Developing A Deterioration Model for Manila Bridges

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***Abstract*— The study looks into an alternative approach in determining the service life of bridges located in the scope of Metro Manila, Philippines. Currently financial depreciation models are used to determine service life of structures by the Commission on Audit and there is no existing alternative formula for predicting service life of bridges in the country. Based on existing research on deterioration models, a similar approach was done in this research. The derived model was based on the latest condition ratings of thirty bridge components and inspection findings of the Department of public works and highways (DPWH) during their regular inspection. The objective was to identify whether such available data can serve as significant variables in identifying a regression model to aid in predicting condition rating of such bridges in Metro Manila. Such similar models as applied in a Philippine setting can provide planning cost estimates for return of investments in terms of service life. It can also aid in maximizing funds and planning budget for infrastructure development and maintenance of DPWH. Using statistical test in identifying the coefficients and dependent variables, the study was able to derive a significant bridge evaluation model that provides a secondary source of information in determining the condition ratings of bridges in Metro Manila.**

***Keywords*— Deterioration Model, Bridge Condition Rating, Regression Model, Service Life, Decision support.**

I. INTRODUCTION

Bridges play an important role in the economic development of any country. They connect island to island, provinces to provinces to transport people, merchandise and the like. All bridges have a natural life span/service life. Determining the exact service life of bridges is a common problem not only in the City of Manila but all over the world. There is a need to calculate the bridge service life for the government agency planning, infrastructure budget allocation and other project implementation. To keep bridges in a safe condition, maintenance and upkeep are scheduled based on inspection results, condition rating, age, transient load and the type of bridge. A rational decision regarding maintenance, repair or replacement of bridges must take into account the expected service life and the impact of maintenance or repair options on service life of bridges. However, there is no existing formula for predicting service life of bridge in our country.

Thus, a need was felt for development of a model for predicting service life of bridges. To meet this need, the proponent initiated a study to develop a mathematical model that can calculate condition rating to predict the service life of a bridge. This model can be used in predicting the service life of all bridges in Manila. It will be a useful instrument for Manila Local government units (LGU), Department of Transportation and Communication (DOTC) and Department of Public works and highways (DPWH) for their planning and infrastructure budgeting. DPWH can strategically schedule bridge maintenance to ensure that repairs and upkeep are done at the most optimal time. This allows the department to ensure that bridges are safe for their entire service life, and that the money for repairs is wisely spent.

II. MODEL GENERATION

A. Background

Modelling is the use of mathematics to describe real-world behaviour as such to be able to investigate important questions about the observed world through a simulation of the derived model. Such model goal is to explain real-world behaviour by testing the idea and make predictions about the real world.

In the study of Morcous [1],he developed deterioration models for Nebraska bridges that are based on the condition ratings of bridge components obtained from bridge inspections since 1998 up to 2010. The impact of governing deterioration factors, such as structure type, deck type, wearing surface, deck protection, averaged daily traffic, averaged daily truck traffic, and highway district are considered in developing his models.

This study also stated the 1993 American association of state highway and transportation officials (AASHTO) deterioration models are integral components of life cycle cost assessment because maintenance costs and user costs are highly dependent on bridge condition that varies over the analysis period. The quality of life cycle cost-based decisions depends primarily on the accuracy and efficiency of the deterioration models used to predict the time-dependent performance and remaining service life of highway bridges.

According to Dadson [2], service life estimates, together with cost information, are used to develop life-cycle cost of bridges. These estimates are necessary to prioritize and optimize bridge improvement programs within budgetary constraints. Several factors including age, traffic and environment have been identified in current bridge management system literature as being directly responsible for the deterioration of bridge components and elements.

According to Moser [3], in order to calculate service life in the sense of the Engineering Design Method an equation containing the relevant factors at their relevant levels has first to be set up. Density distributions instead of plain factors in the equation for service life greatly improve the information content and the relevance of the results at a significantly reduced intellectual, mathematical and time-wise input, compared the quite often elaborate original equations.

