A MODEL FOR PREDICTING CONCRETE DECK DAMAGE RATE OF STEEL TRUSS BRIDGE IN INDONESIA

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ABSTRACT

Bridge maintenance is structural repair work so that it is always in good condition to serve goods and services transportation traffic. There are three levels of maintenance: routine, periodic, and rehabilitation. Effective treatment depends on the scale of the damage, starting from 0 (Excellent), 1, 2, 3, 4, and 5 (Very Bad). So it is crucial to create a reference model for changes from 0 - 5. Floor elements, as the primary function of bridge services, are damaged faster, so the type of maintenance should be precise.

Research shows that the age of destruction varies from 2 to 45 years. The researchers make the model for 220 bridges, with construction age, traffic load, concrete quality, and others as independent variables.

SPSS processing produces the expected model curve. Multiple linear regression analysis points non-linear curve consisting of the dominant factors causing the damage, while the ordinal logistic regression makes an integer scale. The model demonstrates a 5-scale collapse, which occurred around 54 years, and others. So, this prediction is the right program for handling with optimum financing.

Keywords: Bridge maintenances, concrete deck, deterioration, 5-scale, regression

Introductions

Backgrounds

The bridge is a part of the road that plays a vital role in smoothing traffic flow. The structure above a river or road requires attention to keep it in a serviceable state. BMS, Bridge design code (1992)[1], explains that the deck is those parts of the bridge that directly carry vehicular and pedestrian traffic.

The part often destroyed is the floor that directly supports the load, which represents bridge service performance. The research focuses on making a predictive model of the destruction to the steel bridge base. Various things that affect are age, quality, and load. Meanwhile, SPSS 23 looks for the relationship between the value of the impairment and the independent variables with an effect.

Damage Scale

Indonesian Bridge Management System (IBMS) establishes five tiers of component destruction. The assessment started from zero, new, very good to very good (1), light impairment (2), moderate (3), critical (4), and collapsed (5). The curve model is made from the initial condition 0 to broken (5).

To get the value of the bridge condition, the researchers assess following the hierarchy, from the smallest element (level-5), group (level-4), component (level-3), part (level-2), to final (level-1), namely the structure bridge. The final results are summed up according to the category.

Bridge Management Ausroads [2] determines the failure rate into four: (1) As-built, (2) Good, (3) Fair, and (4) Poor.

Meanwhile, [3] divides it into ten levels: 1. Excellent (9), 2. Very good (8), 3. Good (7), 4. Satisfactory (6), 5. Fair (5), 6. Poor (4), 7. Serious (3), 8. Critical (2), 9. Imminent failure (1), 10. Failed condition (0).

The function of this model is following the opinion of A. [4]. Recently, Indonesia's bridge construction has experienced more cracks due to excessive loading and increasingly aggressive weather. If not appropriately anticipated, repairs require more considerable funds. His research proves that the strength of reinforced concrete composite bond decreases due to repeated loads, where the strain reaches the limit so that only the reinforcement works. The ideal treatment is the cost-efficient one, where technical requirements are practical[5].

[6] argues that various data and models are needed to develop maintenance policies covering multiple national and regional road construction levels. The critical data is the bridge part rating. Optimization models and deterioration rates help with the maintenance.

Routine maintenance, rehabilitation, and element replacement are required to keep up performance within the limits of functional feasibility. However, there is a massive difference between the three from a financing perspective.

The percentage of bridge handling types in 2015 is below.

Table 1

Routine maintenance handling ratio

No	Description	Number	Routine	Non-routine
1	Total	18,009	12,723	5,286
2	Ratio (%)	100	70.65	29.35

Routine care reflects good performance and level of service. On the other hand, non-routine has the low one. The handling ratio is the ability to serve road users.

Research purposes are: 1) To create a predictive model for deterioration concrete deck, using a 0 - 5 scale. 2) To find factors that influence the damage, and finally create a systematic maintenance management program to overcome the problem of bridge floor damage.

