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Analysis of Dump Truck Tire Wear Rate Using Kruskal Wallis Nonparametric Statistics in R

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Abstract - **Dump truck is a tool for transporting materials in mining activities. One of the important components of the dump truck that is directly in contact with the road surface and is a determining factor in the safety of the driver from the risk of accidents is the tire. For good tire rotation, the size for the front, rear, right and left positions must be the same. Therefore, it is important to know the wear rate of each tire position. This paper study aims to analyze whether there is a difference in the wear rate of dump truck tires on the UD Quester CWE 370 and Mercedes Benz AXOR 2528 C types. The tire wear rate analyzed was in the front right, rear outer right, rear outer left, and front left positions. Data collection was carried out directly in the field and has been documented in an academic report. Data analysis used Kruskal Wallis nonparametric statistics because the sample size was small and if it met the parametric assumptions then One Way ANOVA was carried out. Data processing was done using R software. Kruskal Wallis analysis in R with a 5% error resulted in no difference in the tire wear rate of the UD Quester CWE 370 and Mercedes Benz AXOR 2528 C dump trucks. Meanwhile, the One Way ANOVA analysis in R with a 5% error was only performed on the Mercedes Benz AXOR 2528 C tires and resulted in no difference in the tire wear rate as well.**

Keywords: Tire, Wear rate, Dump truck, Kruskal Wallis, One Way Anova, R.

I. INTRODUCTION

Generally, mining activities include excavation, loading, and transportation. Mechanical equipment is usually used to expedite the transportation of mining materials. Tires are one of the important elements of a vehicle that comes into direct contact with the road surface [1]. In reality, vehicle tires can experience several problems while driving, one of which is wear on the surface. Because tires are an important part of a vehicle, their wear can cause a large number of traffic accidents [2]. The consequences of traffic accidents can cause large social and economic losses, losses for individuals, families, companies or institutions, and even countries. Therefore, the safety of transportation users is an important element of every transportation system [3]. Tire wear is an inevitable consequence of friction between the road and the tire that is necessary for the safe operation of vehicles on the highway [4]. Wear is the loss of material from a surface or the transfer of material from its surface to another part or the movement of material on a surface. Wear occurs throughout the life of the tire and is influenced by various conditions. Factors that can affect wear include travel speed, load size, surface profile, and the hardness of the tire material itself. The hardness of the tire material can affect its performance [5]. Other studies also analyzed factors affecting tire wear [6], [7]. The hardness of tire materials almost always varies. Tires used on paved roads are usually softer than those used in mining.

The most important factor in efficient tire usage is the selection according to working conditions. The main production unit used in open coal or nickel mining is the dump truck [8]. Mining dump truck tires have special requirements, because their operation is carried out in difficult road conditions [9]. In the mining world, dump trucks are categorized based on their carrying capacity, drive system, and flexibility in certain terrain. The types of dump trucks commonly used in mining are Rigid, Articulated, Off-Highway, Side, and Rear. The class of trucks often used in medium-class mines is the Rear dump truck or standard heavy class and is often called heavy duty truck. Types of this truck include the Mercedes Benz AXOR 2528 C and UD Quester CWE 370. The Mercedes Benz AXOR 2528 C is very popular in Indonesia, especially for transporting medium-scale coal or nickel mines. While the UD Quester CWE 370 is more powerful for steep inclines than the Mercedes Benz AXOR 2528 C.

In general, the tires for the right and left sides of the same axle, both front and rear, do not have specific differences from the manufacturer. However, if you look at the relationship between the front axle (steer) and rear axle (drive), there are crucial differences. The difference is in the function between the front and rear and the right and left rules of one axle. Dump trucks usually use different types of tires based on the front and rear positions to optimize performance. Meanwhile,

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for the right and left positions of one axle, although the tire type is the same, there are rules to ensure the dump truck remains stable and safe, namely the tire size, wear level, and air pressure must be the same. Several studies state that pure tire wear only occurs in a small amount in the environment, most tire wear is related to road materials [10]. For safety reasons, it is important to know the difference in wear rates of each dump truck tire position as a tool for transporting materials in mining activities.

