Analysis of Haul Truck Tyre Failures Using Log Dispersion Plot

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Abstract

Haul truck tyre consumption forms one of the most significant direct cost centres in most surface mining operations. The need to achieve and maintain optimum tyre performance to prolong tyre service life at the mine site is, therefore, very crucial for a sustainable mining operation. To optimise tyre performance and hence reduce tyre usage cost, mine operators need to record, maintain and critically analyze reliable data on tyre failures in order to identify their root-causes, so as to find antidotes to them, especially with regards to premature failures, In this paper, log dispersion plot was used to analyze 425 datasets on prematurely failed tyres over a period of 30 months at the Edikan Gold Mine in Ghana. The failure types were categorized into acute, chronic and acute & chronic. This enabled failure types, key to optimising tyre performance to be identified and prioritized to ensure prolonged tyre service life.

Keywords: Tyre life, tyre failure types, premature tyre failure

1 Introduction

Haul truck tyre consumption forms one of the most significant direct cost centres in most surface mining operations. The need to achieve and maintain minimal tyre consumption at the mine site is, therefore, very crucial for a sustainable mining operation. The achievement of this objective, however, is a herculean task since most open pit mines experience significant premature tyre failures during their mining operations. Since haul trucks run on tyres, the situation becomes even worst as tyre consumption increases with the increasing scale of mining production, especially when most mining companies have adopted the strategy of large-scale production as a means of cost mitigation (Rodovalho & Tomi, 2017).

According to Pascual et al. (2019), tyres only come second to fuel in terms of operational costs which amount to several millions of US dollars per year for an average mine. Additionally, tyres have a direct effect on equipment performance and availability with the consequent risk on the capacity of the haul fleets to meet planned production targets. Studies have shown that, many factors including higher real site TKPH (tonnes-kilometre per hour) values, poor haul road, pit and dump conditions and poor tyre management cultures are causes of many premature tyre failures such as heat separation, tread impact, tread cut, sidewall cut, shoulder cut, etc. and about 80 percent of these tyres fail before they wear out, with cuts being responsible for about 45 percent of them, and impacts causing nearly 30 percent (Anon., 2020). A review of data from five Australian mining operations revealed that 70 per cent of premature tyre failures were operational, and improvement in haul road conditions could have both immediate and dramatic impact on tyre performance (Anon, 2019).

Unfortunately, in most mines, tyre damage reports are not accurately kept, and if kept at all, are just kept for keeping sake without any thorough analysis to diagnose the root-causes of the failures and hence formulate preventive measures to avert reoccurrence. According to Temeng and Eshun (2008), log dispersion plot has been proposed to analyze unplanned equipment downtimes data by separating the data into acute, chronic and acute & chronic categories for effective decision making. Similarly, in this paper, the log dispersion plot was employed as a novel approach to analyze 425 datasets on prematurely failed tyres obtained over a period of 30 months at the Edikan Gold Mine in Ghana to identify the causes and find antidotes to failure types critical to minimizing tyre usage costs.

2 General Information About the Mine

The Edikan Gold Mine, Ayanfuri, is located within the Western and Central Regions of Ghana, on the eastern flank of the highly prospective Ashanti Gold Belt (Anon, 2009). It is approximately 57 km to the SW of the Obuasi town and by road, 195 km WNW of the capital Accra. The Mine Licenses are located between 1°50’00” west and 2°00’00’’ west and 5°48’49’’ north and 6°00’00” north, (Anon, 2009). The Mine is located in south-western Ghana in the Man Shield (also referred to as Leo Shield) of the Precambrian West African Craton. Figure 1 is the location map of the Edikan Gold Mine.

Figure 1 Location of Edikan Mine on the map of Ghana

The Edikan Mine runs a total of thirty-one 90 t Komatsu HD 785-7 haul trucks with two Komatsu PC2000 and four Komatsu PC1250 excavators in two active pits (the Fetish and AG Pits) and two waste dumps (Fobinso and Fetish Waste Dumps). The return cycle distances from the Fetish Pit to the Fetish Waste Dump and the RoM Pad are about 6.8 km and 14.4 km respectively whilst that from AG Pit to Fobinso Waste and RoM Pad are 5.6 km and 4.8 km respectively.

