PROCEEDINGS —

Twenty-third Annual Meeting

Volume XXIII • Number 1 1982

TRANSPORTATION RESEARCH FORUM

PROCEEDINGS —
Twenty-third Annual Meeting

Theme:

"Developing Concinnity in Transportation"

October 28-30, 1982
Fairmont Hotel
New Orleans, LA

Volume XXIII • Number 1 1982

T R F

TRANSPORTATION RESEARCH FORUM

Development of a Computer Model for Lifecycle Cost Analysis of Statewide Bridge Replacement and Repair Needs

by William A. Hyman and Dennis J. Hughes**

INTRODUCTION

CURRENTLY THE Wisconsin Department of Transportation is developing a computer simulation model that will estimate both current and future bridge replacement and repair needs. The model applies lifecycle cost analysis to bridges on the state trunk highway system (STH). The model will aid the Department in determining the required level of funding for repairing and replacing STH bridges and to keep these bridges at a desired system average condition level. Likewise, the model should be useful to other states and the federal government. The purpose of this paper is to describe the model, discuss issues regarding its development and present some interim results.

BACKGROUND

Every two years the Department reevaluates Wisconsin's bridge replacement needs over a six year time horizon as part of the highway programming process and the development of a biennial budget proposal. In the past, bridge replacement needs have been determined largely on the basis of field inspections and engineering judgment. Field ratings for superstructure, substructure, load capacity and deck condition were combined into overall condition and load appraisals, as well as a sufficiency rating, all of which served as input into selecting the bridges replaced. Also entering the replacement decision has been whether the highway which a bridge served was scheduled for improvement. In addition, the Department informally assessed whether it was cheaper to repair or replace a bridge over its expected lifestyle.

As transportation revenues have declined in real dollar terms, Wisconsin, like many other states, must look more closely at its highway and bridge expenditures to make sure they are used as efficiently as possible. The state must avoid the fallacy of composition: if it maximizes the net benefits of expenditures on individual projects, it may fail to maximize the net benefits of expenditures on a statewide or systemwide basis.

**Division of Planning and Budget, Wisconsin Department of Transportation, Madison, WI.*

TRADITIONAL NEEDS STUDIES VS. LIFE CYCLE COST ANALYSIS

Traditionally state transportation agencies and the federal government have performed "needs" studies to determine highway and bridge revenue requirements. This has been done by comparing the physical characteristics of a roadway segment, or a bridge, to accepted improvement standards. The estimated cost of improving a road or bridge to satisfy the relevant standards constituted the "need." To some extent WisDOT continues to perform "needs" studies. However, the Department now recognizes that "need" is a relative term. If attaining the accepted improvement standards is economically or politically unrealistic, then such "needs" have little practical meaning.

To avoid the pitfall of traditional needs studies, WisDOT has focused increasingly on identifying a minimum, or base level, program. This is defined in terms of the level of expenditures necessary to keep the systemwide average highway conditions at roughly current levels to avoid both deferred maintenance and unnecessary expenditures. For example, the department has performed studies using the Pavement Serviceability Index (PSI) to determine the level of surface renewal effort necessary to keep STH pavement surfaces at the current systemwide average level of smoothness.[1] WisDOT is currently supplementing its PSI evaluations with new pavement distress studies.

As a further step away from traditional "needs" studies, the Department is developing the ability to perform explicit lifecycle cost analysis to identify the minimum expenditure required to maintain highway conditions at their current systemwide levels. The development of a computer model for lifecycle cost analysis of bridge repair and replacement needs, described in this paper, represents WisDOTs first major effort to apply lifecycle cost analysis to a significant element of the state highway program on a systemwide basis and for time horizons ranging from one to twenty years.

SCOPE OF THE PROBLEM

Some statistics are useful in gauging the magnitude of the bridge replacement problem in Wisconsin. The state owns nearly 4,600 bridges on the STH system. However 300 are sign bridges and other non-highway service bridges, leaving nearly 4,300 state-owned bridges, of which 292 are single units of large multi-unit bridges. WisDOT bears 100% responsibility for replacement of these state-owned bridges.

Table 1 shows the distribution of these bridges bv structure type. These categories are based on span material and configuration. The three most common structure types are steel deck girders, prestressed concrete, and concrete slabs, accounting for nearly 80 percent of all bridges.

The distribution of state-owned federal aid bridges by construction year appears in Figure 1 and closely resembles that of New York and presumably other states.[2] Several observations can be made from this illustration.

- A surge of bridge construction occurred during the 1930's — the era of the Work Progress Administration — followed by a lull during World War II.
- A tremendous increase in bridge construction occurred during the 1960's as a result of construction of the Interstate Highway system and other major highway improvements.

