APPLICATION OF STATISTICAL MODEL TO DETERMINE THE PERFORMANCE LEVEL DUE TO DAMAGE OF THE CONCRETE STRUCTURAL ELEMENTS

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ABSTRACT: Bridges must always be in good condition to support public transit, and traffic flow must provide road users with comfort and safety. Consequently, bridge repair must adhere to the criteria. Good performance requires four levels of maintenance: non-structural, structural, periodic, and restoration procedures. The deterioration of the bridge's components caused by public transit diminishes its functionality. The major performance benchmark then moves from zero to five. The bridge's concrete floor is one of the essential components since it rapidly absorbs traffic strain, making it more vulnerable to damage. Therefore, for optimal treatment, further care is necessary. Included in the observation data for the model are 240 bridges located on heavily used national roads in Indonesian provinces. Examples of changeable data include bridge age, traffic volume, concrete quality, superstructure features, and others. The ages of bridges vary from 5 to 40 years. Using a statistical model, a relationship between the value performance and damage variables is established, resulting in a model curve. A study of many linear regressions indicates a nonlinear angle produced by the most damaging factors. On the other hand, Ordinal logistic regression provides an integer scale; the benefit of this model is that its value drops in response to restoration to the prime state by its maintenance program. Over 52.5 years, the model represents deterioration on a scale of 5 from good to incorrect. Consequently, this curve model is essential for properly managing the decline in finance.

Keywords: Bridge performance, level scale 0-5, ordinal multi-regression, performance changing period, programming.

1. Introductions

The purpose of bridges is to facilitate public transportation. The bridge's construction, which is not elevated above the subgrade, distinguishes it from other road structures; hence, maintaining the bridge floor, typically composed of concrete, is of utmost importance to ensure its safety and stability.

According to IBMS, the Indonesian Bridge Design Code, the bridge deck is the section immediately traversed by vehicular and foot traffic (1993).

A bridge's "service performance" is determined by the intensity and frequency of the impact of traffic loads "on the floor directly supporting the load." In contrast, age, load, and quality all influence performance. This research focuses on developing a damage-related performance level curve. Here, the SPSS statistical model looks for a correlation between "impairment and independent variables" that affect it (Li et al., 2019).

Routine maintenance, rehabilitation, and element replacement are required to maintain acceptable performance levels (Flah et al., 2021). Regarding financing, however, there is a significant difference between the three.

The performance condition and kind of management of national bridges in 2020 are outlined here (Table 1).

Table 1. Status of Bridge performance

No.	Description	Amount	Stable	Non-Stable
1	Total (Ea)	18,917	16,498	2,419
2	Length (m)	524,501	457,417	67,084
3	Ratio (%)	100	87.21	12.79

*) Book of national roads conditions, Directorate of road and bridge engineering, 2020

Stable performance status implies that a regular maintenance program is necessary to maintain a high-performance level. In contrast, non-stable needs for non-routine services have limited access to public services. Regular functioning ratio weights demonstrate the capacity to give appropriate road user safety and comfort. This model reduces non-routine work programs due to the equilibrium of field conditions.

Performance Condition Value

IBMS defines five performance-level scales (Haensch et al., 2006). It begins with a brand-new condition when the bridge begins to function for the first time and is "rated excellent (0), very good (1), good (2), moderate (3), critical (4), and collapsed (5)." The period change from initial condition 0 to failure is represented by the curve model (5).

The researcher examined the state of the bridge using the following hierarchy (Xia et al., 2022): "smallest element (level-5), group (level-4), component (level-3)," portion (level-2) until the end (level-1), which was the structural bridge score.

AUSROADS, 2004, Bridge Management Guidelines, Structural information (Marquez et al., 2021) classifies performance levels as "(1) Built as-is, (2) Good, (3) Fair, and (4) Poor." AASHTO (Moharekpour et al., 2022) divides it into eight categories: "1. Excellent, 2. Very good, 3. Good, 4. Satisfactory, 5. Adequate, 6. Not good, 7. Serious, 8. Critical, 9. Nearly failed, and 10. Failed." This model analysis pertains to AG's viewpoint (Peng, 2021). The bridge's condition is deteriorating due to heavy use and worsening weather. If there is no answer, the cost of repairs will be high. The research demonstrates that repetitive loads diminish the bond strength of reinforced concrete composites to the point where rinsing reaches a limit and only fortification is effective. The optimal conduct is economical and has few technological prerequisites (Martinez & Kowalsky, 2022). Several data are required to build maintenance policies for all levels of national and regional road development. The lack of data on scale conditions of 4 or 5 is owing to the rapid replacement of crucial location conditions. In this instance, the commencement of bridge operations signals the conclusion of the time of harm. Crash rates and optimization models aid in maintenance. This research seeks to describe the curve model of bridge performance decline, identify the damage factor using a standard 0 to 5 scale, and build a system management program for an excellent long-term level of bridge performance.

