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ASSESSING THE EFFECT OF UTILIZATION AND AVAILABILITY ON PRODUCTION IN OPEN-PIT MINING: STATISTICAL PERSPECTIVE

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Abstract: The profitability of a mine today is dependent on the careful management of its operations. The study seeks to examine the effect of availability and utilization on mine production. Daily data used in this study spanned from January 2016 to June 2016 were queried from the Modular fleet management system (FMS) at the Anglogold Ashanti Iduapriem Limited AAIL. The key variables in the study are production, availability and utilization which were computed from the cycle time analysis, operational delays and breakdown records for the two primary loading units of same type, thus, Liehberr 9250 with bucket capacity of 13m³ (i.e. EO737 and EO752), and the dataset from these loading units were used to construct a panel data. The three conventional panel data models namely the pooled, fixed effects and the random effects models were fitted to the dataset. Based on the R^2 adjusted criterion and comparison of hypothesis tests, the fixed effects model was the suitable model for our dataset. It was observed that, the percentage utilization of the two loading units (i.e. E0752 and E0737) are 1% and 11% less than the budget target. However, the percentage availability of E0752 was 5% higher and E0737 was 1% less than the budget target. Thus, the performance of the loading unit (i.e. E0752 and E0737) with respect to availability, utilization and production are heterogenuous (different), which supports the usage of the panel data models. From the fixed effects model, it was observed that the effect of utilization (i.e., 171.29) on production is higher than the effect of availability (131.56) on production, all things being equal. Therefore, we recommend that more attention should be focused on improving utilization in other to improve production.
Keywords: Fixed effects, Availability, Utilization, Production and Random effects.

Introduction

The activities or operations of open-pit mining require heavy equipment with high operating costs. For instance, large open pit mines utilize fleets of haul trucks to transport ore and waste from the pit. Most of today's open pit mines employs some form of Fleet Management System (FMS) consisting of both software and hardware components to manage and track the allocation of these complex and costly equipment. The profitability of a mine today is dependent on the careful management of its operations. Production and cost figures in mining

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operations depend to a large extent on the performance of the equipment employed. Since modern machinery is increasingly sophisticated and capital intensive, it is appropriate that it becomes highly efficient (Paraszczak, 2005).

As a result of the current economic downturn, mining operators seek to maximize the bottom-line through process optimization. In mechanized mining, poor equipment efficiency can endanger the success of the operation by increasing the total production cost (Fourie, 2016). The mining equipment efficiency is measured by availability, utilization and productivity (Fourie, 2016). These factors of efficiency of mining equipment vary considerably as a far as the ratio of the incurred cost. Thus, it is crucial to analyze where the efforts to improve the situation should be focused. In other words, appropriate optimization of availability and utilization of mining equipment to improve productivity in the mining operation is desirable.

According Kansake and Suglo (2015); and Elevli and Elevli (2010) much research have been done on selection of mine equipment and policies to improve equipment availability and utilization, however little information is known about the effect of availability and utilization on mine production. In other words, little is known about which equipment efficiency parameter should more emphasis be placed. Infact, Kansake and Suglo (2015) in their study tried to examine the impact of availability and utilization of drill rigs on production at Kanjole Minerals limited. However, the statistical basis of their model selection was weak, thereby affecting the accuracy of the findings. Therefore, in this study, appropriate model selection procedures are followed to select suitable model to study the effect of these factors on mines production using Anglogold Ashanti Iduapriem Limited (AAIL) as a case study.

Thus, in this study, we seek to test three different hypotheses on these factors, namely: (1) utilization affects production, (2) availability affects utilization and (3) availability affects production.

MATERIALS AND METHODS

Data Source

Daily data used in this study span from January 2016 to June 2016 were queried from the Modular fleet management system (FMS) at the AAIL. The key variables in the study are productivity, availability and utilization which were computed from the cycle time analysis, operational delays and breakdown records for the two primary loading units (i.e. EO737 and EO752), and the dataset from these loading units were used to construct a panel data.

Selection of the study site (AAIL)

AAIL was used as a case study because it uses fleet management system (FMS), a real-time computerized GPS system, which provides an operation the ability to accurately record time equipment spent in the various statuses and operating modes. The Modular FMS promotes high level of efficiency as a result of its interactive and passive data collection in real-time for decision making. According to Liliane et al (2008) and Mohammadi et al (2015) such systems can help to optimize the performance of existing capacity. We are able to report on key performance indicators (KPI’s) such as availability, utilization and other productivity measures much more accurately. Thus, the FMS was used in this study to capture data.

