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Tonne Kilometre Per Hour (TKPH) Prediction for Lifetime Tire Estimate Using Statistical Analysis: A Case Study at Coal Mine

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Abstract — **To expedite mining production activities, the condition of the transportation equipment of fuel and spare parts must be ready because the loss of time due to refueling and waiting for spare parts can reduce the Physical Availability value of the dump truck. In this study, the type of tire used as the research object is a tire measuring 33.00-51. The initial identification of tire conditions showed that the Hours meter average was smaller than the Key Performance Indicator (KPI) Hours meter, which was 2719 HM. The type of tire damage that dominates is Sidewall Separation, with a damage percentage of 54%. This study aims to predict the value of TKPH with ten independent variables that exist in the activity of the transportation cycle. The method used to predict is the Multiple Regression and ARIMA statistical methods. From the results of Multiple Regression using the SPSS application, three models are produced, each with different independent variables. As for ARIMA seen from the choleogram of the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF), the number of lags = 1, so ARIMA models that can be applied may be (1,0,1) and (1,1,0). The results of the study prove that the prediction model that is close to this is the Multiple Regression Model 3 where the Mean Absolute Deviation (MAD) value is 69.16, the Mean Absolute Prediction Error (MAPE) is 66.07, and the R-square value is 52.41%.**

Keywords—**Tire; TKPH; KPI; multiple regression; ARIMA.**

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I. INTRODUCTION

Mining operational costs, which are the main consumption of transportation equipment in coal mines other than fuel, are tires [1], [2], [3]. Without realizing it, tires are an important spare part of wheeled transportation equipment, and tires are made of rubber. If the main material is in crisis, it will affect the procurement of tires in a company [4], [5]. Tire procurement must also be under the production target strategy that the company has determined through Key Performance Indicators (KPI). The company suffers a considerable loss if the procurement is not adjusted to the production target (overstock or less stock). The overstock condition is not good for the company because the tires have an expiration date, while the less stock condition results in a lower Physical Availability (PA) value of the transportation equipment because the breakdown time is long enough to wait for spare parts availability [6], [7].

The increasing demand for coal production causes the performance of mechanical equipment in the mine to be improved. Mining companies use digging tools in the form of excavators and transportation equipment in the form of dump trucks in mining activities. In loading and hauling work, dump trucks are tools prone to damage, especially on tires, due to traveling long distances and carrying heavy loads [8]. If one of the dump trucks is damaged while hauling, this will hinder the trajectory of the other dump trucks. One of the components that directly affect the performance of mechanical devices is tires [9]. Dump truck tires are an important component for wheel-type unit operational activities that must be checked regularly because tires are directly related to the availability and performance of dump truck transportation equipment [6],[8],[9]. For the HD785 type unit the number of tires used is six, where the position in front of two tires and the position behind four tires.

This prompted him to conduct research on tire inventory prediction analysis using 2 methods, namely multiple regression analysis and ARIMA. Previously ARIMA was used to predict the fuel demand for transportation equipment [10], [11], but this statistical method can be tried to predict TKPH to help procure spare parts.

II. Material and Method

Tire life can be calculated by comparing the actual HM and HM KPI through the 'History Scrap Performance Tire' data in the SAP Application. Determination of Hoursmeter Key Performance Indicators (KPI) is influenced by the achievement of tire life in the previous year with optimistic achievements from tire manufacturers. By comparing the actual conditions and KPIs, it can be seen the achievement of the production target. If the actual HM is smaller than the HM KPI, it is necessary to evaluate the scrap tire data further [12]. Followed by tire damage analysis using supporting data consisting of distance, cycle time, speed, and payload to get the actual TKPH value of the tire [13],[14].