1.1 Bridge Inspections

A general inspection consists of three types (Jeong et al., 2018): a yearly evaluation, a complete examination at least once every three years, and a review of specific issues or severe damage. As shown in Table 2, IBMS splits the calculation of condition values into five inspection aspects: element shape, damage kind, damage quantity, function, and impact.

Table 2. Assessment Criteria

Elements	Criteria	Score
Shape (S)	Change significant	1
	Fixed, Dimension tolerable.	0
Damage (D)	Severe to structure	1
	Light, no structural type	0
Quantity (Q)	More than 50 %	1
	Small, less than 50 %	0
Function (F)	Broken	1
	Full working	0
Impact (I)	Impact on other elements	1
	No impact, no effect on others	0
IBMS, 1993		

Form, damage, and amount necessitated observations and testing with laboratory instruments or equipment to get numerical data, whereas the fourth and fifth required technical analysis. At the time of the evaluation, the researcher determined the conditional value of each element, where the total element scores were S, D, Q, F, and I. The computation accounted for all harmed building components, including those in the foundation and superstructure (Figure 1a and Figure 1b).

Figure 1a. Crack damage pattern at the bottom slab

Fig 1b. Surface crack at the end joint

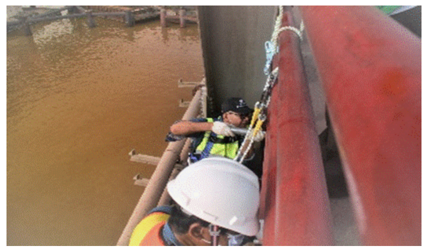

Fig 2a. Test concrete Slab

Fig 2b. Testing Girder

In 2020, our team examined the components of the Musi Bridge in the province of South Sumatera: concrete compressive in Figure 2a. and steel girder Brinel in Figure 2b.

2. A framework of Thought and Literature Review

The fundamental components of the bridge structure are the upper and lower systems. The substructure transfers the building's weight from the bridge's foundation to the subgrade. In contrast, the superstructure supports all direct loads, including traffic loads transmitted through the bridge deck components. As with other bridge systems, concrete is frequently used for floors and some bridge girders, which is essential for accommodating traffic comfortably. It is structural concrete used for structural purposes and comprises both plain steel and reinforcing steel (Zhou et al., 2018; Zulyadi et al., 2021).

The modeling technique will focus on the existence of bridge deck plates, which represent bridge engineering services. These variables include the age of the concrete deck, the quality of the concrete, the traffic volume, the number of truck vehicles, the plate dimensions, the span, the zone area, and the type of steel frame; statistical approaches aid in the building of models containing these variables (Valente, Sibai, & Sambucci, 2019; Yanti et al., 2022).

2.1. Concrete Element Specifications

Damage to reinforced concrete, which consists of reinforcing steel, gravel, sand, cement, and water (Deng et al., 2018; Yağcı & Özbozkurt, 2022), can be viewed from two procedural vantage points: "material strength and loading effects." Researchers must concentrate on the quality of concrete and steel mixture's quality. The factory-produced quality uniformity of steel is far more precise than that of concrete, whose endurance depends on material adhesion.

Unless indicated in the specific specifications and contract agreement (Cadenazzi et al., 2020), structural concrete shall be referenced 28 days following placement. "Concrete strength" over time possesses the "correlation factors" listed below (Table 3).

Table 3. Concrete Age vs. Types of Portland Cement (PC).

AGE of Mix, days	3	7	14	21	28	90	365
Ordinary PC	0.40	0.65	0.88	0.95	1.00	1.20	1.35
High initial PC	0.55	0.75	0.90	0.95	1.00	1.15	1.20
*) Indonesian Reinforcement concrete Code, 1971.							

The table indicates that "full strength occurs when the concrete mixture has been hardened for at least 28 days with a coefficient of one."

According to Xue et al. (2020), reinforced concrete is ideal for all types of bridges due to its resilience to stiffness, affordability, ease of fabrication, and aesthetic appeal.

Shim et al. (2019) state that "deck destruction is a common occurrence in many countries." Although numerous engineers are observing for solutions, a few reasons are accurate. Scaling, cracking, spalling, and rust is common forms of deterioration. There are four distinct types of cracking: transverse, longitudinal, diagonal, and map.

