OPBRIDGE: An Integrated Bridge Budget Forecasting and Allocation Module at the State Level

KAMAL M. AL-SUBHI, DAVID W. JOHNSTON, AND FOAD FARID

An overview is provided of the optimum bridge budget forecasting and allocation module (OPBRIDGE), a decision support system for bridge management at the state level. OPBRIDGE has the capability of predicting funding requirements to achieve bridge system objectives specified by the bridge manager. Alternately, the program can optimally allocate limited budgets and predict performance of the bridge system.

A bridge management system (BMS) is a systematic framework that formalizes the decision-making process involving maintenance, rehabilitation, and replacement of bridges. The BMS applies systems engineering to assist decision makers in defining optimum strategies for maintaining bridges at predefined performance standards during a given period of time, called a horizon. The BMS attempts to gradually upgrade the entire inventory of bridges so that eventually condition ratings and user levels of service will not be deficient.

Decisions in a comprehensive BMS can be analyzed at two different levels—at the bridge (project) level and at the system level. A bridge system consists of a number of bridges under the jurisdiction of an agency. At the bridge level, the BMS prescribes the best action for a specific bridge. At the system level, the BMS supports decision makers in developing an agency-wide program of maintenance, rehabilitation, and replacement that will make optimum use of the available budget.

An overview of the optimum bridge budget forecasting and allocation module (OPBRIDGE), a decision support system for bridge management at the system level, is provided. OPBRIDGE, which was developed for the North Carolina Department of Transportation (NCDOT), can answer the following bridge-level question at the beginning of each year in the analysis horizon—What action should be selected for each bridge in the system: replacement, rehabilitation, major maintenance, or routine maintenance? OPBRIDGE may also answer the following system-level questions:

1. What are the annual budgets needed over the forecasting horizon?
2. How can budgets granted be allocated optimally at the state level?
3. What are the impacts of manager objectives and funds available on the estimated future user level of service (LOS) and condition ratings of the bridge system?

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OPBRIDGE adopts and improves a methodology for computing the user and agency costs associated with the different alternatives for a bridge, on the basis of the findings of Chen and Johnston (*1*). OPBRIDGE applies concepts of strategic planning for setting long-range bridge management objectives and policies that constitute the user input for the analysis module developed. The mathematical formulation for budget forecasting is adapted from the work of Chen and Johnston, while a budget allocation module is developed at the system level under constrained budgets. OPBRIDGE analysis procedures applied to an existing bridge data base are evaluated.

MATHEMATICAL FORMULATION AND APPROACH OVER HORIZON

OPBRIDGE attempts to resemble the real-life decision process. At the beginning of every year, OPBRIDGE analyzes the budget limitation that was entered by the user for that particular year. If the budget is limited (budget granted or limited maximum allowable budget), OPBRIDGE uses a 0–1 integer-linear programming formulation with multiple-choice constraints, also called "generalized upper bound" (GUB) constraints, to optimize budget allocation according to the decision criterion, thus maximizing overall reductions in equivalent uniform annual costs (EUAC). On the other hand, if the budget is unlimited, OPBRIDGE selects the alternative that has the highest reduction in EUAC for every bridge in the system. The routine maintenance alternative protects the bridges from accelerated deterioration. Therefore, the base alternative is provided if a major improvement alternative is not economical, not enforced by requesting immediate improvement for deficient bridges, or not possible because of budget limitation. Figure 1 shows the sequence of events in OPBRIDGE, as follows:

1. The user enters budgets, objectives, and policies into the file INPUT.DAT.
2. OPBRIDGE extracts data from the bridge database and the cost and parameter file.
3. OPBRIDGE optimizes decisions for every year in the analysis horizon. At the end of every year, OPBRIDGE ages bridges 1 year and predicts condition ratings, average daily traffic (ADT), etc. This process allows the system to repeat the analysis for the next year.

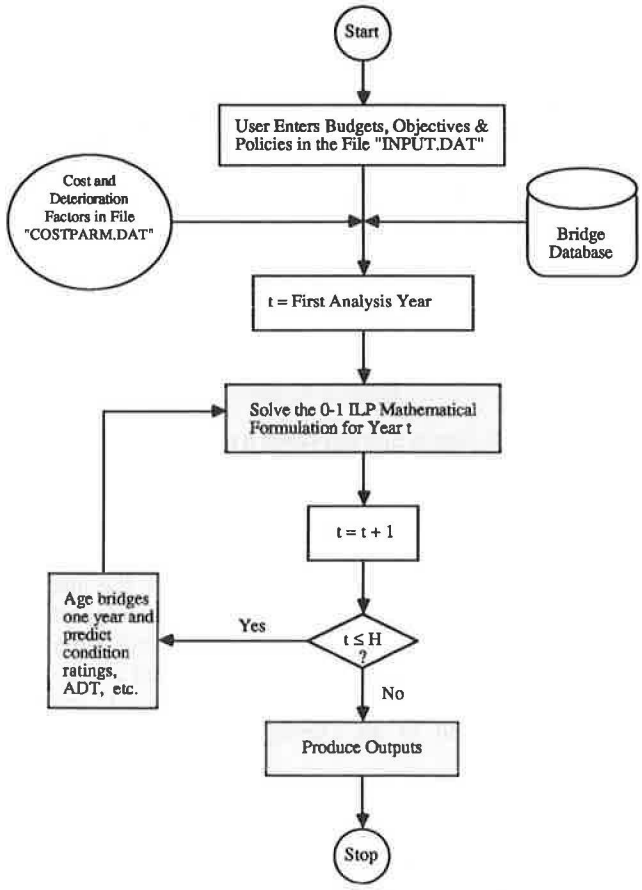

FIGURE 1 Flowchart for OPBRIDGE analysis.

