Abridgment

Data Collection and Analysis of Bridge Rehabilitation and Maintenance Costs

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Analysis of rehabilitation and maintenance work is essential for effective bridge management. Only by correctly understanding costs, timing, and service life of rehabilitation and maintenance work can realistic life-cycle cost analyses of bridges be made. Bridge rehabilitation and maintenance work were evaluated to determine representative cost models that can be used in a bridge management system. Cost and other data needed for the analysis were extracted from the bridge rehabilitation cost file (contract costs), rehabilitation records, rehabilitation design plans, and maintenance records maintained by the Indiana Department of Transportation. Several problems related to the existing rehabilitation and maintenance work recording procedures were identified during the study. A major problem encountered was an inconsistent grouping of rehabilitation activities. Also, unit costs were found to vary substantially within the same rehabilitation category. The difference was partly caused by the wrong classification of rehabilitation activities and partly by the way bridge rehabilitation activities are let for contract. Often, two or more bridges are included in one rehabilitation contract, and only one unit cost per contract is computed despite the differences in the type and amount of work required for individual bridges in the same contract. It was necessary to discount these effects before determining representative unit costs. In addition, a manual inspection of maintenance records indicated the need for a refinement of the bridge maintenance work categories.

Analysis of rehabilitation and maintenance work is essential for effective bridge management. Only by correctly assessing the cost, timing, and service life of rehabilitation and maintenance activities can a realistic life-cycle cost analysis of bridges be made. The number of the types of bridge rehabilitation activities is large. Grouping rehabilitation activities into a manageable number of categories is a necessary step toward developing a practical bridge management program. However, the number of categories should not be too small to maintain the desired level of precision of the estimated costs.

Bridge rehabilitation costs are often estimated using a unit cost calculated for various types of rehabilitation work together. However, a large variation exists among the unit costs of different rehabilitation activities and within each rehabilitation category. There is a danger of overestimating or underestimating future rehabilitation costs if such variations are overlooked. Similar arguments can be made for the estimation of maintenance costs. Bridge maintenance costs are often treated as an annual lump sum amount. But not all maintenance activities are annual events.

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The purpose of this cost analysis was to evaluate the method of record keeping and to determine representative cost estimates that can be incorporated into a network level bridge management system of the Indiana Department of Transportation (INDOT). The results of the assessment and the procedure employed to statistically analyze rehabilitation and maintenance unit costs are summarized. Also discussed are problems that were encountered during the study.

Records of about 440 bridges rehabilitated in 1984, 1985, and 1986 were extracted from INDOT's bridge rehabilitation records. Rehabilitation categories recorded more than once are shown in Table 1. Deck and superstructure work accounted for most of the activities. Substructure rehabilitation accounted for only a small portion of total bridge rehabilitation cost in any year, and there were only a few types of such work.

There were three primary problems in the recording of rehabilitation activities. First, the categorization of rehabilitation activities was often inconsistent, making the task of determining representative costs difficult. Second, there were large variations in unit costs among the different rehabilitation categories and within each category, as shown in Table 1. Third, a large number of rehabilitation contracts contained more than one bridge in one contract, making it difficult to attribute proper expenditures to each bridge.

ANALYSIS OF DECK RECONSTRUCTION AND OVERLAY COSTS

The only category feasible for subsequent statistical analyses was deck reconstruction and overlay. Out of 360 bridges receiving deck reconstruction and overlay, 84 met the data selection criteria: (*a*) one bridge per one contract and (*b*) rehabilitation work that met the definition of the deck reconstruction and overlay category. Unit costs in different years were adjusted to the 1985 level by using the FHWA construction price indices (*1*). Unit costs are expressed in dollars per square foot of deck area. Unit costs shown in this paper are costs of the structure portion of the rehabilitation work. Costs of other miscellaneous items were, on the average, about 110 percent of the structure cost. The analysis of variance (ANOVA) technique was used to determine the effects of various factors on unit costs. ANOVA helps to identify what factors might most affect the values in question (*2*). The SPSS statistical package (*3*) was used for statistical analyses.

TABLE 1 REHABILITATION CATEGORIES USED BY INDOT AND THEIR UNIT COSTS

Rehabilitation Category	Number of Bridges	Unit Cost ($/ft^2)*	
		Min.	Max.
1. Deck Reconstruction & Overlay	360	1.37	32.28
2. Deck Reconstruction & Widening	17	13.93	69.49
3. Deck Reconstruction & Joint Replacement	10	3.18	3.28
4. New Deck	8	14.68	63.21
5. New Deck & Widening	7	6.81	36.28
6. Deck Reconstruction	6	6.49	30.58
7. New Superstructure	5	19.29	65.31
8. Deck Replacement & Widening	4	11.07	72.70
9. Superstructure Replacement	3	23.18	35.23
10. Superstructure Reconstruction & Widening	2	24.73	n.a.
11. Major Reconstruction	2	27.57	n.a.
12. Replacement of Beams	2	3.97	25.68
13. Deck Replacement	2	20.52	30.19
14. All others**	15		

Note: n.a. - Only one unit cost was available.
* - Cost data were obtained for bridges rehabilitated in 1984, 1985, and 1986.
** - Each activity category had only one case.
Remarks: These unit costs are of the structural portion of the total rehabilitation cost.

