

Development of a Value Evaluation Model of Highway Box-Girder Bridge

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Abstract—Taiwan's infrastructure is gradually deteriorating, while resources for maintenance and replacement are increasingly limited, raising the urgent need for methods for maintaining existing infrastructure within constrained budgets. Infrastructure value evaluation is used to enhance the efficiency of infrastructure maintenance work, allowing administrators to quickly assess the maintenance needs and performance by observing variation in infrastructure value. This research establishes a value evaluation model for Taiwan's highway box girder bridges. The operating mechanism and process of the model are illustrated in a practical case.

Keywords—Box girder bridge, deterioration, infrastructure, maintenance, value evaluation.

I. INTRODUCTION

INFRASTRUCTURE development has played a key role in driving Taiwan's economic development over the past four decades, including highway construction. Today, Taiwan's highway system is largely mature, and the emphasis has shifted from new construction to maintenance of existing highways.

To assess maintenance requirements and formulate budgets, administrators must first understand variation in infrastructure performance. Value evaluation allows administrators to quickly grasp the variation of infrastructure physical condition through adjusting monetary amounts [1]. Following this concept, this research uses Taiwan's highway box-girder bridges to establish a value evaluation model for improving highway bridge maintenance work.

The established value evaluation model can reasonably convert the physical condition of box-girder bridges into monetary units, allowing the administrator to quickly assess the bridge's deterioration status through its discrepancy between the Gross Replacement Cost (GRC) and Depreciated Replacement Cost (DRC). The value difference can be regarded as the maintenance plan budget and can also indicate maintenance performance. The monetization report also helps to enhance budgeting accountability.

II. INFRASTRUCTURE VALUE EVALUATION

Many countries have adopted infrastructure value evaluation techniques to elevate the efficiency of infrastructure asset management, and thus to better address infrastructure aging and deterioration. Taiwan's relatively late infrastructure development resulted in a relative lack of technical knowledge and experience in these techniques.

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Highway Infrastructure Asset Management Guidance, a document published by Taiwan's Highways Maintenance Efficiency Program, describes how value evaluation techniques are applied for maintenance work over the highway infrastructure life cycle [2]. It includes some essential skills for highway infrastructure value evaluation work, such as asset unit price calculation and the application of adjustment factors (ADf).

The Structural Asset Management Planning Toolkit includes methods for assessing a structural asset's current value by integrating the value of all components in terms of their current physical condition [3]. The value of each element is calculated by a Straight-line Depreciation Method. Therefore, the definition of service life for each different functional element influences the accuracy of calculation. Implementing this method requires considerably advanced research to obtain highly precise service lifetime data for each functional element.

The main goal of the Interim State Highway Asset Management Plan of the NZ Transport Agency is to reduce traffic congestion safely and maintain good service levels at reasonable costs, and infrastructure asset value evaluation methods comply with accounting and financial reporting standards through the use of straight-line depreciation [4].

Federal and state governments apply stringent infrastructure asset maintenance requirements [5]. Local authorities lack a common management method for transportation asset management, and the Transportation Asset Management Guide was developed to help the local authorities to develop a suitable management model for transportation infrastructure, relying heavily on quantitative assessment [6].

III. ESTABLISHMENT OF A VALUE EVALUATION MODEL FOR HIGHWAY BOX-GIRDER BRIDGE

Current approaches to infrastructure asset valuation include GRC valuation and DRC valuation. This paper adopts both approaches to establish a value evaluation model for highway box-girder bridges.

A. Highway and Box-Girder Bridges

Box-girder bridges account for a large portion of Taiwan's highway bridge maintenance budget. In order to get the budget of maintenance work, the value evaluation model should precisely estimate both GRC and DRC for box-girder bridges.

B. Gross Replacement Cost (GRC)

GRC is based on the concept of the total admissible cost of replacing a highway asset as a part of the existing highway network. It was designed to precisely calculate the asset's replacement cost accounting for inflation. GRC calculation is

based on the asset's original construction cost and its current unit price, and these two concepts have been used to develop a variety of approaches to calculate infrastructure asset GRC as below [6].

C. Price Index Method

The price index method was designed to calculate GRC based on the original construction cost and inflation over the service life time of the infrastructure asset. However, when the asset management authority cannot acknowledge the original constructed cost of the infrastructure, the unit price method can also be used to calculate GRC. For instance, in 2000 there was a bridge for which the original construction cost could not be acknowledged to calculate GRC. To compensate for this, the unit price of the same type bridge in 2000 can be used as the unit price of the bridge for which GRC calculation is needed.

D. Infrastructure Unit Pricing Method

The unit price is the fundamental component for calculating the price index. The unit price can be divided into the integrated unit price and the subdivision unit price. The integrated unit price represents the cost of the structure per unit of area or volume. For the subdivision unit price, the GRC is calculated according to each main component or material subdivided from the object structure.

In general, the infrastructure management authority lacked data for both structural element unit prices and quantity of structural materials, making it impossible for this study to calculate infrastructure GRC in the subdivision unit price.