3 Materials and Methods Used

Tyre failure records over a period of 30 months were obtained from the Tyre Services Department of the Mine in MS Excel format. The data indicated the tyre size, brand, pattern, serial number, tyre fitment date, tyre removal date, tyre achieved hours, original tread depth, remaining tread depth, percentage wear at time of failure and reason for removal from service. The data was sorted and arranged to exclude all other tyre sizes except the Goodyear 27.00R49 tyre size, which is the dominant haul truck tyre size being used on the Mine.

In MS Excel format, individual tyre failure types were grouped into categories and special codes assigned to each category as shown in Table 1. Frequencies, total tyre life lost (in hours) and mean tyre life lost as well as percentage of total lost hours were computed. For the purposes of this analysis, tyre failure categories that occurred after having achieved service lives of 5 000 hours (which was the planned life hours for tyres on the Mine) were excluded from the data since they had already served their planned lives and therefore, presented no losses in any form as a result of their failures. This resulted in a total of 300 967 tyre hours lost from 21 failure categories. Summaries of failure descriptions and lost hours respectively are shown in Tables 1 and 2.

3.1 The Log Dispersion Plot

According to Temeng and Eshun (2008), the log dispersion plot is a method that facilitates the categorization of a certain dataset into acute (occurring for long durations), chronic (occurring very frequently) or combination of both acute and chronic (occurring very frequently with long duration of occurrence). In its application to the analysis of the scrap tyres, the plot provides the opportunity to effectively represent the pattern in tyre failures and enables the diagnosis of the root causes of short service life of haul truck tyres.

In the production of the log dispersion plot for tyre failure analysis, the total tyre life lost (in hours) is considered as cost and given by the expression according to Temeng and Eshun (2008);

$$Cost_i = n_i \text{ x } mean_i \qquad (1)$$

Where, n_i is the frequency associated with failure code i and $Mean_i$ is mean time of failure code i.

Taking logarithm of (1);

$$\log(cost_i) = \log(n_i) + \log(mean_i) \qquad (2)$$

The log dispersion plot is a graph of log($mean_i$) against log(n_i). From the log dispersion plot, tyre failure types with large $mean_i$ values are considered as acute whilst failures types with large frequency values of n_i are considered as chronic. Those failure types with both large mean lost hours of $mean_i$ and large frequencies values of n_i are considered acute & chronic. The log dispersion plot can thus, be partitioned into four quadrants based on the threshold values of $mean_i$ and n_i. In the log dispersion plot, the upper quadrants represent the region of acute failures whilst the right-hand quadrants represent the region of chronic failures. Hence, the upper right-hand quadrant represents a region of acute & chronic failures whilst the lower left quadrant represents the region of neither acute nor chronic failures. This region is thus, the region with the least problematic failure types.

