APPLICATION OF THE WEIBULL DISTRIBUTION MODEL TO ESTIMATE MAINTENANCE INTERVAL AND OPERATIONAL LIFESPAN OF VEHICLE INSPECTION EQUIPMENT

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ABSTRACT
Periodic inspection equipment for vehicles includes exhaust emission inspection equipment, noise level, brake, front wheel alignment, headlight capability and radiance, and speedometer. All of this equipment is often used without definite maintenance schedules or service life estimates. A common obstacle in the field is the lack of an efficient maintenance period for the equipment. Consequently, sudden breakdowns can disrupt operations. Data was collected from 14 vehicle inspection agencies, each handling 70-90 inspection vehicles per day. After the goodness of fit test was carried out, the data was found to follow a Weibull distribution. Therefore, this study aims to estimate the service life and efficient maintenance period for vehicle inspection equipment using the Weibull distribution. The longest estimated service life was for the noise level inspection equipment, at 19.2 years, while the shortest was for the speedometer inspection equipment, at 13.3 years. The longest estimated maintenance period was for the gasoline emission inspection equipment, at 5.5 months, and the shortest was for the front wheel alignment inspection equipment, at 4.9 months.

Keywords: transportation; maintenance efficiency; equipment procurement efficiency

INTRODUCTION
Public transportation and freight vehicles often lack proper maintenance, unlike private vehicles. Therefore, public and freight transport operators must conduct vehicle inspections to ensure safety. As detailed in Government Regulation of the Republic of Indonesia Number 55 of 2012, vehicle inspection is a critical process for ensuring safety, reliability, and regulatory compliance (Mashadi & Crolla, 2013). This process involves a series of tests and evaluations to verify that vehicles meet technical, safety, and environmental requirements before operating on public roads where failures risk public safety (Borbón Angulo et al., 2025).

The Vehicle Inspection Service Unit (UPPKB), an agency under Indonesia’s Ministry of Transportation, is tasked with facilitating periodic vehicle inspections. Consequently, every UPPKB maintains all necessary inspection equipment, including tools for exhaust emissions, noise levels, brakes, wheel alignment, headlight capability/radiance, and speedometer accuracy. This equipment is used daily for periodic inspections (Priambudi et al., 2020). A key operational challenge is the absence of efficient maintenance schedules, resulting in reactive maintenance (repairs only after failure). Sudden equipment breakdowns thus disrupt ongoing inspections (Sutaryo & Nugroho, 2020).

Operational duration is a primary factor in determining equipment service life and maintenance intervals (Ahmadi & Hidayah, 2017). For vehicle inspection equipment, the daily volume of Mandatory Inspection Vehicles (KBWU) during operational hours is the critical determinant. Currently, no statistical method exists to estimate maintenance periods or service life for such equipment (Nurkusheva et al., 2024).

Statistical approaches for determining service life and maintenance intervals include the Weibull distribution and exponential distribution methods (Barabadi et al., 2014). Method selection depends on whether sample data follows a Weibull or exponential distribution. Initial distribution tests confirmed that the sample data follows a Weibull distribution (Alsyouf et al., 2018).

METHOD

The method adopts the Weibull distribution after a goodness-of-fit test confirms the data's conformity to this pattern. The model then estimates the service life and maintenance intervals of vehicle inspection equipment, due to its ability to model three failure patterns: (1) increasing, (2) decreasing, or (3) constant failure rates.

Data Collecting

Data collection involved gathering historical records for periodic vehicle inspection equipment from 14 inspection agencies across randomly selected areas. These agencies each handle rate 70-90 Mandatory Inspection Vehicles (KBWU) daily and include as Table 1.

Table 1.
Location of Research Area

No.	Location
1.	UPPKB Cilincing
2.	UPPKB Pulogadung
3.	UPPKB Ujungmenteng
4.	UPPKB Sleman
5.	UPPKB Bekasi City
6.	UPPKB Bandung City
7.	UPPKB Tangerang
8.	UPPKB Boyolali
9.	UPPKB Bogor
10.	UPPKB Bogor City
11.	UPPKB Kedaungangke
12.	UPPKB Jagakarsa
13.	UPPKB Cirebon
14.	UPPKB Kuningan

The data collected includes the brand of the equipment, name and type of equipment, year of manufacture, year of procurement, service life (years), and maintenance history.

Data Analysis

Using the collected data, we apply the Weibull distribution method to estimate maintenance intervals and service life for vehicle inspection equipment handling 70–90 Mandatory Inspection Vehicles (KBWU) daily rate. This analysis derives the shape parameter (β) and scale parameter (η), which directly determine the equipment's maintenance schedule and operational lifespan. Finally, the results are visualized graphically to facilitate interpretation (Khuntia et al., 2023; Ramos et al., 2017).

