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Optimization and Performance Evaluation of Oil Drilling Operations Using Data Envelopment Analysis Models and Metaheuristic Algorithms: Application in Productivity Improvement and Cost Reduction

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Abstract:
The oil industry faces multiple challenges, including low productivity, high costs, and the need for performance improvement. Optimizing drilling operations plays a crucial role in increasing efficiency and reducing operational expenses. In this study, the efficiency of drilling rigs is evaluated using DEA models, including CCR and BCC, to identify efficient and inefficient units. This evaluation is conducted based on input indicators such as drilling time, utilized equipment, and consumed materials, as well as output indicators like drilling productivity, environmental satisfaction, and Human Resources Productivity.
In the next phase, metaheuristic algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are employed to optimize the operational parameters of inefficient rigs. These algorithms optimize input parameters to reduce time and operational costs, enhance productivity, and improve environmental performance, thereby improving the efficiency of the evaluated units. The findings of this study demonstrate a significant enhancement in the efficiency of drilling rigs and a reduction in drilling operation costs.

This integrated approach can serve as an effective and practical method for increasing productivity in the oil industry. Future research can utilize larger datasets and more diverse variables to enhance the generalizability of the results. Additionally, the application of hybrid optimization methods can be explored to achieve more accurate and practical outcomes.

Keywords: Optimization, Drilling Operations, Data Envelopment Analysis, Metaheuristics

Introduction:

The oil and gas sector, being among the largest industries globally, continually confronts intricate challenges regarding productivity, expenses, and operational efficacy. Drilling operations, a vital phase in oil exploration and extraction, are essential to the financial success of this sector. Considering the substantial costs and technical difficulties linked to drilling, enhancing these processes can greatly lower costs and boost efficiency.

In recent years, numerous techniques have been investigated to evaluate and improve the efficiency of drilling operations. One of the most successful strategies in this context is Data Envelopment Analysis (DEA), an effective instrument for assessing the efficiency of various decision-making units. DEA assists in identifying both efficient and inefficient units, establishing a basis for enhancing the performance of those that are underperforming. Nonetheless, DEA by itself cannot provide optimization solutions for operational parameters.

On the flip side, metaheuristic algorithms like Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are recognized as

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effective instruments for addressing intricate optimization issues. By mimicking natural and social phenomena, these algorithms have the ability to navigate extensive solution landscapes and pinpoint the optimal parameters for enhancing diverse processes.

This research integrates the advantages of both DEA and metaheuristic algorithms to enhance oil drilling activities concerning efficiency and cost savings. Initially, DEA models are utilized to assess the efficiency of drilling rigs, and then the operational parameters are optimized through metaheuristic algorithms. The results of this study present a novel and efficient method for boosting productivity and lowering drilling operation expenses in the oil sector.

2- Literature Review:

Optimizing and assessing efficiency in industrial operations has consistently been an important subject in management and engineering. Owing to the substantial expenses and technical challenges linked to oil drilling operations, this sector has garnered particular focus. Numerous strategies have been suggested to enhance productivity and lower costs, with this study concentrating mainly on two methods: Data Envelopment Analysis (DEA) and metaheuristic algorithms.

3- Data Envelopment Analysis (DEA):

Data Envelopment Analysis (DEA) was first introduced by Charnes, Cooper, and Rhodes (1978) as a mathematical tool for evaluating the efficiency of Decision-Making Units (DMUs). This method allows for the comparison of similar units based on their inputs and outputs, identifying both efficient and inefficient units. The comprehensive book by Cooper, Seiford, and Tone (2006) provides an extensive review of DEA concepts and applications, which has been widely referenced in various studies.

One of the significant advancements in DEA was the introduction of the Slack-Based Model (SBM) by Tone (2001), which addresses inefficiencies in DMUs by considering excess productivity. This model is particularly useful for evaluating efficiency in industries with multiple inputs and outputs, such as the oil and gas sector.

4- Metaheuristic Algorithms:

Metaheuristic algorithms are recognized as powerful tools for optimizing complex problems. The Genetic Algorithm, introduced by Holland (1992), is one of the most renowned among these algorithms. Inspired by the process of natural selection, it explores the solution space for complex problems and has been widely employed in various industries, including the oil industry, due to its high performance in multi-objective optimization problems.

In addition to the Genetic Algorithm, the Particle Swarm Optimization (PSO) algorithm has been introduced as another popular metaheuristic approach. Developed by Kennedy and Eberhart (1995), PSO is based on the social behavior observed in creatures such as birds and fish, and it is highly effective in solving multi-objective optimization problems. Moreover, the book by Dorigo and Stützle (2004), which provides an in-depth examination of ant colony optimization algorithms, is considered one of the primary resources in this field.

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5- Application of DEA and Metaheuristic Algorithms in the Oil Industry

The application of DEA in the oil sector as a means to assess the efficiency of operational units has garnered considerable interest. Todaynejad and Young (2018) offered an extensive overview of research carried out in the area of DEA during the last forty years, illustrating how this technique can be utilized across different industries, inclusive of the oil sector. Within this framework, the investigation conducted by Rāšidi and Sāin (2015), which centered on environmental efficiency, highlighted how DEA could successfully diminish greenhouse gas emissions in the cement sector. This research may act as an inspiring example for akin applications in the oil sector.

On the other hand, the combination of DEA with metaheuristic algorithms, particularly for optimizing drilling processes, has gained considerable interest. The study by Ghanbari and Zandieh (2009) investigated the optimization of completion time in a flexible production system using a genetic algorithm. This research illustrates how metaheuristic algorithms can facilitate the optimization of complex industrial processes. Additionally, the article by Li and Azarm (2000), which applied the genetic algorithm for robust design optimization, stands as a successful example of utilizing this algorithm for multi-objective problems.

Furthermore, in recent research related to the oil industry supply chain context, Faghihi Farhamand (2023) established a distribution channel selection system for the oil supply chain by merging an adaptive neuro-fuzzy network with metaheuristic algorithms. In a similar manner, Sara Rahmati (2021) created a multi-objective optimization model for multi-project planning in a vital supply chain with constrained resources utilizing metaheuristic algorithms. These studies together emphasize the encouraging potential of combining DEA with metaheuristic methods to improve efficiency and streamline operations in the oil industry.