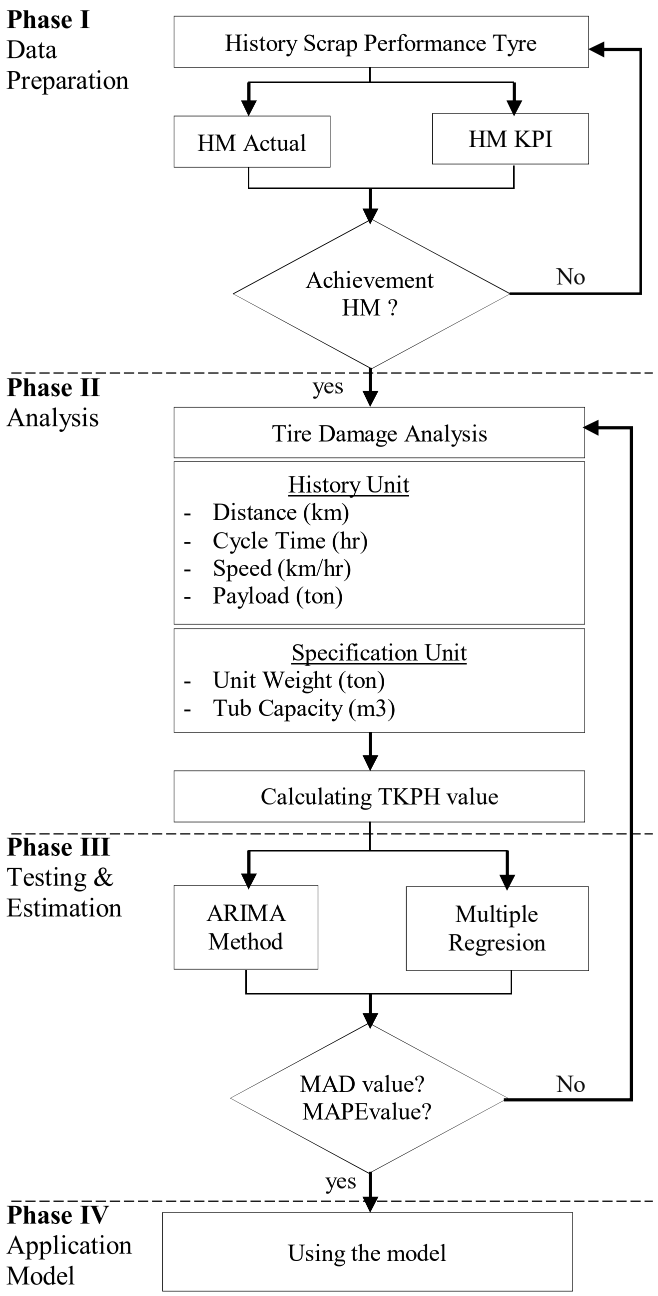


Fig. 1 Flowchart of research methods

The TKPH data were analyzed and modeled via the ARIMA technique within the context of time series analysis. Data preparation/pre-processing is one of the first and most important steps in time series analysis. The basic statistics of the TKPH data are summarized in **Table 2**. ARIMA models provide a statistically robust approach to time series forecasting. ARIMA models aim to describe autocorrelations in the data [10],[11]. In an ARIMA model, the future value of a variable is supposed to be a linear combination of the past values and errors, expressed as equation (1):

$$y_t = \vartheta_0 + \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \cdots + \varphi_p y_{t-p} + \varepsilon_t - \vartheta_1 \varepsilon_{t-1} - \vartheta_2 \varepsilon_{t-2} - \cdots - \vartheta_q \varepsilon_{t-q} \quad (1)$$

Where yt is the actual value, εt is the random error at time t, 4i and wj are coefficients, and p and q are integers often referred to as autoregressive and moving average polynomials, respectively. For example, the ARIMA (1,0,1) model can be represented as the equation (2):

$$y_t = \vartheta_0 + \varphi_1 y_{t-1} + \varepsilon_t - \vartheta_1 \varepsilon_{t-1} \quad (2)$$

A multiple linear regression model with k variables can be written in the form.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots\ldots + \beta_k X_k + \mu \quad (3)$$

Where β_0 is the intercept and β_j; j = 1 to k are parameters related to variable j. While is an error term (disturbances) which is a reservoir for other factors that are not included in the model, for example, independent variables outside k = 1 to k, functional errors, measurement errors, and so on. The parameter β_j (i = 1,2,….,k) indicates the magnitude of the relationship between the independent variable i and the dependent variable by assuming all other factors (covered in μ) as constant. Equation (3) is linear, thus a change in X_1 of ΔX_1 will have implications for a change in y of Δy.