"Bridge defects: reinforcement corrosion, carbonation, alkali-aggregate reaction, cracking, spalling, surface defects, delamination, scaling, disintegration, chloride ingress, and water wash," according to Stoiber, Hammerl, and Kromoser (2021).

According to TRB, the national academies press in non-destructive testing to detect concrete bridge foundation deterioration (Akeed et al., 2022; Wolfe, 2021), "the causes of damage are complex, with cause and effect from one factor to the next. Rebar corrosion, deck delamination, vertical cracking, and concrete deterioration are all common occurrences".

As stated in Table 4, the "concrete material specification" for the deck is improved annually to make it stronger, more pleasant, and more durable. Listed in Table 4:

Table 4. Change of Concrete Specification

No.	Strength (fc'-MPa)	Specification In 1972	Specification In 1993	Specification In 2010
1.	Deck Slab	20	25	30

SNI 1725:2016 Siwowski, Rajchel, and Kulpa (2019) control "bridge loading standards: dead load, additional load, traffic, trucks, dynamic factors, brake force, pedestrians, fatigue, and environmental actions (temperature, wind, flood, and other natural occurrences)."

The loads alter the deflection of the constituents of concrete. It shows that the pattern of the deterioration model is nonlinear.

The concrete quality Sulistyono, Alisjahbana, and Ma'soem (2022) govern "the use of quality concrete tailored to the strength requirements of the structural elements, starting from low: Base work/lean concrete, substructure, beam, deck, retaining wall, etc." as outlined in Table 5 below.

Table 5. Concrete Specification

No.	Type	Quality fc' (MPa)	Construction Elements
1	High	X> 45	Concrete: Prestressed concrete (PC) piles, PC girders, PC-deck slab, etc.
2	Moderate	20<X<45	Concrete: Reinforced Concrete (RC) bridge deck slab, RC-girder, RC-Diaphragm, substructures, etc.
3	Low	15<X<20	Concrete non-reinforcement: mortar, masonry, pedestrian walkways, cyclopean concrete, etc.
		10<X<15	Based on lean concrete, re-embankment for subgrade.

*) General Specification for Bridge Structure, IBMS, 2010

The quality of the concrete deck contains a reasonable type of 20<X<45 Mega Pascal. ACI establishes categories for medium and high-grade structural concrete, with the fc' of structural concrete above 17 MPa.

2.2. Traffic Loading

Because the reinforced concrete floor elements are immediately subjected to traffic stress, they must withstand repeated loads. General and heavy vehicles, particularly trucks, contribute to traffic congestion. Other loads include line loads influencing the bridge deck's deflection (Tang, 2018; Vo & Ngo, 2021), whereas public transit represents a uniform load. The link between the loading code and site circumstances is depicted in Figure 3. Figure 3b shows the traffic load on the bridge, including a graphic of uniform and line loads and the traffic simulation at maximum conditions depicted in Figure 3a.

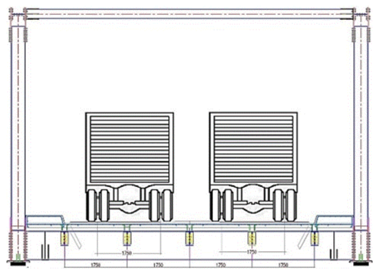

Fig. 3a. Forces diagram on the slab

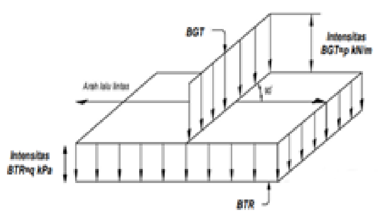

Fig3b. Maximum loading conditions

Figure 3. Traffic loading on a bridge

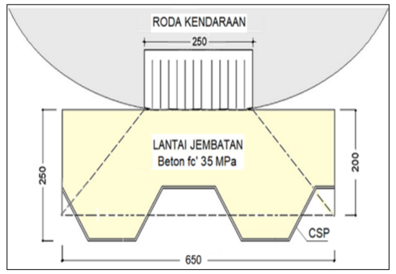

Figure 4a. The wheel on the concrete slab

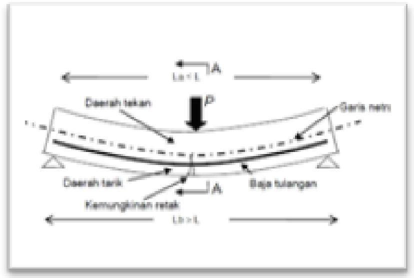

Fig. 4b. Deflection pattern

Figure 4. Loading distribution pattern on Slab and Girder.