4. OPBRIDGE produces detailed bridge-by-bridge output showing recommended current and future major actions, county-by-county output showing costs of major actions and budget required for each county, and tabular and graphical outputs showing the future performance level of the bridge system over the horizon, *H*.

INPUT DATA FOR USING OPBRIDGE

Figure 2 shows the OPBRIDGE user input computer screen layout. The input data consist of the following items.

1. *Horizon, H?* Enter the number of future years over which the analysis is made. This integer variable may have a value between 1 and 20.

2. *First-Analysis Year?* Enter the first year in the analysis horizon, *H*.

3. *Bridges for Analysis?* Specify whether all bridges or bridges with a certain federal-aid classification, a certain state system, or a certain division number are to be included in the analysis.

4. *Immediate Improvement for Deficient Bridges?* Specify whether improvement (rehabilitation or replacement) is mandatory for bridges that are deficient with respect to the requested user LOS goals as defined by Johnston and Zia (*2*). If the entry is N, then an improvement alternative is selected only if it is economical. If the entry is Y and the bridge is deficient in meeting the user LOS goals, an action will be taken to correct the deficiency, even if the action is not economical. However, in this second case, bridges with economic alternatives will be improved first, and then noneconomic bridges, if there are funds remaining.

5. *User LOS Goals?* Assign 1 or 2, depending on whether the user LOS goals are (a) acceptable, or (b) desirable with respect to the following bridge characteristics: load capacity, clear deck width, and vertical roadway underclearance and overclearance. The goals vary depending on highway functional classification and traffic volume. At the beginning of each year, decision rules select appropriate alternatives for a bridge, if its LOS characteristics are below the user LOS goals. Acceptable levels are mainly applicable to existing bridges permitted to remain in service. Desirable levels are usually applied to new bridge construction.

6. *Minimum Allowable Condition Rating?* Enter any integer on the scale of condition rating. The 0-to-9 scale, from critical to new condition, has been used in the federal bridge inspection standard to record conditions of the bridge elements. Whenever the condition rating of a bridge element becomes lower than or equal to the minimum allowable element condition, that bridge should be recommended for rehabilitation, major maintenance, or replacement, depending on the economic attractiveness of each. Usually, the minimum element condition allowed is 3, 4, or 5.

7. *Highest Rehabilitation Condition Rating?* Define the condition rating at which a bridge element should be rehabilitated if its condition rating and LOS trigger a possible rehabilitation action. Generally, this variable is estimated as 7 or 8 on the scale of condition ratings.

8. *Real Required Rate of Return and Rate of Inflation?* Input the required rate of return (RRR) to be used in computing the EUAC of all possible improvement alternatives for a bridge. The RRR is the minimum acceptable rate of return on an investment after taking into account all the circumstances surrounding that investment. Inflation is a persistent increase in price levels that results in the decline of the purchasing power of future budgets. As shown in Figure 3, OPBRIDGE can take into account the effect of inflation on the output it produces (*3*). The nominal required rate of return (NRRR) is composed of two components—the real required rate of return (RRRR) and a component that is larger than the perceived rate of inflation (f), $NRRR = RRRR + (1 + RRRR)f$.

9. *Factor to Transfer 1985/86 Dollars to Today's Dollars?* Enter index needed to convert cost tables (*1*) from 1985–1986 dollars to today's dollars (see Figure 3).

10. *Are Your Budgets in Constant (Today's) Dollars?* Enter N if the budgets are in future dollars and need to be transferred to the present time to account for inflation. This entry is needed to ensure that both the budgets and the cost estimation tables would have the same purchasing power. The inflation rate used in this case is entered by the user as the average yearly inflation rate expected over the analysis horizon.