Factors Used in Cost Analysis

Four classification factors for general bridge management were initially considered: highway system type, traffic volume, climatic region, and bridge type. ANOVA indicated that their effects on the unit costs of this rehabilitation activity were not significant, implying that differences in the unit costs were due to other factors. However, this result does not suggest the complete exclusion of these factors from all other analyses. The test says only that there was no substantial evidence to prove that unit costs were affected by these factor groupings.

Effects of Bridge Attributes on Unit Costs

Bridge attributes that can be readily estimated by inspectors were subsequently evaluated. They included structure length, deck area, and percentage of deck area needing patching. The percentage of deck area needing patching is obtained by dividing the total of shallow patching and full-depth patching by the deck area, both expressed in square feet. This attribute was tested because it is a primary factor in selecting a deck reconstruction and overlay work.

The effects of bridge length and deck area on unit costs were significant at $\alpha = 0.05$ and 0.10, respectively. The deck area needing patching was not significant by itself at these significance levels. Two-way ANOVAs were then performed to see the interaction effect of length and deck area: one for the combination of deck area and percentage of deck area needing patching and the other for the combination of bridge length and percentage of deck area needing patching. The former model provided more distinct unit costs among the factor combinations than the latter. Table 2 shows results of the two-way ANOVA performed on the combination of deck area and percentage of deck area needing patching. The effect of the two attributes (main effects) and their interaction on unit costs were significant at $\alpha = 0.05$. This result implied that unit costs were dependent on both the size of deck area and the percentage of deck area needing patching. Unit costs determined in this manner are more precise than a single mean unit cost.

BRIDGE MAINTENANCE COST ANALYSIS

At the time of the study, five activity types were used to record bridge maintenance work. They were (*a*) hand cleaning of bridges (Activity 241), (*b*) bridge repairs (Activity 243), (*c*) deck flushing (Activity 244), (*d*) patching (Activity 245), and (*e*) other bridge maintenance (Activity 249). The hand cleaning and flushing activities are performed annually on each bridge. The remaining three activities are done whenever the need arises or as recommended by bridge inspectors. Maintenance activities are customarily summarized by highway type (Interstate and Other State Highway) within subdistricts. At the time of the study, maintenance workers were not required to record the specific bridge locations. Hence, the maintenance history for individual bridges was not available. It was necessary to use average values at the subdistrict level to determine representative bridge maintenance costs. An assumption was made on the basis of the result of a previous study (*4*) that each subdistrict follows the same work standards.

TABLE 2 EFFECTS OF DECK AREA AND PERCENTAGE OF DECK AREA NEEDING PATCHING ON UNIT COSTS OF DECK RECONSTRUCTION AND OVERLAY (1985 DOLLARS)

		Deck Area (DA) in Square Yards		
		Small DA<500	Medium 500≤DA<2,000	Large DA≥2,000
Percent of Deck Area Needing Patching (PA)	Low (PA<15%)	N = 6 Mean = 13.74 LL = 9.78 UL = 19.30	N = 37 Mean = 9.09 LL = 7.94 UL = 10.40	N = 6 Mean = 5.73 LL = 4.65 UL = 7.01
	High (PA≥15%)	N = 6 Mean = 16.09 LL = 11.45 UL = 22.60	N = 26 Mean = 10.11 LL = 8.60 UL = 11.88	N = 3 Mean = 8.11 LL = 5.02 UL = 13.12

Definitions: N = Number of samples
Mean = Mean unit cost in $ per square foot
LL = Lower limit of the 95% confidence interval of the mean
UL = Upper limit of the 95% confidence interval of the mean

Remark: The unit costs shown here are of the structural portion of the total rehabilitation cost. Miscellaneous items require an additional 110% of the structure cost.

Data Base and Study Approach

There are 37 subdistricts of INDOT, resulting in 37 data points per year for each activity. The data base for this analysis was prepared using the annual accomplishment and performance summary reports of the past 6 years, from fiscal years 1980–1981 through 1985–1986. Information on the amount of work done, the number of man-hours required, and the number of crew days spent for the five activities was obtained. Cost data were taken from the 1985–1986 reports; hence, computed unit costs were considered to be close to the 1985 price. Cost data consisted of three elements: labor, material, and equipment. Labor was the major portion of the costs for maintenance activities except Activity 243 (bridge repair), for which labor was slightly more than 50 percent of the total cost. All activities were first expressed in terms of man-hours per production unit. At the same time, the total maintenance cost of each activity was converted into cost per man-hour. The cost per man-hour was then multiplied by the number of man-hours required at the work site to determine the unit cost per production unit.