One of the main challenges in maximizing vehicle performance is knowing, predicting and optimizing tire behavior under various working conditions, such as temperature, friction, and wear. Based on the principles of physics, experimental data, or statistical methods available in the literature, research has been conducted to propose a new tire wear model that combines physical and statistical analysis on a large amount of data [11]. The wear rate at each position of the dump truck tire can be determined through statistical tests using data in small or large sizes from the measurement results. If the data size is small, the analysis is carried out using the nonparametric Kruskal Wallis statistical test tool [12], otherwise it is parametric One Way ANOVA. The work of testing whether or not there is a difference in tire wear rate data in this paper uses R software.

II. MATERIALS AND METHODS

2.1 Dump Truck for Mining

The industrial world today has experienced rapid developments in technology. Mining is one of the expensive and complex industries. Extensive studies have been conducted on related sections such as geology, canalization, and excavation planning and operation processes. In open pit mining, the movement of raw materials is considered one of the most challenging tasks with truck transportation representing the most influential factor on mining costs [13]. Industries engaged in the mining sector mostly carry out work using mechanical heavy equipment dump trucks in the process of transporting mined materials. Generally, mining companies use dump trucks to move materials from one location to another. dump trucks are a type of mechanical heavy equipment used in mining activities with the aim of work efficiency. The mining industry encounters significant challenges in managing operational costs, especially those related to the maintenance of transport truck tires [14]. PT Djava Berkah Mineral (PT DBM) is a mining service provider company that carries out production operations in the Mining Business Permit Area (WIUP) owned by PT Bukit Makmur Istindo Nikeltama (PT BUMANIK). The mining commodity is Nickel Laterite which uses the Open Cast Selective Mining method due to the distribution of nickel ore on the hillsides. PT DBM carries out its production at the Syukur Pit, Peboa Block. Mining activities begin with stripping topsoil using a Komatsu D85ESS Bulldozer unit. The activity of removing overburden (waste) is continued with the extraction of nickel ore (ore getting) using Komatsu PC 200-8MO and Komatsu PC 300-8MO Excavators. The activity of transporting nickel ore (hauling) uses UD Quester CWE 370 dump truck and Mercedes Benz AXOR 2528 C which is carried out from the Syukur Pit to the Exportable Transit Ore (ETO) Melati with a haul road length of 1069 m.

Figure 1: UD Quester CWE 370

Figure 2: Mercedes Benz AXOR 2528 C

2.2 Dump Truck Tires

Tires are one of the most important components of a vehicle due to their role in the safety, directional stability, and comfort of the vehicle. Tires are also automotive devices that function to reduce vibrations from irregularities in the road surface, support the vehicle's load and its cargo, transmit propulsion and braking forces, and provide stability between the vehicle and the ground to expedite movement. The interaction between tires and the road plays a fundamental role in vehicle safety because insufficient friction between the two contributes to accidents [15]. Tires are generally designed to achieve the best compromise between rolling resistance, slip resistance, and wear. Designing safe, fuel-efficient, and durable tires requires a thorough understanding of tire-road

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interaction. heavy goods vehicle (HGV) tire design has an additional level of complexity because heavy vehicles use multi-axle groups that produce high lateral forces and can cause friction when turning [16]. Dump truck tires for mining are the final drive of vehicles that come into direct contact with uneven, rough, bad, rocky roads, and have good resistance to wear and cuts compared to other types of tires. The main construction of a tire consists of 4 parts, namely tread, carcass, breaker, and bead. Meanwhile, the parts that have the main function consist of crown, shoulder, sidewall, and bead. In dump truck, smaller tire positions can be used on the front wheels, however, for good rotation, the size for the front and rear, right and left should be the same. However, in cars, tire rotation is necessary because the front and rear wear levels are different. Generally for dump truck units the number of tires used is 6 (six), where the front position is 2 (two) tires and the rear position is 4 (four) tires [17]. The naming of the dump truck tire position starts from the front left tire, which is

1. Front left.
2. Front right.
3. Rear outer left.
4. Left inside back.
5. Right inside back.
6. Rear outer right.

Figure 3: Dump Truck Tire Position

The dump truck tires tested for wear were the right front, rear outer right, rear outer left, and left front tires. The rear tires were tested for wear on the outside tires because they are more prone to wear than the inside tires.