Compared with the unit price method, the price index method is more simple and conventional in terms of data retention. In addition to calculating GRC by the original construction cost, a modified practice allows for calculation without the asset unit price by using the cost of the same type structure that constructed in different years. Therefore, this research adopts the index price method to calculate of bridge gross replacement cost (BGRC).

E. Calculating the Bridge Depreciation Replacement Cost BDRC

Estimating bridge depreciation is the key function of the BDRC calculation process. Three methods are used to calculate BDRC in practical cases: straight-line depreciation, accumulated depreciation at the element level, and the depreciation factor method.

F. Straight-Line Depreciation Method

Straight-line depreciation obtains the annual depreciation value by apportioning the infrastructure value into its own service life. According to this principle, maintenance costs are regarded as value increments and contribute to infrastructure value. Thus, the annual depreciation value should be re-calculated due to infrastructure value variation.

G. Accumulated Depreciation at the Element Level

Applying this method requires knowing the service life, maintenance cost, maintenance timing and overhead cost for each infrastructure element. However, Taiwan's highway

administration does not preserve such data, making this approach infeasible.

H. Condition Indicator/Depreciation Factor Relationship (CI/DFR) Method

In the CI/DFR method, the depreciation of an infrastructure asset is estimated according to the overall condition of infrastructure elements. The infrastructure value is a variable that will increase with maintenance, and decrease with depreciation, thus asset value reflects infrastructure condition and maintenance work.

The data requirements for CI/DFR are relatively light, and the calculation process is relatively simple. Thus, CI/DFR is an ideal basis for developing the bridge value estimate model in Taiwan, and this research adopts CI/DFR to establish the BDRC calculation model.

To develop the calculation model for highway box-girder bridges, sample bridges are selected by the factor of bridge condition evaluation and historical maintenance records. Based on the depreciation factor and bridge condition indicator (CI), regression analysis obtains the CI/DFR. Finally, the theoretical maintenance cost and the BDRC of the sample bridges can be calculated with the CI/DFR formulation.

IV. PRACTICAL CALCULATION OF BOX-GIRDER BRIDGES

The sample data of box-girder bridges were obtained from the National Freeway Bureau Northern Region Engineering Office. Five of 40 sample bridges were excluded due to lack of sufficient data, and the remaining 35 bridges were used in the process of value evaluation and regression analysis as follows:

1. To establish the basic data for valuation and regression analysis, the sample bridges were sorted by scale in terms of the numbers of spans, bridge deck area and year of construction.
2. Use the price index method to calculate the BGRC of each sample bridge based on the unit price and bridge deck area.
3. Record the impairment cost and condition indicator (CI) according to historic maintenance data for each sample bridge.
4. Use the recorded impairment cost and BGRC to calculate the depreciation factor for each bridge.
5. Perform regression analysis using the relationships between the depreciation factor and condition indicator (CI) of all sample bridges to form the equation for depreciation calculation.
6. Use the equation developed in step 5 to calculate the theoretical depreciation cost.
7. Obtain the BDRC by subtracting the theoretical depreciation cost from the BGRC of each bridge.

A. Regression Analysis of Box-Girder Bridges

A condition indicator/depreciation factor relationship formulation was established using the 35 sample box-girder bridges. Regression analysis was conducted based on the relationships between the depreciation factor and condition indicator of the sample bridges, with results shown in Fig. 1.