The traffic loading has the configuration in Figures 3b. and 4a. It consists of a line (P) and uniform load (q) that affect deflection, as shown in figure 4b. The deflection causes a crack at the bottom of the slab when the internal force of concrete cannot bear loading.

The deflection ( ) formula for single linear span (L) follows as below:

$$\text{Line load t}: \partial = \frac{P.\ L^2}{48\ EI}$$

$$\text{Uniform load}: \partial = \frac{5 * q.\ L^4}{384\ EI}$$

Notes: EI is Modulus Young and Inertia of Slab dimension.

Due to traffic load, the bridge's concrete deck has a distribution pattern that covers the contact area of vehicle wheels (Sweet, 2022; Vatulia et al., 2019; Verma, Kadyan, & Gupta, 2022). As a deflection formula, the internal process of the material raises stress and strain during nonlinear phases.

The significance of this formula for deflection is not linear. To date, the model has required alteration to meet the requirements of the regression model. A similar change is valid for the influence of the length and width of the deck slab. The type of bridge, number of spans, and area zone are variables with simple linear relationships.

2.3. Common elemental damage

Frequent traffic loads harm the concrete floor and steel reinforcement. Meanwhile, structural supports, pile tops, and other substructure components experience slight deterioration [5, 6, 9]. Reinforcement corrosion, carbonation, alkaline aggregate reaction, cracking, flaking, surface rust, delamination, scaling, disintegration, chloride, and water leaching" are the most common damage to concrete bridge elements.

a) Concrete Slab damage

Damage to the concrete floor begins with load-induced deflection (Makul, 2020; Syarief, 2022), which develops fissures. It continues with the deterioration of the reinforcement, which dissolves the composite with the concrete and allows the bonds to break.

Examples of crack damage include peeling of the concrete cover, bending fracture, shear cracking, and compression area damage.

b) Overloading

By exceeding the concrete and reinforcing steel's allowable capacity, overloading lowers the durability of bridge components (He et al., 2020; Thi-Huyen, Xuan-Lam, & Thanh Tu, 2021). Physically, the directly affected floor of the bridge would deflect and crack. The bottom will sustain additional damage, rendering it unworkable.

c) Environmental impact

Temperatures at the investigated bridge locations in Indonesia range from 10 to 45 degrees Celsius, suggesting that changes in material quality have little effect. Normal to 120 degrees Celsius temperature changes have minimal impact on the performance of concrete. At 120-250 degrees Celcius, it will undergo fracture modifications, cement paste dehydration, moisture content loss, and strength loss.

3. Research Method and Data Analysis

3.1. Location.

Researchers investigated the condition of 240 bridges in all areas and islands. The number of bridges located in the same state or island as the total data column. The scale range column displays condition values ranging from 0 to 5. According to Table 6, the period is categorized in the final column.

The data comes from conventional bridges that span provinces and islands on national highways. This is especially true for information regarding bridges on critical roadways in Java and Sumatra, where large vehicles enter and exit the capital city and industrial areas. Data selection matches the bridge database maintained by the Bina Marga Head Office for 2005, 2006, and 2017 conditions (Dong, 2018). Methods for collecting data include internal-external sources, parallel-series time, qualitative and quantitative measurement, and primary-secondary acquisition—quantity of 240 data plus 10 data for the validation model. The summary of fundamental facts is presented in Table 7.

Table 6. Bridge Condition Data

No.	Province/ Island	Total data (240)	Scale Range	Year Period
1	West Java	60	0-5	1974-2013
2	Banten	25	0-4	1973-2010
3	Central Java	30	0-5	1975-2012
4	East Java	15	0-4	1972-2009
5	Bali	5	1-2	1998-2001
6	Nusa Tenggara	15	0-5	1978-2008
7	Sumatera	50	0-4	1975-2018
8	Kalimantan	10	0-3	1985-2011
9	Sulawesi	10	0 - 3	1980-1998
10	Maluku	10	0 - 4	1980-2003
11	Papua	10	0 - 2	1991-2009

Table 7. Basic data Summary

Performance Level		N (240)	Percentage (100%)
0	Very good-newly	18	7.5%
1	Good	49	20.4%
2	Fair	88	36.7%
3	Poor	57	23.8%
4	Very bad	23	9.6%
5	No Functional	5	2.1%

3.2. Application of Statistical model

Single linear, multilinear, multinomial logit, and ordinal logistic regression are all statistical regression models. In this case, researchers apply multiple linear regression and ordinal logistic regression. Multilinear regression generates "a continuous model curve." In contrast, ordinal logistic regression produces integers to regulate the results of the multilinear regression model.