Time Usage Model

Time categories can vary from mine site to mine site. In order to improve the accuracy of industry equipment performance benchmarking, it is logical to make the time categories used in the KPI's standardized as well. From Figure 1, it can be concluded that, utilization is a function of availability; therefore it is not statistically appropriate to fit utilization together with availability as independent variables.

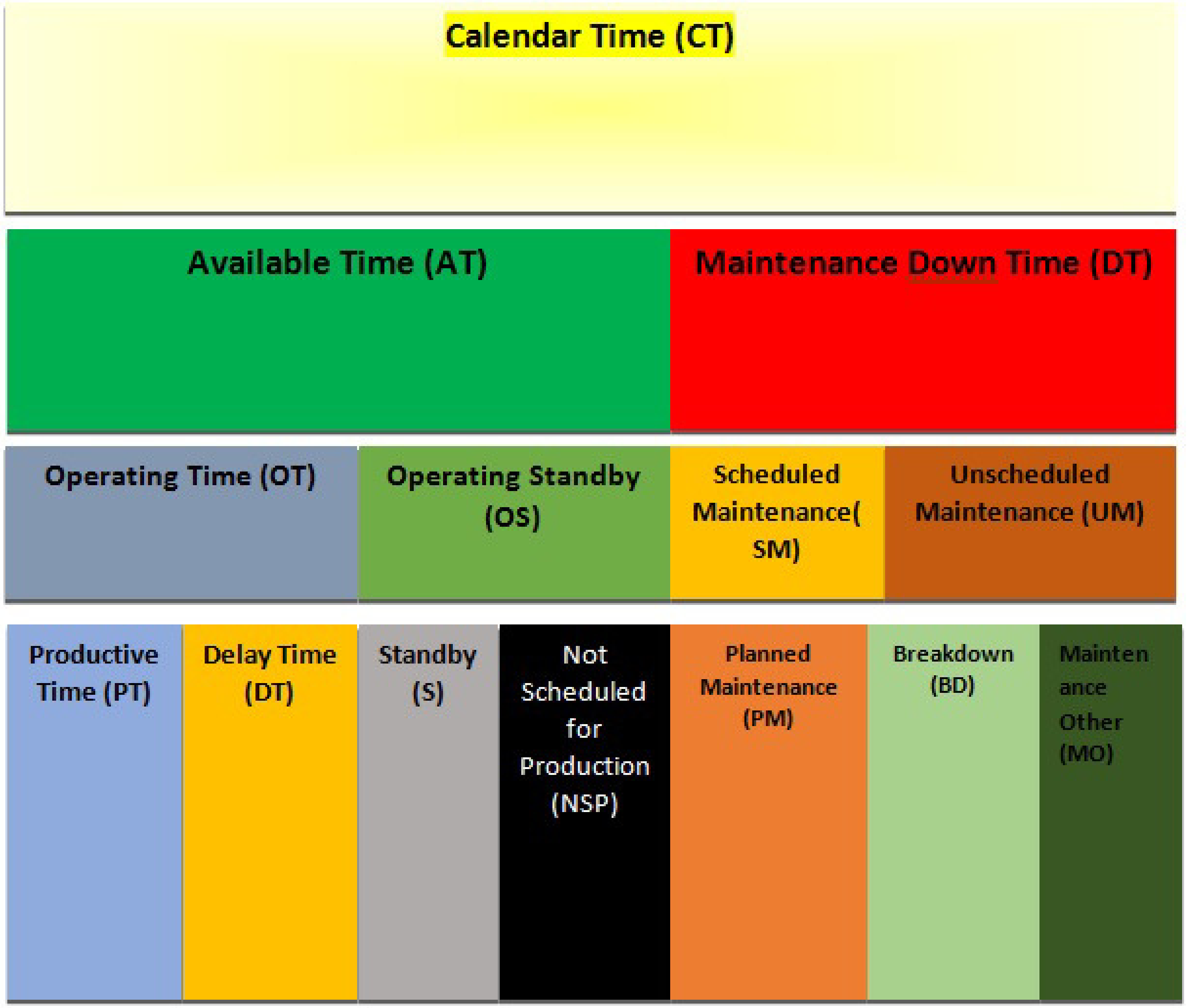

Figure 1 Typical Time Usage Model

KPI Measures

Availability and utilisation are the key performance indicator for equipment and is use for decision making with respect to maintenance performance and sustainability and production growth in mining operations. Campbell and Jardine (2001) give the following definitions for availability and utilisation.