Corrosion-induced deterioration of reinforced concrete bridge superstructure elements is a common problem and recurring problem in the United States. Sohanghpurwala [4] developed a manual on service life prediction of corrosion-damaged reinforced concrete bridge superstructure elements. This manual provides protocol for assessing the condition of reinforced concrete bridge superstructure elements subjected to corrosion-induced deterioration, predicting the remaining service life, and the impact of alternative maintenance and repair option on service life of such elements. The author found out that in general, the model seems to provide reasonable accuracy for the near future when the output of the model is calibrated to know damage at a given age based on the structural materials used which has different deterioration behaviour in terms of corrosion. It is expected that the error in the prediction would increase with the age from which the calibration was made. This is expected as corrosion induced damage increases, other deterioration processes are enhanced and the rate of increase of damage is then governed not only by the rate of the corrosion process.

It is clear that monitoring of constructed systems is of considerable interest since the consequences of failure can have a significant effect on the society at large. It follows that structural health monitoring techniques may prove to be useful for maintaining and preserving aging civil infrastructure. Pines [5] noted the importance of structural health monitoring as an emerging research area for a variety of aerospace, civil and mechanical applications.

B. Method

The focus of this research study was statistical estimation of the condition rating of bridges and the use of a mathematical equation to predict the service life of the bridge. This was based on a similar approach by Liang [6] that looked into a derived calculation method to aid in making reliable predictions for the service life of bridge structures. The method started on the assumption that the variables that affect service life had linear dependence and later showed that reinforced concrete bridges in Taipei service life can be linearly computed based on multiple regression. The result identified the dependent variables to be corrosion initiation time constant due to a chlorine laden environment plus the de-passivation time of corrosion propagation upon discovery contribute to service life.

In gathering data to derive the calculation methods this time for Manila bridges. The bridge selection was based on the completeness of the data gathered. DPWH's data for the year 2010 were used in the study. The accumulated data coming from the bridge inspector report was based on a mandatory visual assessment the overall condition of the bridge based on the condition of the bridge components. The summary sheet of the inspection form will be completed for the overall condition of the bridge. Overall Condition of the Bridge refers to the rating given by the bridge inspector to a certain bridge. The bridge can be evaluated as good, fair, poor or bad. Note that the bridge inspector must rely on his/her engineering knowledge and judgement for the evaluation of the bridges' condition.

In general, structures are described as

- Good – condition shall be free of defects affecting structural performance, integrity and durability.
- Fair – condition may have defects which affect the durability.
- Poor – condition may have defects which affect the performance and structural integrity of the structure.
- Bad – shall have major defects and are considered to be beyond repair.

The bridge inspector shall determine the overall condition of the bridge based on the result of the condition rating of the bridge primary components/attributes and secondary components/attributes that affects structural performance such as bearings/restraints. In general, the worst condition state of any primary component and secondary component that affects structural performance will be the overall condition state of the bridge as referenced in Table 1

TABLE I

GUIDELINES IN ASSESSMENT OF BRIDGE CONDITION

Bridge Condition Rating	**Assessment Indicators** **Primary Components and Secondary Components that Affects Structural Performance (Attribute Condition State)**	**Recommended Countermeasures**
Good	0	Routine Maintenance
Fair	1	Major Maintenance (Repair, Protective works, Strengthening)
Poor	2	Major Maintenance or Upgrading
Bad	3	Upgrading or Replacement

Upon review of the completeness of the available data, a purposive sample of 30 bridges located in Manila was selected, as seen in Table 2, and the corresponding variables were identified for the derivation of preliminary variables of the mathematical model for investigation as seen in Fig. 1.

TABLE II
2011 METRO MANILA BRIDGES DPWH MONITORING REPORT

Reference Number	Condition Rating	Age of Bridge	Average Daily Traffic	Structural Materials
1	0	42	30,093	1
2	0	30	42,938	1
3	2	49	18,784	1
4	1	25	78,373	1
5	1	33	54,352	1
6	1	20	48,593	1
7	0	8	28,733	1
8	1	21	50,554	1
9	1	41	14,222	1
10	2	62	11,655	1
11	0	20	123,788	1
12	1	64	42,049	1
13	1	39	46,893	1
14	1	44	46,893	1
15	0	5	45,402	0
16	1	37	55,665	0
17	0	37	81,319	0
18	1	47	6,193	1
19	0	19	119,856	1
20	2	44	148,769	1
21	1	42	13,314	1
22	1	42	20,571	1
23	0	41	29,335	1
24	3	66	15,508	1
25	0	8	19,968	1
26	1	42	19,636	1
27	0	21	18,784	1
28	1	50	18,233	1
29	1	47	7,836	1
30	0	17	22,636	1

