BIUST Teaching, Research, & Innovation Symposium 2023 (TRDAIS 2023)
Botswana International University of Science and Technology
Palapye, Botswana, 18 - 19 September 2023
ISSN: 2521-2293

Correlation analysis of tonnage and cost factors for productivity management: an open pit mine case study

Nonduduzo B. Mamba
Department of Mining and Geological Engineering
BIUST
Palapye, Botswana
nonduduzo.mamba@studentmail.biust.ac.bw

Desmond B. Munyadzwe
Department of Mining and Geological Engineering
BIUST
Palapye, Botswana
desmond.munyadzwe@studentmail.biust.ac.bw

***Abstract*— Correlation analysis is a data interpretation tool that draws inferences between two or more variables. Mine dispatch systems produce massive amounts of data that requires interpretation in order to identify contributing factors to both tonnage and cost losses. These losses are analysed to identify the significance of factors that contribute to these losses. Such factors as: loading rate, daily tonnage and truck loads, particle size distribution, fuel costs, labour costs, tyre costs, repairs and maintenance etc. For each analysis, the R (correlation coefficient) parameters were determined to classify the significance of each loss factor. A scatter graph was generated to determine the correlation factors for each key performance indicator (KPI) and corresponding loss. The scatter graphs illustrated the strength, direction, correlation coefficient and association of the relationship between the two variables. This analysis was run using data from an open pit mines' January 2021 to October 2021 production reports sourced from the mine's Modular Dispatch System. The analysis showed that labour costs and tyre costs both had the highest correlation factor of 1 when inferred to total mining costs, meaning they were the most significant contributors to mining costs and could contribute greatly to financial losses. Loading rate had the highest correlation factor (0.7147) out of all the other factors inferred to tonnage losses. The results showed the importance of correlation as a tool to reveal information about the root causes of productivity losses.**

Keywords*— *tonnage losses; cost losses; correlation

I. INTRODUCTION

Data interpretation requires drawing inferences regarding the association between two or more variables, this is termed correlation. Statistical analysis methods can be used on data produced by mine dispatch systems to identify the contributing factors to tonnage and financial losses. In this case the inference is between the productivity key performance indicators (KPIs) with the associated losses or factors. Tonnage and cost factors are analysed to identify the significance of major contributors to costs and tonnage losses. These factors include loading rate, daily tonnage and truck loads, particle size distribution, fuel costs, labour costs, tyre costs, repairs and maintenance etc.

A. Key performance indicators

KPIs are used to standardise performance measurement. Tonnage and costs are studied as key performance indicators in materials handling processes. The equations used to calculate factors in each of the indicators are also established.

B. Tonnage

Tonnage is an important KPI in mining because it reflects the amount of work done by machinery and operators. Tonnage per given time as a performance indicator is mainly affected by fragmentation quality, loading techniques and operator skills[1]. Among the factors, the degree of fragmentation is usually quantitatively reported to express muck pile performance. The dig rate and loadability are the main parameters used to indicate fragmentation impact on load and haul performance [1]. Dig rate is measured by the percentage of particle size in range, the range of which is determined by the equipment that will be used for the load and haul operations. Loadability is measured by the loading rate expressed as tons per hour as shown in equation 1. It is difficult to express other factors quantitatively, but operator skill is usually loosely expressed as truck loads per ton.

$$\text{Loading rate} = \frac{\text{Material moved}}{\text{Time taken to move the material}} \quad (1)$$

C. Costs

Mining costs affect productivity and in turn, distribution of costs is affected by the production inputs. According to reference [2] , a capital-intensive mine has the cost of operating machinery being higher than labour costs. Conversely, a labour-intensive mine has higher labour costs. Reducing the mining cost is a direct goal to reduce the total production cost and increase the mine's profitability. It is important to ensure that minimum resources are utilised to achieve maximum results in order to achieve high productivity. Therefore, limiting the working time of employees or machinery reduces costs, increasing both productivity and profitability [3]. This might increase worker morale and wellbeing due to short working hours and reduce machine downtimes, but it can also drop the workers morale

ISSN: 2521-2293

due to less remuneration and reduce machine utilisation as these factors also affect productivity [4].