Availability: Percentage of scheduled resource time in which equipment is physically available to the production department for operation, and this is given as:

$$\text{Availability}=\frac{\text{nominal time - down time}}{\text{nominal time}}\times 100 \qquad (1)$$

Utilisation: A measure of the utilization of the equipments physical available time for primary operation, and it is also expressed as:

$$\text{Utilization}=\frac{\text{nominal time - down time - standby - delay}}{\text{nominal time}}\times 100 \qquad (2)$$

$$\text{Production} = \frac{\textit{material moved}(\textit{volume})}{\text{nominal time(hrs)}} \quad (3)$$

Statistical Models

In this study, the three panel data models used are the pooled, fixed effects and the random effects models.

Fixed Effect Models

In the fixed effects model, the assumption is that the intercepts vary for the various individual units but the slope coefficients, α_i, remain constant for all individual units. This is shown by equation 1 below:

$$Z_{it} = \alpha_{1i} + \alpha_2 X_{2it} + \cdots + \alpha_k X_{kit} + e_{it} \cdots \quad (4)$$

The subscript, i, assigned to the intercept means that the intercept could differ for each individual unit. It is assumed that the intercept will capture the individual heterogeneity. In estimating the model in equation 4, we allow each units to have its own intercept dummy variable (indicator variable), and this is called the least squares dummy variable estimator for fixed effects models:

$$Z_{it} = \alpha_{1i} D_{1i} + \alpha_2 D_{2i} + \ldots + \alpha_{1,10} D_{10,i} + X_{2it} + \ldots + \alpha_k X_{kit} + e_{it} \ldots (5)$$

Random Effect Model

The model can cater for random individual unit variations by specifying the intercept parameters, α_{1i}, to consist of a fixed part that represents the average of the population, $\overline{\alpha_1}$, and random individual differences from the population average, u_i. The random effect model is given as:

$$Z_{it} = \bar{\alpha}_1 + \alpha_2 X_{2it} + \cdots + \alpha_k X_{kit} + (e_{it} + u_i)$$

$$Z_{it} = \bar{\alpha}_1 + \alpha_2 X_{2it} + \cdots + \alpha_k X_{kit} + v_{it} \quad \ldots (6)$$

Where now $\bar{\alpha}_1$ is the intercept parameter and the error term v_{it} is composed of a component, u_i that represents a random individual effect and the component e_{it} which is the usual regression random error.

Comparison of Fixed and Random Effects

Formal statistical test was conducted to know the presence of fixed and/or random effects in our panel data. A fixed effect is tested by F-test, while a random effect is examined by Breusch and Pagan's Lagrange multiplier (LM) test. The former compares a fixed effect model and OLS to see how much the fixed effect model can improve the goodness-of-fit, whereas the latter contrast a random effect model with OLS. The similarity between random and fixed effect estimators is tested by a Hausman test.

RESULTS AND DISCUSSION

DESCRIPTIVE STATISTICS

Availability and Utilization of Loading units

Figure 2 shows the percentage of equipment availabilty and utilisation as evaluated by the Modular FMS. In Figure 2, the actual percentage utilisation of E0737 is 61% which is below the target (or budget) of 72%, that is 11% less the utilization budget. Again, the actual percentage utilisation of E0752 is 71% which is 1% less the budget target. However, the actual percentage of availability of E0752 is 90% which is 5% higher than the budget target of 85%. The actual percentage of availability of E0737 is 84% which is 1% below the budget target. It is obvious that loading unit E0752 is efficient than E0737, this indicates that loading units are heterogenuous, which supports the usage of the panel data models.