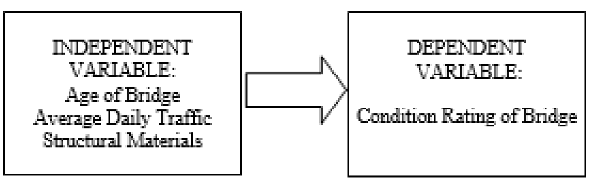

Fig. 1: Paradigm of the Study

The statistical tool used to properly analyse the gathered data and information is multiple regression. This method determined the relationship between the variables in the form of an equation, with an objective of predicting the value of the dependent variable using values of the independent variables. Due to its complexity, the calculations were done using standard computer program. In this study, the software Statistical Package for Social Sciences (SPSS) version 17.0 was utilized.

The general equation is written as:

$$y = a + b_1x_1 + b_2x_2 + b_3x_3$$

Where y = predicted dependent variable
x_i = independent variables
a, b_i = coefficient derived after regressing

Statistical Tests:

- Coefficient of Determination (R)
- Adjusted Coefficient of Determination (R^2)
- Normality Test

C. Model

The independent variables treated in this study are age of the bridge (AOB), average daily traffic (ADT) and structural materials (SM). Resulting to the sole dependent variable condition rating (CR).

Rewriting the full model regression equation:

$$(CR) = a + b_1(AOB) + b_2(ADT) + b_3(SM)$$

Inputting the 30 sample data into the regression table for analysis, the resulting computed summary is reflected in table 3 and table 4.

TABLE III
MODEL SUMMARY[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.712[a]	.507	.451	.564
2	.708[b]	.502	.465	.557
3	.704[c]	.496	.478	.550

a. Predictors: (Constant), SM, ADT, AOB
b. Predictors: (Constant), SM, AOB
c. Predictors: (Constant), AOB
d. Dependent Variable: CR

TABLE IV
COEFFICIENT SUMMARY[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	T	Sig.
1	(Constant)	-.648	.434		-1.491	.148
	age of bridge	.033	.007	.709	4.909	.000
	average daily traffic	1.697E-6	.000	.080	.554	.584
	structural materials	.216	.353	.086	.611	.546
2	(Constant)	-.521	.364		-1.429	.164
	age of bridge	.032	.007	.690	4.983	.000
	structural materials	.191	.345	.076	.552	.585
3	(Constant)	-.373	.245		-1.524	.139
	age of bridge	.033	.006	.704	5.249	.000

a. Dependent Variable: CR

Analysing the resulting values shows the effects of changes in age of bridge (AOB) in predicting the condition rating of bridge is significant. Hence, the analysis made will serve as the independent variable in predicting the condition rating of bridges in Manila. This can be represented by the equation below.

The overall model in function form:

$$CR = f\,(AOB)$$

The overall model equation derived from regression is:

$$CR = -\,0.373 + 0.033(AOB)$$

The research was able to identify that in the City of Manila setting and the available variables in consideration for the mathematical model of deterioration of bridges. The age of bridge is the significant variable to solve for the condition rating of bridges in Manila. The age rage of the sample used in the study was from 5 years to 64 years of use with a mean average of 35 years. It was also determined that structural materials used in the construction of the bridges under study was not significant given that the sample comprised of two types only having 27 reinforced concrete bridges and 3 steel bridges. In terms of average daily traffic, it was also found to not significant with a data range of 6,193 to 148,769 vehicles per day having a mean average of 42,698 vehicles per day. Finally there was a balance distribution of the different condition rating scores of the bridges from 12 good, 14 fair, 3 poor and 1 bad as provided by the city inspector report.

III. CONCLUSIONS

The ability to determine service life of bridges based on a calculation method derived from a Metro Manila environmental setting can provide planning estimates in terms of service life of existing and newly constructed infrastructure. City engineers can now schedule a more time specific approach in planning and preparing preventive maintenance, retrofits, upgrades or even replacement of bridges. It can also aid in maximizing funds and planning budget for infrastructure development and maintenance of DPWH. Using statistical test in identifying the coefficients and dependent variables, the study was able to derive a significant bridge evaluation model that provides a secondary source of information in determining the condition ratings of bridges in Metro Manila. This can serve a basis of determining return of investments of the allocated government funds or serve as determined constants for third party contractors in determining toll collections in terms of build-operate-transfer in privatized outsourced infrastructure development program of the government.

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