After the projection is done, the accuracy between the modeled and actual projections is carried out with a projection accuracy measuring instrument using the Mean Absolute Deviation (MAD) and Mean Absolute Prediction Error (MAPE) instruments. The formula for each measuring instrument can be seen in equations (4) and (5):

$$MAD = \frac{\Sigma\,|yt - yt'|}{n} \quad (4)$$

$$MAPE = \frac{1}{T}\sum_{t=1}^{T}\left|\frac{y_t - y_{f,t}}{y_t}\right| \quad (5)$$

where y_t; $y_{f,t}$ is the actual value and the projected value of the dependent variable, T is the number of observations.

The greater the value of MAD and MAPE, the lower the ability of the regression model to project the actual value. These measures can be used to compare different models as long as the associated variables are the same.

III. Results and Discussion

Based on the 'Scrap Performance Tire' report, the type of tire damage for each size varies. Sidewallcut and Run Flat dominate the size of 12.00R24 because this tire operates in the hauling road area, so run-flat damage is normal as long as it is not premature, while sidewall cut needs further investigation. However, this research only focuses on tires operating at mining sites, namely tires with sizes 33.00-51 [6], [15], [16] The table below explains the dominance of the biggest tire damage is sidewall separation of 45% and impact of 23%.

TABLE I
TIRE DAMAGE

No	Size	Type of Damage	Total	Percentage
1	12.00R24	Foreign Object	5	4%
		Impact	1	1%
		Irregular Wear	1	1%
		Run Flat	45	37%
		Seized Brake	3	2%
		Sidewall Cut	49	40%
		Tread Chipping	6	5%
		Tread Cut	1	1%
		Worn Out	6	5%
		(blank)	5	4%
		Total	**122**	**100%**
2	23.5R25	Sidewall Cut	1	100%
		Total	**1**	**100%**
3	24.00-35	Sidewall Separation	1	100%
		Total	**1**	**100%**
4	33.00-51	Bead Damage	1	8%
		Impact	3	23%
		Sidewall Cut	1	8%
		Sidewall Separation	7	54%
		(blank)	1	8%
		Total	**13**	**100%**

Sidewall separation is a type of damage that separates the sidewall rubber and the casing. This condition can occur due to excessive pressure due to load (overloading) [17],[18],[19], excessive vehicle speed (Over speeding), and speeding up when cornering (Fast cornering) [13], [20]. In addition to this, the condition of the material on the road also affects the performance of the tires and the type of damage to the tires. [9], [20], [21]

After knowing the dominant damage to the tire, it is necessary to compare it with the company's standard Key Performance Indicator (KPI). It can be seen in Figure 2 that for 10 consecutive periods, the actual HM value is below the KPI standard, and the average HM achievement is still below the standard, which is 60%. Many parameters affect the HM value of the tire, not only through external factors due to operations but also because of the inappropriate use of tire specs to the conditions of the work area.[16], [20], [22] So, there is a need for further analysis to find out the causes that are the constraint factors for not achieving HM.

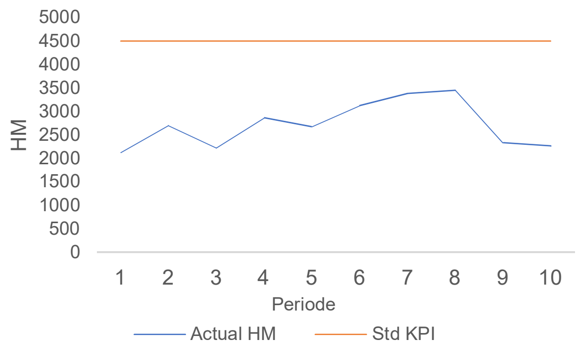


Fig. 2 HM achievement on tires size 33.00-51

From the causes of tire damage and failure to meet the KPI standards, it can be concluded that the independent variables that affect tire performance are the cycle of transportation equipment, payload, distance, and speed [2], [21].

