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Utilization of Multi Regression Analysis to Obtain Weight On Bit for Optimum Drilling Rate of Penetration

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ABSTRACT

R is a system for analyzing statistical data included in open source software group or also called *freeware*. *R* software less popular when compared with other paid statistical software such as *SPSS*, *MINITAB*, *SAS* or *Eviews*. Limited references and support especially in Indonesian, is one of the reasons statistical users prefer commercial statistical packages over free R software and provide results that are no less powerful and interesting graphics systems. Among many statistical techniques that R software can accomplish, one of the most popular is multiple regression analysis. In this article, we will discuss about multiple regression analysis modeling using R software as an alternative software for determining Weight on Bits (WOB) and optimal Rate of Penetration (RPM) in oil and gas drilling. Multi-regression analysis aims to get maximum drilling rate at drilling process, which is reduce drilling time and drilling cost. Bourgoyne and Young ROP models have been chosen to observe effects of several parameters during drilling operations such as drilling depth, pore pressure, equivalent circulation density, bit weight, rotating speed, bit tooth wear and jet collision force were extracted from the final drilling report. Results of the analysis are used to determine the optimum value of the weight of the bit which provides optimal drilling operations and optimized WOB has been calculated for several data points. the results show that *R* software can be used for multi regression analysis, and and produce a multi-regression equation that can be used to predict the optimum WOB and RPM for further drilling in equivalent rock formations.

Keywords: numerical modeling; optimum rop; r for drilling environment; geology; geophysics; mining; petroleum (alphabetically arranged and lowercase)

I. INTRODUCTION

In a drilling operation, the rate of penetration (ROP) is a very important factor. So what is expected in a drilling operation is to achieve a large and optimum ROP (Husein, 1982). The shorter the time required to conduct drilling operations, the better the drilling operations will be, because it is likely to be cheaper (Maurer, 1962). Large ROP is not always associated with low costs, for example if there is a bit, formation strength, pressure, and others. Factors that influence ROP we call the independent variable (Maratier J, 1971). in this study will use a statistical model of multiple linear regression analysis, by knowing how much influence some independent variables have on the dependent variable and can also predict the value of the dependent variable if all independent variables have known values.

Multiple linear regression analysis is one of the statistical methods used to determine the functional relationship of an independent variable with two or more independent variables (Bourgoyne, 1974). The purpose of the multiple linear regression analysis is to find out how much influence some independent variables have on the dependent variable and can also predict the value of the dependent variable if all independent variables have known values (Moore, 1974). In multiple linear regression analysis with many independent variables, problems often arise because of the relationship between two or more independent variables. Interrelated independent variables are called multicollinearity.

The purpose of this paper is to provide an overview of the procedure and use of multiple linear regression analysis and want to measure the impact of the independent variables (parameters that affect ROP) in determining WOB and RPM at the time of oil and gas drilling. The benefits of this study are expected to be used for find out the optimum WOB and RPM figures for new well drilling. In addition, results of this study are expected to facilitate engineers in easy calculating / operating / analyzing multi-regression with software.

II. METHODS

According to Bourgoyne-Young parameters affect the ROP at the time of drilling (Bourgoyne A, 2003). The parameters are called independent variables such as. Detailed flowchart as follows.