STATE-OWNED FEDERAL AID BRIDGES
Count By Construction Year

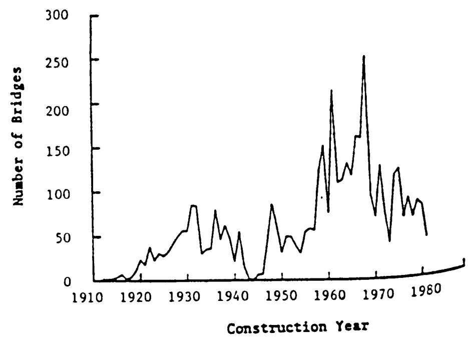

FIGURE 1

- Bridge construction dropped during the 1970's as the Interstate system neared completion and attention turned to replacing older, deficient or substandard bridges.

Accepted engineering wisdom assumes an average life expectancy of 50 years, and so bridges constructed during the Depression era are coming due for replacement. Thus in Wisconsin there are currently 500 state-owned bridges of immediate concern, and an additional 800 bridges which will pass the 50 year benchmark by the year 2000.

A considerable portion of typical bridge repair and replacement costs are based on deck area. Therefore, the larger bridges, which are generally on

TABLE 1

STATE-OWNED FEDERAL AID BRIDGES WITH HIGHWAY SERVICE "ON"
Distribution by Structure Type

	Structures		Deck Area		Average
	Number	% of Total	Total (ft^2)	% of Total	Age
STRUCTURE TYPE					
Concrete Deck Girder	403	9.4	1,665,891	4.9	46.2
Concrete Slab(Pre-1955)	88	2.1	260,563	0.8	44.4
Concrete Slab(1955+)	629	14.7	3,747,424	11.0	15.4
Other Concrete	12	0.3	88,680	0.3	45.7
Culvert	350	8.2	1,573,028	4.6	17.5
Prestressed	755	17.6	6,771,811	20.0	11.7
Steel Deck Girder	1,894	44.2	18,280,416	53.9	25.4
Other Steel	130	3.0	1,113,031	3.3	46.8
Miscellaneous	25	0.5	394,124	1.2	33.4
Total	4,286	100.0	33,894,968	100.0	24.0

the higher function roads, have higher repair and replacement costs per bridge. Over 60 percent of the state-owned bridges are on the highest functional systems (i.e. Interstate and principal arterials) and account for 70 percent of the total deck area. The average size of bridges also has increased over time, which is reflected in the growth of the average deck area from 3,250 square feet for bridges more than 50 years old to roughly 10,000 square feet for bridges built in the last 20 years.

On a two year cycle, the Department performs field inspections of all state-owned bridges in Wisconsin. Inspectors rate key structural and situational factors. Two well known indexed ratings, which represent combinations of several field ratings, are condition appraisal and sufficiency rating. Ten percent of the state-owned bridges, representing six percent of the total deck area, have condition appraisals less than 4. This is a level which is considered "deficient" and suggests that replacement or rehabilitation is required. About eleven percent of the state-owned bridges have a sufficiency rating below 50, the threshold to qualify for federal bridge replacement funds.

In recent years alternative six year bridge replacement or rehabilitation programs have ranged from a low six-year total of $85 million to a high of $175 million. In the current six year improvement program for the 1981-1987 period, the Department proposes to replace 159 bridges, and rehabilitate 24 others, at a cost of $115 million in 1982 dollars. This level of effort, if sustained over a long period of time, implies bridges must have an average life expectancy of more than 100 years. In light of this greatly exaggerated life span relative to the traditional rule of thumb of 50 years, the Department feels compelled to look more closely at STH bridge replacement requirements to verify that the current level of effort is indeed too low to maintain current systemwide bridge conditions.

DESCRIPTION OF MODEL AND SOME ILLUSTRATIVE RESULTS

The development of a computer simulation model that uses lifecycle cost analysis to assess statewide bridge replacement and repair needs must embrace a combination of approaches and perspectives to be appealing to potential users, which include engineers, economists, planners and administrators.

First, the model must allow for the application of engineering experience and judgment. Engineers have developed much knowledge and historical data to evaluate the cost, type and timing of repairs many kinds of bridges require. However, when historical data is lacking, judgment is required. No data exists, for example, to evaluate the future repair costs and condition of the types of bridges only recently constructed, such as prestressed concrete structures.

Second, a systemwide or a "top down" perspective is required. The model must be capable of examining a large number of bridges simultaneously on a systemwide basis. We have incorporated part of WisDOTs system planning process into this model. WisDOT's highway system plan sets deficiency thresholds which signal a possible need for replacement. The system planning process also defines alternative futures and corresponding responses, and it treats bridges on different functional highway systems differently.