TABLE II
DATA DESCRIPTION

Variables	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variant
Independent					
Payload (Ton)	77.800	184.800	145.205	17.082	0.118
Empty Travel Distance (km)	1.000	4.700	2.280	0.842	0.369
Load Travel Distance (km)	0.800	4.300	2.307	0.853	0.370
Empty Speed (km/hr)	13.091	31.086	20.922	3.705	0.177
Load Speed (km/hr)	10.655	30.000	20.721	3.472	0.168
Empty Travel Time (hr)	0.053	0.199	0.108	0.031	0.291
Empty Stop Time (hr)	0.001	0.369	0.055	0.055	0.992
Load Time (hr)	0.026	0.089	0.048	0.015	0.305
Load Stop Time (hr)	0.009	0.066	0.017	0.008	0.462
Load Travel Time (hr)	0.052	0.198	0.111	0.034	0.306
Dependent					
TKPH (Ton.Km/Hr)	28.183	439.721	144.782	107.440	0.742

TKPH of a tire depends on the design and variations of tires based on the type and size. And the tire manufacturer concerned issues technical specifications on the TKPH rating value of the tires it produces [23]. Where TKPH is a function of weight (load) and the number of kilometers in 1 hour of operation at a standard temperature of use [6],[24],[25].

Tires of size 33.00-51 are used in the production area so many parameters are taken into consideration to see the factors that influence the TKPH value of the tires. These parameters can be seen in Table 2 divided into two namely independent variables consisting of ten variables and one dependent variable, namely TKPH. We will see the effect of the independent variable on the dependent variable by looking at the correlation matrix in Table 3.

Through the TKPH stationary data in Figure 3 you can see the ARIMA model used. Before the data is processed for the forecasting system using ARIMA, the data must be seen whether it is stationary or not. If it is not stationary, it is necessary to divert once before it is ready to be processed using the ARIMA method [10], [11].

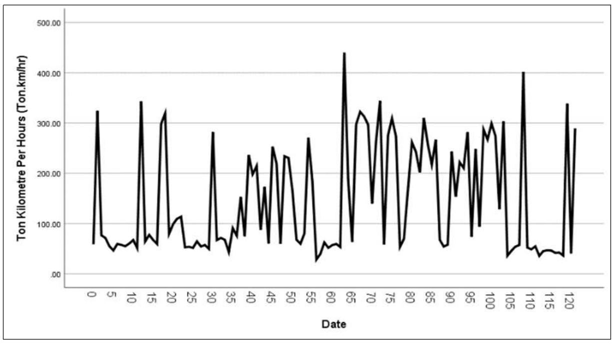
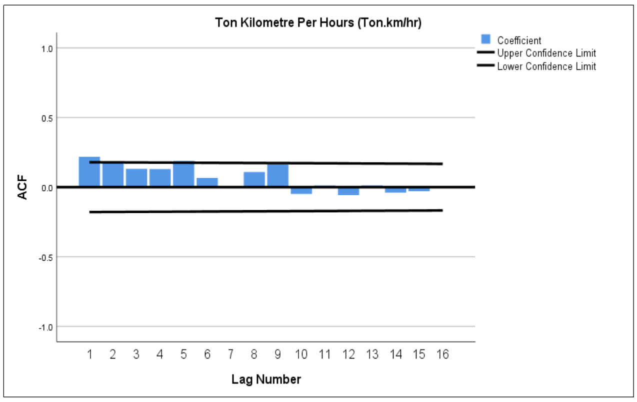
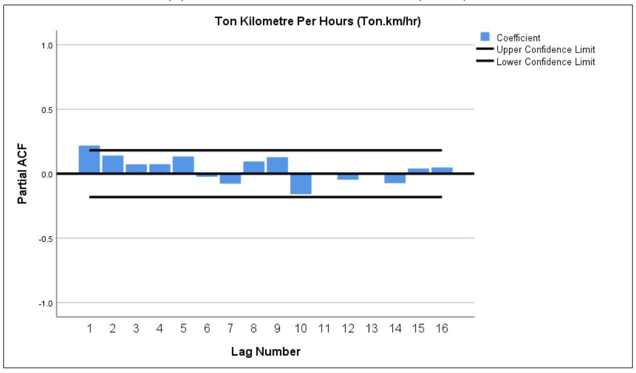


Fig. 3 TKPH Data Stationary



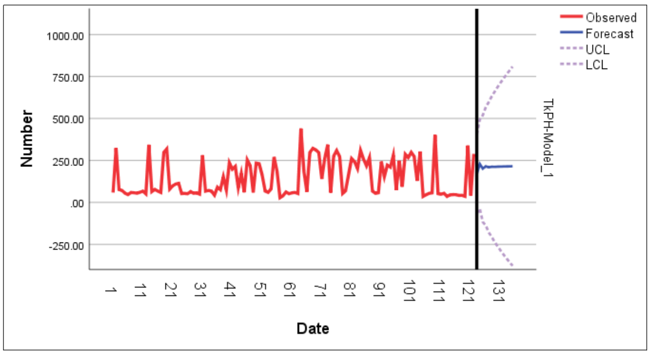
(a) Autocorrelation Function (ACF)



