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Research Paper

Optimization of Drilling Parameters Using Response Surface Method for Improved Drilling Efficiency

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ABSTRACT
Using Response Surface Method (RSM), the study optimized drilling parameters for improved hole quality and productivity in some selected gas wells in Niger Delta, Nigeria. The study used a statistical approach where set of drilling data from twelve (12) development wells were analyzed. The data comprised of the weight of the bit (WOB), revolutions per minute (RPM), flow rate (FR), mud characteristics, depth, and rate of penetration (ROP). Descriptive statistics were calculated using Microsoft XLSTAT program. Pearson correlation analysis determined the links between drilling parameters. The descriptive statistics revealed that the mean values of drilling parameters and ROP offered information about the general drilling circumstances in Niger Delta wells. Pearson correlation analysis indicated significant correlations between WOB, RPM, FR, and ROP. The results from the statistical analysis of the drilling parameters gave a better insight into the interdependence among the critical drilling parameters.Therefore, this study has shown that statistical modeling could aid in improving hole quality and achieving substantial productivity when the drilling parameters are controlled.

Keyword: *Weight-on-bit, Pearson correlation,contour plot,flowrate,Minitab software,power setting, angle, statistics.*

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I. Background to the Study

The economics of a project often influence whether or not it will succeed. It is consequently crucial to evaluate the hurdle rate. A hurdle rate is the minimal rate of return on an investment set by a corporation or investor [1]. It establishes a suitable level of compensation for the risk involved in a venture. As a result, drilling optimization is an unavoidable requirement for businesses to break even.Drilling optimization is critical throughout drilling operations since it saves time and money, increasing profits. The analytical results are used to calculate the optimal RPM, ROP, and flow rate to provide optimal drilling performance [2]. Future oilfield resource developments are vulnerable to drilling wells in cost-effective ways. As a result, future management of oilfield drilling operations will confront new challenges in lowering overall costs, improving performance, and reducing the likelihood of experiencing issues. Drilling wells for energy exploration from the ground has seen significant technological advancements in recent years. Different approaches from several disciplines are now applied in drilling activities to achieve safe, environmentally friendly, and cost-effective well construction. Communication and computer technology are among the most essential areas that can help with drilling optimization. Large amounts of data could be piped via many areas on the earth in a reliable and time-efficient manner. Advanced computer technologies are currently being used to store vast volumes of data and solve challenging challenges. Since the very beginning of the drilling campaigns, the operators have constantly sought to cut drilling expenses, mostly by increasing drilling speed. In the drilling industry, the first well drilled in a new field (a wildcat well) typically has the greatest cost. With greater experience with the area, improved drilling could be performed, lowering the expenses of each consecutive well to be drilled until a point is reached where there is no more meaningful improvement [3]. The relationship between drilling parameters is complex; the goal is to find what combination of operating circumstances results in the lowest cost drilling.The commonly accepted convention for properly planning any drilling effort is to maximize operations while minimizing costs

[4]. In 1998, Samuel and Miska[5] stated that another important part of optimization is to improve technology and make the system more effective. Recently, environmentally friendly activities have become normal practice in several areas, which could be achieved by lowering the risks associated with technical problems.Because of the intricacy of the activities being offshore and/or in the form of clusters, operators are preventing themselves from inflicting damage, which could result in the destruction of multiple wells due to their close proximity. Directional techniques made it possible to drill numerous wells from a single location, avoiding the need for expensive structures for each well [6]. Because the drilling needs of wells located at close distances are similar, collecting previous data and utilizing it in a beneficial manner is thought to have a substantial impact on drilling cost reduction as long as the optimum parameters are always in place.

Major drilling variables thought to affect drilling rate of penetration (ROP) are poorly understood and difficult to model [7]. For this reason, a reliable mathematical model for the rotary drilling penetration rate procedure has yet to be developed. Many mathematical models have been presented in an attempt to incorporate known relationships between drilling parameters.The proposed models optimized drilling operations by determining the appropriate bit weight and rotation speed to minimize costs. The use of accessible mathematical models has resulted in significant drilling cost savings.

II. Methodology

2.1 Research Design

The simulation and analysis were carried out following the procedures below:
1.Drilling data comprising of weight on bit, rotary speed (RPM), flow rate, mud parameters, depth, rate of penetration (ROP) were collected from Niger delta wells in Nigeria.
2. The dataset included a large sample size to ensure the reliability and validity of the results.
3.The descriptive statistic was carried out using Microsoft XLSTAT software.
4.Using Microsoft XLSTAT, Pearson correlation analysis was done to establish the relationship between drilling parameters and rate of penetration.
5.Using the Pearson relationship, the drilling parameters were predicted to optimize drilling operation while RSM was used created model to establish the relationship between WOB, torque, SRPM, TFA, power setting and ROP.