Third, a "bottoms up" perspective is needed. The model should take into account different types of bridges and account for each bridge's current condition, capacity and geometric characteristics, as well as dimensions (length, width, deck area), traffic levels and functional class of the highway it serves. Unsafe, posted, or closed bridges should be identified and treated appropriately.

Fourth, a statistical approach is desirable. The model should deal with the average behavior of bridges both in assigning lifecycle costs and for making forecasts of condition and operating capacity.

Fifth, an economic perspective is crucial. The program should apply lifecycle cost analysis and discount the costs back to the base year of analysis in order to determine whether bridge replacement or repair is less expensive. Taking into account budget constraints is also desirable.

Last, the model should evaluate bridge repair and relacement needs over time and keep track of the costs and changes in bridge condition.

Figure 2 illustrates a flow chart of the computer simulation model WisDOT is developing. The program is written in Fortran and one of the significant input data items is a series of lifecycle activity profiles, which define what type of bridge repair work is performed in each year over the expected life of a given structure type. More than one profile may be assigned to a single type of structure since the course of repair work can proceed on different tracks as shown in Figure 3. Input data includes specifying the percent of time a particular profile applies to a structure type and the life expectancy of bridges with

FLOWCHART OF COMPUTER SIMULATION MODEL

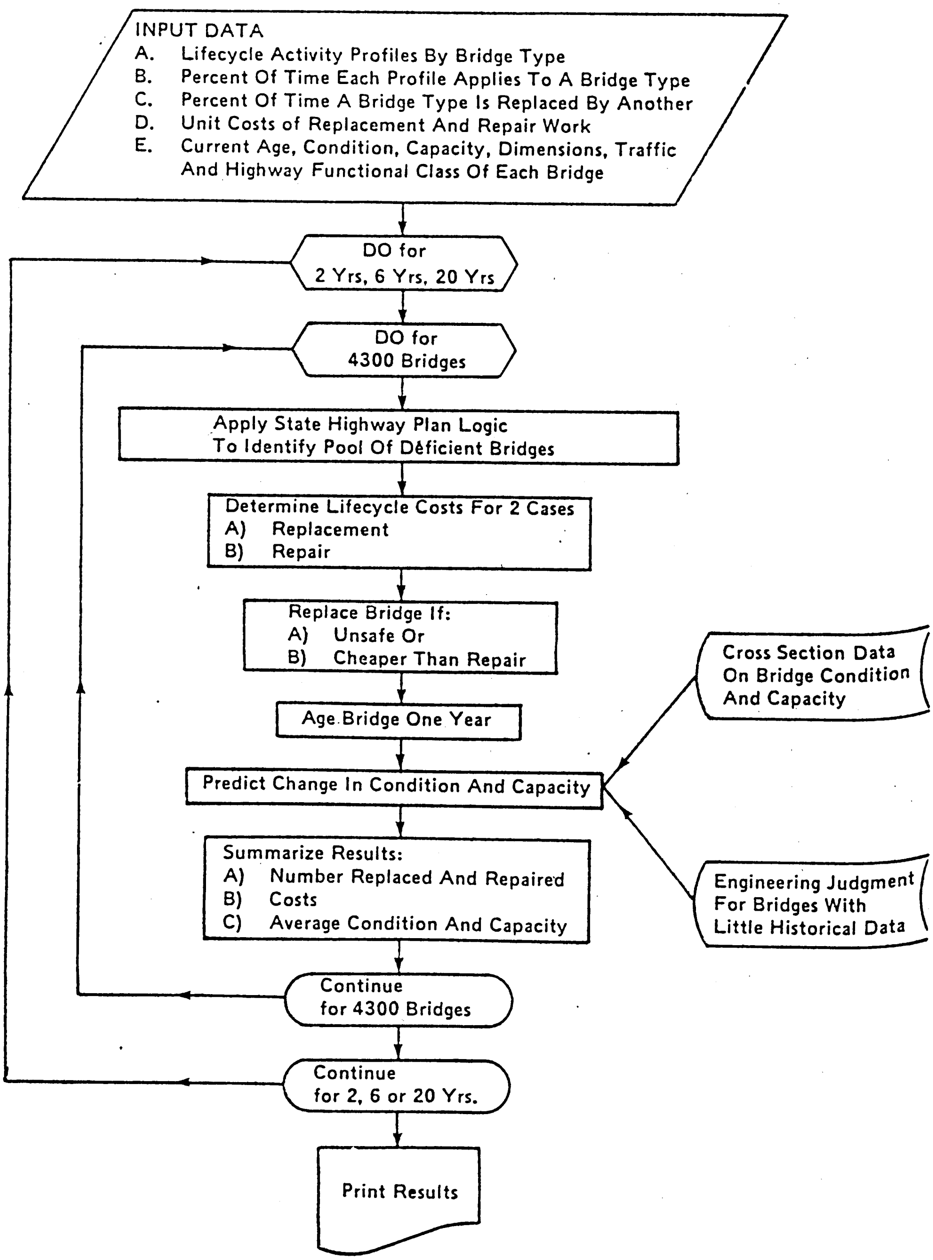

FIGURE 2

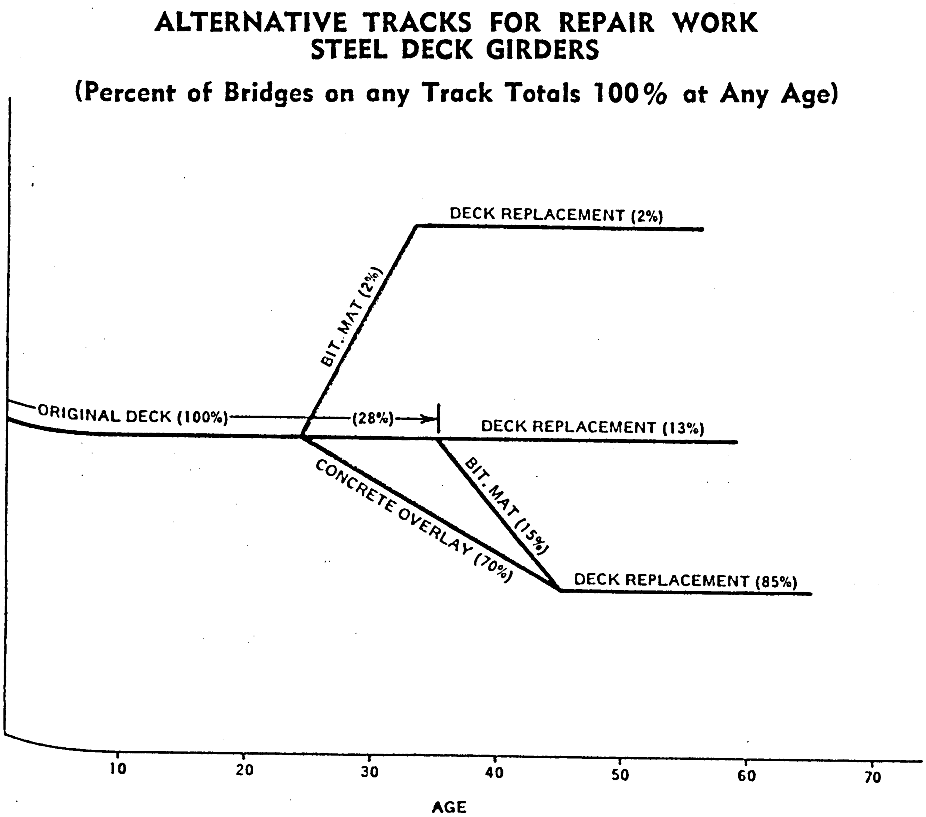

FIGURE 3

different profiles. In addition it is necessary to specify the percent of time a bridge of one type is replaced by a different structure type. Other input items include unit cost data and bridge standards. These items are used in calculating bridge replacement, widening and repair costs. One subroutine converts the lifecycle activity profiles to cost profiles using the unit cost data and information specific to each bridge, including width, length, deck area, traffic on the bridge and the functional class of the highway served.