Table 1 Description of Tyre Failure Codes

Failure Type	Description	Failure Code
Body Ply Damage	Loss of adhesion between the sidewall rubber and the body ply.	A
Cut Separation	When the tread or sidewall lifts off the casing of the tyre.	B
Heat Separation	When the tyre gets excessively hot, the rubber begins to degrade and leads to seperation.	C
Tread Burst	Direct impact on the tread causing the tyre to fail	D
Tread Cut	When the tyre tread area sustains damage or cut.	E
Tread Impact	Results from the interaction between the tread blocks and the pavement texture.	F
Tread Separation	A portion of tread rubber, located in any area of the tyre, lifts and seperates from the the buffed surface of the tyre body.	G
Tread Burst Due to Heat Build-up	An increased friction, high speed driving and frequent braking during periods of high temperatures cause tyre heat up beyound design ratings. Once this happens, tread burst can occur	H
Tread Cut Separation	When the tread of the tyres (the outer part of the tyre with grooves in it that uses grip to keep you on te road) starts to come off the body (casing) of the tyre.	I
Sidewall Cut Separation	A damage/cut on the tyre sidewall which allows permeation of air to enter the affected area causing a bubble effect.	J
Sidewall Separation	When bubble appears on the side of the tyre. This seperation is as a results of underinflation followed by an impact to the sidewall	K
Shoulder Cut	Cut on the shoulder of the tyre	L
Sidewall Cut	Cut on the sidewall of the tyre	M
Sidewall Burst	This is a reacction to a sudden occurrence or an impact on the tyre sidewall causing the tyre to fail.	N
Shoulder Chip Cut	A cut on a non-repairable area of a tyre	O
Shoulder Heat Separation	Abnormal heat-up on the tyre shoulder.	P
Sidewall Impact	An external visible bulge on the sidewall of the tyre indicates that cords have been destroyed inside the carcass.	Q
Shoulder Impact	Damage on the tyre shoulder, the tyre shoulder offers support and protection to both the tread and the sidewall.	R
Worn Out	Small bars of rubber running across the grooves in between the tyre tread-called tread wear indicators. If the tread is worn to these bars on any part of the tyre, it's worn out.	S
Repair Failure	This is a secondary cause of tyre failure on the repaired area.	T
Rock Ejector Impact	This is a tyre ejector impact on the tyre.	U

Table 2 Summary of Tyre Failure Data

Failure Code	Frequency	Total Tyre Life Lost (Hours)	MeanTyre Life Lost (Hours)	% Frequency	% Mean	% Tyre Life Lost
A	1	3,430.00	3,430.00	0.002	0.11	0.01
B	2	5,082.00	2,541.00	0.005	0.08	0.02
C	6	16,623.00	2,770.50	0.014	0.09	0.06
D	11	15,751.00	1,431.91	0.026	0.04	0.05
E	134	32,875.00	245.34	0.315	0.01	0.11
F	147	114,699.00	780.27	0.346	0.02	0.38
G	16	21,113.00	1,319.56	0.038	0.04	0.07
H	1	3,855.00	3,855.00	0.002	0.12	0.01
I	19	20,295.00	1,068.16	0.045	0.03	0.07
J	2	2,958.00	1,479.00	0.005	0.05	0.01
K	1	189.00	189.00	0.002	0.01	0.00
L	2	3,429.00	1,714.50	0.005	0.05	0.01
M	27	160.00	5.93	0.064	0.00	0.00
N	1	646.00	646.00	0.002	0.02	0.00
O	4	8,369.00	2,092.25	0.009	0.07	0.03
P	2	3,985.00	1,992.50	0.005	0.06	0.01
Q	8	10,488.00	1,311.00	0.019	0.04	0.03
R	3	3,284.00	1,094.67	0.007	0.03	0.01
S	29	15,857.00	546.79	0.068	0.02	0.05
T	7	15,197.00	2,171.00	0.016	0.07	0.05
U	2	2,682.00	1,341.00	0.005	0.04	0.01
Total	**425**	**300,967.00**	**32,025.37**			

3.2 Determining the Threshold Values

To produce log dispersion plots, threshold values are usually determined. Temeng and Eshun (2008), cites Knights (1999) as saying that these values are usually based on company policy or relative magnitudes and quantity of a dataset. The threshold values are values above which the frequency of occurrence or the amount of lost tyre life due to premature failure is considered to be either acute, chronic or a combination of both. In this analysis, the relative magnitude and quantity of dataset approach was used to determine the threshold values from (3) and (4) according to Temeng and Eshun (2008) as follows:

For a given dataset where D represents the total duration of lost tyre hours, N represents total frequency, and Q represents the number of distinct codes used in categorizing the failure types, the expressions for determining the threshold values for acute failures ($Limit_{mean}$) and that of the chronic failures ($Limit_{n}$) are;

$$Limit_{mean} = \frac{D}{N} \qquad (3)$$

and;

$$Limit_{n} = \frac{N}{Q} \qquad (4)$$

Where,

D is total duration of lost tyre hours;

$$D = \sum d_i \qquad (5)$$

And di is duration of lost hours due to failure code i. The total frequency N, is given by

$$N = \sum n_i \qquad (6)$$

4 Results and Analysis

Figures from Table 2 were substituted into equation (3) to (6) to generate the threshold values for $Limit_{mean}$ and $Limit_{n}$. From Table 2, the total frequency, N = 425, the total lost hours, D = 300 967 and total failure categories, Q = 21.