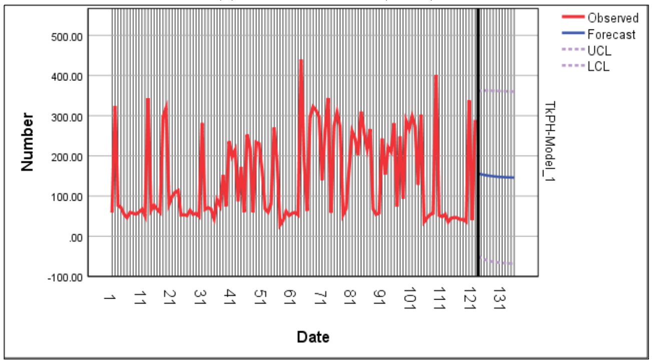
(b) Partial Autocorrelation Function (PACF)

Fig. 4 Result Chart ACF (a) and PACF (b)

The autocorrelation function (ACF) in Figure 4(a) shows how the realization of a variable at time t is related to the realization of that variable at a point in the past. While the Partial Autocorrelation Function (PACF) in Figure 4(b) shows the correlation between the realization of a variable at time t and the realization at time t – k by controlling or removing all effects. From the results of the correlograms in Figure 4, the resulting lag results exceed the conditions of the Upper Confidence limit or Lower Confidence Limit = 1. So that the possible ARIMA models that can be analyzed are ARIMA models (1,0,1) and (1,1,0), it will not only compare the two ARIMA models (1,1,0) and (1,0,1) but will also compare the results of multivariant regression with various models. From Table 3. It can be seen that there is a relationship between TKPH and Load Travel Distance, Load Travel Time and Payload. Other variables also have an influence relationship on TKPH but are not too significant. Tons of Kilometers per hour on each tire vary according to each tire manufacturer.



(a) ARIMA Model (1,1,0)



(b) ARIMA Model (1,0.1)

Fig. 5 ARIMA Model

TABLE III
CORRELATION MATRIX FOR THE TEN INDEPENDENT VARIABLE AND ONE DEPENDENT VARIABLES

Variables	Payload	Empty Travel Distance	Loaded Trave Distance	Empty Speed	Loaded Speed	Empty Travel Time	Empty Stop Time	Load Time	Load Stop Time	Load Travel Time	TKPH
Payload	1.000	-0.086	-0.033	-0.102	-0.431	-0.064	-0.003	0.374	0.087	0.165	0.583
Empty Travel Distance	-0.086	1.000	0.853	0.585	0.419	0.897	-0.123	0.419	0.044	0.771	-0.183
Loaded Travel Distance	-0.033	0.853	1.000	0.517	0.522	0.745	-0.167	0.453	0.008	0.883	-0.139
Empty Speed	-0.102	0.585	0.517	1.000	0.446	0.182	-0.384	0.233	-0.048	0.383	0.071
Loaded Speed	-0.431	0.419	0.522	0.446	1.000	0.261	0.023	-0.009	-0.140	0.080	-0.170
Empty Travel Time	-0.064	0.897	0.745	0.182	0.261	1.000	0.078	0.360	0.048	0.726	-0.274
Empty Stop Time	-0.003	-0.123	-0.167	-0.384	0.023	0.078	1.000	0.057	-0.016	-0.202	-0.084
Load Time	0.374	0.419	0.453	0.233	-0.009	0.360	0.057	1.000	0.156	0.534	0.198
Loaded Stop Time	0.087	0.044	0.008	-0.048	-0.140	0.048	-0.016	0.156	1.000	0.061	0.012
Loaded Travel Time	0.165	0.771	0.883	0.383	0.080	0.726	-0.202	0.534	0.061	1.000	-0.068
TKPH	0.583	-0.183	-0.139	0.071	-0.170	-0.274	-0.084	0.198	0.012	-0.068	1.000

From the results of multiple regression through the SPSS application, it is found that there are three models to be able to predict the value of TKPH.