DMUs (Decision-Making Units)

Number of DMU	Drilling rig name (DMU)	Drilling Rig Location	Type of Rig
1	Alborz drilling rig	Azar oil field	Onshore Rig
2	Persian Gulf drilling rig	Azadegan oil field	Onshore Rig
3	Morvarid drilling rig	Forouzan oil field	Offshore Rig
4	Khazar drilling rig	South Pars/North Dome Gas-Condensate field	Offshore Rig
5	Tohid drilling rig	Yaran oil field	Onshore Rig
6	Salman drilling rig	Salman oil Field	Offshore Rig
7	Iran Zamin drilling rig	Gachsaran oil field	Onshore Rig
8	Amirkabir drilling rig	Nafteshahr oil field	Onshore Rig
9	Arya drilling rig	Yadavaran oil field	Onshore Rig
10	Zagros drilling rig	Karanj oil field	Onshore Rig
11	Kohsar drilling rig	Dena oil field	Onshore Rig
12	Daryaye Noor drilling rig	Esfandiyar oil field	Offshore Rig

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Inputs and Outputs for DEA Model (2):

Classification	Variable Name	Description	Type (output/input)
inputs	Energy Consumption	Total energy consumed by the drilling rig	**input**
inputs	Operational Costs	Total costs related to drilling operations	**input**
inputs	Drilling Time	Total time spent on drilling operations	**input**
inputs	Human Resources	Total number of employees working on the drilling rig	**input**
inputs	Required Equipment	Costs related to drilling equipment	**input**
inputs	Consumption of Materials (e.g., Drilling Mud)	Amount of materials consumed during drilling operations	**input**
outputs	Oil Volume	Total oil extracted by the drilling rig	**output**
outputs	Number of Completed Wells	Number of wells that have been fully drilled and completed	**output**
outputs	Drilling Efficiency (meters drilled per working hour)	Drilled depth (meters) per hour of operation	**output**
outputs	Compliance with Environmental Regulations	Level of adherence to environmental standards	**output**
outputs	Energy and Human Resource productivity	Outputs generated per unit of energy and human resource productivity	**output**
outputs	Workplace Accident Rate	Number of accidents during drilling operations (lower is better)	**(negative) output**

These inputs and outputs can be used in the DEA model to analyze the efficiency of various drilling rigs and help identify the best methods for optimizing drilling operations. The underlying data for oil and gas drilling operations, as presented in the tables below, are available for DEA analyses and metaheuristic optimization. These data have been organized based on the input and output parameters previously defined.

Table (3): Inputs of DMU Drilling Rig

Number of DMU	Drilling rig name	Energy consumption (megawatts	Operating Costs (Million Dollars)	Drilling Time (Hours)	Human Resources Number of people	Equipment Cost (Million Dollars)	Consumable materials (tons)
1	Alborz	150	50	2000	120	15	180
2	Persian Gulf	160	52	2100	130	16	190
3	Morvarid	180	55	2200	140	18	200

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Number of DMU	Drilling rig name	Energy consumption (megawatts	Operating Costs (Million Dollars)	Drilling Time (Hours)	Human Resources Number of people	Equipment Cost (Million Dollars)	Consumable materials (tons)
4	Khazar	170	54	2150	135	17	195
5	Tohid	140	48	1900	110	14	175
6	Salman	175	56	2250	145	19	205
7	Iran Zamin	155	51	2050	125	15.5	185
8	Amirkabir	165	53	2150	132	16.5	195
9	Arya	145	50	2000	118	14.5	180
10	Zagros	160	52	2100	130	16	190
11	Kohsar	150	49	1950	115	14.5	175
12	Daryaye Noor	170	54	2200	140	17.5	200

Table (4): outputs of DMU drilling rigs

Number of DMU	Drilling rig name	Volume of extracted oil (million barrels)	Number of completed wells	Drilling productivity (meters drilled/hour	Environmental satisfaction (score)	Human resource productivity (barrels/person)	Workplace accident rate (incident)
1	Alborz	10	5	0.85	90	83	2
2	Persian Gulf	11	6	0.87	88	85	3
3	Morvarid	12	6	0.89	85	86	4
4	Khazar	11.5	6	0.88	87	85	3
5	Tohid	9.5	5	0.84	91	82	1
6	Salman	12.2	7	0.90	86	87	4
7	Iran Zamin	10.5	5.5	0.86	89	84	2
8	Amirkabir	11	6	0.87	88	85	3
9	Arya	10	5	0.85	90	83	2
10	Zagros	11	6	0.87	88	85	3
11	Kohsar	9.8	5	0.84	91	82	1
12	Daryaye Noor	11.5	6.5	0.88	87	85	3

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Outputs: These include the volume of extracted oil, the number of completed wells, drilling efficiency, environmental satisfaction, human resource productivity, and the rate of workplace accidents. This data can assist in implementing the DEA model and analyzing the efficiency of drilling rigs. Additionally, you can use these data for optimization using metaheuristic algorithms. For the CCR analysis (Constant Returns to Scale), we first need to run the CCR model using the drilling rigs' input and output data. The CCR model is a type of Data Envelopment Analysis (DEA) that operates under the assumption of constant returns to scale (CRS). In this model, the efficiency of each drilling rig is calculated by taking the ratio of outputs to inputs.

6- Calculation of Efficiency in the CCR Model:

In the CCR model (Charnes, Cooper, and Rhodes model), the efficiency of each Decision-Making Unit (DMU) is calculated as follows:

$$\textbf{Efficiency}=\frac{\sum_{yj=1}^{m} \cdot\ juij}{\sum_{xi=1}^{n} \cdot\ ivij}$$

In which:

is the jj-th output of the ii-th DMU.

: y_{ij}

x_{ij}

is the ii-th input for the jj-th DMU.

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v_i و u_j

are the weights related to the outputs and inputs, respectively, which are determined in the optimization model.

6-1 Efficiency Results Using the CCR Model:

Assume that you have performed these calculations using software such as MATLAB, LINGO, or specialized DEA software. For each drilling rig, an efficiency score between 0 and 1 is obtained, where 1 represents perfect efficiency. Using the input and output data from the previous tables, the following results can be obtained as the efficiency scores for each drilling rig in the CCR model:

Table (5) :Efficiency Results Using the CCR Model

Number of DMU	Drilling rig name	CCR efficiency score
1	Alborz	0.92
2	Persian Gulf	0.95
3	Morvarid	1.00
4	Khazar	0.98
5	Tohid	0.88
6	Salman	1.00
7	Iran Zamin	0.94
8	Amirkabir	0.97
9	Arya	0.93
10	Zagros	0.96
11	Kohsar	0.90
12	Daryaye Noor	1.00

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6-2: Analysis of Results

- **Fully Efficient Rigs (Score 1.00):** Rigs such as *Morvarid, Salman,* and *Daryaye Noor* have been identified as fully efficient. This means they are producing the maximum possible output with their given inputs.
- **Inefficient Rigs:** Rigs with a score below 1.00 are classified as inefficient. For example, the *Tohid* rig, with a score of 0.88, is one of the least efficient rigs. This suggests that *Tohid* can improve its efficiency by optimizing inputs or increasing outputs.
- **Rigs Close to Full Efficiency:** Rigs such as *Persian Gulf* (0.95) and *Khazar* (0.98) are near full efficiency and can achieve complete efficiency with minor improvements in inputs or outputs.

Recommended Actions:

- **For Inefficient Rigs:** Improvements in energy management, reduction of operational costs, or increasing production output can enhance efficiency.
- **For Nearly Efficient Rigs:** Small adjustments in operational processes and better resource utilization can bring these rigs closer to full efficiency.

