shut-off performance for heterogeneous composite oil reservoirs. *Applied and Computational Mathematics*, 18(3), 261-271.

13. Suleimanov, B. A., Feyzullayev, Kh. A. (2024). Simulation study of water shut-off treatment for heterogeneous layered oil reservoirs. *Journal of Dispersion Science and Technology*, Published online: 16 Apr.

14. Sallam, S., Ahmad, M., Nasr, M., Gomari, S. R. (2015). Reservoir simulation for investigating the effect of reservoir pressure on oil recovery factor. *International Journal of Advanced Research in Science, Engineering and Technology*, 2(10), 875-882.

15. Asadzadeh, S., de Oliveira, W. J., de Souza Filho, C. R. (2022). UAV-based remote sensing for the petroleum industry and environmental monitoring: State-of-the-art and perspectives. *Journal of Petroleum Science and Engineering*, 208, 109633.

16. Jirjees, A. Y., Jumma, N., Yashar, J., Talib, U. (2012). Reservoir modeling using CMG-2007 for single well of radial flow. https://doi.org/10.13140/RG.2.2.19516.28806

17. Anaba, D., Kess-Momoh, A., Ayodeji, S. (2024). Digital transformation in oil and gas production: Enhancing efficiency and reducing costs. *International Journal of Management & Entrepreneurship Research*, 6, 2153–2161.

18. Gakhar, K., Shan, D., Rodionov, Y., et al (2016) Engineered approach for multi-well pad development in Eagle Ford shale. URTEC-2431182-MS. In: *SPE/AAPG/SEG Unconventional Resources Technology Conference, San Antonio, Texas, USA.*

19. Suarez, M., Pichon, S. (2016). Completion and well spacing optimization for horizontal wells in pad development in the Vaca Muerta shale. SPE-180956-MS. In: *SPE Argentina Exploration and Production of Unconventional Resources Symposium, Buenos Aires, Argentina. Society of Petroleum Engineers.*

20. Wilson, A. (2016) Completion and well-spacing optimization for horizontal wells in pad development. *Journal of Petroleum Technology*, 68(10), 54-56.

21. Qin, J., Liu, L., Xue, L., et al. (2022). A new multi-objective optimization design method for directional well trajectory based on multi-factor constraints. *Applied Sciences*, 12(21), 10722.

22. Jeong, J., Lim, C., Park, B-C., et al. (2022). Multi-objective optimization of drilling trajectory considering buckling risk. *Applied Sciences*, 12(4), 1829.

23. Mansouri, V., Khosravanian, R., Wood, D. A., et al. (2020). Optimizing the separation factor along a directional well trajectory to minimize collision risk. *Journal of Petroleum Exploration and Production Technology*, 10, 2113–2125.