For each year over the planning/programming horizon (2 years for the biennial budget cycle; 6 years for the highway improvement program; 20 years for the state highway system plan), the program applies a screening logic based upon condition appraisal, operating capacity and width to identify candidate "deficient' bridges. The categorization of deficiencies varies according to alternative future scenarios of the state highway system planning effort and responses that have been deemed appropriate for reacting to those scenarios. Of most importance to the bridge analysis are alternative scenarios for traffic forecasts and transportation revenues, plus deficiency criteria and design standards that are sensitive to the degree that revenues are large or small.

A bridge which is a candidate for replacement is then examined to see if it is cheaper to replace or repair over its lifecycle. The computer model uses a random number generator to select a lifecycle activity profile for each bridge for two cases: replacement and repair. On average, various profiles are assigned to bridge types in accordance with the percentages specified as input data. The replacement case is defined by a single profile which shows the costs for bridge replacement in the first period, followed by costs for other repair activities in the years they are expected to occur. The lifecycle cost profile for the repair case is composed of two parts. The first is the lifecycle cost profile for the existing bridge; at the end of its expected life the computer splices on a second part, the replacement profile. Then the computer calculates the costs under the replacement case, which is the discounted present value of the cumulative costs of bridge replacement over the lifecycle (e.g. bridge replacement followed by various repairs). This in turn is compared to costs under the repair case — the discounted present value of the cumulative costs of continuing to repair the existing bridge, replacing it at the end of its expected life, followed by repairs to the new bridge.