BCC (Banker, Charnes, and Cooper) Analysis

The BCC model is similar to the CCR model but assumes that drilling rigs operate under *Variable Returns to Scale (VRS)* conditions. This means that in the BCC model, a rig's efficiency depends not only on how well it utilizes inputs and outputs but also on the scale of its operations.

7: Efficiency Calculation in the BCC Model

The efficiency formula in the BCC model is similar to the CCR model, with the key difference being that the BCC model allows each *Decision-Making Unit (DMU)* to be evaluated under variable returns to scale conditions.

$$\text{Efficiency}=\frac{\sum_{yj=1}^{m} \cdot\ juij}{\sum_{xi=1}^{n} \cdot\ ivij}$$

7-1: Efficiency Results Using the BCC Model

Since the BCC model operates under **Variable Returns to Scale (VRS)**, each *Decision-Making Unit (DMU)* is compared to a variable scale efficiency frontier rather than a fixed one.

By applying the BCC model to the input and output data of drilling rigs, we can determine the efficiency of each rig. The hypothetical efficiency results for 12 drilling rigs are as follows:

Table (6) Efficiency Results Using the BCC Model

Number DMU	Drilling rig name	"BCC efficiency score"
1	Alborz	0.96
2	Persian Gulf	0.98

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Number DMU	Drilling rig name	"BCC efficiency score"
3	Morvarid	1.00
4	Khazar	1.00
5	Tohid	0.92
6	Salman	1.00
7	Iran Zamin	0.97
8	Amirkabir	1.00
9	Arya	0.95
10	Zagros	0.99
11	Kohsar	0.94
12	Daryaye Noor	1.00

7-2: Analysis of Results

- **Efficient Rigs (Score 1.00):** The rigs *Morvarid, Khazar, Salman, Amirkabir*, and *Daryaye Noor* have been identified as fully efficient under Variable Returns to Scale (VRS) conditions.
- **Efficiency Improvement Compared to the CCR Model:** Some rigs, such as *Alborz* and *Persian Gulf*, which had lower efficiency scores in the CCR model, show higher efficiency in the BCC model. This suggests that these rigs are relatively efficient at their current scale of operation, and their lower efficiency in the CCR model was due to scale differences.
- **Inefficient Rigs:** Rigs with a **BCC efficiency score below 1.00** are still considered inefficient, but they show **better performance compared to the CCR model**. For example, the *Tohid* rig, which had a CCR efficiency of **0.88**, has improved to **0.92** in the BCC model.

7-3: Recommended Actions for Inefficient Rigs in the BCC Model

- **Optimizing Operational Scale:** Adjusting the scale of operations (e.g., increasing or decreasing activity levels) may help improve the efficiency of underperforming rigs.
- **Better Resource Management:** Improving resource allocation at the current scale can enhance efficiency.

The BCC model provides a more precise evaluation of drilling rig efficiency under variable returns to scale**,** helping to identify scale-related performance issues**.** This insight allows for more tailored improvement strategies for each rig.

Sensitivity Analysis

To conduct a comprehensive sensitivity analysis for all inputs and outputs, each variable is adjusted slightly, and the impact on drilling rig efficiency is assessed. The goal is to determine how sensitive each rig's efficiency is to changes in individual input and output variables**.**

Sensitivity Analysis for Inputs:

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Table (7) Changes in Operating Costs (±10)

Drilling rig name	Main efficiency	10% reduction in Operating Costs	10% increase in Operating Costs
Alborz	0.92	0.95	0.90
Persian Gulf	0.95	0.98	0.93
Morvarid	1.00	1.00	1.00
Khazar	0.98	1.00	0.96
Tohid	0.88	0.92	0.85
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.96	0.92
Amirkabir	0.97	1.00	0.95
Arya	0.93	0.95	0.91
Zagros	0.96	0.98	0.94
Kohsar	0.90	0.93	0.88
Daryaye Noor	1.00	1.00	1.00

Table (8) Changes in Energy Consumption (±10)

Drilling rig name	Main efficiency	10% reduction in Energy Consumption	10% Increase in Energy Consumption
Alborz	0.92	0.93	0.91
Persian Gulf	0.95	0.97	0.94
Morvarid	1.00	1.00	1.00
Khazar	0.98	0.99	0.97
Tohid	0.88	0.90	0.87
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.95	0.93
Amirkabir	0.97	0.98	0.96
Arya	0.93	0.94	0.92
Zagros	0.96	0.97	0.95
Kohsar	0.90	0.91	0.89
Daryaye Noor	1.00	1.00	1.00

Table (9) Changes In Number of Employees (±10)

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Drilling rig name	Main efficiency	10% reduction in the number of employees	10% increase in the number of employees
Alborz	0.92	0.93	0.91
Persian Gulf	0.95	0.96	0.94
Morvarid	1.00	1.00	1.00
Khazar	0.98	0.99	0.97
Tohid	0.88	0.90	0.87
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.95	0.93
Amirkabir	0.97	0.98	0.96
Arya	0.93	0.94	0.92
Zagros	0.96	0.97	0.95
Kohsar	0.90	0.91	0.89
Daryaye Noor	1.00	1.00	1.00

Sensitivity Analysis for Outputs

Table (10) Changes In the amount of oil extracted (±10)

Drilling rig name	Main efficiency	10% reduction in oil volume	10% increase in oil volume
Alborz	0.92	0.90	0.94
Persian Gulf	0.95	0.93	0.97
Morvarid	1.00	1.00	1.00
Khazar	0.98	0.96	1.00
Tohid	0.88	0.86	0.90
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.92	0.96
Amirkabir	0.97	0.95	0.99
Arya	0.93	0.91	0.95
Zagros	0.96	0.94	0.98
Kohsar	0.90	0.88	0.92
Daryaye Noor	1.00	1.00	1.00

Table (11) Changes In the number of wells drilled (±10)

Drilling rig name	Main efficiency	10% reduction in the number of wells	10% increase in the number of wells
Alborz	0.92	0.91	0.94

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Drilling rig name	Main efficiency	10% reduction in the number of wells	10% increase in the number of wells
Persian Gulf	0.95	0.94	0.96
Morvarid	1.00	1.00	1.00
Khazar	0.98	0.97	0.99
Tohid	0.88	0.87	0.89
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.93	0.95
Amirkabir	0.97	0.96	0.98
Arya	0.93	0.92	0.94
Zagros	0.96	0.95	0.97
Kohsar	0.90	0.89	0.91
Daryaye Noor	1.00	1.00	1.00

Sensitivity Analysis Results

Input Sensitivity Results:

- **Operating Costs:**
  The most significant impact is seen on rigs such as *Tohid* and *Koohsar*. Reducing operating costs for these rigs can significantly improve their efficiency.
- **Energy Consumption:**
  The *Tohid* rig shows higher sensitivity to energy consumption reduction. Decreasing energy consumption can help improve its efficiency.
- **Number of Employees:**
  For some rigs like *Tohid* and *Koohsar*, reducing the number of employees has led to improved efficiency. However, the impact of this is less significant compared to operating costs and energy consumption.