Therefore;

$$Limit_{mean} = \frac{300\,967}{425} = \mathbf{708.16}$$

and

$$Limit_{n} = \frac{425}{21} = \mathbf{20.24}$$

Using equation (2) and the figures in Table 2, the log dispersion plot was produced, and the threshold values used to partition the plot into four quadrants as shown in Figure 2. Table 3 is an extract from Figure 2 and shows details of the various failure types or categories, being acute, chronic and acute & chronic.

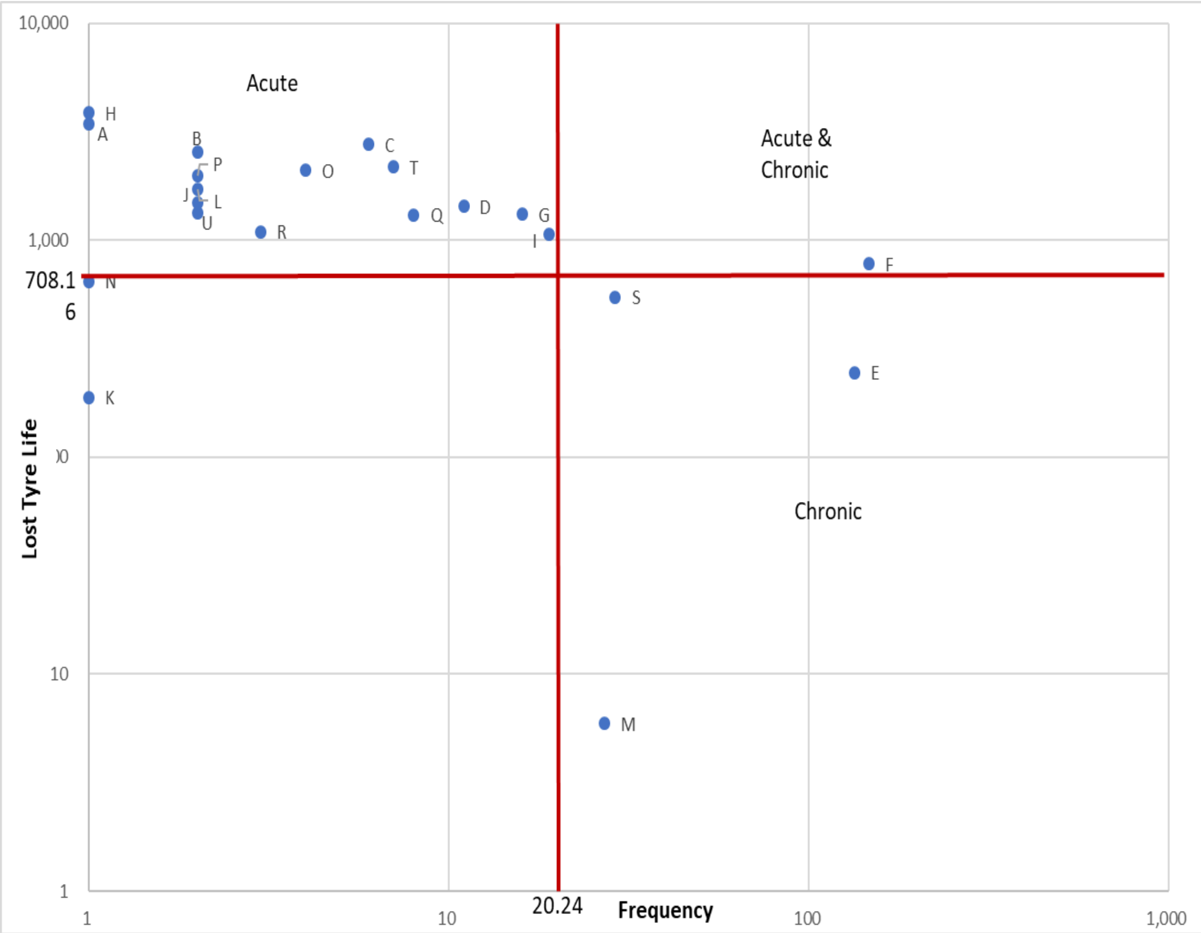

Figure 2 Log dispersion plot of tyre failure types

From Figure 2, the acute failures include body ply damage, cut separation, heat separation, tread burst, tread separation, tread burst due to heat build-up, tread cut separation, sidewall cut separation, shoulder cut, shoulder chip cut, shoulder heat separation, sidewall impact, shoulder impact, repair failure and rock ejector impact. These were categories that had relatively higher mean lost tyre hours (above the threshold value of about 708 hours of lost tyre life) once they occurred. From Table 3, fifteen out of a total of 21 tyre failure types were categorized as acute. This implies that most (71%) of the failures types are causing the tyres to be scrapped too early. Out of the 425 tyres, 86 (about 20%) were categorized as failing too early before the planned service life of 5 000 hours with their individual lost hours high above the threshold value of 708.16 hours.

Studies have shown that poor haul road and pit floor conditions (potholes, undulations, sharp and exposed rock surfaces), higher real site tonnes-kilometer per hour (TKPH) values than tyre manufacturers' ratings as well as bad operator habits (trucks backing into muckpiles and tip heads) are the primary causes of the above-mentioned failure types. For example, cut separation, sidewall cut separation, shoulder cut, sidewall impact, shoulder impact, tread cut separation etc. are all due to unfavorable haul road, in-pit and waste dump conditions, where the tyres are exposed to sharp rock surfaces, whilst tread burst due to heat build-up, shoulder heat separation and heat separation are due to higher real site TKPH values