The first step is determining which components are dependent and which are independent. The age of the bridge or floor in years (X1), traffic volume (X2), concrete quality (X3), truck vehicle weight in percentage (X4), span length in meters (X5), width in meters (X6), number of individual spans (X7), steel frame type category (X8), and zone category (X9) are the possible independent variables, according to the database (X9). The performance of the bridge is the dependent variable, with 240 observations. Using statistical software to handle data for decision-making is easier and more accurate, despite the requirement to acknowledge the theoretical foundation.

Regression is described by Mooi and Sarstedt (2011) as "the prediction of the effect of one data on another to anticipate future symptoms. In contrast, linear regression projects the dependent variable partially or simultaneously through the independent variables.

SPSS (Statistical Package for the Social Sciences) uses regression analysis to simulate strong correlations between independent and dependent variables.

a. Multiple linear regression

Linear regression follows the rule of satisfying the linear relationship between the independent and the dependent. In a multilinear analysis, all independent variables must fluctuate linearly. Independent variables are subjected to transformation. To transform the connection pattern into one that is linear. Independent variables with a straightforward linear relationship to dependent variables can be utilized directly without transformation.

Transformation formulae can take several forms, including squared powers, fractional powers, exponentials, natural logarithms, sine, and cosine. A linear connection pattern requires a comprehensive evaluation of the effect of each independent variable on the dependent variable.

The transformations of the independent variables were adjusted for the following:

- X1: Age of concrete, early linear due to little traffic, after traffic regular and repeat load the material restrains nonlinear, so combined linear and quadratic exponential type.

X_1=0.0025. (p2+3p), from the variable, p is the age in years

- X2: Traffic volume as loading the floor causes deflection, then indicates crack as exponential.

$X_2 = 0.2 \text{ Ln } (\frac{Vt}{2000})$ in PCU(Passenger Car Unit). Vt is the Average Annual Daily Traffic.

- X3: concrete strength re-strains the loading from deflection and stressing: quadratic type.

$X_3 = -(\frac{fc}{15})2$, from the variable f_c' concrete strength in Mega Pascal MPa.

- X4: Truck or heavy vehicles, as loading, similar to traffic volume, small quadratic type.

$X_4 = 0.4.(\frac{Tr}{15})$, from the variable T_r is the percentage of the truck.

- $X_5 = 0.5 * (\frac{L}{40})^{0.2}$, $X_6 = (\frac{w}{3.5})^{0.2}$, the variable length and width, as a small effect on the deflection, and X_7, X_8, and X_9 are assumed linear.

b. Ordinal Logistic Regression

This model generates a probability value for the dependent variable, with the resulting amount being more significant than 50%. Researchers use a 5-level performance classification, with one equation model for each level. This model yields two elements, namely performance and probability values, which are extremely useful in prediction and validation.

3.3. Data Analysis

1). Multiple linear regression model

In three phases, the researchers conducted their examination. The initial step entails identifying all variables. The second phase focuses on significant elements that will be further investigated, with the resulting model as the starting point. Validation with data from sources other than data analysis is the third step. After the validation phase, researchers selected which model to adopt.

The analysis of variance provides three independent variables with a significance value of 0.00 0.05 based on the initial analysis of nine (nine) independent variables: Age (X1), Traffic Vt (X2), X3, X4, X5, X6, X7, X8, and X9. R: 0.951, R^2: 0.905, and adjusted R^2: 0.901 are the related factors. All relationship factors more significant than 0.80 suggest that the independent and dependent variables have a strong link. It implies that the relationship model is correct.

Because the remaining six independent factors did not achieve the significance criterion, the three significant variables were studied further. They are the concrete age, traffic volume, and quality of concrete.

Repeat analysis of inputting the three variables produces a more accurate model. The model Summary and coefficient of the model equation as outputs of the analysis program are as follows:

The model summary (Table 8) shows a factoring relationship of R=0.951, R^2=0.904, and adjusted R^2= 0.903 means a strong correlation between both variables of independents and dependence. Factor t is the distribution value, threshold 5 indicates strong while 2-5 indicates fair, and Significant F change=0.000<0.05 indicates a valid model (Table 9).