2.2 Data Analysis

Drilling metrics affecting penetration rate, such as weight of bit (WOB), revolution per minute (RPM), and flow rate (FR), were collected from producing wells in Nigeria's Niger Delta region. The dataset had a large sample size to ensure the results are reliable and valid. The collected data were cleaned and preprocessed to remove missing values, outliers, and inconsistencies. This phase ensured the quality of the data utilized for further investigation. Response Surface Methodology was used to conduct a variety of analyses, including descriptive statistics, Pearson correlation analyses, regression analysis, and model optimization.

2.2.1 Descriptive Statistic

The descriptive statistic was calculated using Microsoft XLSTAT program. The mean drilling parameter values and rate of penetration would provide insight into the overall drilling parameter values for Niger Delta wells. The standard deviation would provide information on the divergence of drilling parameters from the mean for the Niger Delta well. The skewness of the drilling parameters would provide insight into the distribution of the drilling parameters, allowing for the decision of the method of analysis to be used (parametric or non-parametric) as well as the type of data processing that would be performed on the dataset.

2.2.2 Pearson Correlation Analysis

The Pearson correlation coefficient was be used to assess the strength and direction of the linear relationship between drilling parameters (WOB, RPM, and FR) and ROP. The Pearson correlation helped to comprehend the relationship between drilling parameters and penetration rate. Pearson correlation analysis can also help identify the most relevant elements affecting ROP and provide suggestions for further regression research. The Pearson correlation analysis was performed using Microsoft XLST.

III. Results and Discussion

3.1Descriptive statistic of the drilling parameters

The descriptive statistic result for the drilling parameters was presented in Table 1 and the box plot showing the distribution of the parameters were presented in Figure1.

Table 4.1: Descriptive statistic of drilling parameters and rate of penetration

Parameters	mean	median	std	min	Max	Skew
TF Angle (deg.)	74.41	0.00	128.79	-18.00	342.00	1.21
Power Setting	34.42	0.00	41.96	0.00	100.00	0.60
WOB (1000lbf)	11.71	15.00	4.77	1.00	18.00	-0.57
SRPM (c/min)	95.96	100.00	18.52	70.00	120.00	-0.03
Torque (ft. lbf)	7.99	8.00	1.83	3.00	10.00	-0.99
Slack Off Weight (1000lbf)	155.32	150.00	7.18	150.00	170.00	0.94
PU Weight (1000lbf)	220.22	220.00	25.89	190.00	270.00	0.50
Flow (gal/min)	468.46	470.00	6.66	440.00	480.00	-3.61
ROP (ft/hr)	67.29	67.82	35.46	5.14	274.29	2.35