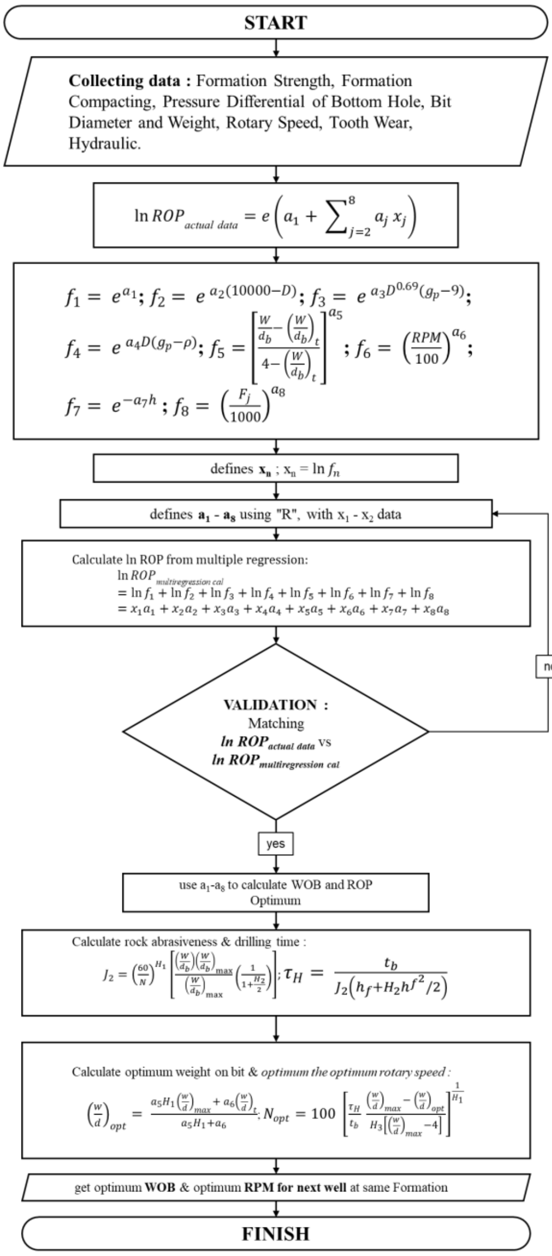

Figure 1. Step by step of Multiregression to get WOB & RPM Optimum

The independent variable will be analyzed to find out how much influence it has on the dependent variable (RPM, WOB and ROP). Next, we can calculate and predict the optimum value of RPM, WOP and ROP that will be used in the next drilling well.

Explain step by step in the study flow shown in ***Figure 1***. Beginning with those collected in ***Table* 2** namely formation strength, formation compacting, pressure differential of bottom hole, bit diameter and weight, rotary speed function, tooth wear, hydraulic. The data is independent variable data. The data used in this study is drilling well data in the geothermal field. (Bourgoyne, 1974), the data is processed to get the numbers x1 to x8.

The equation used is (Bourgoyne, 1974) to process the data to get the numbers x_1 to x_8. Explanation of the symbol of the equation in figure 1, among others,

- $\mathbf{a_1}$ is coefficient for the effect of formation strength and $\mathbf{f_1}$ is called the drillability of the formation of interest.
- $\mathbf{a_2}$ is affect of normal compaction trend, $\mathbf{f_2}$ is called the primary effect of formation compaction consider an exponential decrease in penetration rate with increasing depth

- **a_3** is effect over the penetration rate in regards of the formation compaction, **f_3** is called exponential increase in penetration rate with increasing pore pressure gradient
- **a_4** is pressure differential coefficient, **f_4** is pressure differential between the hole bottom and formation is zero, the effect of this
- function is going to be equal to “1”
- **a_5** is bit diameter and weight coefficient, **f_5** is bit weight and bit diameter are considered to have direct effect over penetration
- **a_6** is rotary speed coefficient , **f_6** is effect of rotary speed on penetration rate assumes that penetration rate is directly proportional to rotary speed (Graham and Muench, 1959)
- **a_7** is tooth wear is defined by coefficient, **f_7** is respective tooth height, a bit record for similar bit type that has been used within the same formation
- **a_8** is hydraulic effect coefficient , **f_8** is based on microbit experiments performed by (Eckel, 1968). The hydraulics function represents the effects of the bit hydraulics. Jet impact force was chosen as the hydraulic parameter of interest with a normalized value of 1.0.

Next step is define **x_1** to **x_8** by independent data namely with **Ln f_n**, calculation results are shown in ***Table 3***. Next determine **a_1** through **a_8** with multiregression. This multiregression equation uses R software.