Bridge Element Assessments

There are two types of inspections: routine annual assessments and detailed assessments of at least three years, or if the inevitable happens. Also, there are five aspects of examinations: the shape of elements, rate of damage, the quantity of failure, function, and impact. The benchmark value is in the following table:

Table 2

Assessment Criteria

No	Grading System	Criteria
1	Shape (S)	Stabil, fixed (0), Change significant (1)
2	Rate (R)	Light (0), Severe (1)
3	Quantity (K)	Less than 50% (0), More than 50% (1)
4	Function (F)	Working (0), Broken (1)
5	Impact (P)	Not impact to other elements (0)
		Effect on other elements (1)
6	Condition Value	NK = S+ R+ K+ F+ P (SRKFP), 0-5.

Base strength is from crossbeams, stringers, rubber bearings, expansion joints, and quality. On the contrary, loading and environment cause the defect.

Framework of Thought and Literature Review

The model approach is carried out on the age of the concrete deck, the concrete quality, the destruction factors, and the reinforcing steel grade.

Concrete deck age

Damage to the reinforced concrete base structure can be viewed from two technical aspects: the material's strength and loading effect. The material consists of a mixture of steel, gravel, sand, cement, and water. Here, it is necessary to pay attention to the quality of steel and the mix. The durability of homogeneous steel from the factory is relatively more than concrete, where the resistance is highly dependent on the bonding of the materials.

[7]say that reinforced concrete is very suitable for use as a material for all types of bridges due to its good resistance to rigidity, economy, ease of craft, and pleasing appearance.

[8] argues that the destruction of the deck is a common phenomenon and occurs in several countries. Many engineers are looking for solutions, but no single cause is right on target. Some of the common types of damage are scaling, cracking, spalling, and corrosion. Breaking consists of various kinds, namely transverse, longitudinal, diagonal, and map cracking.

Queensland Department of Transportation and [9]describes 11 symptoms of the mixture failure mechanisms on bridges: reinforcement corrosion, carbonation, alkali-aggregate reaction, cracking, spalling, surface defects, delamination, scaling, ds-integration, chloride ingress, and water wash.

TRB, the national academies press in nondestructive testing to identify concrete bridge base deterioration [10], explains that the causes of damage are complex and often cause and effect from one factor and another. Rebar corrosion, deck delamination, vertical cracking, and concrete degradation often occur.

The specification of the concrete material for the deck is improved year by year to make it stronger, more comfortable, and have more extended durability, as shown in the following table:

Table 3

Quality changes of the concrete floor

NO	QUALITY	BM-1970	BMS 1992	RSNI 2005	SPEC 2010	SPEC 2018
1.	(fc'- MPa)	20	25	25	30	30

SNI 1725:2016 regulates bridge loading standards: dead load, additional, traffic, trucks, dynamic factors, brake force, pedestrians, fatigue, and environmental actions (temperature, wind, flood, earthquake, other natural phenomena).

The loads change the deflection of concrete ingredients. It indicates that the deterioration model pattern is non-linear.

Concrete strength against time, with correlation factors, is below.

Table 4

Concrete Age vs Type of Portland cements

Age (days)	3	7	14	21	28	90	365
Ordinary portland cement	0,40	0,65	0,88	0,95	1,00	1,20	1,35
High inital portland cement	0,55	0,75	0,90	0,95	1,00	1,15	1,20

The table exhibits that full strength occurs after the hardening of the concrete mixture is at least 28 days old.

[11], Concrete strain due to loading is very dependent on the design quality, and correlation the stressing vs the strain shows increase non-linear until maximum stressing then slow down until broken, as shown below.

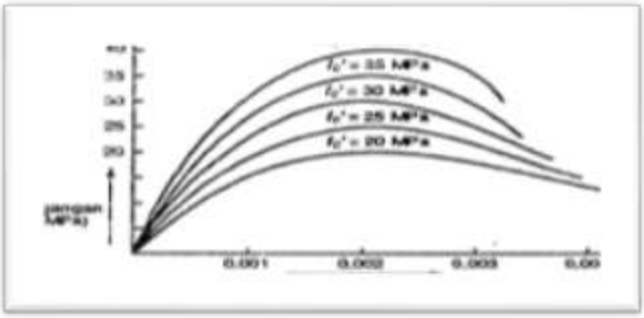

Figure 1. Stress vs. Strain

Concrete Specifications

[12] regulate 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 described below:

Table 5

Concrete Specification

Type	Quality (MPa)	Use Description
High	X > 45	Prestressed and the like
Moderate	20< X <45	Reinforced and the like Bridge concrete deck
Low	15< X <20	Concrete without reinforcement
	10< X <15	Base work – Lean concrete

The quality of concrete deck is categorized moderate type: 20< X <45 Mega Pascal. The strength of the deck is composite material with reinforcing steel to serve traffic loading.