Figure 4 presents an example of the computer calculations for the replacement and repair case for a bridge whose current age is 40, whose life expectancy is 80 years (BREAKM) and whose life expectancy in the replacement case is also 80 years (BREAKR). In this example, replacement is cheaper over the lifecycle than repair. In five years (age=45), the existing bridge is scheduled for widening at a cost of $1,340,523 which compares with replacing the bridge immediately at $795,499. Repairing the existing bridge to the end of its life, followed by bridge replacement, would require cumulative costs over the next 50 years that has a discounted present value of $948,991 (assuming a 10% discount rate). This compares with discounted lifecycle costs of only $828,265 over the same time period in the replacement case.

The model next determines if each bridge should be replaced. Replacement rules can consist of several criteria. As currently being written, the model will replace a bridge (reset the age to zero) if it is unsafe based on data from the bridge deficiency file or if it is cheaper to replace it than repair it over its lifecycle.

The computer program ages each bridge by one year and forecasts (adjusts) the change in condition appraisal and load capacity. The program then records whether the bridge has been replaced or repaired, keeps track of the costs, broken down by components of replacement cost (structure cost, approach cost, demolition cost, engineering cost, total cost) and by repair activity (concrete overlay, patching, etc.). Finally the model repeats this process for

EXAMPLE OF LIFECYCLE COST CALCULATIONS

NET PRESENT VALUE CALCULATIONS FOR BRIDGE NO. 1 BRIDGE TYPE 1 PROGRAM PERIOD 1 YEAR 1982

INPUT AGE 40.0 BREAKR 80.0 BREAKM 80.0

LIFE CYCLE PERIOD	YEAR	REPLACEMENT CASE AGE	REPLACEMENT CASE COST PROFILE	REPLACEMENT CASE NPV	REPAIR CASE AGE	REPAIR CASE COST PROFILE	REPAIR CASE NPV
1	1982	1.	REPLACE = 795499	795499.	41.	0	0.
2	1983	2.	0	795499.	42.	0	0.
3	1984	3.	0	795499.	43.	0	0.
4	1985	4.	0	795499.	44.	0	0.
5	1986	5.	0	795499.	45.	WIDEN = 1340523	915598.
6	1987	6.	0	795499.	46.	17000	926154.
7	1988	7.	0	795499.	47.	0	926154.
8	1989	8.	0	795499.	48.	0	926154.
9	1990	9.	0	795499.	49.	0	926154.
10	1991	10.	0	795499.	50.	0	926154.
11	1992	11.	0	795499.	51.	0	926154.
12	1993	12.	0	795499.	52.	0	926154.
13	1994	13.	3000	796455.	53.	0	926154.
14	1995	14.	69230	816509.	54.	0	926154.
15	1996	15.	0	816509.	55.	0	926154.
16	1997	16.	0	816509.	56.	0	926154.
17	1998	17.	0	816509.	57.	0	926154.
18	1999	18.	0	816509.	58.	0	926154.
19	2000	19.	0	816509.	59.	0	926154.
20	2001	20.	0	816509.	60.	0	926154.
21	2002	21.	0	816509.	61.	0	926154.
22	2003	22.	0	816509.	62.	0	926154.
23	2004	23.	0	816509.	63.	0	926154.
24	2005	24.	0	816509.	64.	0	926154.
25	2006	25.	0	816509.	65.	3000	926459.
26	2007	26.	0	816509.	66.	0	926459.
27	2008	27.	0	816509.	67.	0	926459.
28	2009	28.	0	816509.	68.	0	926459.
29	2010	29.	0	816509.	69.	56000	930342.
30	2011	30.	0	816509.	70.	17000	931414.
31	2012	31.	0	816509.	71.	0	931414.
32	2013	32.	0	816509.	72.	0	931414.
33	2014	33.	3000	816651.	73.	0	931414.
34	2015	34.	0	816651.	74.	0	931414.
35	2016	35.	296700	828265.	75.	0	931414.
36	2017	36.	0	828265.	76.	0	931414.
37	2018	37.	0	828265.	77.	0	931414.
38	2019	38.	0	828265.	78.	0	931414.
39	2020	39.	0	828265.	79.	0	931414.
40	2021	40.	0	828265.	80.	0	931414.
41	2022	41.	0	828265.	1. (SPLICE)	795499	948991.
42	2023	42.	0	828265.	2.	0	948991.
43	2024	43.	0	828265.	3.	0	948991.
44	2025	44.	0	828265.	4.	0	948991.
45	2026	45.	0	828265.	5.	0	948991.
46	2027	46.	0	828265.	6.	0	948991.
47	2028	47.	0	828265.	7.	0	948991.
48	2029	48.	0	828265.	8.	0	948991.
49	2030	49.	0	828265.	9.	0	948991.
50	2031	50.	0	TOTAL: REPLACE 828265.	10.	0	TOTAL: WIDEN 948991.