11. *Enter Some or All of the Following Budgets:*

- Granted Budgets: The funding authority usually grants in advance certain budgets to be used during an allocation

```
ANALYSIS HORIZON
    HORIZON ? (YEARS) . . . . . . . . . . . . . . . . . . . . 20
    FIRST-ANALYSIS YEAR ? . . . . . . . . . . . . . . . . . . 1989

BRIDGES FOR ANALYSIS
    RANGE OF BRIDGE NUMBERS ? . . . . . . . . . . . . . . . . 00000-99999
    WHAT FEDERAL AID SYSTEM ? (F/N/A) . . . . . . . . . . . . A
    WHAT STATE SYSTEM ? (P/S/U/A) . . . . . . . . . . . . . . A
    WHAT DIVISION NUMBER ? (15 = ALL DIVISIONS) . . . . . . . 15

ANALYSIS PERFORMANCE REQUIREMENTS
    IMMEDIATE IMPROVEMENT FOR DEFICIENT BRIDGES ? (Y/N) . . . Y
    USER LEVEL-OF-SERVICE GOALS ? (1 OR 2). . . . . . . . . . 1
        1) ACCEPTABLE,
        2) DESIRABLE.
    MINIMUM ALLOWABLE CONDITION RATING ?. . . . . . . . . . . 4

GENERAL SPECIFICATIONS
    HIGHEST REHABILITATION CONDITION RATING ? . . . . . . . . 8
    REAL REQUIRED RATE OF RETURN ? (%). . . . . . . . . . . . 5.00
    ARE YOUR BUDGETS IN CONSTANT (TODAY'S) DOLLARS? (Y/N) . . Y
    RATE OF INFLATION ? (%) . . . . . . . . . . . . . . . . . 3.00
    FACTOR TO TRANSFER 1985/86 DOLLARS TO TODAY'S DOLLARS ? 1.1

ENTER BELOW SOME OR ALL OF THE FOLLOWING  BUDGETS: BUDGETS GRANTED,
LIMITED OR UNLIMITED MAXIMUM ALLOWABLE BUDGETS.
INCLUDE DECIMAL POINTS IN BUDGETS.
 $ = BUDGET DISTRIBUTED BY DOLLARS.
 % = BUDGET DISTRIBUTED BY PERCENTAGE (MUST ENTER TOTAL BUDGET).
 T = ONLY TOTAL BUDGET IS ENTERED.
 U = UNLIMITED BUDGET.

      % $  ------------------------------------------------------------
YEAR  T U    MAINTENANCE    REHABILITATION    REPLACEMENT    TOTAL BUDGET
----  ---  -------------- ---------------- --------------- ---------------
1989   %           20.            30.             50.        80000000.
1990   $     15000000.      30000000.       45000000.        90000000.
1991   T             .              .               .        85000000.
1992   U             .              .               .               .
----   -             .              .               .               .
----   -             .              .               .               .
2008   U             .              .               .               .

OUTPUT SPECIFICATION
    DETAILED BRIDGE-BY-BRIDGE OUTPUT ? (Y/N). . . . . . . . . Y
    TABULAR OUTPUTS (BUDGETS AND PERFORMANCE) ? (Y/N) . . . . Y
        BY FEDERAL/NON-FEDERAL AID ? (Y/N). . . . . . . . . . Y
        BY PRIMARY/SECONDARY/URBAN ? (Y/N). . . . . . . . . . Y
    GRAPHICAL OUTPUTS (BUDGETS AND PERFORMANCE) ? (Y/N) . . . Y
        BY FEDERAL/NON-FEDERAL AID ? (Y/N). . . . . . . . . . Y
        BY PRIMARY/SECONDARY/URBAN ? (Y/N). . . . . . . . . . Y
    COUNTY-BY-COUNTY OUTPUT OF ACTIONS ? (Y/N). . . . . . . . Y
        UP TO WHAT YEAR ? . . . . . . . . . . . . . . . . . . 1989

CURRENT NEW-BRIDGE COST PARAMETERS
    UNIT COST ? ($ / SF DECK AREA). . . . . . . . . . . . . . 46.0
    FIXED COST ? ($)  . . . . . . . . . . . . . . . . . . . . 55000.
    DESIGN FEE ? (%)  . . . . . . . . . . . . . . . . . . . . 12.0
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FIGURE 2 OPBRIDGE user input computer screen layout.

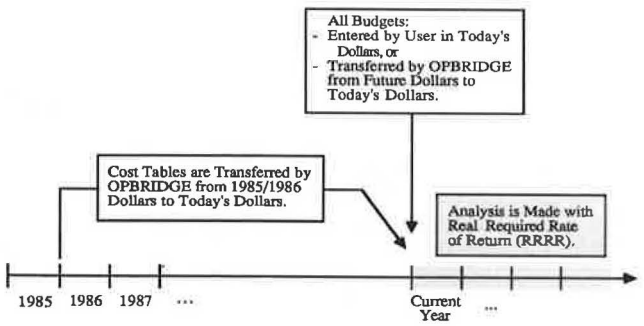

FIGURE 3 Dealing with inflation in OPBRIDGE analysis.

horizon, as shown in Figure 4. This allocation horizon may be 1 year or more.

- Limited Maximum Allowable Budgets: The decision maker does not know the budgets that will be granted during the years after the allocation horizon (see Figure 4). However, experience can be used to estimate the expected budgets granted to make reasonable forecasts about the bridge system performance. This term is the maximum allowable budget, MAB(t), which serves as an upper limit to the budget computed for year t. This concept allows modeling of the system performance and behavior under realistic assumptions of future budgets.

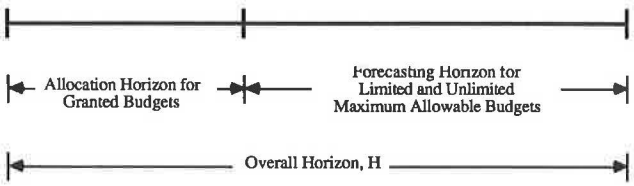

FIGURE 4 Relationship between horizons.

• Unlimited Maximum Allowable Budgets: If the user elects to enter unlimited MAB(t), the OPBRIDGE analysis will be made for year t under the assumption of unlimited budget.