Element Deteriorations

1) Causes of deck deterioration are:
Concrete: Mechanical, chemical, physical
Mechanical: Deflection, vibration, impact, fatigue, wear
Chemical: Sulfuric acid, salt, oil, alkali-aggregate,
Physical: Erosion, shrinkage, beach environment, boat backrest.
Reinforcement Steel: Carbonation, corrosion
Carbonation: Type of cement, water/cement ratio, curing, moisture
Corrosion: Seawater, chloride content, environmental air

2) Overloading:

Flexibility, spalling of concrete covers, flexural breaks, shear cracks, compression area destruction.

3) Hot temperature: (DTMR Queensland, 2016)

Normal – 120^{o}c: No changes
120^{o}c–250^{o}c: Break, cement paste dehydration, moisture loss, strength loss
300^{o}c – 600^{o}c: The cement paste starts cracking, the aggregate expands, and the color turns reddish

600^{o}c – more: The paste shrinks, causing porous cracks, which is brittle, and easily broken

RESEARCH METHOD

3**.1. Location.**

Researchers collect 210 destruction rate data from several provinces in Indonesia

Table 6

Concrete deck damage rate data

NO	Province	Total	Interval Scale	Years
1	West Java	64	0-4	1974-2013
2	Banten	24	0-4	1973-2010
3	Central Java	27	0-4	1975-2012
4	East Java	12	0-4	1972-2009
5	Bali	2	1-2	1998-2001
6	Nusa Tenggara	10	0-3	1978-2008
7	Sumatera	53	0-4	1975-2018
8	Kalimantan	10	0-3	1985-2011
9	Sulawesi	6	1-3	1980-1998
10	Maluku	1	2	1992
11	Papua	1	2	1992
	Total	210		

Damage data was taken on congested roads, including those in northern and central Java and between provincial cities with heavy traffic.

Secondary data of the value of the deck's condition is based on the records in years 2015, 2017, and 2019.

Statistical method approach

Statistical approaches to model deterioration are multiple linear regression and ordinal logistic regression methods. The linear regression method produces a continuous model curve while the ordinal logistic regression produces an integer discrete damage condition value.

The first thing to do is group 210 data into the dependent variable (the value of the condition of the concrete deck) and the independent variable, consisting of age (X_1), LHR traffic volume (X_2), concrete quality (X_3), heavy truck vehicles (X_4), long span (X_5), width (X_6), number of spans (X_7), type of steel Truss (X_8), and area zone (X_9).

The research instrument yang digunakan untuk memodelkan hubungan variabel bebas dengan variable tingkat kerusakan lantai adalah software statistic SPSS 23 edition.

Multiple linear regression

A way to correlate the destruction and the independent variables.

The value of the transformation is made so that it is linearly proportional to the failure.

Transformation is carried out on the independent variable to transform it into a linear connection pattern to the dependent one.

The independent variable transformation is adjusted: X_1=0.025.(U^2+3U), $X_2=0.02.\mathrm{Ln}(\frac{\mathrm{Lhr}}{2000})$, $X_3=-(\frac{fc}{15})^{2}$, $X_4= 0.4(\frac{Tr}{15})^{0.3}$, $X_5=0.5^{*}(\frac{L}{40})^{0.2}$, $X_6=(\frac{W}{3.5})^{0.2}$ and, X_7, X_8, X_9 are assumed linear.

3.2.2. Ordinal Logistic Regression

- A method is used to determine the independent and dependent variables' interconnection (an integer).
- It is helpful for prediction and validation purposes.

[13]states that Norman H Nie, C. Hadlai (Tex), Hull, and Dale H. Bent have developed a statistical-based software system to process decision-making information.

[14] explain that regression predicts the effect of one data on another to anticipate future symptoms. On the other hand, linear regression projects the dependent variable through the independent variables partially or simultaneously.