Effects of Management Factors on Work Requirements

The only significant management factor was the highway type (Interstate or Other State Highway), and this was true only for Activities 241 and 243. The difference was moderately significant for Activities 244 and 245. The highway type was not, however, significant for Activity 249. For Activities 241 and 244, the production unit would depend on the size of the deck. Therefore, work requirements would vary considerably for bridges of different deck areas. On the other hand, man-hour requirements of Activities 243 and 249 are the number of man-hours to perform these activities in 1 crew day. Hence, if a repair requires more than 1 crew day, the work requirement for that bridge would have to be adjusted by the number of days. No adjustment is required for Activity 245 (patching), because the unit cost was determined according to the square feet of patching work.

Representative Maintenance Unit Costs

Table 3 shows the unit costs of maintenance activities computed in the manner discussed. The table also shows the 95 percent confidence intervals of the mean unit costs. Deck-cleaning and bridge-flushing costs for particular bridges can be computed by multiplying the unit costs by the ratio of the actual bridge size to the state average deck size as indicated in Table 3.

CONCLUSIONS

The primary goal of this study was to assess the procedures for recording rehabilitation and maintenance activities and to determine representative unit costs. Although the numerical results apply only to Indiana, the analytical procedure followed can be of assistance to other states interested in determining similar unit costs.

The existing grouping of bridge rehabilitation projects was found to be rather inconsistent. Reorganization of rehabilitation categories was recommended to improve the precision of unit costs. A list of suggested categories was prepared on the basis of the literature and opinions of state bridge inspectors.

Bridge rehabilitation is site specific. Therefore, there is a large variability in the amount of work done for each reha-

TABLE 3 UNIT COSTS OF ROUTINE MAINTENANCE ACTIVITIES FOR FISCAL YEAR 1985–1986 (DOLLARS PER PRODUCTION UNIT)

Activity Type	Production Unit	Interstates	Other State Highways
241. Hand Cleaning Bridges *	Per Deck	Mean = 64.87 95%CI = 61.54 to 68.12	Mean = 51.26 95%CI = 49.32 to 53.27
243. Bridge Repair	Per Repair Per Day	Mean = 463.28 95%CI = 413.96 to 512.61	Mean = 455.87 95%CI = 436.19 to 475.43
244. Flushing Bridges**	Per Deck	Mean = 38.67 95%CI = 35.40 to 42.01	Mean = 34.14 95%CI = 32.16 to 36.04
245. Patching Bridge Decks	Per Square Foot	Mean = 12.15 95%CI = 9.64 to 14.66	Mean = 10.34 95%CI = 9.24 to 11.45
249. Other Bridge Maintenance Activities	Per Maintenance Per Day	Mean = 378.90 95%CI = 329.00 to 428.82	Mean = 337.32 95%CI = 311.70 to 362.94

Note: M = Mean value
95%CI = 95% confidence interval of the mean

* Adjustment for Activity 241

- Interstate (INT):

$$\text{Cost per Deck} = \frac{\text{Deck Area } (yd^2)}{1{,}172.3\ (yd^2)} \times (\$64.87)$$

- Other State Highways (OSH):

$$\text{Cost per Deck} = \frac{\text{Deck Area } (yd^2)}{549.1\ (yd^2)} \times (\$51.26)$$

** Adjustment for Activity 244

- Interstate (INT):

$$\text{Cost per Deck} = \frac{\text{Deck Area } (yd^2)}{1{,}172.3\ (yd^2)} \times (\$38.67)$$

- Other State Highways (OSH):

$$\text{Cost per Deck} = \frac{\text{Deck area } (yd^2)}{549.1\ (yd^2)} \times (\$34.14)$$

bilitation, and the variability is reflected in unit costs. Statistical principles were applied to analyze rehabilitation alternatives. The ANOVA on unit costs resulted in a list of stratified unit costs for the deck reconstruction and overlay alternative. The stratified unit costs should result in more precise cost estimates.

The maintenance cost analysis required a special procedure to deal with the lack of maintenance history of individual bridges. Recording the specific locations of maintained bridges is essential to collect data for life-cycle analysis. The unit costs presented in this paper reflect the characteristics of maintenance activities in Indiana, and they may not be directly transferable to other states. Nevertheless, the analysis procedure can be useful to other states.

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REFERENCES

1. *Value of New Construction Put in Place*. Construction Reports, C30-86-11. Bureau of the Census, U.S. Department of Commerce, Jan. 1987.
2. J. Neter and W. Wasserman. *Applied Linear Statistical Models: Regression, Analysis of Variance, and Experimental Designs*. Richard D. Irwin, Inc., Homewood, Ill., 1974.
3. C. H. Hull and N. H. Nie (eds.). *SPSS Update 7–9: New Procedures and Facilities for Release 7–9*. McGraw-Hill Book Company, New York, 1981.
4. S. M. O'Brien. *The Identification of Factors That Influence Routine Maintenance Activities*. M.S. thesis. Purdue University, West Lafayette, Ind., 1985.