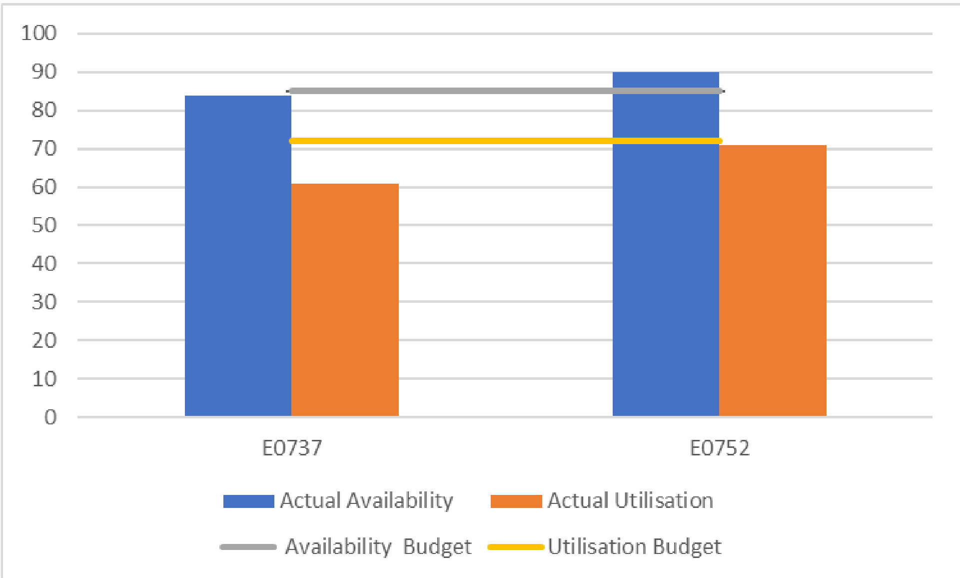

Figure 2: Percentage Availability and Utilization of E0737 and E0752

Production

In Figure 3, the actual production of loading units EO737 and EO752 are all below the budget target of 11750 (BCM) and 12614 (BCM) respectively. In other words, EO737 loading unit is 1601.71 (BCM) less the budget target whereas EO752 is 803.24 (BCM) less than the budget target.

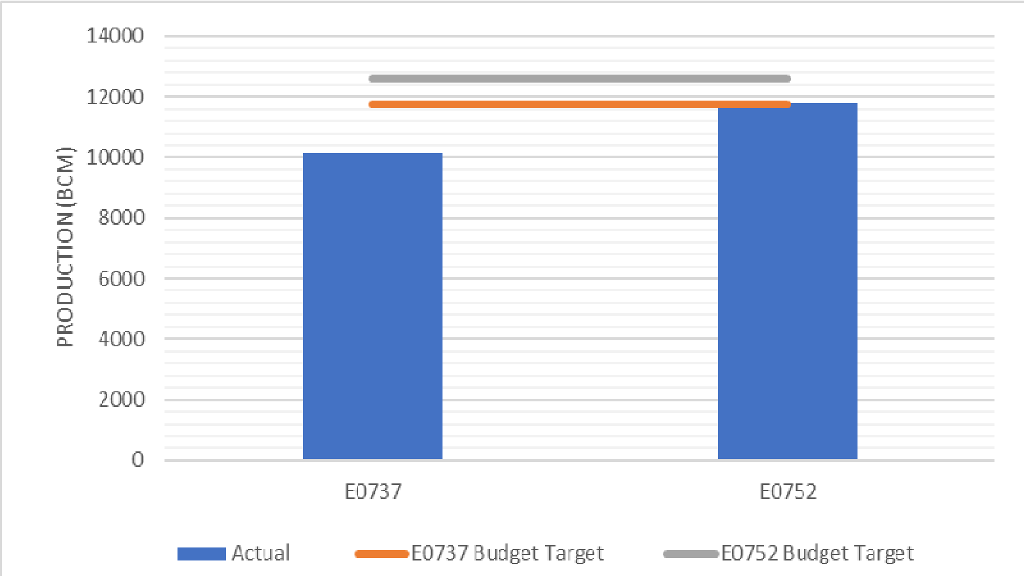

Figure 3: Production of loading units EO737 and EO752

PANEL DATA MODEL

A panel dataset is constructed using the two loading units (i.e. EO737 and EO757). The three conventional panel data models, that is pooled, fixed effect and random effect models are fitted to the panel dataset. These models with their R^2 adjusted and F-statistics are reported in Table 1.

The three different hypotheses that this study seeks to test are: (1) utilization affects production (this is called CASE 1 in Table 1), (2) availability affects utilization (i.e. CASE 2 in Table 1), and (3) availability affects production (this is called CASE 3 in Table 1).

From Table 1, in all the three cases, the overall suitable model is the fixed effects model, which has the highest R^2 adjusted.

Table 1. Comparison of Pooled, Fixed Effect and Random Effect Models

Term	Pooled Model	Fixed Effect Model	Random Effect Model
CASE 1 - Dependent variable: Production			
Utilisation	-40.49* (19.15)	171.29* (7.32)	170.55* (7.40)
Intercept	17909.39* (1282.90)		4208.85* (2119.47)
Factor (E0737) 1		-1541.14* (531.72)	
Factor (E0752) 2		-656.70 (562.75)	

F-Test	4.47*	6219*	531.39*
R^2adj	0.007	0.98	0.52
CASE 2 - Dependent variable: Utilisation			
Availability	0.79* (0.03)	0.79* (0.02)	0.80* (0.02)
Intercept	-4.03 (2.75)		-4.54 (8.24)
Factor (E0737) 1		-0.14 (1.83)	
Factor (E0752) 2		12.54* (1.87)	
F-Test	650.43*	10790*	293.15*
R^2adj	0.57	0.99	0.37
CASE 3 - Dependent variable: Production			
Availability	141.00* (19.01)	131.56* (7.69)	131.56* (7.68)
Intercept	2969.97 (1687)		3794.30 (5610.97)
Factor (E0737) 1		-1158.46 (693.76)	
Factor (E0752) 2		12347.90* (706.96)	
F-Test	54.99*	4646*	293.15*
R^2adj	0.10	0.97	0.38

Comparison of Models

It has been concluded with the R^2 adjusted criterion that the fixed effects model is the suitable model for our dataset. However, appropriate hypothesis tests of comparison are performed to confirm the R^2 adjusted criterion.