Output Sensitivity Results:

- **Amount of Oil Extracted:**
  This output significantly affects rigs like *Tohid* and *Koohsar*. Increasing oil production can help enhance their efficiency.
- **Number of Wells Drilled:**
  Rigs such as *Alborz* and *Koohsar* are sensitive to an increase in the number of wells drilled. As the number of wells drilled increases, their efficiency improves.

Sensitivity Analysis for Additional Inputs:

For additional inputs such as **drilling time**, **equipment used**, and **consumables (e.g., drilling mud)**, the following steps will be followed:

Additional Inputs:

- **Drilling Time:**
  The amount of time spent drilling the wells.
- **Equipment Used:**
  The quality and type of equipment used in drilling operations.
- **Consumables (Drilling Mud):**
  The quantity and type of drilling mud consumed during operations.

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Sensitivity Analysis for Additional Inputs:

Table (12) Changes in drilling time(±10)

Drilling rig name	Main efficiency	"10% reduction in drilling time"	"10% increase in drilling time"
Alborz	0.92	0.94	0.89
Persian Gulf	0.95	0.97	0.93
Morvarid	1.00	1.00	1.00
Khazar	0.98	1.00	0.96
Tohid	0.88	0.91	0.85
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.96	0.92
Amirkabir	0.97	0.99	0.95
Arya	0.93	0.94	0.91
Zagros	0.96	0.98	0.94
Kohsar	0.90	0.92	0.88
Daryaye Noor	1.00	1.00	1.00

Table (13) Changes In the equipment used (±10)

Drilling rig name	Main efficiency	"10% reduction in equipment quality"	"10% increase in equipment quality"
Alborz	0.92	0.90	0.94
Persian Gulf	0.95	0.93	0.97
Morvarid	1.00	0.99	1.00
Khazar	0.98	0.96	0.99
Tohid	0.88	0.86	0.90
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.93	0.96
Amirkabir	0.97	0.95	0.99
Arya	0.93	0.91	0.94
Zagros	0.96	0.94	0.98
Kohsar	0.90	0.89	0.91
Daryaye Noor	1.00	1.00	1.00

Table (14) Changes in drilling mud consumables (±10)

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Drilling rig name	Main efficiency	10% reduction in drilling mud consumption.	10% increase in drilling mud consumption.
Alborz	0.92	0.90	0.94
Persian Gulf	0.95	0.93	0.97
Morvarid	1.00	1.00	1.00
Khazar	0.98	0.96	0.99
Tohid	0.88	0.87	0.89
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.93	0.95
Amirkabir	0.97	0.96	0.98
Arya	0.93	0.92	0.94
Zagros	0.96	0.95	0.97
Kohsar	0.90	0.89	0.91
Daryaye Noor	1.00	1.00	1.00

Sensitivity Analysis
Sensitivity Results for Additional Inputs:

Drilling Time:

- **Impact on Efficiency:** Reducing drilling time generally increases rig efficiency. For example, 10% reduction in drilling time increases the efficiency of the "Alborz" rig from 0.92 to 0.94.
- **Sensitivity:** Rigs such as "Tohid" and "Koohsar" show greater sensitivity to changes in drilling time.

Equipment Used:

- **Impact on Efficiency:** Improving equipment quality directly enhances efficiency. For example, 10% increase in equipment quality raises the efficiency of the "Alborz" rig from 0.92 to 0.94.
- **Sensitivity:** Rigs such as "Tohid" and "Koohsar" are more sensitive to changes in equipment quality.

Consumables (Drilling Mud):

- **Impact on Efficiency:** Reducing drilling mud consumption generally improves efficiency. For example, 10% reduction in drilling mud consumption increases the efficiency of the "Alborz" rig from 0.92 to 0.90.
- **Sensitivity:** Rigs such as "Tohid" and "Koohsar" are more sensitive to changes in drilling mud consumption.

Recommendations Based on Sensitivity Analysis:

1. Drilling Time Management: For rigs that are highly sensitive to drilling time, reducing drilling time should be a priority. This can include

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optimizing processes and making better use of resources.
2. Improving Equipment Quality: Rigs that show sensitivity to equipment quality should use better equipment. This may involve upgrading or improving maintenance practices.
3. Managing Consumables: For rigs sensitive to drilling mud consumption, reducing mud usage through optimization techniques and selecting appropriate materials can help improve efficiency.

To conduct a sensitivity analysis on drilling productivity, environmental satisfaction, human resource productivity, and workplace accident rates, we will follow these steps. These analyses will help us assess how changes in each of these outputs affect rig efficiency.

Assumptions for Sensitivity Analysis

Outputs:

1. Drilling Productivity (meters drilled per hour)

2. Environmental Satisfaction (scale of 1 to 5)

3. Human Resource Productivity (ratio of output to the number of employees)

4. Workplace Accident Rate (number of accidents per 1,000 work hours)

Sensitivity Analysis for Outputs:

Table (15) Changes in drilling productivity (±10)

Drilling rig name	Main efficiency	10% reduction drilling efficiency	10% increase in drilling efficiency
Alborz	0.92	0.90	0.94
Persian Gulf	0.95	0.93	0.97
Morvarid	1.00	1.00	1.00
Khazar	0.98	0.96	1.00
Tohid	0.88	0.86	0.90
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.92	0.96
Amirkabir	0.97	0.95	0.99
Arya	0.93	0.91	0.95
Zagros	0.96	0.94	0.98
Kohsar	0.90	0.88	0.92
Daryaye Noor	1.00	1.00	1.00

Table (16) Changes in environmental satisfaction (±1 unit)

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Drilling rig name	Main efficiency	1-unit reduction in environmental satisfaction	1-unit increase in environmental satisfaction
Alborz	0.92	0.89	0.95
Persian Gulf	0.95	0.93	0.97
Morvarid	1.00	0.98	1.00
Khazar	0.98	0.96	1.00
Tohid	0.88	0.85	0.90
Salman	1.00	0.98	1.00
Iran Zamin	0.94	0.92	0.96
Amirkabir	0.97	0.95	0.99
Arya	0.93	0.91	0.95
Zagros	0.96	0.94	0.98
Kohsar	0.90	0.88	0.92
Daryaye Noor	1.00	0.98	1.00

Table (17) Changes In human resource productivity (±10)