Table 1. a value from Multiregression

	Estimate
(Intercept)	-21.69
a1	NA
a2	0.002198
a3	-0.07116
a4	-0.000157
a5	-0.4295
a6	-0.6459
a7	-3.261
a8	0.2517

After finding the values a_1 and a_8, calculate (Ln ROP) a_1 and a_8 using from (R studio). Matching data analysis use In ROP from the model with Ln ROP from data. Ln ROP from the data use data model f_1 - f_8, where f is a multiplied by x. calculation results on ***Table 4***. Plot between Ln Rop in ***Table 4*** and Ln Rop in ***Table 3***, can be seen in the ***Figure 2***

Figure 2. Matching Model vs Actual data

In the matching process, the predictions y-axis and actual y-axis (x4 data) are matched (in figure 3)

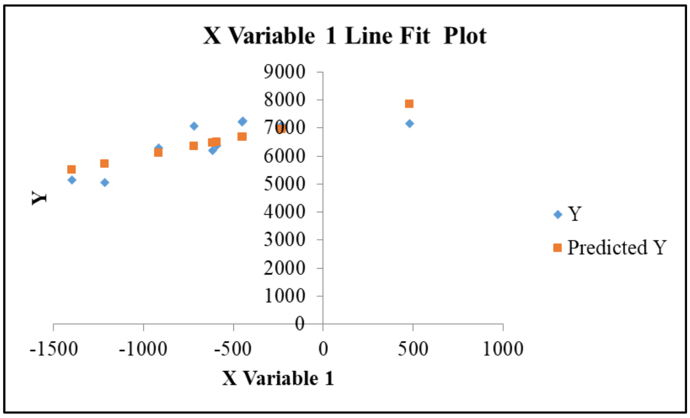

Figure 3. Matching predictions y and actual y (x4 data)

if it is still not matching (the valid model is not used) and still needs to be changed (x) to produce a different (a). if it is valid as shown ***Figure 2*** and ***Figure 3***, the values (a1, a2, ..., a8) can be used to build the already (valid) model.

III. RESULTS AND DISCUSSION

The multiple regression results show that a_1, a3, a5, and a8, with an average error value after correction is 1.2%. Thus, the equation of empirical penetration rate modeling is as **(1)** - **(9)** follows,

$$ROP_{predict} = f_1 * f_2 * f_3 * f_4 * f_5 * f_6 * f_7 * f_8 \quad \textbf{(1)}$$

Where :

$$f_1 = e^{-21.69} \quad \textbf{(2)}$$

$$f_2 = e^{0.002198(10000-D)} \quad \textbf{(3)}$$

$$f_3 = e^{-0.07116 * D^{0.69}(g_p-9)} \quad \textbf{(4)}$$

$$f_4 = e^{-0.0001565 * D(g_p-\rho)} \quad \textbf{(5)}$$

$$f_5 = \left[\frac{\frac{W}{d_b} - \left(\frac{W}{d_b}\right)_t}{4 - \left(\frac{W}{d_b}\right)_t}\right]^{-0.4295} \quad \textbf{(6)}$$

$$f_6 = \left(\frac{RPM}{100}\right)^{-0.6459} \quad \textbf{(7)}$$

$$f_7 = e^{-3.261 * h} \quad \textbf{(8)}$$

$$f_8 = \left(\frac{F_j}{1000}\right)^{0.2517} \quad \textbf{(9)}$$

The next step is to calculate the value of rock abrasiveness from bit specification data. Calculation of rock abrasiveness in this study was only done for A-7 wells in Bunyu lithology. The data that will be used for analysis of abrasiveness, weight validation on the tool and optimum rotational speed are the specification data on Bits (B # 3-3), i.e. the bit numbering according to IADC ***Table 5*** is presented in ***Table 6***.

Calculation of rock abrasiveness in lithology penetrated by bit with number B#3.3 is value of J_2 is calculated by the equation **(10)**

$$J_2 = \left[\frac{\left(\frac{W}{d_b}\right)_m - \left(\frac{W}{d_b}\right)}{\left(\frac{W}{d_b}\right)_m - 4}\right]\left(\frac{60}{N}\right)^{H_1}\left(\frac{1}{1 + H_2/2}\right) \quad \textbf{(10)}$$

$$J_2 = \left[\frac{10 \ - 0.65}{10 \ - \ 4}\right]\left(\frac{60}{130}\right)^{1.60}\left(\frac{1}{1+2/2}\right)$$

$$\boldsymbol{J_2 = 0.226}$$

After obtaining the J_2 value, the rock abrasiveness level is calculated by **(11)**, where the drilling time (t_b) = 14 hrs, and the final tool wear rate (h_f) = 2.