RESULT AND DISCUSSION

Goodness of Fit Test

The Anderson-Darling goodness-of-fit test is a statistical method used to assess how closely sample data follows a specified distribution (e.g., normal, Weibull, or exponential) (Anderson & Darling, 1954). It quantifies the discrepancy between the empirical cumulative distribution of the sample and the theoretical cumulative distribution by calculating a test statistic weighted toward distribution tails (Stephens, 1974). A larger test statistic indicates a stronger deviation from the theoretical distribution, suggesting the data does not conform to it. Compared to other goodness-of-fit tests like Kolmogorov-Smirnov (Massey, 1951)), the Anderson-Darling test is more sensitive (Razali & Wah, 2011). The test conclusion is determined by comparing the P-value to a chosen significance level (α) (D'Agostino & Stephens, 1986). Calculating the P-value requires several key inputs, including:

$$S = \sum_{i=1}^{N} \frac{(2i-1)}{N}\left[ln\, ln\, F(y_i) + ln\, ln\left(1 - (Y_{N+1-i})\right)\right]$$

Where:

S = Sum of Anderson-Darling values for all data points

F = Theoretical cumulative distribution function (CDF)

Y_i = Ordered sample data sequence (with $Y_1 \leq Y_2 \leq \cdots \leq Y_n$)

The statistic S is used to calculate the Square Anderson-Darling test statistic A^2, defined as:

$$A^2 = -N - S$$

After that we calculate the Anderson Darling (AD) value with the following equation:

$$AD = A^2\left(1 + \frac{0,2}{\sqrt{N}}\right)$$

From this AD value, the p-value will be determined using the equation as in Table 2 below.

Table 2.
P-value Equation

No.	Statistik AD	P-*value* Equation
1.	$AD \geq 0,6$	$p = exp(1,2937 - 5,709(AD) + 0,0186(AD)^2)$
2.	$0,34 < AD < 0,6$	$p = exp(0,9177 - 4,279(AD) + 1,38(AD)^2)$
3.	$0,2 < AD < 0,34$	$p = 1 - exp(-8,318 + 42,796(AD) - 59,938(AD)^2)$
4.	$AD \leq 0,2$	$p = 1 - exp(-13,436 + 101,14(AD) - 223,73(AD)^2)$

After the P-value is known, it is then compared with the significance level value (α = 0.05). If the P-value is greater than the significance level value, then the data is Weibull distributed. Table 3 and Table 4 below will show the results of the Anderson Darling test calculation from the service life and maintenance period data of vehicle inspecting equipment.

Table 3.
Anderson Darling Test Results Vehicle Test Equipment Lifespan Data

No.	Inspection Equipment	P-*value*	Conlusion
1.	Emission (Gasoline)	0,64	Weibull Distributed
2.	Emission (Diesel)	0,86	Weibull Distributed
3.	Brake	0,06	Weibull Distributed
4.	Noise Level	0,46	Weibull Distributed
5.	Frontwheel Alignment	0,13	Weibull Distributed
6.	Headlight capability and radiance	0,06	Weibull Distributed
7.	*Speedometer*	0,07	Weibull Distributed

Table 4.
Anderson Darling Test Results Vehicle Test Equipment Maintenance Data

No.	Inspection Equipment	P-*value*	Conlusion
1.	Emission (Gasoline)	0,06	Weibull Distributed
2.	Emission (Diesel)	0,08	Weibull Distributed
3.	Brake	0,09	Weibull Distributed
4.	Noise Level	0,06	Weibull Distributed
5.	Frontwheel Alignment	0,11	Weibull Distributed
6.	Headlight capability and radiance	0,06	Weibull Distributed
7.	*Speedometer*	0,07	Weibull Distributed

To estimate the service life of motor vehicle inspection equipment, the scale parameter (η) must be determined using the equation.

$$\eta = -exp\left(\frac{intercept}{slope}\right)$$

While the shape parameter (β) is the slope of the graph (Abernethy, 2006). It should be noted that the intercept and slope are obtained from the graph of the relationship between ln (lifetime) and ln (-ln (reliability)) (Weibull, 1951). After that, the estimated life time and maintenance period can be calculated using the equation (Nelson, 1982).

$$R(t) = e^{-\left[\frac{t}{\eta}\right]^{\beta}}$$

$$t = \eta \times \left(-\ ln\ ln\ (R)^{\frac{1}{\beta}}\right)$$

Where:

t	=	Life time or Maintenance Period
R	=	Reability
η	=	Scale Parameter
β	=	Shape Parameter

The calculated scale parameter (η) and shape parameter (β) values differ across equipment types. The reliability value used for service life estimation is set at the minimum threshold of 0.357, representing the point where equipment is considered near total failure. Table 5 and Figure 1 presents the estimated lifetime results for all motor vehicle inspection equipment.