D. Correlation analysis

Reference [5] defines correlation as a way of denoting the association between two quantitative variables based on a linear relationship between the variables. The result of a correlation analysis is a correlation coefficient which is a single value or number which establishes a relationship between the two variables. These values generally range from -1 to +1. For analysis, the Karl Pearson's product moment correlation coefficient, r is utilised. Where r is calculated as in equation 2.

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{\left\{n\sum x^2 - \left(\sum x\right)^2\right\}\left\{n\sum y^2 - \left(\sum y\right)^2\right\}}} \quad (2)$$

where: y = variable 1

x = variable 2

Three assumptions used as the basis for the establishment of the Pearson's correlation coefficient are:

- The relationship is linear;
- Variables are independent of each other;
- Variables are normally distributed.

The correlation coefficient can further be interpreted and the relationship between the variables placed in perspective through a spectrum of the correlation coefficients as illustrated in Fig. 1. A correlation coefficient of +1 indicates that the two variables are perfectly related in a positive manner, a correlation of -1 on the other hand indicates that two variables are perfectly related in a negative manner, while a correlation coefficient of zero indicates that there is no relationship between the two variables being studied (Gotgay and Thatte, 2017). This statistical measure is integral in productivity management because inference is important when interpreting data.

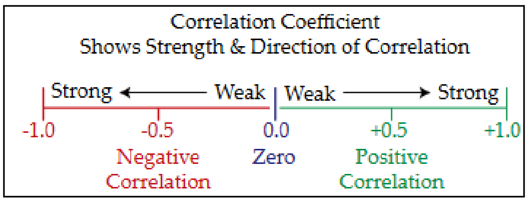

Fig. 1. Spectrum of Correlation Coefficient (Source: Reference [5])

II. OBJECTIVES OF RESEARCH

The objectives of this research paper are to firstly analyse different tonnage and cost factors to identify their significance as major contributors to costs and tonnage losses, and then run correlation analysis between the productivity key performance indicators (KPIs) and the associated tonnage and financial losses.

III. RESEARCH METHODOLOGY

Firstly, the general productivity KPIs were classified into tonnage and cost indicators. These indicators are the availability, utilisation, production rate, tonnage and mining costs. The trend of each indicator was analysed using line graphs, bar charts and stacked charts. Secondly, correlations between the losses and KPIs were then determined. The data used was obtained from January 2021 to October 2021 open pit mine production reports compiled from Modular Dispatch system..

The data was collected from databases as Excel files. The data was processed firstly in Microsoft Excel to sort, classify, analyse and interpret the data. The output data from Excel was inputted into R-software to ascertain the correlation for analysis. For each analysis the R (correlation coefficient) was determined.

IV. DATA ANALYSIS

The degree of correlation between the data sets was calculated from the data for each of the identified function parameters. Pearson's correlation factor analysis was run using Microsoft Excel and verified using R software.

A. Key performance indicators trend

The data collected from the Modular Dispatch System was analysed to find the production trends of the mine before analysing the details of productivity management.

Tonnage indicator

The tonnage produced reflects the performance equipment and workforce in a given period. The tonnage produced over a period of 10 months was studied. The results are shown in Fig. 2. It shows that there were wide fluctuations in production from January to October and the trendline shows a general slight declining trend with a gradient of -0.0456 over the period. The lowest value reported was 0-tonnes in May and highest value of 248,000 tonnes in March.