2.3 Tire Wear Rate

Wear is caused by many factors and involves three main consequences are loss of performance, loss of safety, and environmental pollution. Usually, wear is related to sliding friction and is measured by the amount of material removed, but various types of wear can be observed, with the rate and extent of wear depending on various mechanical, physical, chemical, and electrical phenomena that may occur separately or simultaneously [18]. Tire wear occurs throughout the service life and is influenced by a variety of conditions. Condition factors that influence tire wear include internal and external factors. Internal factors include pressure, temperature, and tire material properties. Different types of materials have different properties, some are wear-resistant and some are not, some are heat-resistant and some are not. These properties influence tire wear directly or indirectly. External factors can be divided into two parts, namely vehicle setup and environmental factors. Modern vehicles provide a variety of toe and camber angles, which cause different wear patterns. Environmental factors include weather, such as temperature, whether it is raining or not, and road conditions. A study stated that tire wear behavior is influenced by many factors, including tire type, tire pressure, vertical load, driving style, and road surface properties. Besides that, tread temperature also affects tire performance [19]. Poorly maintained mining roads affect tire life. In loading and hauling operations, dump trucks are susceptible to damage, especially to tires, due to having to travel long distances and carry heavy loads. To minimize the risk of tire damage, tire management is necessary, namely evaluating tire performance by analyzing key performance indicator (KPI) parameters, one of which is tire life, which is calculated from the time it is assembled on the unit until the tire is no longer assembled.

$$\text{Tire Life} = \text{Tread Utilization Rate} \times \text{Tread Thickness of New Tire} \times \text{Tire Wear Rate Time per millimeter [20].}$$

The wear rate can be measured by deriving a formula based on the tire's age. The tire wear indicator indicates the tire wear rate indicator or when it needs to be replaced. The tire wear indicator shows the bulges in the tread, the amount of which depends on the variations around the tire.

2.4 Kruskal Wallis Nonparametric Statistics in R

Nonparametric tests are statistical methods used for hypothesis testing that do not assume a specific data distribution, making them useful for skewed or ordinal data. Nonparametric models are flexible and not predetermined in terms of their parameters, making them distribution-free. This test is suitable when the data does not meet parametric assumptions, such as normality and uniform variance. One nonparametric test that is the Kruskal Wallis test, an alternative to One-Way ANOVA parametric tests. The Kruskal Wallis test is advantageous because of its minimal dependence on data format assumptions and its robustness to outliers. This test is very useful when parametric assumptions are violated, although it may have lower statistical power and be more difficult to interpret [21]. The Kruskal Wallis test,

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developed by Kruskal and Wallis in 1952, is a widely used nonparametric statistical method for comparing multiple independent groups when the normality assumption is not met. Conducting about to sample size, the ANOVA F test is preferred for cases of large sample sizes. While the Kruskal Wallis test is preferred for cases of small sample sizes [22]. The Kruskal Wallis test is widely recommended as a nonparametric equivalent of the parametric ANOVA F procedure for comparing more than two treatments. However, the asymptotic chi-square distribution under the null hypothesis of equality of associated locations tends to be conservative, especially for small sample sizes or large number of groups. The currently available formula for the Kruskal Wallis test is based on the noncentral chi-square distribution under the assumption of local alternatives [23]. In small sample sizes, even if the assumptions of normality and equal variance are met, the inaccuracy of a One-Way ANOVA test becomes very large. The Kruskal Wallis test is widely used in various fields such as medicine, social sciences, psychology, and engineering due to its robustness and applicability to non-normally distributed data. This test is implemented in various statistical software packages, including R, making it easily accessible for practical applications [24]. R provides a series of interconnected facilities that make fitting statistical models very simple [25]. Despite its wide application, investigations into trends and collaborative research surrounding the Kruskal Wallis test based on bibliometric analysis that can provide a comprehensive picture of the development and impact of research related to this test over time are still limited [24]. However, the nonparametric Kruskal Wallis procedure is widely documented in statistical texts as a viable alternative to the ANOVA F test when the underlying population distribution is unknown [23]. The work in this paper is to analyze the tire wear rate data of dump truck of UD Quester CWE 370 and Mercedes Benz AXOR 2528 C type using the Kruskal Wallis test with a small sample and the normality requirements are not met. If the sample size turns out that the normality requirements are met, a One-Way ANOVA test is also carried out.

III. RESULTS AND DISCUSSIONS

3.1 Dump Truck Tire Wear Rate Measurement Data

The wear rate measured in this study was the right front, right rear outer , left rear outer, and left front tire on the dump trucks of UD Quester CWE 370 and Mercedes Benz AXOR 2528 C type used as nickel ore transport equipment at PT Djava Berkah Mineral Petasia Timur, North Morowali, Central Sulawesi, Indonesia. The tire wear rate data from the measurement results for the UD Quester CWE 370 type are presented in table 1.