FIGURE 4

as many years as specified and prints the final results.

While all the elements of this model have been programmed at this writing, they have not been integrated into a single model yet. Running the model without the lifecycle cost module included shows the following number of state-maintained bridges (nearly equals the number of state-owned bridges) will require replacement in each year out to 1900. The criteria for screening "deficient" bridges is a condition appraisal of 3 or less.

Year	Number Replaced	Number in Repair Cycle
1982	494	3879
1983	0	4373
1984	0	4373
1985	0	4373
1986	0	4373
1987	0	4373
1988	0	4373
1989	95	4278
1990	2	4371

Using a threshold of 3 would eliminate the backlog of bridge replacement needs for nearly a decade. Not until 1989 would additional bridges come on line for replacement. We expect more stringent screening criteria, such as replacing a bridge only if it is cheaper than repairing it over its lifecycle, will substantially reduce the number of bridges indicated as needing replacement in the first period.

Obviously suddenly replacing all 'deficient' bridges would significantly raise the average condition of bridges in the state. Currently the average condition appraisal is 6.532 for bridges from 0 to 40 years old, and 4.941 for bridges more than 40 years old. The model estimates that replacing 494 bridges in 1982 would increase the condition appraisal of bridges in the 0 to 40 year age group to 6.822. The average condition appraisal of bridges more than 40 years old would increase to 6.151.

These results show a threshold criteria of 3 is too liberal for identifying "deficient" bridges. Also they illustrate the fallacy of making inferences about the expected life of bridges based on the current levels of bridge replacement and repair work. Whereas the level of bridge replacement and rehabilitation work in WisDOT's current six year program implies an average bridge life of 100 years, replacing 495 bridges in a single year implies an average bridge life of less than ten years and replacing zero bridges in the following period implies an infinitely long life. Many analysts judge the adequacy of highway and bridge funding levels based on the current rate of work, which can be misleading.

SPECIAL ISSUES IN MODEL DEVELOPMENT

In the course of developing this model, a number of issues have arisen which need to be addressed in the future.

a. Input Data

Because Wisconsin has had little previous experience examining bridge replacement costs using both lifecycle analysis and a system planning perspective, input data is not conveniently available, in a useable form, or may not measure the most appropriate deficiencies.

The most crucial input data is the description of repair activities over the lifecycle of a bridge. It has been necessary to rely on engineering judgment and seat-of-the-pants estimates to produce the initial set of lifecycle activity profiles used for testing and evaluating the simulation model. Where we are dealing with bridge types for which ample historical experience exists, we can ultimately compile data from bridge construction and maintenance records to determine the types of repair activities that occur, their timing and unit costs, and thus corroborate or modify the lifecycle activity and cost profiles we have used so far. However, some structure types, such as prestressed concrete, have only been constructed since approximately 1955, and there is no firm basis for determining their repair costs when they become 50 years old.

Another problem is that as bridges near the time when they become unsafe, they are replaced. Consequently there are few really bad bridges to examine in order to determine what the repair costs would be if bridges were allowed to deteriorate further, were posted or even closed. It would be helpful if funding were available to examine lifecycle repair costs under more extreme conditions in a controlled, statistically sound experiment.

A related problem is that the Department has current data on bridge conditions, but has not kept historical records of how bridge conditions change over time. From WisDOT's existing data, it is possible to reliably estimate equations to predict future condition appraisal only over certain age groups and bridge types. Figure 5 shows a regression equation for a piecewise linear function that describes the relationship between age and condition appraisal. For bridges