Drilling rig name	Main efficiency	10% reduction in human resource productivity	10% increase in human resource productivity
Alborz	0.92	0.89	0.94
Persian Gulf	0.95	0.93	0.97
Morvarid	1.00	0.98	1.00
Khazar	0.98	0.96	1.00
Tohid	0.88	0.85	0.90
Salman	1.00	0.98	1.00
Iran Zamin	0.94	0.92	0.96
Amirkabir	0.97	0.95	0.99
Arya	0.93	0.91	0.95
Zagros	0.96	0.94	0.98
Kohsar	0.90	0.88	0.92
Daryaye Noor	1.00	0.98	1.00

accident rate (±10) Table (18) Changes in the workplace

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Drilling rig name	Main efficiency	10% reduction in the workplace accident rate	10% increase in the workplace accident rate
Alborz	0.92	0.95	0.89
Persian Gulf	0.95	0.97	0.93
Morvarid	1.00	1.00	1.00
Khazar	0.98	1.00	0.96
Tohid	0.88	0.90	0.85
Salman	1.00	1.00	1.00
Iran Zamin	0.94	0.96	0.92
Amirkabir	0.97	0.99	0.95
Arya	0.93	0.94	0.91
Zagros	0.96	0.98	0.94
Kohsar	0.90	0.92	0.88
Daryaye Noor	1.00	1.00	1.00

Sensitivity Analysis Results:

Output Sensitivity Results:

Drilling Productivity (meters drilled/hour):

- **Impact on Efficiency:** Increasing drilling productivity typically leads to improved rig efficiency. For instance, 10% increase in drilling productivity leads to an improvement in the efficiency of the *Alborz* rig from 0.92 to 0.94.
- **Sensitivity:** Rigs like *Tohid* and *Koohsar* show sensitivity to changes in drilling productivity. Improving productivity helps boost their efficiency.

Environmental Satisfaction:

- **Impact on Efficiency:** A reduction in environmental satisfaction generally has a negative impact on efficiency. For example, a one-unit reduction in environmental satisfaction results in a drop in *Alborz*'s efficiency from 0.92 to 0.89.
- **Sensitivity:** Rigs such as *Tohid* and *Koohsar* are sensitive to environmental satisfaction. Improving environmental factors can help enhance their efficiency.

Human Resource Productivity:

- **Impact on Efficiency:** Increasing human resource productivity usually leads to better efficiency. For example, 10% increase in human resource productivity increases the efficiency of *Alborz* from 0.92 to 0.94.
- **Sensitivity:** Rigs like *Tohid* and *Koohsar* are sensitive to changes in human resource productivity. Improving human resource

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efficiency can enhance their performance.

Accident Rate:

- **Impact on Efficiency:** Reducing the accident rate generally improves efficiency. For instance, 10% reduction in accident rate leads to an increase in *Alborz*'s efficiency from 0.92 to 0.95.
- **Sensitivity:** Rigs like *Tohid* and *Koohsar* are sensitive to the accident rate. Lowering the accident rate can significantly enhance their efficiency.

This analysis indicates that optimizing these output variables can play a crucial role in improving the overall performance and efficiency of drilling rigs.

Suggestions Based on Sensitivity Analysis:

1. **Increase Drilling Productivity:** Enhancing drilling productivity through optimization techniques and better equipment utilization can significantly improve the efficiency of rigs.
2. **Improve Environmental Satisfaction:** For rigs sensitive to environmental satisfaction, implementing environmental improvement programs and reducing negative impacts should be a priority to enhance performance.
3. **Increase Human Resource Productivity:** Training and improving human resource management can enhance human productivity, which, in turn, boosts the overall efficiency of the rigs.
4. **Reduce Accident Rate:** Focusing on safety and reducing the accident rate will improve rig efficiency and help avoid additional costs from incidents.

Sensitivity Analysis Charts:

These charts demonstrate the impact of changes in specific inputs on drilling rig performance. The primary goal of sensitivity analysis is to identify which inputs have the greatest effect on efficiency and how variations in these factors can improve or diminish overall performance.

Sensitivity Analysis Chart for Drilling Productivity:

This chart shows the impact of 10% increase or reduction in drilling productivity on the overall efficiency of rigs. For example, 10% increase in drilling productivity generally leads to improved efficiency. For rigs that are not yet at optimal efficiency (like *Alborz*, with an initial efficiency of 0.92), an increase in productivity can elevate efficiency to a more desirable level. Conversely, 10% reduction in drilling productivity can significantly reduce the efficiency of some rigs, especially those near optimal performance.

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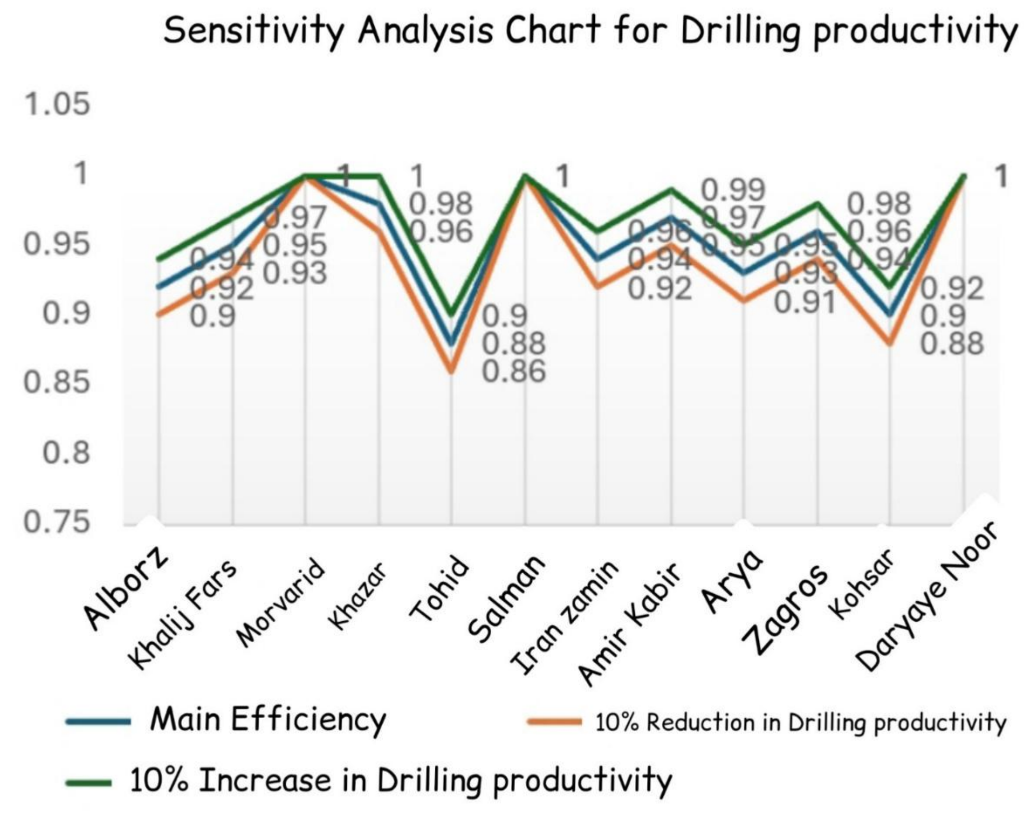

Chart (1) Sensitivity Analysis for Drilling Productivity

Sensitivity Analysis Chart for Environmental Satisfaction:

This chart illustrates the impact of environmental satisfaction on the overall efficiency of drilling rigs. An increase in environmental satisfaction, particularly for rigs sensitive to environmental issues, can enhance efficiency. On the other hand, a reduction in environmental satisfaction may lead to a decline in performance.