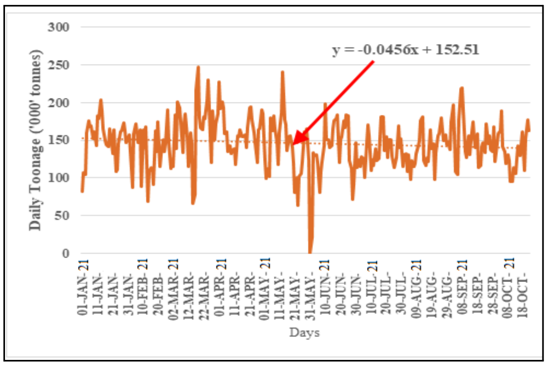

Fig. 3. Line Graph of daily material loaded for January - October 2021

Cost indicator

Mining costs have been classified into 5 groups namely labour, repair and maintenance, business expenses, fuel and tyres. Fig. 3 shows the trend of mining costs and the contribution of each type of cost to the total cost over time. The total mining cost declined from January to December (i.e., from BWP 3,552,150.05 to BWP 3,508,605.12). The contribution of each type of cost also varied with business expenses with the highest value of BWP 15,111,095.20 to tyres with the lowest value of BWP 1,868,330.64. Repairs and maintenance cost contributed the highest amount of BWP 1,383,037.54 from January to June and business expenses was the highest at BWP 1,784,257.93 from July to December.

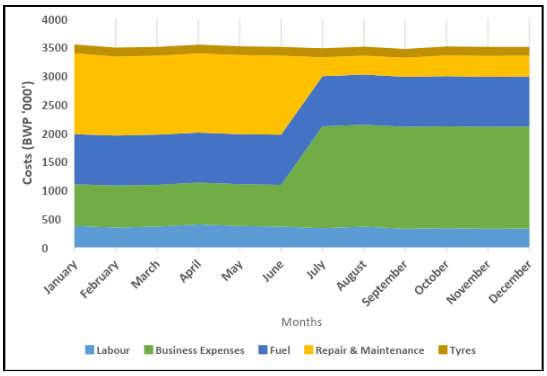

Fig. 3. Stacked graph of trend of mining costs in 2021

B. Correlation analyses

Pearson's correlation analysis was run in Microsoft Excel. The results are shown in scatter graphs and the correlation coefficient reported for each graph.

Tonnage correlation

Factors affecting tonnage were correlated with tonnage to find their linear relationship, and the results shown in scatter graphs.

Daily tonnage and loading rate correlation

The scatterplot of daily tonnage against loading rate is shown in Fig. 4. The strength, the form, the direction, correlation coefficient and the association of the relationship between the two variables are shown in the graph. The plot shows a strong significant relationship having points that strongly resembled a straight line as indicated by the concentration of points along the trend line.The loading rate and daily tonnage are strongly positively correlated with a correlation coefficient of 0.7147.

Correlation between daily tonnage and truck loads

Shown in Fig. 5 is a scatter plot of daily tonnage against the number of truck loads. It shows that there is a very strong correlation between the two variables. The plot shows a statistically significant relationship having points that strongly resembled a straight line as indicated by the concentration of points along the trend line. The slope of the trendline is close to 45°, meaning that as the value of the daily tonnage increased, there was a corresponding increase in the number of truck loads. It is important to note that there was a positive outlier which could have a strong impact on the correlation coefficient. The value of the correlation coefficient, measured as 0.4122 (including the outlier), indicates a positive linear relationship with a weak strength between the daily tonnage and truck loads.

Particle size distribution and loading rate correlation

A plot of particle size distribution of the muck pile against the loading rate produced the scatter graph shown in Fig. 6. With the limited data points, it is hard to detect any relationship between the two variables. The correlation coefficient of 0.5082 signifies a moderate strength relationship.