REGRESSION OF CONDITION APPRAISAL ON AGE

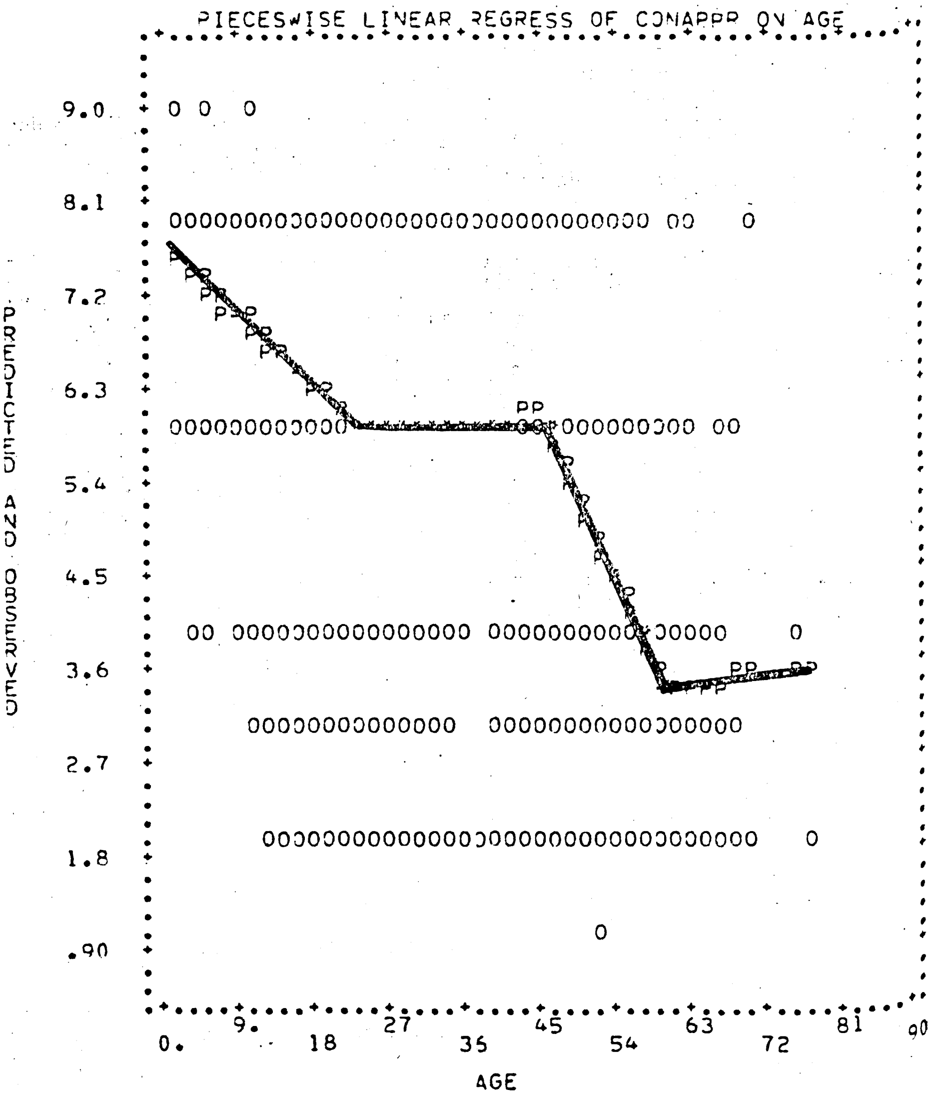

FIGURE 5

less than 20 years old, the regression equation captures fairly well the influence of time on declining condition. However, for bridges between 20 and 45 years old, the regression may mainly reflect the influence of maintenance activities, not the passage of time. Finally, for bridges older than 45 years, the regression equation may reflect changes in design standards or maintenance policies as much as it reflects the wear and tear of aging. For example, bridges built before World War II were constructed to much lower standards than today and often the low condition or capacity appraisal associated with older bridges has less to do with the aging process than it does with changing design standards.

To overcome this difficulty, it is desirable that pooled time series and cross section data for bridge ratings and indices (condition appraisal, sufficiency rating, and the like) be developed for use in estimating equations to forecast changes in these "state" variables. Data of this sort would allow analysts to separate the influence of design standards, maintenance practices and the aging process.

b. Other issues related to forecasting condition

Our experience shows that simple linear regression equations for forecasting condition appraisal as a function of age have heteroscedastic errors (i.e. the variance of errors grows with the age). Heteroscedasticity is present for bridges of ages up through twenty years, but F tests used to determine the difference in forecasting errors between five year age groups of bridges over 20 years old show the errors are not significantly different at the 95% confidence level. Standard econometric procedures can be used to correct the heteroscedasticity evident for bridges less than 20 years old.

However, we have avoided this issue to a large degree by keeping track of the forecast errors for each bridge in the initial period. Then in future periods, we add the error to the mean predicted value of condition appraisal of bridges with a specific age. This procedure maintains a one-to-one relationship between the distribution of condition appraisal in the base year and in future years, except when the model replaces a bridge. It is not possible to meaningfully forecast condition for individual bridges using only an equation that predicts the average condition of bridges at each age. The result will be every bridge of the same age will have the same forecasted condition appraisal. This is an unrealistic portrayal of condition when looking at bridges systemwide and in future years.