Model 1:

$$TKPH_1 = -710.406 + 4.415PYL + 81.347ETD - 162.724LTD - 3.956ES + 21.230LS - 2341.518ETT - 99.814EST + 457.489LT - 119.453LST + 2924.924LTT \quad (6)$$

Model 2:

$$TKPH_2 = -387.790 + 3.668\ PYL \quad (7)$$

Model 3:

$$TKPH_3 = -280.588 + 3.648\ PYL - 2065.111\ ETT + 52.051\ ETD \quad (8)$$

Model 1 (equation 6) explains that all variables are related but there are variables whose values are negative, which means that the independent variable has no significant effect on the TKPH value. The independent variables that have no effect on the TKPH value are Load Travel Distance, Empty Travel Distance, Empty Stop Time, and Loaded Stopped Time [3]. Model 2 (equation 7) explains that only the Payload value has an effect, but it can be seen that TKPH is not only influenced by the payload independent variable.

Model 3 (equation 8) explains that TKPH is influenced by three independent variables, namely payload, Empty Travel Time, and Empty Travel Distance where one of the other variables is negative. If the speed increases, there will be an increase in tire temperature exceeding 380C, the TKPH value will increase. On the other hand, if the temperature is below 38°C, the TKPH will decrease [24],[25],[26].

In **Table 3** the correlation matrix above explains that of the ten independent variables, not all of them have a close relationship and influence on the TKPH value. External factors such as road conditions are one of independent variables that cannot be measured because they are influenced by the company's periodic maintenance time for mining roads. [15],[27]