Pooled vrs Fixed effect model (F-test)

The H_o: Pooled is better than fixed effect model; and the H_1: fixed effect model is better than Pooled. From Table 2, the hypothesis of pooled model being better than fixed effect model is rejected in all the models. Thus, there is significant fixed effect in the data and the fixed effect model is better.

Table 2: F- test for individual effects for comparing pooled and fixed effects models

Models	Test Statistic	P-value	Decision
CASE 1	1937.9	0.001	Fixed effect model is better than pooled
CASE 2	326.64	0.001	Fixed effect model is better than pooled
CASE 3	1243.9	0.001	Fixed effect model is better than pooled

Pooled vrs Random effect model (Breusch-Pagan Lagrange Multiplier Test)

The null hypothesis that individual (or time) specific variance components are zero was rejected in all the models (because their p-values were less than 0.05 in Table 3. Thus, we conclude that the random effect model is better than the pooled OLS model in all the three CASES (CASE 1, CASE 2 and CASE 3).

Table 3: Breusch-Pagan Lagrange Multiplier Test for comparing pooled and random effects

Models	Test Statistic	P-value	Decision
CASE 1	18912	0.00	Random effect model is better than pooled
CASE 2	12833	0.00	Random effect model is better than pooled
CASE 3	27355	0.00	Random effect model is better than pooled

Fixed effect vrs Random effect model (Hausman Test)

Table 4 shows a significant *p*-value (0.034) of the Hausman test, which indicates that the null hypothesis of individual random effects being exogenous is rejected. Therefore, the fixed effect model is appropriate.

Table 4: Hausman Test for comparing Random and fixed effect models

Models	Test Statistic	P-value	Decision
Model 1	0.4598	0.49	Fixed effect model is better than random
Model 2	0.000105	0.99	Fixed effect model is better than random
Model 3	0.000205	0.98	Fixed effect model is better than random

Discussion

The overall best model which can explain the effect of utilisation on productivity, availability on utilization and availability on production is the fixed effects model. The fixed effects model passed other diagnostic tests such as serial correlation and heteroskedasticity. For fixed effects model, the difference in the loading units is captured by the individual intercepts, therefore the coefficients are the same.

CASE 1: Hypothesis 1 - Utilization affects Production

A percentage change in utilization will increase production by 171.29, and this effect is statistically significant.

E0737: Production = -1541.14 + 171.29 Utilization
E0752: Production = -656.7 + 171.29 Utilization

CASE 2: Hypothesis 2 – Availability affects Utilization

A percentage change in availability will increase utilization by 0.79 in all the loading units (machines), and this effect is statistically significant.

E0737: Utilization = -0.14 + 0.79 Availability
E0752: Utilization = -12.54 + 0.79 Availability

CASE 3: Hypothesis 3 – Availability affects Production

A percentage change in availability will increase production by 131.56 in all the machines, and this effect is statistically significant.

E0737: Production = -1158.46 + 131.56 Availability
E0752: Production = -12347.9 + 131.56 Availability

It is observed that the effect of utilization (i.e., 171.29) on production is higher than the effect of availability (131.56) on production. This implies that no matter how high availability is achieved, it only improves production largely when the engine is effectively running. In other words, the machine can be available and still parked or doing secondary jobs which does not improves production.

CONCLUSION

The following conclusions are drawn from our findings:

- It was observed that, the percentage utilization of the two loading units (i.e. E0752 and E0737) are 1% and 11% less than the budget target. However, the percentage availability of E0752 was 5% higher and E0737 was 1% less than the budget target. Thus, the performance of the loading unit (i.e. E0752 and E0737) with respect to availability, utilization and production are heterogenuous (different), which supports the usage of the panel data models.

- The various hypotheses test comparison indicated that fixed effects model is the suitable model. From the fixed effects model, it is observed that the effect of utilization (i.e., 171.29) on production is higher than the effect of availability (131.56) on production, all things being equal.

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