Table 8. Model Summary

Model	R	R Square	Adjusted R Square	Std. error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	Df2	Sig F
1	.947[a]	.896	.895	.361503	.896	680.065	3	236	0.000

Table 9. Coefficients

Model		Unstandardized		Standardized	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.172	.191		6.124	.000
	Age	.647	.029	.793	22.467	.000
	Traffic Vt	.611	.213	.085	2.867	.005
	Quality fc'	.287	.064	.128	4.507	.000

Then the model of performance value is:

$$Y_n = 1.172 + 0.647.X_1 + 0.611.X_2 + 0.287.X_3 \quad 1)$$

The variable Xi needs to be re-transformation, and the result is:

$$Y_n = 1.172 + 0.647.(0.0025.p^2 + 3.p) + 0.611.(0.2.\text{Ln}\frac{vt}{2000}) + 0.287.(-(\frac{fc}{15})^2)$$

$$Y_n = 1.172 + 0.00161.p^2 + 0.00485.p + 0.1222.\text{Ln}(\frac{vt}{2000}) - 0.287.(\frac{fc}{15})^2 \quad 2)$$

Y_n is the performance model of the bridge, and p is the time in years.

Data validation for the linear model

Model validation improves accuracy by assessing the relationships of the updated model with independent factors outside the study data. There are ten new bridge data from various provinces, including Siak (Riau), Serdang (West Java), Cikuda (West Java), Way Civil (Lampung), Brang Simu (Nusa Tenggara), Musi 2A (South Sumatra), Wae Mese (Maluku), Angsau (Kalimantan), Kayutangi (Kalimantan), and Ngujang (Kalimantan) (East Java).

The following is the status model after validation with the new data (Table 10):

Table 10. Data Validation

No.	Name of Bridge	Age of element --years	Traffic Volume (Vt)	Quality (fc')	Prediction Model (Y_n)	Reported	Field Data	Status (7)-(8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1.	Siak	7	9,290	30	0,3249	**0**	0	*Valid*
2.	Serdang	12	11,761	25	0,8824	**1**	1	*Valid*
3.	Cikuda	20	17,152	25	1,3814	**1**	1	*Valid*
4.	WayPerdata	22	17,907	25	1,5323	**2**	2	*Valid*
5.	Brang Simu	27	21,477	20	2,2620	**2**	2	*Valid*
6.	Musi 2	30	26,116	20	2,5711	**3**	3	*Valid*
7.	Wae Mase	35	31,332	20	3,1492	**3**	3	*Valid*
8.	Angsau	39	37,826	20	3,6705	**4**	4	*Valid*
9.	Kayutangi	42	43,576	20	4,0954	**4**	4	*Valid*
10.	Ngujang	48	61,044	20	5.0392	**5**	5	*Valid*

Notes:

1. Mode (6): $Y_n = 1.172 + 0.00161.\ p^2 + 0.00485.\ p + 0.1222.\ \text{Ln}\ (\frac{vt}{2000}) - 0.287.(\frac{fc}{15})^2$
2. Column (3) is the age of the element, represented by the concrete slab in years.
3. Column (4) is the Value of Traffic volume AADT in year n or column (3).
4. Column (5) is the strength of concrete, fc' in MPa.
5. Column (8) is the Condition value official records.
6. Status: Comparing data (7) vs (8), similar means Valid.

2). Logistic Regression model

The Logistic or Logit regression model aims to improve the linear model's precision. The model value represents the matter's occurrence probability over a specified period. Field observations compute the likelihood of predicting the state of the elements

[20]. Ordinal logistic regression, where the ordinal component is the dependent variable, will have an independent value probability through the formulation model.

The logit equation model comprises age, traffic volume, and concrete quality independent variables. The following factors are indicative of the analysis:

- Case processing summary: contains the number of valid data
- Model fitting information: suitability of variable relationships,
- The goodness of fit: fit the model curve,
- Pseudo R-Square (R^2): variable correlation coefficient, and,
- Model parameters.

1) The logit model equation is:

$$\text{Logit}(Y_n) = \text{Ln}\left(\frac{Yn}{1-Yn}\right) = K_n + \alpha.X_1 + \beta.X_2 + \gamma.X_{3,} \quad 03)$$

- Where K is constant and α, β, γ is the coefficient for independent variables.
- Values of K, α, β, γ produced by the calculation program after inputting data.
- A α is coefficient X_1 (age), β is for X_2 (traffic volume), and γ for X3 (quality).

2) The main point of the model is the calculation probability (***p***) for the assumption value Y_n, which generally determines above 50 % is accepted.
3) The equation derivative for ***p*** is:

$$p = \frac{e^{(Kn-(\alpha.X_1+\beta.X_2+\gamma.X_3))}}{(1+e^{(Kn-(\alpha.X_1+\beta.X_2+\gamma.X_3))})} \quad 4)$$

Researchers use the Kn, Constant to predict the performance value of n. When we have n level, it means the equation of each n.