Table 1: Tire Wear Rate on UD Quester CWE 370

T1	T2	T3	T4
18,61	10,63	9,18	47,86
34,09	27,28	27,97	21,82
27,45	10,76	9,38	26,14
24,63	15,97	32,29	30,27
17,35	6,8	22,39	6,09
36,81	19	19	26,18
12,39	13,49	11,46	10,92
5,74	12,41	19,61	12,67
13,76	22,93	17,69	13,76
33,85	33,85	48,36	19,91
13,68	57,74	24,75	21,65
18,15	33,09	17,05	70,31
13,88	18,82	38,65	49,31
8,68	17,37	25,38	16,5

Meanwhile, the measurement results for the Mercedes Benz AXOR 2528 C type, the data are distributed in table 2.

Table 2: Tire Wear Rate on Mercedes Benz AXOR 2528 C

T1	T2	T3	T4
3,89	15,56	11,67	5,38
26,45	14,64	13,9	9,88
44,44	21,05	23,53	16
35,83	26,88	15,93	23,24
15,74	9,8	22,33	10,43
33,97	9,4	11,47	16,67

T1, T2, T3, and T4 shows the position of the dump truck tires which in this study is understood as:

T1 = right front
T2 = rear outer right
T3 = rear outer left
T4 = left front

The data on tire wear rates of dump trucks of UD Quester CWE 370 and Mercedes Benz AXOR 2528 C type in Tables 1 and 2 show small sample sizes (n < 30).

3.2 Normality Test and Equality of Variance of Tire Wear Rate Data in R

Normality and equality of variance tests are performed to make a decision on the use of statistical test tools, whether One-Way ANOVA (parametric) or Kruskal Wallis (nonparametric). If the assumptions of normality and equal variance are met, then a parametric test is performed and if not, then the opposite is nonparametric. The following is the normality test command for the tire wear rate of the UD Quester CWE 370 dump truck in R.

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```
setwd("D:/SEMNASMAT2025 UNNES")
UdQuesterCWE370 <- read.csv("D:/SEMNASMAT2025 UNNES/UdQuesterCWE370.csv")
View(UdQuesterCWE370)
anova <- aov(TireWear~Group, data=UdQuesterCWE370)
anova.residuals <- residuals(object = anova)
shapiro.test(anova.residuals)
```

Based on the output of the R program, the p-value was 0.0002573, indicating that the normality of the tire wear rate data for the UD Quester CWE 370 dump truck was not met.

Meanwhile, the R program for testing the normality of the tire wear rate data for the Mercedes Benz AXOR 2528 C dump truck is

```
setwd("D:/SEMNASMAT2025 UNNES")
MercedesBenzAXOR2528C<-
read.csv("D:/SEMNASMAT2025
UNNES/MercedesBenzAXOR2528C.csv")
View(MercedesBenzAXOR2528C)
anova<-aov(TireWear~Group,
data=MercedesBenzAXOR2528C)
anova.residuals <- residuals(object = anova)
shapiro.test(anova.residuals)
```

The program produced a p-value of 0.9887, indicating that normality was met. Next, a test of equality of variance was performed on the wear rate data for both types of dump trucks. The R program command for the equality of variance test was the tire wear rate of the UD Quester CWE 370 dump truck.

```
setwd("D:/SEMNASMAT2025 UNNES")
UdQuesterCWE370 <- read.csv("D:/SEMNASMAT2025 UNNES/UdQuesterCWE370.csv")
View(UdQuesterCWE370)
anova <- aov(TireWear~Group, data=UdQuesterCWE370)
summary(anova)
anova.residuals <- residuals(object = anova)
bartlett.test(TireWear~Group, data=UdQuesterCWE370)
```

The R program produced a p-value of 0.1599, indicating equal variance (homogeneous). Meanwhile, the R command for the equal variance test on the tire wear rate data for the Mercedes-Benz AXOR 2528 C dump truck is as follows:

```
setwd("D:/SEMNASMAT2025 UNNES")
MercedesBenzAXOR2528C<-
read.csv("D:/SEMNASMAT2025
UNNES/MercedesBenzAXOR2528C.csv")
View(MercedesBenzAXOR2528C)
anova<-aov(TireWear~Group,
data=MercedesBenzAXOR2528C)
summary(anova)
anova.residuals <- residuals(object = anova)
bartlett.test(TireWear~Group,
data=MercedesBenzAXOR2528C)
```

The p-value from the R program results above is 0.08185, indicating equal variance (homogeneous). These results suggest that the Kruskal Wallis test (nonparametric) should be used to analyze the difference in tire wear rates for the UD Quester CWE 370 due to the small sample size and the assumption of normality not being met. Meanwhile, for the Mercedes Benz AXOR 2528 C type, in addition to using the Kruskal Wallis test due to the small sample size, a One-Way ANOVA (parametric) was also carried out considering that the assumptions of normality and equal variance were met.

3.3 Testing for Similarity or Difference in dump truck Tire Wear Rate with R

As the results of the normality and variance assumption tests above, the following program in R is used to test whether there is a difference in the tire wear rate of the UD Quester CWE 370 dump truck using Kruskal Wallis.

```
setwd("D:/SEMNASMAT2025 UNNES")
UdQuesterCWE370 <- read.csv("D:/SEMNASMAT2025 UNNES/UdQuesterCWE370.csv")
View(UdQuesterCWE370)
kruskal.test(data=UdQuesterCWE370,TireWear~Group)
```

The output of the R program above produces a p-value of 0.7258, meaning that there is no difference in the tire wear rate of the UD Quester CWE 370 type dump truck. Meanwhile, to analyze whether or not there is a difference in the tire wear rate of the Mercedes Benz AXOR 2528 C type dump truck using Kruskal Wallis with R is below.

```
setwd("D:/SEMNASMAT2025 UNNES")
MercedesBenzAXOR2528C<-
read.csv("D:/SEMNASMAT2025
UNNES/MercedesBenzAXOR2528C.csv")
View(MercedesBenzAXOR2528C)
kruskal.test(data=MercedesBenzAXOR2528C,TireWear~Gro
up)
```

The R program produces a p-value = 0.3173 which means there is no difference in the tire wear rate of the Mercedes Benz AXOR 2528 C type dump truck. The wear rate of the dump truck tires on the Mercedes Benz AXOR 2528 C type was also analyzed using One-Way ANOVA as follows in the R program.

```
setwd("D:/SEMNASMAT2025 UNNES")
```

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```
MercedesBenzAXOR2528C<-
read.csv("D:/SEMNASMAT2025
UNNES/MercedesBenzAXOR2528C.csv")
View(MercedesBenzAXOR2528C)
anova<-aov(TireWear~Group,
data=MercedesBenzAXOR2528C)
summary(anova)
```

R commands above resulted a p-value of 0.0272, indicating that the tire wear rates of the Mercedes-Benz AXOR 2528 C dump trucks were not the same. The analysis then continued with further testing using the Bonferroni test to determine which pairs of dump truck tires were different. The following R command is used to test which pairs were different as below.

```
setwd("D:/SEMNASMAT2025 UNNES")
MercedesBenzAXOR2528C<-
read.csv("D:/SEMNASMAT2025
UNNES/MercedesBenzAXOR2528C.csv")
View(MercedesBenzAXOR2528C)
anova<-aov(TireWear~Group,
data=MercedesBenzAXOR2528C)
summary(anova)
pairwise.t.test(MercedesBenzAXOR2528C$TireWear,MercedesBenzAXOR2528C$Group, p.adjust.method="bonferroni")
```

The command in the R program above gives the following output.

```
Pairwise comparisons using t tests with pooled SD
data:MercedesBenzAXOR2528C$TireWear and
MercedesBenzAXOR2528C$Group
  1    2    3
2 0.36 -    -
3 0.39 1.00 -
4 0.13 1.00 1.00
P value adjustment method: Bonferroni
```

The output states that each pair of tire positions has a different wear rate but it has a error more than equal to 13%. While the standard error limit tolerated in scientific and technical research is 5%, then that means that tire wear rate of dump truck of Mercedes Benz AXOR 2528 C type is no different.

IV. CONCLUSION

The tire wear rate of the dump truck type UD Quester CWE 370 and Mercedes Benz AXOR 2528 C on the right front, right rear outer, left rear outer, and left front tested using Kruskal Wallis nonparametric statistics resulted in no difference. While the tire wear rate of the dump truck type Mercedes Benz AXOR 2528 C tested using One-Way ANOVA resulted in a difference in each pair of tire positions with a large tolerance error above the standard, namely 13% and above, so that the tire wear rate of the dump truck type Mercedes Benz AXOR 2528 C tested using Kruskal Wallis nonparametric statistics and One-Way ANOVA parametric gave the same result, namely no difference.

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