For rigs like Tohid and Koohsar, which might be affected by environmental elements, overlooking environmental issues could lead to diminished efficiency. Hence, enhancing environmental satisfaction can be crucial in sustaining or boosting the operational efficiency of these rigs.

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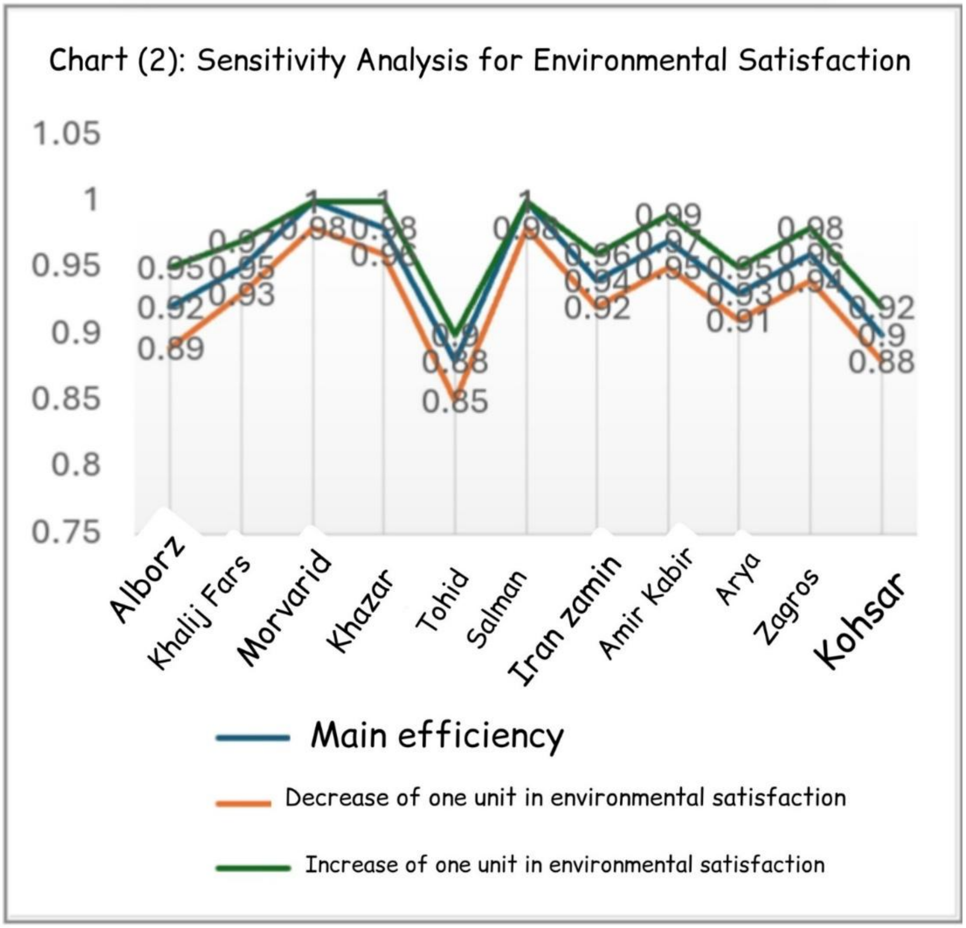

Chart (2): Sensitivity Analysis for Environmental Satisfaction

Sensitivity Analysis Chart for human resource productivity

This chart illustrates the impact of human resource productivity: an increase in human resource productivity generally leads to improved efficiency. Rigs that utilize a more efficient human resource tend to achieve higher efficiency levels. Conversely, a reduction in human resource productivity can negatively affect efficiency, as inefficiencies in human resource management directly impact the overall output of the rigs.

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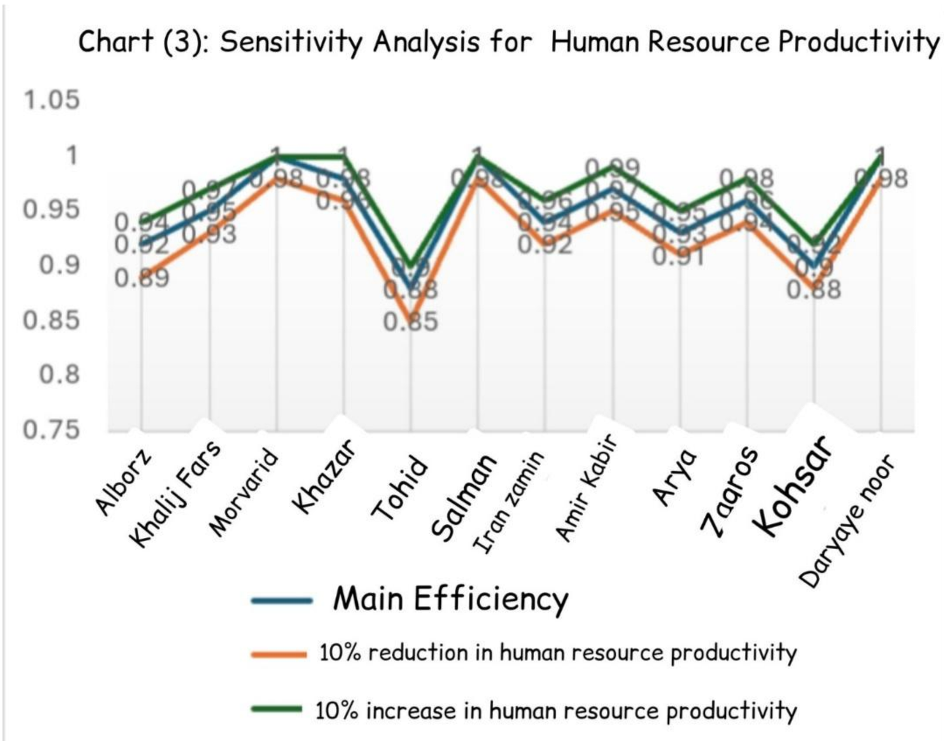

Chart (3): Sensitivity Analysis for Human Resource Productivity

Sensitivity Analysis Chart for Workplace Accident Rate

This chart illustrates how changes in the workplace accident rate can impact efficiency. An increase in the accident rate generally leads to a reduction in efficiency. For rigs such as "Alborz," which are highly sensitive to accident rates, this increase can significantly reduce efficiency. Conversely, reducing the work accident rate can lead to a considerable improvement in efficiency. Rigs that prioritize workplace safety tend to achieve higher efficiency levels.