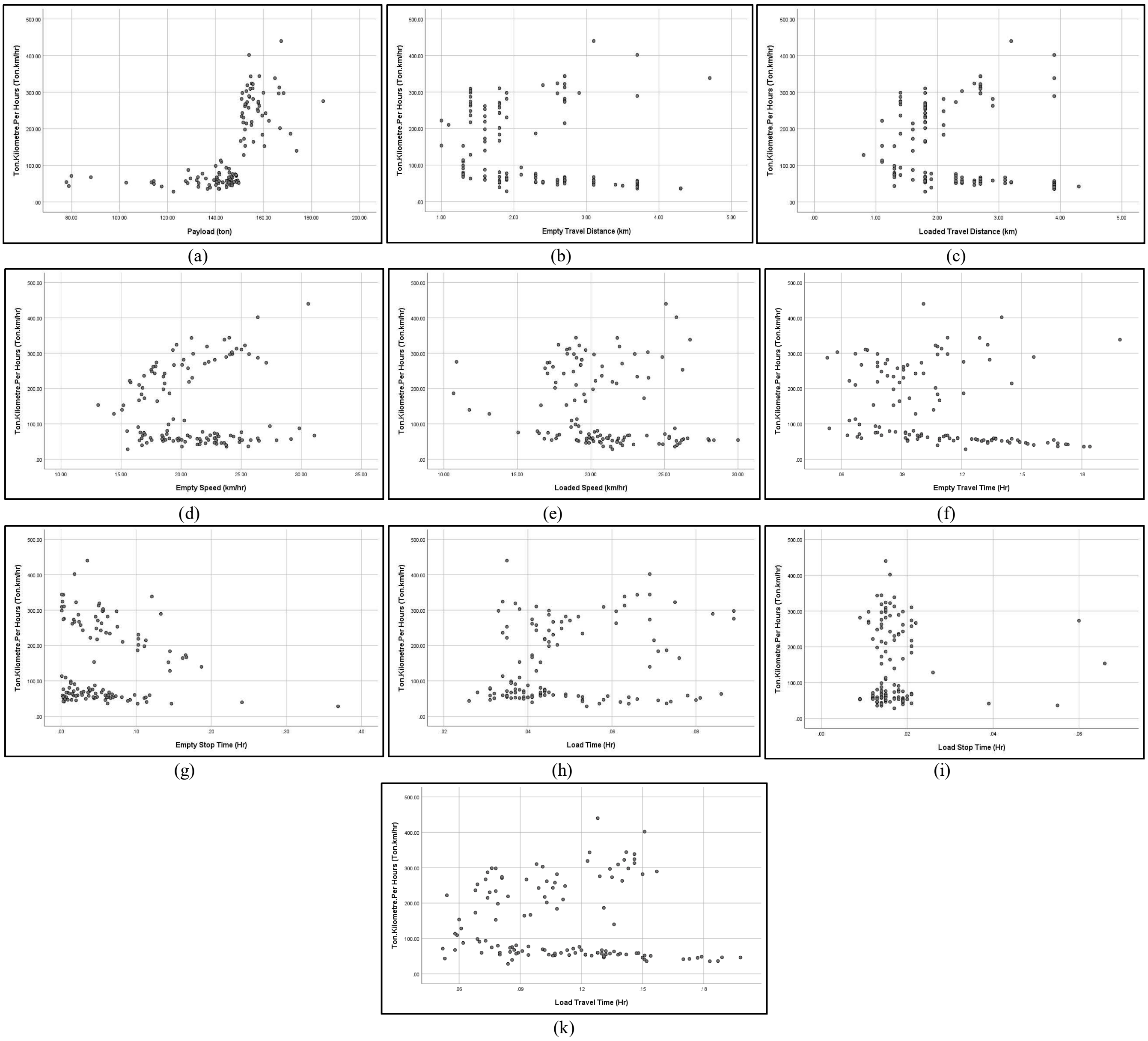


Fig. 6 Graph of the relationship between the independent variable and the dependent variable (a-k)

It can be seen in Figure 6 the graph of the relationship between the independent and dependent variables explains that each variable has a strong correlation between one variable and another. Payload relationship with TKPH (a) here is very important, because the load of one tire supports the load of the load and conveyance [22]. Speed (d & e) is also an important factor that produces hot conditions in the tires and makes the pressure in the tires unstable, so it is necessary to monitor the condition of the tires of the conveyance periodically. Pressure must be controlled during hot and cold conditions [17], [18], [19], [28]. The transportation distance (b & c) of the overburden material starting from the loading point to the disposal also affects the age of the tire [28]. The operator's habits (f – k) in driving when the conveyance is loaded and the means of transport are empty as well as the condition of the mine road and front-loading area also affect the TKPH value [6], [8], [29] [30].

TABLE IV
MAD AND MAPE VALUE

Statistical Method	MAD	MAPE
Multiple Regression		
1. Model 1	67.29	75.39
2. Model 2	76.09	79.54
3. Model 3	69.16	66.07
ARIMA		
1. Arima (1,0,1)	87.68	95.13
2. Arima (1,1,0)	82.43	83.30

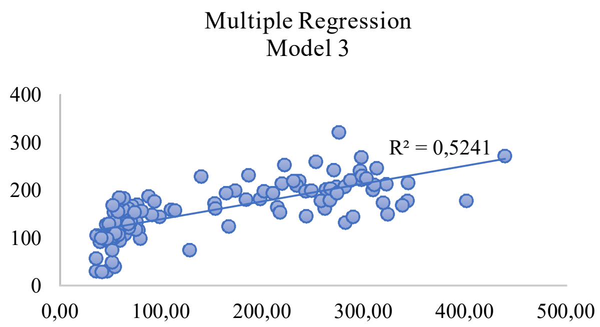


Fig. 7 Graph of R-Square Multiple Regression Model 3

The study's results in Table 4 that the smallest error value is in the Multiple regression Model 3 statistic with a MAD value of 69.16 and a MAPE value of 66.07 with an R-square (R^2) value of 52.41%.

IV. CONCLUSION

The results showed that the R-square value in the multiple regression Model 3 was greater than the other models in the multiple regression and ARIMA, which was 52.41%. This means that 52.41% of tire life is influenced by three independent variables, namely payload, Empty Travel Time, and Empty Travel Distance; the remaining 48.59% is influenced by other variables not included in this study.

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NOMENCLATURE

TKPH	Ton Kilometre per Hours	ton.km/hr
ETD	Empty Travel Distance	km
PYL	Payload	ton
LTD	Load Travel Distance	km
ES	Empty Speed	km/hr
LS	Load Speed	km/hr
ETT	Empty Travel Time	hr
EST	Empty Stopped Time	hr
LT	Loaded Time	hr
LST	Loaded Stopped Time	hr
LTT	Loaded Travel Time	hr

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