Granted budgets or limited maximum allowable budgets for year t can be entered in three ways: total budget only; budget distributed by percentage, for example, 20 percent for maintenance, 20 percent for rehabilitation, and 60 percent for replacement (in this case, the total budget must be entered to allow OPBRIDGE to internally compute the budgets in dollars available for maintenance, rehabilitation, and replacement activities); and budget distributed by dollars, for example, $15,000,000 for maintenance, $25,000,000 for rehabilitation, and $45,000,000 for replacement. In the $/%/T/U column, the user enters $ if the budget is distributed by dollars, % if the budget is distributed by percentage, T if only the total budget in dollars is limited, or U if the budget is unlimited.

12. *Detailed Bridge-by-Bridge Output?* Enter Y if output is desired showing the status and actions recommended for the first analysis year, and major actions (replacement and rehabilitations) and their timings recommended thereafter for every bridge in the system (see Figure 5). All dollars in the detailed bridge-by-bridge output are in constant (today's) dollars.

13. *Tabular and Graphical Outputs?* Enter Y if output is desired showing funding needs or budget limits and the behavior of the state-wide, system-level performance indicators over the horizon. The outputs can be listed by federal- or non-federal-aid bridges and by primary, secondary, or urban bridges. All dollars in the tabular and graphical outputs are in future (then-current) dollars.

14. *Yearly County-by-County Output?* Enter Y if output is desired showing a list of bridges needing major actions (replacement and rehabilitations), cost of the major actions, and total funds needed for each county in the state (see Figure 6). The total budget is also subdivided into federal-aid and state system funds. The county-by-county output is provided for each year up to the year (≤ horizon) specified by the user. All dollars in the county-by-county output are in constant (today's) dollars.

15. *Unit Cost?* Enter cost per square foot of deck area for constructing a new bridge, currently $46/ft^2.

16. *Fixed Cost?* Enter the fixed cost associated with new bridge construction, currently about $55,000.

BRIDGE NO. / COUNTY / FACILITY	DK SPTY FC RL CG A / SP SUFF SV DL UG G / SB DPA FA TT LENG YR E	ADT SV WG CDW VCLU D S S / K P B	USER COST $00	EQUIV. UNIFORM ANNUAL COST (EUAC) AND OPTIMUM ACTION — MN#1 / REP. / MN#2 / REH.							
				COST $	PROVID $	COST $000	EUAC $00	COST $00	EUAC $00	COST $00	EUAC $00
1	TM M-BM LO 7 16.0 89 31	200 11 20 19.2 99.9 6 6 6	45	101	0	95	77	0	0	0	0
ALAMANCE	TM 45.0 S 4 14.0 89 31	200 34 20 27.0 99.9 9 9 9				LOAD CAPACITY DEFICIENCY				ACTION=REP.	
SR1576	TM 13.0 SR 20 19										
2	TM F-BM MI 8 16.0 89 33	2100 11 24 24.4 99.9 5 8 6	397	1263	1263	343	286	0	0	0	0
ALAMANCE	ST 41.0 S 4 14.0 89 33	2100 11 24 24.4 99.9 5 8 6				LOAD CAPACITY DEFICIENCY				ACTION=MN#1	
SR1529	TM 22.0 SR 14 121										
		95 39 2396 10 24 24.4 99.9 4 7 5	486	2273	0	343	286	0	0	0	0
		95 39 2396 34 24 31.0 99.9 9 9 9				CONDITION RATINGS				ACTION=REP.	
3	TM M-BM MI 12 16.0 89 35	2100 29 24 23.1 99.9 8 5 5	76	431	0	178	148	0	0	575	114
ALAMANCE	TM 54.0 S 5 14.0 89 35	2100 29 24 31.0 99.9 8 8 8				WIDTH DEFICIENCY				ACTION=REH.	
SR1529	TM 3.0 SR 37 52										
		8 54 3038 28 24 31.0 99.9 4 5 5	36	1387	0	186	154	0	0	302	100
		8 54 3038 29 24 31.0 99.9 8 8 8				CONDITION RATINGS				ACTION=REH.	
16	RC T-BM MC 11 25.0 89 36	4300 34 26 26.0 14.3 6 6 6	404	714	714	627	530	0	0	1117	941
ALAMANCE	RC 79.0 P 0 14.0 89 36	4300 34 26 26.0 14.3 6 6 6				ECONOMICAL COMPARISON				ACTION=MN#1	
NC119	RC 2.0 FS 37 193										
		97 44 5108 34 26 26.0 14.3 4 5 6	480	2154	0	627	530	1062	1090	1486	1090
		97 44 5108 34 26 26.0 14.3 6 6 6				CONDITION RATINGS				ACTION=MN#2	
		7 54 6119 34 26 26.0 14.3 4 5 5	610	2604	0	627	530	0	0	1589	1281
		7 54 6119 34 26 26.0 14.3 8 8 8				CONDITION RATINGS				ACTION=REH.	
28	ST M-BM MI 28 16.0 89 3	700 34 20 28.0 99.9 8 8 8	0	384	384	0	0	0	0	0	0
ALAMANCE	ST 97.0 S 4 14.0 89 3	700 34 20 28.0 99.9 7 8 8				NEEDS ONLY MAINTENANCE				ACTION=MN#1	
SR1587	ST 0.0 SR 37 121										
		8 22 1013 34 22 28.0 99.9 4 6 6	0	1227	0	318	264	596	101	869	114
		8 22 1013 34 22 28.0 99.9 6 6 6				CONDITION RATINGS				ACTION=MN#2	
30	TM M-BM LO 6 16.0 89 35	115 18 20 17.1 99.9 6 7 6	37	64	0	95	77	0	0	434	65
ALAMANCE	TM 47.0 S 4 14.0 89 35	115 18 20 27.0 99.9 8 8 8				WIDTH DEFICIENCY				ACTION=REH.	
SR1593	RC 5.0 SR 27 19										

Notes:

1. The output is under the assumption of a limited budget, immediate improvement for deficient bridges, a minimum allowable condition rating of 4, an acceptable user level-of-service goal, and a 20-year horizon.
2. If a bridge needs a major action or one of its major actions is the most economical, but was recommended for a routine maintenance (MN#1), then there is not enough budget to recommend the major action, e.g., bridge # 2.