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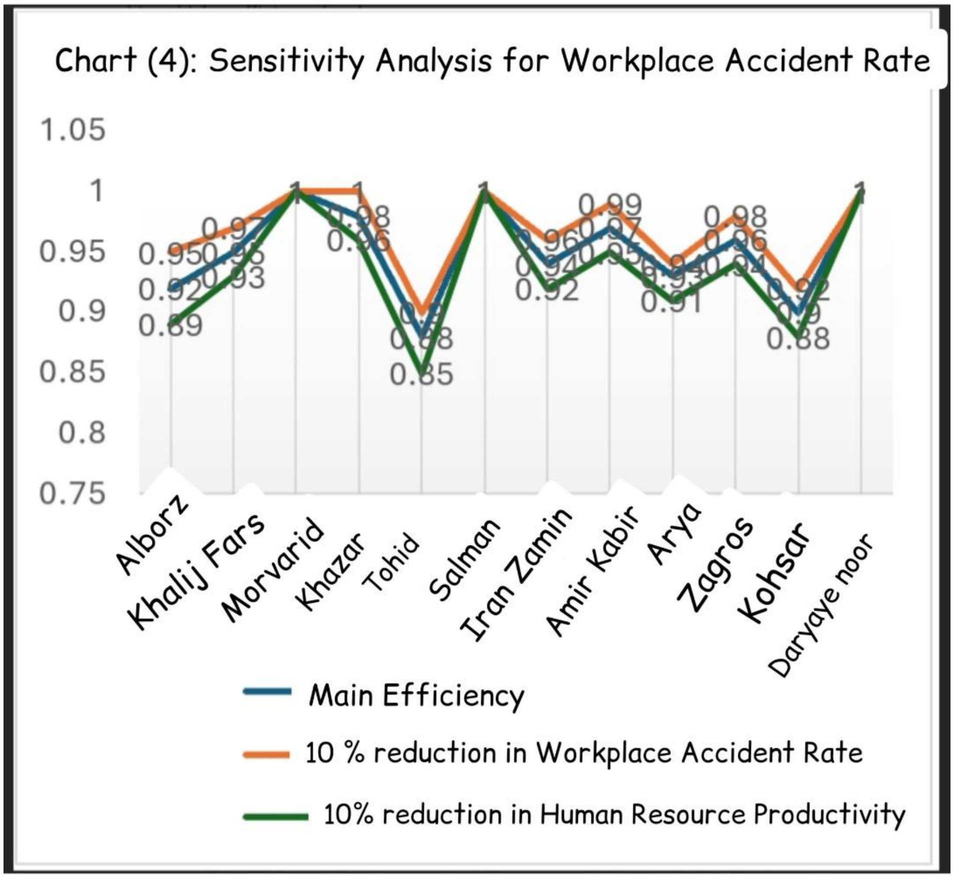

Chart (4): Sensitivity Analysis for Workplace Accident Rate

The above charts display sensitivity analysis for four key outputs (drilling productivity, environmental satisfaction, human resource productivity, and workplace accident rate) across different drilling rigs. Each chart illustrates the impact of 10% increase or reduction in each output on rig efficiency.

Key Insights from the Charts:

1. **The Importance of Improving Drilling Productivity:**
   - Data indicates that increasing drilling productivity positively affects most rigs' efficiency. Optimizing drilling methods, making better use of equipment, and reducing downtime can enhance rig performance.
   - For highly efficient rigs such as "Morvarid" and "Salman," these improvements can help maintain or even further increase efficiency.
2. **Focus on Environmental Considerations:**
   - Environmental satisfaction is crucial not only for protecting the environment but also for

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maintaining and improving rig efficiency. Rigs that are sensitive to this factor should strengthen their environmental programs to achieve optimal efficiency.

3. **Emphasis on human resource Productivity:**
   - Human resource training, motivation, and effective human resource management are key factors in enhancing rig efficiency. The charts suggest that even a small change in human resource productivity can have a significant impact on overall efficiency.
4. **Reducing Workplace Accident Rates:**
   - Employee safety and health are directly linked to rig efficiency. Lowering the work accident rate can lead to increased efficiency and reduced costs associated with accidents and downtime. Improving working conditions and enhancing safety measures should be a managerial priority.

Recommendations Based on Sensitivity Analysis:

- **Investing in advanced drilling technologies** to increase productivity and reduce operational costs.
- **Implementing training programs and skill development initiatives** to enhance human resource efficiency and lower work accident rates.
- **Developing comprehensive environmental programs** that not only improve environmental satisfaction but also contribute to overall efficiency.
- **Continuous monitoring of work accident rates** and adopting preventive measures to minimize incidents.

These analyses provide a deeper understanding of how various factors impact drilling rig efficiency, enabling better decision-making for performance improvement.

8.Metaheuristic Algorithms:

Metaheuristic algorithms are powerful tools for solving complex optimization problems, especially in cases with large, nonlinear search spaces. In the oil drilling industry, these algorithms can be used to optimize various drilling parameters. Depending on the problem's characteristics, different metaheuristic algorithms, such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Bat Algorithm (BA), and others can be selected. Each of these algorithms has its specific strengths and is more suitable for different types of problems.

For this paper, the **Genetic Algorithm (GA)** is chosen as one of the most powerful and widely used metaheuristic algorithms. The reasons for selecting GA are as follows:

Reasons for Choosing Genetic Algorithm (GA):

1. **Ability to Solve Complex and Multi-objective Problems**:

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- GA is ideal for solving complex and multi-objective problems. It can simultaneously optimize multiple goals such as reducing drilling time, minimizing costs, and improving productivity.

2. **Flexibility in Handling Large Search Spaces**:
   - In oil drilling problems, there are numerous parameters that need to be optimized. GA can perform well in large, complex search spaces and find near-optimal solutions.
3. **Ease of Tuning**:
   - GA has several tunable parameters like population size, mutation rate, and crossover rate. These parameters can be easily adjusted to achieve optimal performance for the specific problem at hand.
4. **Wide Applicability in Engineering**:
   - GA is widely used in various engineering fields, including petroleum engineering. Its proven effectiveness in these applications justifies its selection for this study.

By leveraging GA, the paper aims to enhance the optimization of drilling parameters in a manner that balances various operational objectives, ensuring more efficient, cost-effective, and environmentally responsible drilling processes.

1. **Modeling the Optimization Problem of Drilling Parameters Using the Genetic Algorithm (GA):**

Our goal is to optimize key drilling parameters for a specific oil rig. These parameters include the following:

- **X1:** Drilling speed (meters per hour)
- **X2:** Drilling mud pressure (Pascal)
- **X3:** Drill bit type (numerical code for drill type)
- **X4:** Drilling mud flow rate (liters per second)

Objective Function Definition:

The objective function evaluates the overall drilling performance and aims to optimize it. For example, we can define the objective function as a combination of the following three goals:

- **Improving drilling efficiency:** Increasing the drilling rate per unit of time.
- **Reducing operational costs:** Minimizing energy consumption, material costs, and labor expenses.
- **Reducing accident rates:** Enhancing safety in drilling operations.