Table 5.
Vehicle Inspection Equipment Lifetime Estimation Results

No.	Inspection Equipment	Lifetime Estimation (Days)	Lifetime Estimation (Years)
1.	Emission (Gasoline)	5.046,2	13,8
2.	Emission (Diesel)	5.191,9	14,2
3.	Brake	6.041,9	16,6
4.	Noise Level	6.997,7	19,2
5.	Frontwheel Alignment	4.979,8	13,6
6.	Headlight capability and radiance	4.888	13,4
7.	*Speedometer*	4.858,4	13,3

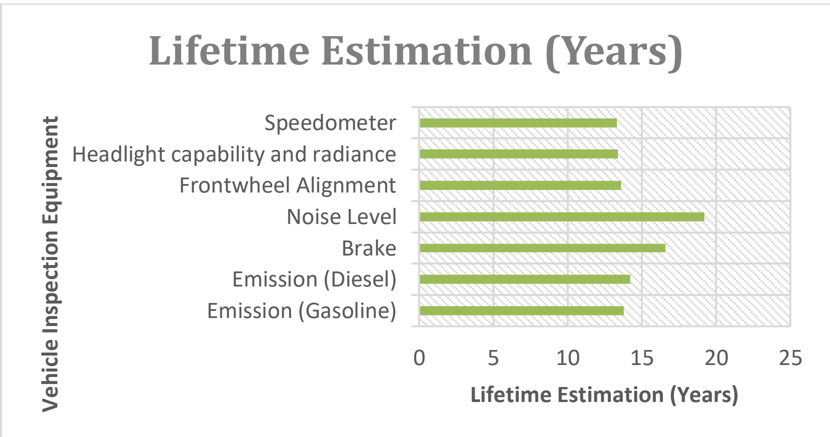

Figure 1. Vehicle Inspection Equipment Lifetime Estimation Results

Based on the estimated service life results for motor vehicle inspection equipment in Figure 1, each equipment type shows varying operational durations before reaching its functional limit. Noise level inspection equipment has the longest service life at 6,997.7 days (~19.2 years), attributable to its straightforward operation using sound level meters. Conversely, speedometer inspection equipment has the shortest service life at 4,858.4 days (~13.3 years), indicating either greater maintenance frequency requirements or heightened wear sensitivity in its design. Overall service life ranges from

13.3 to 19.2 years, with most equipment (including emission testers [gasoline/diesel], brake testers, front wheel alignment testers, and headlight testers) falling within the 13-16 year range. Table 6 and Figure 2 presents maintenance period result for all motor vehicle inspection equipment.

Table 6.
Vehicle Inspection Equipment Maintenance Period Estimation Results

No.	Inspection Equipment	Maintenance Period Estimation (Days)	Maintenance Period Estimation (Months)
1.	Emission (Gasoline)	165,4	5,5
2.	Emission (Diesel)	162,4	5,4
3.	Brake	153,7	5,1
4.	Noise Level	155	5,2
5.	Frontwheel Alignment	149,1	4,9
6.	Headlight capability and radiance	156,1	5,2
7.	*Speedometer*	159,1	5,3

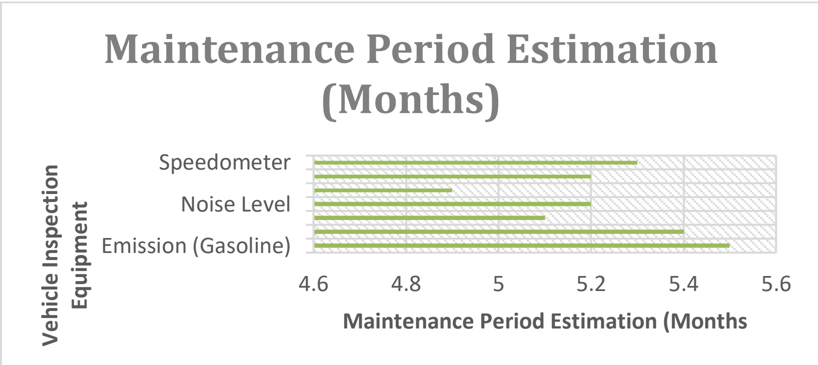

Figure 2. Vehicle Inspection Equipment Maintenance Period Estimation Results

The estimated maintenance periods for motor vehicle inspection equipment in Table 6.4 reveal relatively uniform intervals ranging from 4.9 to 5.5 months. Gasoline emission inspection equipment shows the longest maintenance period at 165.4 days (~5.5 months), suggesting either superior operational durability or less intensive maintenance requirements. Conversely, front wheel alignment inspection equipment has the shortest period at 149.1 days (~4.9 months), indicating more frequent maintenance needs.

CONCLUSION

From the description of the results of the data analysis above, the following conclusions were obtained:

1. Estimated lifetime for gasoline emission tester is 13,8 years, diesel emission tester is 14,2 years, brake tester is 16,6 years, noise level tester is 19,2 years, front wheel alignment tester is 13,6 years, headlight capability and radiance tester is 13,4, and speedometer tester is 13,3 years.
2. Estimated maintenance period for gasoline emission tester is 5,5 months, diesel emission tester is 5,4 months, brake tester is 5,1 months, noise level tester is 5,2 months, front wheel cup tester is 4,9 months, headlight capability and radiance tester is 5,2, and speedometer tester is 5,3 months.

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