FIGURE 5 Detailed bridge-by-bridge output.

COUNTY : ALAMANCE
YEAR : 1989

BRIDGES NEEDING MAJOR IMPROVEMENTS:

BRIDGE NUMBER	FED AID	SYS	REPLACEMENT ($)	REHABILITAT ($)	MAJOR-MAINT ($)	ROUTINE-MAINT ($)
1	SR	S	95103	0	0	0
2	SR	S	342610	0	0	0
3	SR	S	0	57084	0	0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
102	SR	S	0	0	72050	0
103	SR	S	119683	0	0	0
104	FS	P	0	89098	0	0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
313	SR	S	0	35725	0	0
319	SR	S	0	37230	0	0
326	SR	S	287252	0	0	0
328	SR	S	138370	0	0	0
329	SR	S	0	40344	0	0
336	SR	S	0	44370	0	0
FEDERAL AID -- P			2917907	3703689	0	6632
FEDERAL AID -- S			5291855	0	0	3947
FEDERAL AID -- U			1257608	0	0	486
NON FED AID -- P			1551596	0	0	223
NON FED AID -- S			14644449	717812	76245	9627
NON FED AID -- U			828490	0	0	114
TOTAL	31010679		26491904	4421501	76245	21029

NOTE: BRIDGES NEEDING ROUTINE MAINTENANCE ONLY ARE NOT LISTED HERE
(SEE THE DETAILED BRIDGE-BY-BRIDGE OUTPUT).

FIGURE 6 County-by-county output.

17. *Design Fee?* Enter the estimated design fee as a percentage of the basic construction costs for the new bridge, currently 12 percent.

FLOWCHART FOR USING OPBRIDGE

The OPBRIDGE decision-making process, shown in Figure 7, can be explained as follows:

1. The manager enters budgets as granted, limited, or unlimited maximum allowable budgets for each year in the analysis horizon. Other inputs include minimum performance requirements and other parameters.
2. The OPBRIDGE program is executed and, in the calculations, decisions are optimized for every year in the analysis horizon. Outputs include individual bridge performance, as well as tabular and graphical results, showing the trend of future performance of the bridge system over the analysis horizon, *H*.
3. If bridge managers are not satisfied with the results, they can revise the budget constraints and minimum requirements, reexecute the program, and analyze inventory performance again. This process is repeated as necessary to determine the effects of various strategies and options. Experience plays a major role in this process.
4. Once bridge managers have determined performance of the system under varying constraints, the results can support requests for adequate funding.

FINDINGS FOR THE NORTH CAROLINA BRIDGE INVENTORY

Ten different management cases were selected for analysis. Their analysis options are presented in Table 1, where the user LOS goals are those defined for bridges by Johnston and Zia (*2*). The sample bridges used for the analysis were the 14,100 conventional, state-owned bridges in the data base of the NCDOT. This list includes all structures in the North Carolina inventory except pipes and culverts, which are excluded internally by the program. Because all bridges in North Carolina are state owned except for approximately 300 municipal bridges, a full range of roadway functional classifications is represented. Constants for the analyses are shown in Figure 8.

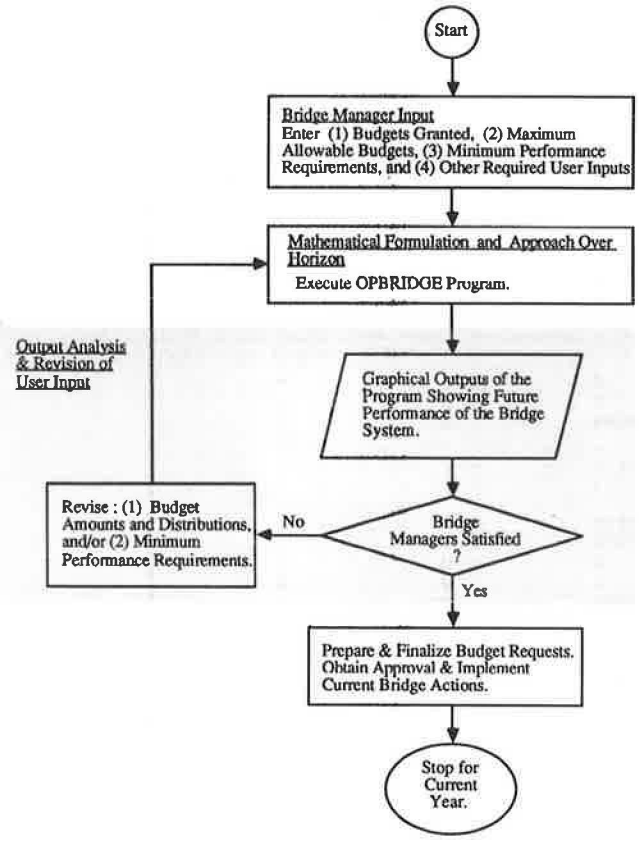

FIGURE 7 Flowchart for use of OPBRIDGE.

TABLE 1 ANALYSIS CASES

Case	Immediate Improvement for Deficient Bridges ? (Y/N)	User Level-of-Service Goals	Total Budget
1	N	Acceptable	Unlimited
2	Y	Acceptable	Unlimited
3	Y	Desirable	Unlimited
4	N	Acceptable	Limited to $60,000,000/Year
5	Y	Acceptable	Limited to $60,000,000/Year
6	Y	Acceptable	Limited to $100,000,000/Year
7	N	Acceptable	Limited to $200,000,000/Year
8	Y	Acceptable	Limited to $200,000,000/Year
9	N	Acceptable	Limited to $400,000,000/Year
10	Y	Acceptable	Limited to $400,000,000/Year

Tables 2 through 5 present outputs showing the following results:

1. On the basis of the assumption of improvement only if economically viable (Case 1), the analysis indicated a backlog of $1.067 billion. If the funds were available, 3,377 bridges would be replaced, 424 bridges would be rehabilitated, and 144 bridges would receive major maintenance during the first year to eliminate the backlog.

2. On the basis of immediate improvement, if either economically viable or deficient in regard to acceptable criteria (Case 2), the analysis indicated a backlog of $1.874 billion. In this case, 5,512 bridges would be replaced, 1,814 bridges would be rehabilitated, and 144 bridges would receive major maintenance during the first year.

3. On the basis of immediate improvement if either economically viable or deficient based on desirable criteria (Case 3), the analysis indicated a backlog of $3.288 billion. In the desirable case, 8,881 bridges would be replaced and 2,292 bridges would be rehabilitated during the first year.