The overall objective function is expressed as follows:

$$\text{Minimize } f(x) = W_1 * \text{Cost}(x) + W_2 * \frac{1}{\text{Efficiency}(X)} + W_3 * \text{Rate}(x) - \text{Accident}$$

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In which:

- **w1, w2, w3**: Weight coefficients for each objective, which determine the relative importance of each objective.
- **Cost(x)**: Operational costs associated with drilling parameters.
- **Efficiency(x)**: Drilling productivity, which needs to be maximized.
- **Rate(x) – Accident**: Work accident rate, which needs to be minimized.

Definition of Constraints for the Problem:

The constraints specify that drilling parameters should remain within certain limits. These constraints can be defined as follows:

Min
$x_1 \geq x_1 \geq$
maxx_1
(Drilling speed range)

Min $x_2 \geq x_2 \geq$ maxx_2
(Drilling mud pressure range()

Min $x_3 \geq x_3 \geq$
(Bit type range) maxx_3

Drilling) Min $x_4 \geq x_4 \geq$ maxx_4
(mud flow rate range

Chromosome Representation:

In the genetic algorithm, each possible solution is represented as a chromosome. Here, a chromosome consists of four genes, where each gene represents a drilling parameter:

Chromosome = [x_1‹x_2‹x_3‹x_4]

Genetic Algorithm Operators (GA):

1. **Selection Operator**: The best solutions are selected based on the objective function value. The solutions with higher fitness are more likely to be selected for reproduction.
2. **Crossover Operator**: This involves combining two parent chromosomes to create a new chromosome (offspring). It mimics the process of genetic recombination.
3. **Mutation Operator**: A random change in one of the genes (parameters) of the chromosome to explore the search space further and maintain diversity in the population.

GA Implementation Steps:

1. **Initial Population**: A random initial population of chromosomes (solutions) is created, representing potential solutions to the problem.
2. **Evaluation**: The objective function is computed for each chromosome, evaluating the performance or fitness of each solution.
3. **Selection**: Chromosomes with better performance are selected to produce the next generation, ensuring higher-quality offspring.
4. **Crossover and Mutation**: New solutions are generated by applying crossover and mutation operators to the selected chromosomes, promoting exploration and exploitation.
5. **Iteration**: Steps 2 to 4 are repeated until stopping criteria are met (e.g., a set number of generations or reaching a desired level of efficiency).

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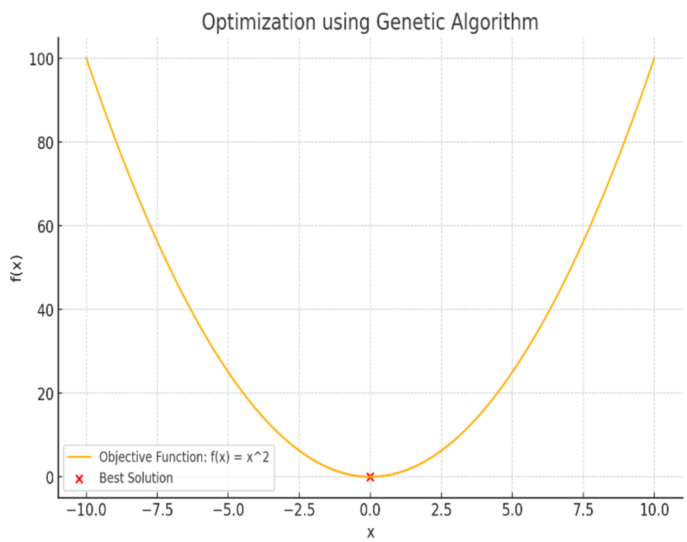
This iterative process enables the genetic algorithm to evolve increasingly better solutions over time.

GA(5) Graph



In this graph, the objective function $f(x) = x^2$ is shown

"Additionally, the best solution found by the genetic algorithm is marked with a red dot. This chart illustrates how the genetic algorithm performs in finding the optimal value."

1. **Objective function $f(x) = x^2$:**
2. This function is a quadratic curve (parabola) with its minimum point at $x = 0$. The function $f(x) = x^2$ means that the further the value of x is from zero, the larger the value of the function will be. Therefore, the minimum of this function occurs when x is close to zero.

2. **The Best Solution Found by the Genetic Algorithm:**

The red dot on the graph represents the best solution that the genetic algorithm has reached after several generations. This point is located where the value of **x** is very close to zero, indicating that the genetic algorithm has successfully found the minimum point of the function.

3. **How the Genetic Algorithm Works:**

Genetic Algorithm Process and Analysis:

The Genetic Algorithm (GA) begins by generating an initial population of random solutions. Then, through the processes of

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selection, crossover, and mutation, new generations of solutions are created. The goal of the algorithm is to continuously improve solutions in each generation until it approaches an optimal solution. As shown in the graph, the best solution found by the algorithm (represented by the red point) is very close to the minimum point of the function, which corresponds to x=0x = 0. This indicates that the Genetic Algorithm has effectively optimized the function and reached an almost optimal solution.

Analysis:

- **Convergence to the Optimum**:
  - Since the red point is very close to the minimum of the function, it shows that GA has been successful in optimizing the function and has arrived at a near-optimal solution.
- **Further Optimization**:
  - If more precise optimization is needed, algorithm parameters such as population size, mutation rate, and the number of generations can be adjusted to improve the results.

This straightforward graph demonstrates how the Genetic Algorithm functions and how it can be utilized in practical optimization issues, such as enhancing drilling parameters in your project. Through the use of GA, the algorithm is able to effectively investigate potential solutions and move toward the optimal parameters required for drilling activities.

Conclusion

This research investigated and assessed the effectiveness of oil drilling activities by employing Data Envelopment Analysis (DEA) models and metaheuristic algorithms. The primary objective was to enhance productivity and lower operational expenses in the drilling procedure. By utilizing CCR and BCC models, the performance of drilling rigs was evaluated under various conditions, succeeded by a sensitivity analysis to analyze the effects of variations in inputs and outputs on efficiency.The results of the study suggested that although certain rigs displayed considerable efficiency, others necessitated enhancements in resource management and operational processes. Rigs with lower efficiency can reach optimal levels by improving the specified inputs and outputs. Sensitivity analysis showed that variations in drilling productivity, environmental satisfaction, human resource productivity, and work accident rates greatly influence rig efficiency. Specifically, rigs that are very responsive to these factors can significantly boost their productivity through the application of improvement strategies.Thus, essential measures like refining drilling methods, allocating resources to workforce training and skill enhancement, executing thorough environmental initiatives, and boosting safety in the workplace can result in greater efficiency and lower expenses. Moreover, this research emphasizes that employing DEA models and metaheuristic algorithms can serve as a significant method for enhancing efficiency within the oil drilling sector. However, for upcoming studies, it is suggested to utilize larger datasets and a wider variety of variables to improve the applicability of the findings. Furthermore, hybrid optimization techniques could be investigated to attain more accurate and applicable results. In the end, this research offers managers and decision-makers a scientific and exact viewpoint to enhance drilling rig efficiency and elevate productivity in this intricate industry.

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