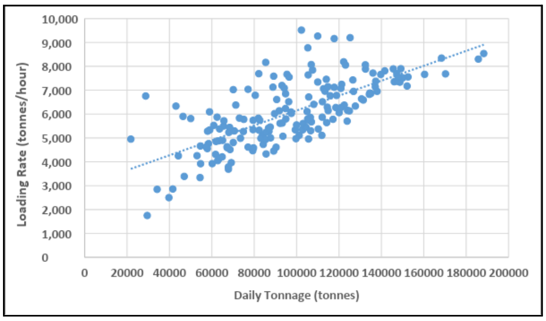

Fig. 4. Scatter graph for daily tonnage and loading rate

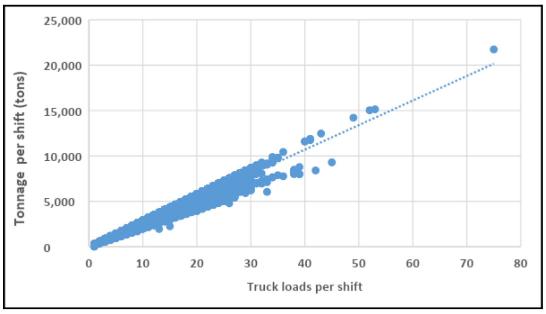

Fig. 5. Scatter graph for tonnage and truck loads

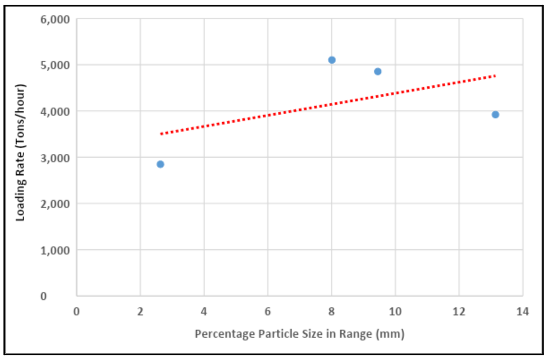

Fig. 6. Scatter graph of particle size and loading rate

Costs correlation

Categories of mining costs were correlated with total mining costs to find their linear relationship, and the results shown in scatter graphs.

Mining labour costs and total mining costs

Fig. 7 is a scatter plot of the mining labour costs against the total mining costs. It shows a linear positive association with correlation coefficient of 1.0000 which shows a perfect strong linear relationship between mining labour costs and total mining costs.

Mining business expenses and total mining costs

Fig. 8 is a scatter graph of mining business expenses against the total mining costs. It shows a negative relationship between them i.e. as the total mining costs decrease, the mining business expenses increase. The scatter graph slope was moderately dipping having equal number of points both below and above the trend line. The measured correlation coefficient is 0.9998 which shows a very strong linear relationship between the two parameters.

Mining fuel costs and total mining costs

A scatter plot of the total mining costs against the mining fuel costs is shown in Fig. 9, with points forming a vertical straight line, showing that the mining fuel costs were constant while the total mining costs increased. This shows that there is neither a positive nor a negative association between the two parameters. The correlation coefficient is 0.9906 which shows a very positive linear relationship between the two variables.

Repair and maintenance costs and total mining costs

Fig. 10 is a plot of the total mining costs against mining repair and maintenance costs. The data points are scattered in small clusters at the beginning and end of the trend line. The correlation coefficient is 0.9815 which shows a very strong relationship between the total mining costs and the mining repairs and maintenance costs.

Mining tyre costs and total mining costs

Fig. 11 is total mining cost versus mining tyre costs. The data points are clustered at almost the same point. This indicates that there is little or no linear relationship between mining costs versus mining tyre costs. The computation of the correlation coefficient gave a value of 1.0000, which clearly indicated a perfect strong relationship between the two variables.