$$\tau_H = \frac{t_b}{J_2\left(h_f + H_2\, {h_f}^2/2\right)} \quad \textbf{(11)}$$

$$\tau_H = \frac{14}{0.226\,(2 + 2 * 2^2/2)}$$

$$\boldsymbol{\tau_H = 10.3}\ hrs$$

Severe operating conditions on bit (WOB) and optimal rotation speed when providing optimal penetration rates and can reduce bit damage rate. WOB calculation and optimal rotation speed on bit with the number of Bits (B # 3-3) using (12 and (13 as follows,

$$\left(\frac{w}{d}\right)_{opt} = \frac{a_5 H_1 \left(\frac{w}{d}\right)_{max} + \ a_6\left(\frac{w}{d}\right)_t}{a_5 H_1 + a_6} \quad \textbf{(12)}$$

Where the initial WOB [(w / b) t] is unknown so it is considered 0,

$$\left(\frac{w}{d}\right)_{opt} = \frac{0.8537 * 1.6 * 10}{0.8537 * 1.6 + (1.0916)}$$

$$\left(\frac{w}{d}\right)_{opt} = \mathbf{5.56}\ (1000\frac{lbf}{in})$$

Maximum tool weight is limited by rig specifications. However, because rig data is not available, the value is considered to exceed weight of maximum on bit.

$$N_{opt} = 100\left[\frac{\tau_H}{t_b}\,\frac{\left(\frac{w}{d}\right)_{max} - \left(\frac{w}{d}\right)_{opt}}{H_3\left[\left(\frac{w}{d}\right)_{max} - 4\right]}\right]^{\frac{1}{H_1}} \quad \textbf{(13)}$$

$$N_{opt} = 100\left[\frac{10.3}{14}\,\frac{10 - \ 5.56}{0.20\,[10 - 4]}\right]^{\frac{1}{1.6}}$$

$$N_{opt} = \mathbf{187}\ RPM$$

Weight value on bit and rotation speed of above modeling results is greater than the weight on bit and actual rotation speed that is equal to 5.56 1000 lbf/in and 187 RPM. The weight value on model bit is very large compared to weight on the actual bit. This is due to heavy use of the bit in geothermal drilling operations which is generally not very large due to abrasive nature of the rock.

IV. CONCLUSION

R studio shows that it can be used multiple regression analysis modeling for modeling drilling parameters. The resulting model can be used to provide recommendations of rate of penetration and weight on bit in propose drilling in order to obtain maximum rate of penetration. That's justification is based on matching of ROP predicted by model with ROP on actual drilling data. Limitation of the model is that only accurate to use on same rock type and in equivalent drilling area, the accuracy of model in other fields needs to be added to input data in making prediction models again.

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Table 2. Collected Data

Well	Depth (m)	Depth out (m)	Interval Depth (ft)	Bit	Pore Grad. (lb/gal)	Drilling Rate (ft/hr)	Tooth Wear	Bit Weight (1000 lb/in)	Rotary Speed (rpm)	ECD (lb/gal)	Jet Impact Force (1000 lbf)	Hardness
A-6	404	589	1629	B #5	8.5	24.1	-0.125	0.74	96	8.66	0.681	Soft
A-6	754	982	2847	B #7	8.5	39.6	-0.25	0.91	91.5	8.75	0.646	Hard
A-6	985	1323	3785	B #9	8.5	31.1	-0.125	1.22	90	8.66	0.721	Hard
A-6	1323	1634	4849	B #10	8.5	27.6	-0.25	1.55	110	8.79	0.673	Hard
A-1	764	930	2778	B #11	8.5	49.1	-0.125	1.06	135	8.66	0.76	Soft
A-2	790	938	2834	B#3.3	8.5	34.7	-0.125	0.65	130	8.33	1.001	Hard
A-2	938	1277	3633	B#4.1	8.5	51	-0.25	0.59	162.5	8.66	1.001	Soft
A-4	30	249	458	B #1	8.5	19.8	-0.125	0.69	115	8.58	0.727	Hard
A-4	390	778	1916	B #2	8.5	28	-0.25	0.91	96	8.66	0.602	Soft
A-4	778	1004	2922	B #3	8.5	34.3	-0.125	1.03	100	8.75	0.602	Hard
A-4	1313	1700	4941	B #5	8.5	35.5	-0.25	1.22	122.5	8.75	0.526	Soft
A-3	39	398	716	B #1	8.5	34.7	-0.125	0.2	107.5	8.58	0.668	Soft
A-3	691	787	2424	B #3	8.5	13.9	-0.125	1.03	105	8.7	0.553	Hard
A-3	833	843	2749	B#4	8.5	36.4	-0.125	1.09	104	8.66	0.553	Hard
A-3	938	1326	3713	B#5	8.5	53	-0.25	1.14	90	8.75	0.833	Soft
A-5	866	909	2911	B #7	8.5	23.7	0	1.43	90	8.58	0.902	Soft