4. Eliminating the backlog under either economic or immediate approaches is unlikely to occur in 1 year. Funding for most agencies depends on revenue sources, which are received at fairly constant rates from year to year. Thus, performance of the bridge system under constrained levels of funding is of significant interest.

5. Under constrained budgets of $60 million/year (Cases 4 and 5), the analysis indicated a slight decrease in user costs and deficient bridges for approximately 5 years. However, average condition declines initially, and for the following 15 years there is a continued decline in condition and a significant increase in deficient bridges and user costs. Funding at $60 million/year, the current level, is insufficient to maintain the system and is not economical to the public.

6. Under constrained budgets of $100 million/year (Case 6), the analysis indicated a slight decrease in the number of deficient bridges with respect to LOS over the next 20 years. However, user costs, which initially decline for 5 years, thereafter gradually increase to higher than current levels because of increased traffic. Average condition ratings gradually decline with a significant increase in conditions that are less than acceptable because of insufficient funding to improve all bridges in need of repair.

7. Under constrained budgets of $200 million/year (Cases 7 and 8), the analysis indicated a gradual reduction of deficiencies over the next 20 years, which virtually eliminates bridge deficiencies versus acceptable LOS criteria. User costs are significantly reduced. Average condition ratings improve slightly with almost no bridges having less-than-minimum element conditions. The budget is fully used in each of the 20 years.

8. Under constrained budgets of $400 million/year (Cases 9 and 10), the analysis indicated a significant improvement in bridge performance indicators over the first 5 years. The full budget is used initially, but after 4 to 5 years, the full funding level is no longer needed and the system can be maintained with funding levels generally between $100 and $200 million/year.

9. From examination of the various cases, it appears that North Carolina needs could economically justify bridge improvement funding at the rate of $200 million/year over the next 20 years. This result is consistent with the findings of Chen and Johnston (*1*) who suggested $194 million/year for the next 10 years. However, because of the effects of delaying the improvements and needs for increasing numbers of bridge lanes, a reduction from that level after 10 years does not appear feasible.

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ANALYSIS HORIZON
  HORIZON ? (YEARS) . . . . . . . . . . . . . . . . . . . . . . 20
  FIRST-ANALYSIS YEAR ? . . . . . . . . . . . . . . . . . . . . 1989

BRIDGES FOR ANALYSIS
  RANGE OF BRIDGE NUMBERS ? . . . . . . . . . . . . . . . . . . 00000-99999
  WHAT FEDERAL AID SYSTEM ? (F/N/A) . . . . . . . . . . . . . . A
  WHAT STATE SYSTEM ? (P/S/U/A) . . . . . . . . . . . . . . . . A
  WHAT DIVISION NUMBER ? (15 = ALL DIVISIONS) . . . . . . . . . 15

ANALYSIS PERFORMANCE REQUIREMENTS
  .
  .
  MINIMUM ALLOWABLE CONDITION RATING ? . . . . . . . . . . . . 4

GENERAL SPECIFICATIONS
  HIGHEST REHABILITATION CONDITION RATING ? . . . . . . . . . . 8
  REAL REQUIRED RATE OF RETURN ? (%). . . . . . . . . . . . . . 8.00
  ARE YOUR BUDGETS IN CONSTANT (TODAY'S) DOLLARS ? (Y/N). . . . Y
  RATE OF INFLATION ? (%) . . . . . . . . . . . . . . . . . . . 0.00
  FACTOR TO TRANSFER 1985/86 DOLLARS TO TODAY'S DOLLARS ? . . . 1.1
.
.
.

OUTPUT SPECIFICATIONS
  DETAILED BRIDGE-BY-BRIDGE OUTPUT ? (Y/N). . . . . . . . . . . N
  TABULAR OUTPUTS (BUDGETS AND PERFORMANCE) ? (Y/N) . . . . . . Y
    BY FEDERAL/NON-FEDERAL AID ? (Y/N). . . . . . . . . . . . . Y
    BY PRIMARY/SECONDARY/URBAN ? (Y/N). . . . . . . . . . . . . Y
  GRAPHICAL OUTPUTS (BUDGETS AND PERFORMANCE) ? (Y/N) . . . . . Y
    BY FEDERAL/NON-FEDERAL AID ? (Y/N). . . . . . . . . . . . . Y
    BY PRIMARY/SECONDARY/URBAN ? (Y/N). . . . . . . . . . . . . Y
  COUNTY-BY-COUNTY OUTPUT ? . . . . . . . . . . . . . . . . . . N
    UP TO WHAT YEAR ? . . . . . . . . . . . . . . . . . . . . . 1989

CURRENT NEW-BRIDGE COST PARAMETERS
  UNIT COST ? ($ / SF DECK AREA). . . . . . . . . . . . . . . . 46.00
  FIXED COST ? ($). . . . . . . . . . . . . . . . . . . . . . . 55000.
  DESIGN FEE ? (%). . . . . . . . . . . . . . . . . . . . . . . 12.0
```