Fig. 7. Scatter graph of mining labour costs and total mining costs

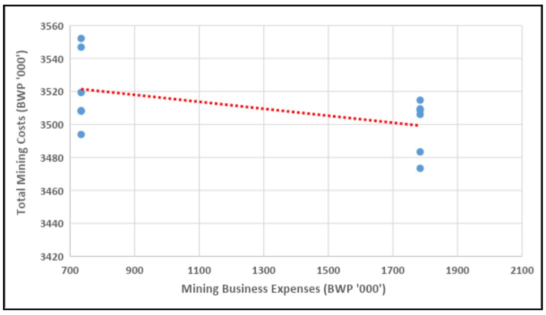

Fig. 8. Scatter graph of mining business expenses and total mining costs

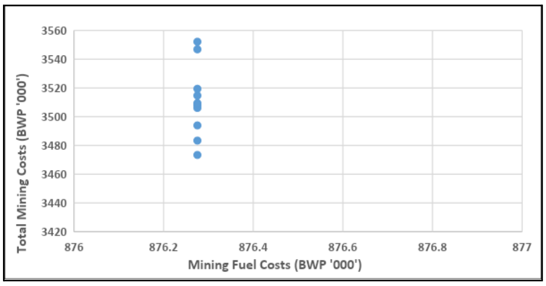

Fig. 9. Scatter graph of mining fuel costs and total mining costs

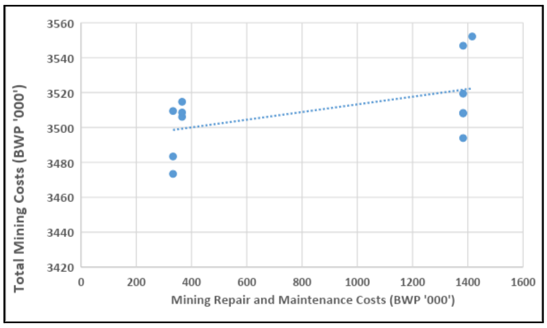

Fig. 10. Scatter graph of mining repair, maintenance costs and total mining costs

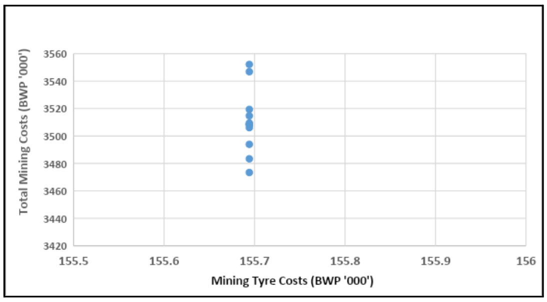

Fig. 11. Scatter graph of mining tyres costs and total mining costs

V. CONCLUSION

In this study, statistical methods were used to identify and analyse major tonnage and cost losses in an open pit mine. The parameters identified for analysis included loading rate, daily tonnage, degree of fragmentation (particle size distribution), labour costs, business expenses, fuel costs, repair and maintenance costs, and tyre costs. The Pearson correlation factors and R-values which measure the degree of relationship between data are sets were calculated from the data for each of the identified objective function parameters. All graphs showed a strong correlation with correlation coefficients ranging from 0.7147 to 1. The value of 1 clearly indicated a perfect strong relationship between the two variables. Labour costs and tyre costs both had the highest correlation factor of 1 when inferred to total mining costs, meaning they were the most significant mining costs and could contribute greatly to financial losses. Loading rate had the highest correlation factor (0.7147) out of all the other factors inferred to tonnage losses. The results showed the importance of correlation as a tool to reveal information about the root causes of productivity losses.

References

[1] Beare, M. (2011). "Costcutters: Efficiency and Productivity in Mining", www.mining-technology.com/features/featurecostcutters-efficiency-and-productivity-in-mining. (Accessed: 14th March, 2022).

[2] Gogtay. N. J., Deshpandes. S., Thatte. U. M, (2016). Principles of Correlation Analysis. Journal of the Association of Physicians of India. Vol. 65, pp.78-81

[3] Khorzoughi, M. B. & Hall, a. R., (2016). A Study of Digging Productivity of an Electric Rope Shovel for Different Operators. Minerals, VI (1), p. 48.

[4] Sloan, D. A. (2013). Mine Management, Springer Science and Business Media, London, pp. 27.

[5] Walters, J. (2010). Positive Management: Increasing Employee Productivity. 2nd ed. Business Expert Press, Atlanta, pp. 54.