than tyre manufactures' ratings. The worst four of the acute failure types were tread burst due to heat build-up (mean of 3 855 hours lost), body ply damage (mean of 3 430 hours lost), heat separation (mean of 2 770.5 hours lost) and cut separation (mean of 2 541 hours lost). In all these four cases, the tyre could not be in service for 50% of its planned life on the average.

The chronic failures were tread cut, sidewall cut and worn out categories. These were the failure types that occurred very frequently (have their frequencies of occurrence higher than the threshold frequency of about 20 in the 30 months period) but had their mean lost hours relatively low (below the threshold value). From Table 3, 190 out of 425 tyres (about 45%) fell in this category. This means 45% of the tyres were failing too frequently. Tread impact failure type fell in the acute & chronic failure category. This meant that, the tread impact failure type had both relatively high frequency of occurrence (has the frequency higher than the threshold value) and high mean lost hours (has lost hours higher than the threshold value) at time of occurrence. Although only one failure type (tread impact) fell in this category, it is important to note that as observed from Table 3, 147 tyres out of 425 (about 35%) had this failure.

Considering total lost hours, Tables 1 and 2 show that tread cut (failure code E with frequency of 134 (31.5%), and total lost tyre hours of 32 875) and tread impact (failure code F with frequency of 147 (34.5%) and total lost tyre hours of 114 699) were the two major tyre failure types plaguing the site. This means that these two failure types alone contributed 281 (66.1%) of the total of 425 premature tyre failures and 147 574 (49.03%) of the total of 300 967 lost tyre hours on the Mine. Tread impact occurs when drivers drive over objects like kerbs, undulations or toes at excessive speeds or at wrong angles, leaving the tyre carcass overstressed and thus, resulting in breaks in its individual cords (Anon., 2021). Tread cut on the other hand, happens when the tyre tread sustains a cut or damage from sharp surfaces.