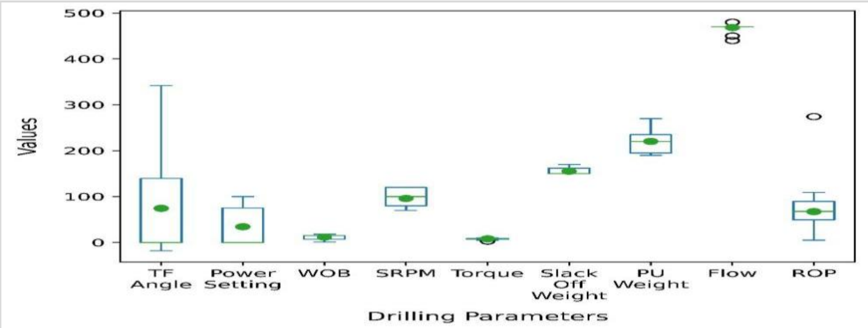

Figure Box plot showing the distribution of the drilling parameters

Table1 revealed that the average Rate of Penetration (ROP), which reflects the speed at which the drill bit moves into the formation, was approximately 67.29 ft/hr. for the UTA 1 field well. The median ROP was 67.82 ft/hr., showing the middle value, while the standard deviation (Std.) of ROP was 35.46 ft/hr., indicating that ROP values were dispersed around the mean. The lowest ROP recorded was 5.14 ft/hr., while the highest was 274.29 ft/hr. The skewness (Skew) was 2.35, indicating a rightward skew in the distribution of ROP values. Figure 4.1 demonstrated that the ROP's strong positive skewness can be attributable to an outlier in the ROP data. The descriptive statistic for the Tool face Angle (TF Angle) which measure the orientation of the drilling tool showed that the mean TF Angle was approximately 74.41 degrees. The median TF Angle was 0.00 degrees while the standard deviation of TF Angle is 128.79 degrees, indicating high variability in tool face orientations. TF Angle ranges from a minimum of -18.00 degrees to a maximum of 342.00 degrees. The skewness was 1.21, suggesting a rightward skew in the distribution of TF Angle values which can be observed by the long tail in the boxplot in Figure 1. Power Setting refers to the modification of drilling machine power, which affects drilling speed and efficiency. The average power setting was at 34.42, with a standard deviation of 41.96. Power Settings can vary from 0.00 to 100.00. The skewness is 0.60, showing a small rightward shift in the distribution of Power Setting values.

Weight on Bit (WOB), which quantifies the force applied to the drill bit and influences drilling efficiency, had a mean value of 11.71 1000lbf and a median WOB of 15.00 1000lbf. The standard deviation for WOB was 4.77 1000 lbf. WOB values vary from 1.00 1000lbf to 18.00 1000lbf. The skewness is -0.57, indicating a leftward skew in the distribution of WOB values.

Standpipe Revolutions per Minute (SRPM), which reflects the drill string's rotational speed, with a mean value of 95.96 RPM, a median of 100.00 RPM, and an SD of 18.52 RPM. SRPM varies from 70.00 to 120.00 RPM. The skewness was -0.03, indicating a fairly symmetric distribution of SRPM values. Torque measures the twisting force applied to the drilling equipment and is critical for drilling efficiency and stability. Torque averaged 7.99 ft. lbf (foot-pounds), with a median of 8.00 ft.lbf and standard deviation of 1.83 ft.lbf. Torque levels vary from 3.00 ft.lbf to 10.00 ft.lbf. The skewness was -0.99, indicating a leftward skew in the distribution of torque values. Figure 4.1 shows an outlier in the Torque values, which could have resulted in the distribution being skewed.Slack-off Weight determines the amount of slack-off weight on the drill string, which is essential for safe and effective drilling. The average Slack off Weight was 155.32 1000lbf, with a median of 150.00 1000lbf and a standard deviation of 7.18 1000lbs. Slack off Weight values range from 150.00 to 170.00

1000 lbf. The skewness was 0.94, showing that the distribution of Slack off Weight values is skewed to the right. Pump-Up Weight (PU Weight) is the pump-up weight used during drilling operations. The median PU Weight was 220.00 1000 lbf, with a standard deviation of 25.89 1000 lbf.The PU weight ranges from 190.00 to 270.00 1000 lbf. The skewness was 0.50, indicating a slightly rightward skew in the distribution of PU weight values.

Flow Rate estimates the rate of fluid circulation throughout the drilling process, which is crucial for stability. The average flow rate is 468.46 gal/min (gallons per minute), with a median of 470.00 gal/min and a standard deviation of 6.66 gal/min. Flow rates vary from 440.00 gal/min to 480.00 gal/min. The skewness was -3.61, showing a strong leftward skew in the distribution of Flow Rates.

3.2 Pearson Relationship between the Drilling Parameters

In order to meet the normality requirement for Pearson correlation, drilling parameters with outliers were corrected by deleting extreme values from the dataset. Figure 2 demonstrated that torque, flow, and ROP exhibited extreme values, which could distort the distribution. The extreme values were removed prior to performing the Pearson correlation. Table 2 presents the Pearson correlation results.

Table 2: Pearson correlation of drilling parameters

Drilling Parameters	TF Angle	Power Setting	WOB	SRPM	Torque	Slack Off Weight	PU Weight	Flow	ROP
TF Angle	**1.00**								
Power Setting	**0.69**	**1.00**							
WOB	**-0.27**	**-0.35**	**1.00**						
SRPM	**-0.33**	**-0.66**	**0.48**	**1.00**					
Torque	-0.05	**-0.24**	**0.50**	**0.61**	**1.00**				
Slack Off Weight	**0.27**	**0.33**	**0.36**	-0.02	**0.61**	**1.00**			
PU Weight	0.12	0.12	**0.49**	**0.27**	**0.76**	**0.92**	**1.00**		
Flow	**-0.23**	**-0.38**	-0.05	0.17	-0.06	**-0.49**	**-0.46**	**1.00**	
ROP	**-0.37**	**-0.43**	**0.34**	**0.39**	**0.28**	0.01	0.17	0.04	**1.00**