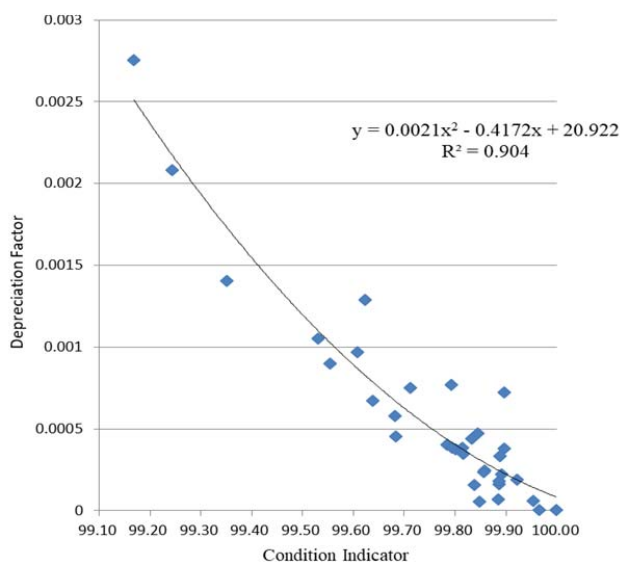


Fig. 1 Regression analysis of 35 box-girder bridges

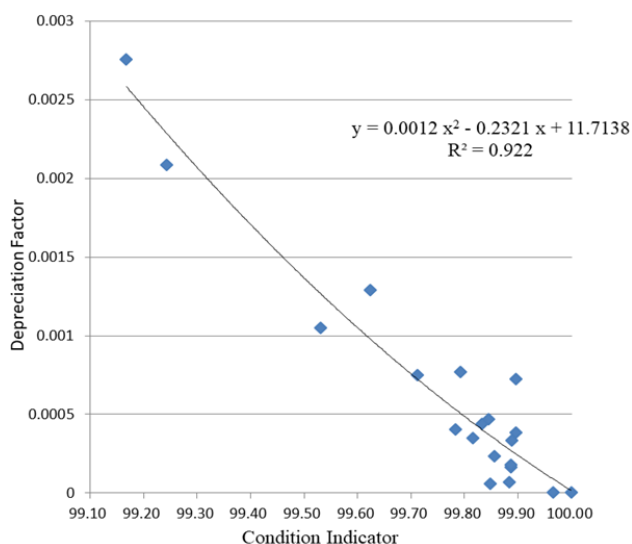


Fig. 2 Regression analysis of bridges with deck area below 5000 m²

To obtain a formula with a better correlation coefficient between the depreciation factor and condition indicator for the box-girder bridges, the sample bridges were divided into two groups for regression analysis. Box-girder bridges were classified into two groups by deck area size, with a cutoff of 5000 m². Figs. 2 and 3 respectively show the regression analysis results for these bridge groups. The figures show that the correlation coefficients are significantly improved by classifying the sample bridges into two groups. Table I compares a representative bridge from each group to present a detailed analysis result.

There is an obvious difference in scale between these two sample bridges, where the larger bridge is more prone to damage and thus incurs higher maintenance costs. However, the depreciation factor calculation should consider the BGRC. Thus, despite its higher maintenance costs, the larger bridge still has a lower depreciation factor.

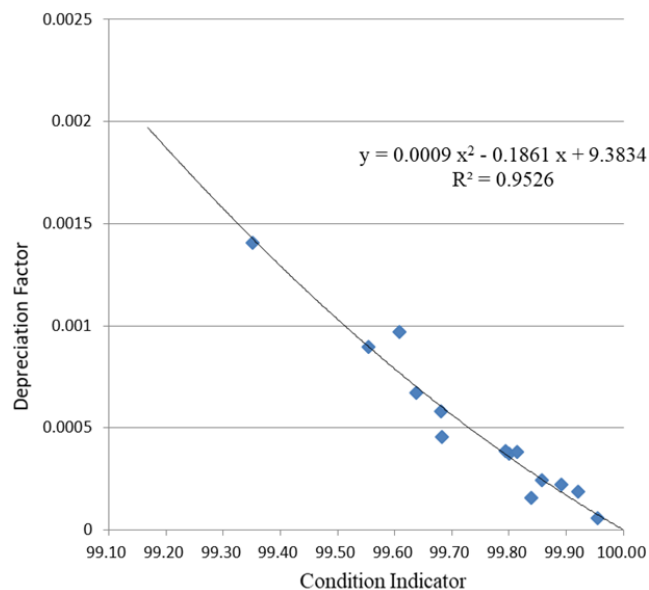


Fig. 3 Regression analysis of bridges with deck area above 5000 m²

TABLE I
COMPARISON OF SAMPLE BRIDGES

Bridge No.	No.110-A4	No.007-N11
Bridge area	374m ²	5790m ²
Condition Indicator, CI	99.91662	99.92170
Maintenance cost	NT\$ 6257	NT\$ 24994
BGRC	NT\$ 8681288	NT\$ 134397480
Depreciation factor relationship	0.000720746	0.000185971

B. Results Analysis

Three equations were used to calculate box-girder bridge value: Equation (1) calculates the value of all bridges. Equation (2) calculates the value of bridges with a deck area under 5000 m². Equation (3) calculates the value of bridges a deck area above 5000 m².

$$y = 0.0020802421x^2 - 0.4172393721x + 20.9215984291 \quad (1)$$

$$y = 0.001500644x^2 - 0.2321444750x + 11.1738713850 \quad (2)$$

$$y = 0.0009223275x^2 - 0.1860664868x + 9.3833720259 \quad (3)$$

Table II summarizes the final calculation results, showing that the difference between theoretical and real maintenance costs in each group are roughly equal, indicating that calculation precision is consistent among all three equations.

TABLE II
BRIDGE MAINTENANCE COST CALCULATION RESULTS

	Average real maintenance cost	Average theoretical maintenance cost	Ratio
All bridges	NT\$ 63236	NT\$ 78014	123.37%
Floor area under 5000 m ²	NT\$ 27500	NT\$ 20408	74.21%
Floor area above 5000 m ²	NT\$ 122797	NT\$ 147697	120.28%

V. CONCLUSION

This research successfully establishes a value evaluation

model of highway box-girder bridges in Taiwan, which accounts for highway maintenance characteristics. The developed model is validated by regression analysis using the relationships between depreciation factor and the condition indicator of 35 sample bridges. The results provide the following implications:

1. Considering the low completeness of infrastructure construction records, the price index method is suitable for calculating GRC, while the depreciation factor method is better for DRC.
2. The regression analysis shows that highway box-girder bridges should be divided into different groups to obtain more precise calculation results.
3. Calculation results for the depreciation cost provide a clear indication of bridge condition and maintenance budget requirements.
4. Value evaluation improves infrastructure management accountability.
5. To improve calculation precision, the regression analysis should be performed under using appropriately classified infrastructure groups.

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