Table 3 Tyre Failure Categories Based on Log Dispersion Plot

Failure Code	Category	Frequency	Total Tyre Life Lost (Hrs)	Mean	% Frequency	% Mean	%Total Tyre Life Lost
Acute and Chronic Failures							
F	Tread Impact	147	114,699	780.27	34.59	2.44	38.11
SUB TOTAL		**147**	**114,699**	**780.27**	**34.59**	**2.44**	**38.11**
Acute Failures							
A	Body Ply Damage	1.0	3,430	3,430.0	0.24	10.71	1.14
B	Cut Separation	2.0	5,082	2,541.0	0.47	7.93	1.69
C	Heat Separation	6.0	16,623	2,770.5	1.41	8.65	5.52
D	Tread Burst	11.0	15,751	1,431.9	2.59	4.47	5.23
G	Tread Separation	16	21,113	1,319.56	3.76	4.12	7.02
H	Tread Burst Due to Heat Build-up	1	3,855	3,855.00	0.24	12.04	1.28
I	Tread Cut Separation	19	20,295	1,068.16	4.47	3.34	6.74
J	Sidewall Cut Separation	2	2,958	1,479.00	0.47	4.62	0.98
L	Shoulder Cut	2	3,429	1,714.50	0.47	5.35	1.14
O	Shoulder Chip Cut	4	8,369	2,092.25	0.94	6.53	2.78
P	Shoulder Heat Separation	2	3,985	1,992.50	0.47	6.22	1.32
Q	Sidewall Impact	8	10,488	1,311.00	1.88	4.09	3.48
R	Shoulder Impact	3	3,284	1,094.67	0.71	3.42	1.09
T	Repair Failure	7	15,197	2,171.00	1.65	6.78	5.05
U	Rock Ejector Impact	2	2,682	1,341.00	0.47	4.19	0.89
SUB TOTAL		**86**	**136,541**	**29,612.05**	**20.235**	**92.46**	**45.37**
Chronic Failures							
E	Tread Cut	134	32,875	245.34	31.53	0.77	10.92
M	Sidewall Cut	27	160	5.93	6.35	0.02	0.05
S	Worn Out	29	15,857	546.79	6.82	1.71	5.27
SUB TOTAL		**190**	**48,892**	**798.05**	**44.706**	**2.492**	**16.24**
Other Failures							
N	Sidewall Burst	1	646	646.00	0.24	2.02	0.215
K	Sidewall Separation	1	189	189.00	0.24	0.59	0.063
SUB TOTAL		**2**	**835**	**835.00**	**0.471**	**2.61**	**0.277**
GRAND TOTAL		**425**	**300,967**	**32,025.37**	**100.00**	**100.00**	**100.00**

5 Conclusions and Recommendations

5.1 Conclusions

The analysis from the log dispersion plot showed that tyre failure codes that were found in the acute category contributed most to the lost tyre hours per single occurrence of failure averagely. This was followed by the acute & chronic failure type and the chronic types in that order. The primary causes of these failures were identified as poor haul road and pit floor conditions, higher real site tonnes-kilometer per hour (TKPH) values than tyre manufacturers' ratings as well as bad operator habits.

Also, tread cut and tread impact are the two major failure types plaguing the site, which need management's critical attention in order to prolong tyre life on the Mine. These two failure types contributed 66.1 of the 425 premature tyre failues and 49% of the total lost tyre life of 300 967 hours.

5.2 Recommendations

Based on the results, analysis and conclusions, it is recommended that, the tyre selection procedure should consider tyres with manufactures' TKPH ratings higher than the real site TKPH values so as to eliminate or minimize the impacts of heat related tyre failures. Since most of the tyre failure types in all three categories are usually the result of tyre contacts with sharp and exposed rock surfaces, undulations and potholes on pit floors, waste dumps and haul roads, it is recommended that, adequate dozers and graders be deployed to mining faces, pit and dump floors and haul roads to keep these areas clear of all sharp and exposed surfaces as well as all potholes and undulations to ensure prolonged tyre life. Furthermore, tyre awareness trainings should be regularly held to educate truck operators to avoid backing into mining faces and tip heads as well as driving in ruts and potholes in order to prevent tread cuts and tread impacts which are the two major failures types plaguing the site. Minimising these two failure types alone would significantly reduce premature tyre failures and yield savings on operating costs, as far as costs on premature tyre failures are concerned.

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