FIGURE 8 Partial OPBRIDGE input screen indicating entries assumed constant for 10 cases.

On the basis of Cases 5, 6, 8, and 10, involving both economical and immediate improvements, results for selected parameters are shown in Figures 9 through 12. The funds of the yearly budget used are shown in Figure 9. As shown in Figure 10, user costs can be reduced initially if funds are directed at bridges with high user costs. However, if long-term funding is low, user costs will eventually climb rapidly. In Figure 11, deck condition ratings improve or remain stable under higher levels of funding but decline under low funding. The condition ratings of other elements respond similarly. In Figure 12, the average single-vehicle posting improves under higher levels of funding but remains low under lower levels of funding.

SUMMARY AND CONCLUSIONS

1. The economic decision-making model developed can be used in strategic planning to help bridge managers set objectives and policies, and forecast and allocate budgets required to maintain a state-wide bridge system. Bridge system objectives include a number of system-level performance indicators to be maintained over time. At a high managerial level, policies consist of distributions of available and potential funds among various bridge classifications. OPBRIDGE is a tool for assessing the impact of various funding levels and distributions.

2. Three improvement alternatives are assumed possible for a bridge at any point in time: replacement, rehabilitation, and major maintenance. Routine maintenance, if provided, is assumed to protect the bridge against accelerated deterioration in varying degrees, but it does not raise the bridge condition ratings or user LOS.

3. Techniques and data for estimating agency costs, user costs, and EUAC are implemented.

4. Two alternatives for two different bridges may have the same EUAC, but their impact in reducing the current bridge annual maintenance and user costs are usually different. For

TABLE 2 BUDGETS AND ACTIONS DETERMINED UNDER UNLIMITED ANNUAL FUNDING ASSUMPTION CASES

Case 1

Economical Improvement; Acceptable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	4965357.	7588001.	144	59614048.	424	994703616.	3377	1066870780.
1990	5021321.	10735712.	93	33425104.	140	161738208.	314	210920336.
1991	5240553.	5457473.	95	21750336.	125	105654032.	288	138102384.
1992	5320226.	6664511.	58	31242400.	129	107301696.	257	150528832.
1993	5777386.	3974461.	55	17011008.	109	81401584.	255	108164432.
1994	6134874.	4789402.	56	15369550.	85	62472800.	191	88766624.
1995	6040673.	18367472.	179	42614416.	230	117788384.	437	184810944.
1996	5894290.	21185840.	171	62617568.	247	117690048.	415	207387744.
1997	5700428.	19659264.	181	77936656.	242	122859744.	372	226156080.
1998	5490963.	17482240.	188	50540576.	260	89247184.	295	162760960.
1999	5630846.	14353487.	141	39933568.	205	74794240.	222	134712128.
2000	5660610.	15663039.	138	33331360.	183	80768416.	195	135423424.
2001	6052728.	17781680.	119	38137536.	199	48239488.	118	110211424.
2002	6265641.	15263466.	119	33433152.	158	53822528.	116	108784784.
2003	6471806.	14761956.	133	38165152.	201	50667392.	108	110066304.
2004	6627848.	13547097.	145	50307744.	218	58377520.	118	128860208.
2005	6581044.	12994815.	122	56724800.	220	75546304.	94	151846960.
2006	6627080.	12709186.	119	47165792.	236	49994080.	86	116496128.
2007	6748567.	10278602.	82	45496272.	219	30843040.	60	93366480.
2008	7038131.	13933733.	158	42999376.	248	18030464.	60	82001696.