Data Analysis

4.1. Multiple linear regression model

The first analysis was conducted on age, traffic volume, truck portion, concrete quality, dimensions, frame type, spans, and area zones. The program produce statistical parameters: R= 0.950, R^2=0.90, and adjusted R^2=0.899, with a significant value of 0.00 ≤ 0.05. It shows that the model relationship is valid.

An analysis of three significant variables with a significant value of 0.00 was carried out to sharpen the model. Summary statistics and the model equations are as follows:

- R=0.949, R^2 =0.900, adjusted R^2= 0.899, Significant F change = 0.000.
- Then the model is:

$$Yn= 0.740 + 0.515\,X_1+2.466\,X_2+0.294\,X_3$$

- The result after re-transformation is:

$$Y_n = 0.00128.U^2 + 0.00384.U + 0.4892.\,\mathrm{Ln}\,(\frac{\mathrm{Lhr}}{2000}) - 0.294.\,(\frac{fc}{15})^2 + 0.740$$

Y_n is the predictive model for the deterioration of the deck.

Data validation by the linear model

Model validation is intended to test the association of the updated model with independent variables outside the research data.

The validation status of the new data is presented below.

Table 7

Linear data validation

No. Jbt	Model: Yn= K+α.X1+β.X2+γ.X3		Site condition value	Status
1.	0.2462	0	0	Valid
2.	1.3431	1	1	Valid
3.	1.7289	2	2	Valid
4.	1.8138	2	2	Valid
5.	1.9012	2	2	Valid
6.	1.9912	2	2	Valid
7.	2.7177	3	3	Valid
8.	2.7177	3	3	Valid
9.	2.9875	3	3	Valid
10.	4.0759	4	4	Valid

Validation data by Logistic Model

Logistical data validation increases the probability of forecasting the value of element states according to field observations. The formulation is ordinal logistic regression, where the ordinal component is in the dependent variable and the condition value of the element. The equation model of the correlation between the dependent variable (condition value) and the independent variable (age, traffic, and concrete quality) exhibits:
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,
The general form of the model equation is:

1. Prediction Y = 0, the equation is:

$$\text{Logit}(Y_0) = \ln\left(\frac{Y_0}{1-Y0}\right) = K+\alpha.X_1+\beta.X_2+\gamma.X_3,$$

In which K is constant and α, β, γ are coefficient for independent variables.

2. The derivative is p:

$$p = \frac{e^{(K-(\alpha.X1+\beta.X2+\gamma.X3))}}{(1+e^{(K-(\alpha.X1+\beta.X2+\gamma.X3))})}$$

3. The last value of Y_n is:

$$p' = 1 - \frac{e^{(K-(\alpha.X1+\beta.X2+\gamma.X3))}}{(1+e^{(K-(\alpha.X1+\beta.X2+\gamma.X3))})}$$

The calculation results reveal:

The number of data: 210 valid,
Model fitting information: Three variables, Significant 0.000 ≤0.005 valid.
Goodness of fit: Significant 0.000 ≤ 0.005 valid
Pseudo R^2: Cox and Snell 0.836, Nagelkerke 0.879, McFadden 0.599.
Parameter estimates of the equation are summarized as below:

K0=-2.335, K1=1.669, K2=7.554, K3=13.784, K4=21.434, α = 2.978, β = 1.521, γ = 2.505, as shown in Table 8.

Table 8

Parameter estimates

Parameter Estimates		Estimate	Std. Error	Wald	df	Sig.
Threshold	[VALUE = ,000]	-2.335	2.331	1.003	1	.317
	[VALUE = 1,000]	1.669	2.320	.517	1	.472
	[VALUE = 2,000]	7.554	2.174	12.070	1	.001
	[VALUE = 3,000]	13.784	2.654	26.977	1	.000
	[VALUE = 4,000]	21.434	3.484	37.850	1	.000
Location	AGE	2.978	.419	50.629	1	.000
	ADT	1.521	.694	4.808	1	.028
	Quality	2.505	.712	12.374	1	.000

The model equation for each Y values then used for validation 10 data of the damage rates as the previous model. The result of validation as shown belows:

Table 9

Logistic data validation

No. Jbt	$Pn = \frac{e^{(\mathrm{Kn}-(2.978\ \mathrm{X1}\ +1{,}521\ \mathrm{X2}\ +\ 2.505\ \mathrm{X3}))}}{(1+\ e^{(\mathrm{Kn}-(2.978\ \mathrm{X1}\ +1{,}521\ \mathrm{X2}\ +\ 2.505\ \mathrm{X3}))})}$			Status
	p	Logit Model	Field Value	
1.	0.76663	0	0	Valid
2.	0.51004	1	1	Valid
3.	0.97311	2	2	Valid
4.	0.95800	2	2	Valid
5.	0.93391	2	2	Valid
6.	0.89587	2	2	Valid
7.	0.98750	3	3	Valid
8.	0.98750	3	3	Valid
9.	0.94327	3	3	Valid
10.	0.98307	4	4	Valid

Validation of 10 data produces a logistic probability value above 50%; thus, the model is valid**.**

Deterioration Model for concrete deck

The equation model for standard condition in year 2021, by concrete fc'=30 MPa, initial ADT of 7.500 Smp, and max growth rate of 3.5% is expressed below:

$f(x) = 0.0013\ X^2 + 0.0208\ X + 0.2159$, where x is the age of concrete floor

a) The period of change in condition can be tabled to determine the treatment program, as shown in the following table:

Table 10

Maintenance Programs

Year	Condition Mark	Type of damage	Work Programs
0 - 17	0 – 1	Good	Routine maintenance
17 - 28	1 – 2	Slightly damaged	Routine maintenance
28 - 36	2 – 3	Moderately impaired	Periodic/ Rehabilitation
36 - 47	3 – 4	Heavily damage	Rehabilitation
47 - 54	4 – 5	Critically failed	Rehabilitation/ Replacement

b) The initial model curve is polynomial, with an accuracy of R^2=1 and an intercept of 0.216. With the smoothing curve method, without intercept, the curve Y=0.001x2 +0.0367x is obtained, with an accuracy of R^2=0.9983.

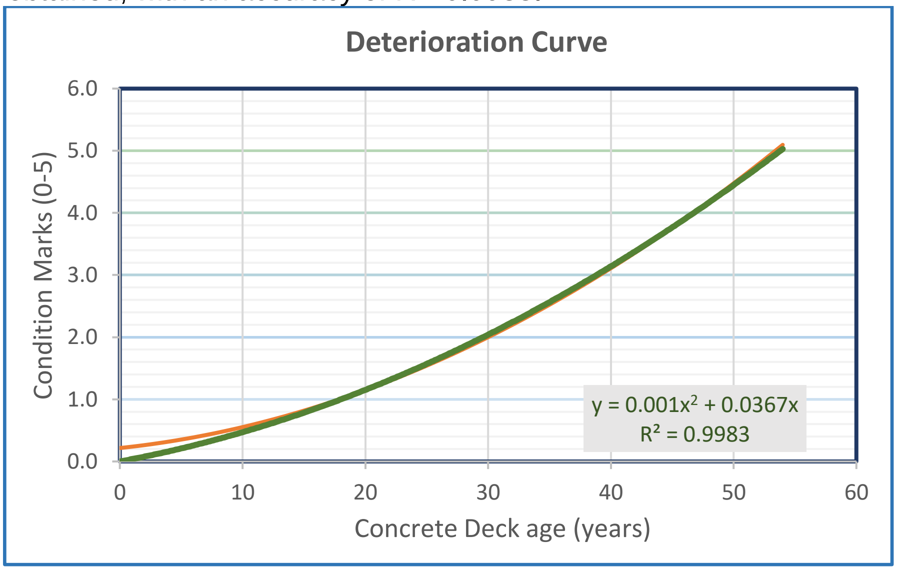

Figure 2. Deterioration rate curve

Conclusion

5.1. Prediction model for Concrete deck deterioration is:

- $\mathbf{Y_n = 0.00128.U^2 + 0.00384.U + 0.4892.\ Ln\ (\frac{Lhr}{2000}) - 0.294.\ (\frac{fc}{15})^2 + 0.740}$

5.2. The dominant influencing factors consist of three variables: Concrete deck age, Traffic Volume, and Concrete Quality.

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