We have also written a subroutine that adjusts the forecast errors depending on the five year age group that applies. We make adjustments based on changes in the mean and standard deviation of errors of the predicted value of condition appraisal in the base year as one proceeds from one five year age group to another. This approach fully overcomes the problem of heteroscedasticity. An analytical process has also been sketched out that treats the change in condition of bridges passing from one five year age group to another as a Markov-like process.

Finally we have searched for richer explanations of the causes of bridge deterioration. Regression analysis has shown that deterioration varies by bridge type in addition to age and that traffic volumes and deck area are significantly and inversely related to condition appraisal. In further research we expect to be able to show that these factors plus overburden depth are significantly related to load capacity.

c. Budget constraints and the issue of optimization

When we first conceived this study in 1980, we sketched out a mathematical model that treated the bridge replacement problem as one of dynamic optimization. We wished to minimize lifecycle costs in each highway programming period subject to explicit budget constraints. However, it soon became apparent that neither linear, integer or dynamic programming was as tractable as a simulation model. The size of the problem we are dealing with (examining 4300 bridges over 20 years) precluded integer or dynamic programming. Linear programming seemed feasible if bridges could be put in homogeneous classes. In this case the instrumental variables of the linear programming model would be the number of bridges of each type that should be replaced in each year in order to minimize lifecycle costs and simultaneously satisfy budget constraints.

The model discussed in this paper currently takes into account budget constraints only indirectly through the highway system planning logic. As explained earlier, the deficiency thresholds used to identify bridges as candidates for replacement vary with the Department's proposed responses to future scenarios which are partly determined by revenue forecasts.

We envision taking budget constraints more explicitly into account without using mathematical programming. This can be accomplished by marginal analysis: subject to revenue availability, select the set of bridges for replacement whose marginal cost savings over their lifecycle is larger than for any other set of bridges. Essentially this is the same procedure used for project selection in the Highway Investment Analysis Package (HIAP) developed for the Federal Highway Administration by Multisystems, Inc. and used by WisDOT for benefit cost analysis of major highway improvement projects.[3]

d. Policy Issues

In addition to the technical issues discussed above, numerous policy issues have become evident in this study. Briefly some of these are:

- Some bridges have enormous replacement costs. Should these high cost bridges be treated in a separate program with specially earmarked funds, and should they be analyzed separately?
- Should closing a bridge or turning it over to a lower level of government be treated as an alternative to replacing or repairing a bridge?
- To what extent should the highway improvement program dictate bridge replacement needs? Many bridges in good condition are replaced because they are narrow and located on highways that are reconstructed or reconditioned.

CONCLUSION

Work performed by WisDOT to date offers optimism that lifecycle cost analysis can be used to examine bridge replacement and repair needs on a system wide basis. This approach is a departure from traditional "needs" studies and from the method the Department has used to identify desirable bridge funding levels in the past.

The model described here is useful for determining the effects of various repair and replacement strategies on bridge condition over time. It is concerned with the behavior of bridges in the aggregate. Errors in determining lifecycle profiles for specific bridges and in forecasting future condition for individual bridges are expected to wash out as a result of using a statewide level of analysis. It would be wrong to conclude that the model here could be relied upon to evaluate whether each bridge in the state should be repaired or replaced in a given year. Evaluation of specific bridges is still best performed by relying on field inspections. However, it is expected this model will greatly improve the ability of the Department to justify its budget requests to the state legislature, and to avoid deferred maintenance and unnecessary costs for all state-owned bridges taken as a group.

REFERENCES

1. Wisconsin Department of Transportation, *Pavement Life*, Special Report, Wisconsin Transportation Planning Program, State Highway Plan, August 1980.
2. Fitzpatrick, M. W., Law, D. A., and Dixon, W. C., "Deterioration of New York State Highway Structures," *Transportation Research Record*, No. 800.
3. Batchelder, J., Lange, R., Rodes, T., Neumann, L., "Application of the Highway Investment Analysis Package," *Transportation Research Record*, No. 698.

DISCLAIMER AND ACKNOWLEDGEMENTS

The results, views, conclusions, and recommendations are solely those of the authors, and not necessarily the Wisconsin Department of Transportation.

The authors wish to thank Joe Dresser, George Gunderson, Wendy Fearnside and Ken Leonard for their strong support for this work and also Don Flottmeyer, Cliff Benz, Jim Ziehr, Walter Scott, and Tom Dobson for their valuable input. We also thank Michael Fitzpatrick of the New York DOT for sharing his work with us.