Values in bold are different from 0 with a significance level alpha=0.05

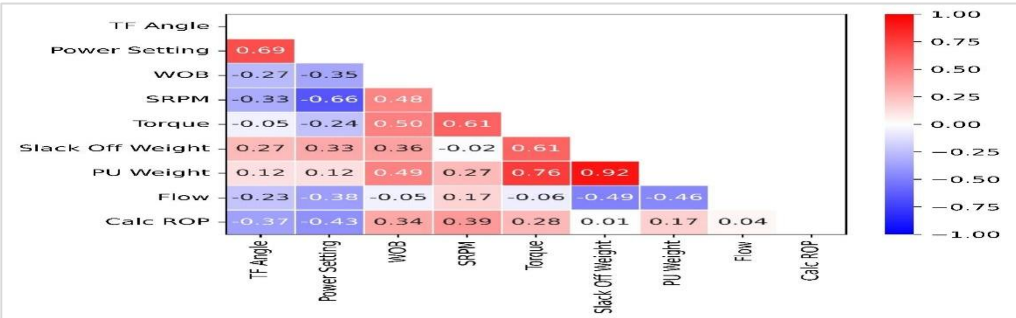

Figure 2: Heat map showing the relationship between drilling parameters

In order to meet the normality requirement for Pearson correlation, drilling parameters with outliers were corrected by deleting extreme values from the dataset. Figure 4.1 demonstrated that torque, flow, and ROP exhibited extreme values, which could distort the distribution. The extreme values were removed prior to performing the Pearson correlation. Table 2 presents the Pearson correlation results. The Pearson correlation revealed that various drilling parameters were connected with one another.A very substantial positive association was found between PU weight and slack off weight. The Pearson correlation between PU weight and slack off weight was 0.92, which was statistically significant. The results show that increasing the PU weight causes an increase in the slack of weight. There was also a strong positive association between torque and PU weight (Pearson correlation = 0.76). An increase in PU weight leads to a rise in torque, and vice versa. The TF angle was positively correlated with the power setting (r=0.69). An increase in the power setting causes an increase in the TF angle, and vice versa. WOB showed a positive and significant correlation with SRPM, torque, slack off weight, and PU weight. Pearson correlation was also employed to determine the link between drilling parameters and rate of penetration. Table 2 revealed that the rate of penetration had a Pearson coefficient of -0.37 with TF angle, which was significant. The results show that increasing the TF angle causes a decrease in the ROP, and vice versa. In other words, a higher TF Angle correlates with a slower drilling rate. ROP has a statistically significant negative association (-0.43) with Power Setting. The results show that as the power setting increases, the ROP decreases. In practice, greater power settings result in lower drilling rates. Weight on Bit (WOB) has a positive correlation coefficient of 0.34 with ROP, indicating that as WOB grows, so does ROP. The association is statistically significant. This shows that using additional weight on the drill bit can result in a faster drilling rate. Standpipe Revolutions per Minute (SRPM) has a positive correlation coefficient of 0.39 with ROP, meaning that as SRPM grows, so does ROP. This relationship is statistically significant and the result implies that higher SRPM values are associated with faster drilling rates. Torque demonstrates a positive correlation of 0.28 with ROP, meaning that as Torque increases, ROP tends to increase. This correlation is statistically significant and the result implies greater torque applied during drilling operations corresponds to higher drilling rates. Slack off Weight has a negligible correlation of 0.01 with ROP, indicating a weak relationship. This correlation is not statistically significant. Pump Unit Weight (PU Weight) exhibits a positive correlation of 0.17 with ROP, suggesting that as PU Weight increases, ROP tends to increase slightly. This correlation was not statistically significant. Flow shows a positive correlation of 0.04 with ROP, indicating a minor positive relationship. However, this correlation is not statistically significant.

IV. Conclusion

1.The Rate of Penetration (ROP) during drilling operations exhibits a high level of variability, with a mean ROP of 67.29 ft/hr., and is significantly influenced by various operational parameters.

2.Torque has a positive correlation of 0.28 with ROP, which means that as Torque increases, ROP tends to rise. This association is statistically significant, and the findings suggest that greater torque used during drilling operations corresponds to increased drilling rates. Slack off Weight has a correlation coefficient of 0.01 with ROP, indicating a poor association.

3. The Tool face Angle (TF Angle) and Power Setting are critical parameters with high variability, significantly affecting the drilling performance. TF Angle and power setting were found to have a strong negative correlation with ROP.

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