4) Logit inputting data (Table 11)

- The number of data: 240 valid,
- Model fitting information: 2 variables,
- X1 Sig 0.000 and X2, Sig 0.039 ≤ 0.05 valid, X3 Sign is 0.60> 0.05, is not furthered used
- The goodness of fit: Significant 1.0 Integer line. The fixed value is accepted.
- Pseudo R^2: Cox and Snell 0.952, Nagelkerke 0.999, McFadden 0.991.
- Parameter estimates of the equation summary are from the outputs:

K_0=3.088, K_1=10.964, K_2=18.851, K_3=30.751, K_4=44.360, α=7.714, β=3.581.

Table 11. Parameter Estimate

		Estimate	Std. Error	Wald	df	Sig.
Threshold	[Value = .000]	3.088	2.194	1.982	1	.159
	[Value = 1.000]	10.964	2.407	12.961	1	.000
	[Value = 2.000]	18.851	2.778	41.279	1	.000
	[Value = 3.000]	30.751	4.179	54.143	1	.000
	[Value = 4.000]	44.360	5.720	60.152	1	.000
Location	Age (X1)	7.714	.922	69.968	1	.000
	Traffic (X2)	3.581	1.739	4.243	1	.039
	Concrete (X3)	.325	.686	.225	1	.635

1) The logit regression equation is:

$$p = \frac{e^{(Kn-7.714.X_1+3.581.X_2))}}{(1+e^{(Kn-(7.714.X_1+3.581.X_2))})} \quad 5)$$

Describe the model into each performance level will bind to the probability (p):

Y=0, ko= 3.088, $p(0) = \frac{e^{(3.088-7.714.X_1+3.581.X_2))}}{(1+e^{(3.088-(7.714.X_1+3.581.X_2))})}$

Y=1, k1= 10.944, $p(1) = \frac{e^{(10.964-7.714.X_1+3.581.X_2))}}{(1+e^{(10.964-(7.714.X_1+3.581.X_2))})}$

Y=2, k2= 18.851, $p(2) = \frac{e^{(18.851-7.714.X_1+3.581.X_2))}}{(1+e^{(18.851-(7.714.X_1+3.581.X_2))})}$

Y=3, k3= 30.751, $p(3) = \frac{e^{(30.751-7.714.X_1+3.581.X_2))}}{(1+e^{(30.751-(7.714.X_1+3.581.X_2))})}$

Y=4, k4= 44.360, $p(4) = \frac{e^{(44.360-7.714.X_1+3.581.X_2))}}{(1+e^{(44.360-(7.714.X_1+3.581.X_2))})}$

Y=5, no K5, but for P5 using X1 and X2 of level 5 substitute to formula P4, then P5 = 1- P_4.
In the case of the ordinal logit model, the last performance level is 5. It means that after many years level 4 is over, and level 5 will take over.

Ten bridge data in the previous linear model were re-calculated for substitution in the Logit equation, and the results are as described below :

1) Bridge Siak Riau (3 years, Traffic 9,290 PCU): Level 0, ***p(0)*** : 56.03 %. Ok, valid.
2) Bridge Serdang (12 years, Traffic 11,761 PCU): Level 1, ***p(1)*** : 94.76 %. Ok, valid.
3) Bridge Cikuda (20 years, Traffic 17,752 PCU): Level 1, ***p(1)***: 53.49 %. Ok, valid.
4) Bridge Wperdata (22 years, Traffic 17,907 PCU): Level 2, ***p(2)***: 94.83 %. Ok, valid.
5) Bridge Brangsimu (27 years, Traffic 21,477 PCU): Level 2, ***p(2)***: 70.61 %. Ok, valid.
6) Bridge Musi 2 (30 years, Traffic 26,116 PCU): Level 3, ***p(3)***: 94.99 %. Ok, valid,
7) Bridge Waemase (35 years, Traffic 31,322 PCU): Level 3, ***p(3)***: 88.67 %. Ok, valid,
8) Bridge Angsau (38 years, Traffic 36,083 PCU): Level 4, ***p(4)***: 95.00 %. Ok, valid.
9) Bridge Kytangi (42 years, Traffic 43,576 PCU): Level 4, ***p(4)***: 94.45 %. Ok, valid.
10) Bridge Ngujang (48 years, Traffic 61,045 PCU): Level 5, ***p(5)***: 95.00 %. Ok, valid.

A probability model with a success rate of more than 50.00% is considered valid. The result near the threshold for the Cikuda bridge is 53.49%, indicating that a change to a higher level of performance is required. In other words, the situation is deteriorating. This point is critical in demonstrating the rate of improvement in the year toward enhancing program recovery.