Table 3. Collected Data

x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	Ln (rop)
1	7222	-118.89	-453.4	-1.327	0.3	-0.125	-0.274	3.3893
1	7166	-120.54	481.8	-1.812	0.262	-0.125	0.001	3.546
1	6367	-143.06	-592.8	-1.917	0.486	-0.25	0.001	3.932
1	7251	-118.02	-448.6	-1.304	0.039	-0.125	-0.592	3.596
1	6287	-145.24	-915.2	-1.253	-0.105	-0.25	-0.183	3.971
1	7078	-123.12	-720.4	-1.358	0	-0.125	-0.507	3.536
1	5059	-176.9	-1218	-1.184	0.203	-0.25	0.642	3.568
1	7089	-122.79	-232.6	-1.03	-0.105	0	-0.103	3.166
1	6215	-147.18	-617.7	-1.184	-0.105	-0.125	-0.327	3.439

1	5151	-174.62	-1397.4	-0.947	0.095	-0.25	-0.396	3.319

Table 4. Data Matching Analysis

No	f_1 (a_1*x_1)	f_2 (a_2*x_2)	f_3 (a_3*x_3)	f_4 (a_3*x_4)	f_5 (a_5*x_5)	f_6 (a_6*x_6)	f_7 (a_7*x_7)	f_8 (a_8*x_8)	Ln rop ($f_1+f_2+\ldots+f8$)
1	-21.690	15.874	8.460	0.071	0.570	-0.194	0.408	-0.069	3.430
2	-21.690	15.751	8.578	-0.075	0.778	-0.169	0.408	0.000	3.580
3	-21.690	13.995	10.180	0.093	0.823	-0.314	0.815	0.000	3.903
4	-21.690	15.938	8.398	0.070	0.560	-0.025	0.408	-0.149	3.510
5	-21.690	13.819	10.335	0.143	0.538	0.068	0.815	-0.046	3.983
6	-21.690	15.557	8.761	0.113	0.583	0.000	0.408	-0.128	3.605
7	-21.690	11.120	12.588	0.191	0.509	-0.131	0.815	0.162	3.563
8	-21.690	15.582	8.738	0.036	0.442	0.068	0.000	-0.026	3.150
9	-21.690	13.661	10.473	0.097	0.509	0.068	0.408	-0.082	3.442
10	-21.690	11.322	12.426	0.219	0.407	-0.061	0.815	-0.100	3.338

Table 5. Data Spesifikasi Pahat H1 , H2 , and (w/d)max, IADC classification

Bit Class	H1	H2	H3	(W/d)max
1-1 to 1-2	1.9	7	1,0	7
1-3 to 1-4	1.84	6	0,8	8
2-1 to 2-2	1.8	5	0,6	8.5
2-3	1.76	4	0,48	9
3-1	1.7	3	0,36	10
3-2	1.65	2	0,26	10
3-3	1.6	2	0,20	10
4-1	1.5	2	0,18	10

Table 6. Bit Specifications Data on Bunyu lithology penetration

Well name	bit no	bit weight (1000lb/in)	rpm	tooth wear	Hrs	w/db max	h1	h2	h3
A-7	3-3	0.65	130	0.125	14	10	1.60	2	0.20