After the formation of the ordinal regression logit model and its validation successfully matched with official website records, the linear model is considered valid.

- $\mathbf{Y_n = 1.172 + 0.00161.\ p^2 + 0.00485.\ p + 0.1222.\ Ln\ (\frac{Vt}{2000}) - 0.287.\ (\frac{fc}{15})^2}$

Substitute the current concrete specification fc' is 30, and the equation becomes:

- $Y_n = 0.024 + 0.00161.\ p^2 + 0.00485.\ p + 0.1222.\ Ln\ (\frac{vt}{2000}).$

Assuming that the average traffic volume Vt is 7,000 PCU with a 3.5% growth, it found that Yn=0.00161. p2+0.0091.p+ 0.1291 (R^2=1). The equation Yn= 0.0015X2+0.0187.X (R^2= 0.9994) is the curve with the intercept of Zero. The curve model is shown in Fig.5 Bridge Performance Curve.

The Bridge Performance Curve is Yn = 0.0015.X2+ 0.0187.X, with present specification circumstances, predicted traffic volume, average growth, and its relationship to the annual period. The condition level thresholds achieved are: (1) in the 21st year, (2) in the 31st year, (3) in the 38th year, (4) in the 47th year, and (5) in the 52.5th year. The indication level is at the midpoint of the threshold in actual field conditions: Excellent: 0-10 years, good: 10-25 years, moderate: 25-34 years, bad: 34-43 years, critical to collapse: 43-49 years, and integral to collapse: 49-52.5 years.

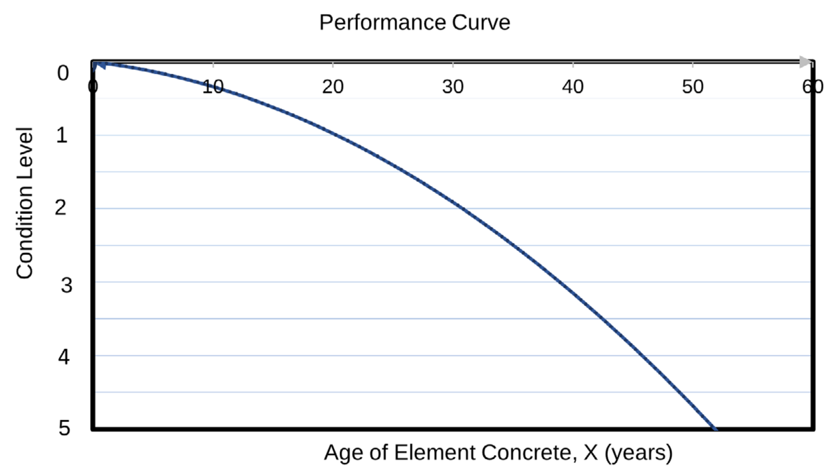

Figure 5. Bridge Performance Curve

This curve model pertains to origin data analysis from Indonesian regions; thus, it applies to all provinces due to comparable characteristics (Figure 5).

4. Conclusion

A bridge performance model may be developed by determining the relationship between performance values and essential variables such as bridge strengthening and deterioration. Statistical tools facilitate and improve the accuracy of the SPSS model's results. In the coming years, the model predicts that bridge performance will decline. Very Good to Good at the end of the 21st, Moderate at the end of the 31st, Poor at the end of the 38th, Very Poor at the end of the 47th, and inoperable at the end of the 52.5th year. In addition, to achieve high and sustainable performance, it is important to 1) conduct research and development on durable concrete materials, 2) produce high-quality concrete strength, and 3) control traffic loading.

5. Implications and Future Directions

This research has substantial ramifications due to the development of a novel model of bridge performance. By working on this model, the relevant department may ensure that the bridge's safety is increased. In addition, this model is applicable in a variety of nations due to the generalizability of its conclusions. Indeed, the long-term performance and safety of a bridge are essential; hence, reasonable efforts should be taken to implement this model and improve the performance of bridges. In addition, this research confirms that the concrete's strength is essential for the bridge's durability but that the bridge's material and design substantially impact its durability.

This research accomplishes its purpose and considerably advances the development of a new model for the durability of bridges. However, this model must be revised in light of specific future directions. This study recommends that government department operations determine the performance of bridges. Second, the role of innovation and material design in the durability and sustainability of the bridge should be evaluated. In addition, the durability and sustainability of the bridge should be compared to the model created and executed in developed countries to provide a fresh perspective on the bridge's durability and sustainability.

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