Case 2

Immediate Improvement; Acceptable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	3488013.	7588001.	144	311066624.	1814	1552334340.	5512	1874476800.
1990	3954589.	10735712.	93	37518640.	82	56678128.	124	108887056.
1991	4201249.	5457473.	95	10312592.	56	56458496.	92	76429808.
1992	4331535.	6664511.	58	20839312.	71	53641152.	107	85476496.
1993	4976562.	3974461.	55	19682992.	52	39863040.	84	68497040.
1994	5434614.	4789402.	56	15394375.	47	38019120.	77	63637504.
1995	5561729.	18367472.	179	52047712.	98	50785680.	123	126762592.
1996	5581043.	21185840.	171	36981712.	136	51688944.	141	115437536.
1997	5574434.	19659264.	181	30635728.	150	73462864.	137	129332288.
1998	5395930.	17482240.	188	50033424.	194	50750384.	129	123661968.
1999	5641173.	14353487.	141	27169776.	137	41308928.	96	88473360.
2000	5765154.	15663039.	138	29591856.	132	44164496.	79	95184544.
2001	6289930.	17781680.	119	26918672.	142	31048144.	54	82038416.
2002	6594817.	15263466.	119	34064848.	128	38686208.	74	94609328.
2003	6839733.	14761956.	133	34722848.	166	48261120.	74	104585648.
2004	7217678.	13547097.	145	43360528.	188	34088384.	84	98213680.
2005	7365423.	12994815.	122	46519024.	197	69223600.	99	136102848.
2006	7382101.	12709186.	119	51278656.	214	42579248.	115	113949184.
2007	7648110.	10278602.	82	42082608.	206	25125520.	60	85134832.
2008	7804030.	17428976.	296	44761264.	356	28578528.	107	98572784.

Case 3

Immediate Improvement; Desirable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	1214663.	2849938.	18	768880128.	2292	2515520000.	8881	3288464640.
1990	2021307.	3506736.	20	17085488.	121	30186544.	55	52800064.
1991	2175912.	903686.	10	14562842.	83	23695440.	45	41337872.
1992	2306159.	1874651.	11	9972803.	60	13555536.	32	27709136.
1993	3028985.	790588.	12	13714163.	44	16819808.	25	34353536.
1994	3892941.	860448.	5	13481829.	37	8091966.	18	26327168.
1995	4173550.	3941115.	23	16059015.	48	17347952.	37	41521632.
1996	4275464.	7320168.	35	18532336.	64	20338880.	28	50466848.
1997	4323338.	9110234.	47	17270928.	54	22259744.	45	52964240.
1998	4249634.	6462658.	40	20234960.	62	64122432.	53	95069680.
1999	4392132.	6235563.	33	10443553.	41	23330128.	41	44401376.
2000	4562677.	6944057.	34	16614977.	44	11692852.	31	39814544.
2001	5397656.	6049120.	33	11134879.	49	9407896.	36	31989536.
2002	6127752.	8108084.	40	14412369.	51	14376552.	25	43024736.
2003	6481819.	8000053.	46	19331712.	66	18144608.	43	51958192.
2004	7228040.	7735232.	48	17618384.	71	6936907.	20	39518544.
2005	7410542.	7050124.	43	23776800.	86	37134704.	27	75372160.
2006	7609617.	6082785.	44	23373184.	77	11734301.	22	48799872.
2007	8359915.	6309981.	42	19754880.	64	3877593.	12	38302352.
2008	8637147.	14032047.	179	23318464.	146	62888960.	148	108876608.

TABLE 3 SYSTEM-LEVEL PERFORMANCE INDICATORS FOR UNLIMITED ANNUAL FUNDING ASSUMPTION CASES

Case 1

Economical Improvement; Acceptable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST $MILLIONS
CURRENT	6.55	6.86	6.37	192	24.97	3234	8086	6697	11566	566.58
1989	7.18	7.46	7.10	0	28.51	1661	5131	3663	7952	61.93
1990	7.13	7.40	7.06	0	28.84	1489	4857	3380	7648	57.53
1991	7.07	7.33	7.02	0	29.12	1340	4613	3083	7340	53.05
1992	7.00	7.26	6.96	0	29.35	1247	4410	2855	7067	49.07
1993	6.95	7.21	6.93	0	29.59	1147	4212	2621	6814	42.97
1994	6.88	7.14	6.87	0	29.76	1105	4130	2468	6646	40.20
1995	6.92	7.17	6.93	0	30.22	882	3790	2014	6229	36.44
1996	6.96	7.19	6.99	0	30.62	690	3508	1628	5843	32.71
1997	6.99	7.21	7.03	0	30.97	494	3263	1289	5509	29.03
1998	7.01	7.21	7.06	0	31.24	364	3089	1054	5259	26.46
1999	6.98	7.18	7.05	0	31.42	284	2956	871	5049	23.99
2000	6.95	7.14	7.03	0	31.57	201	2854	702	4874	21.46
2001	6.91	7.09	6.99	0	31.65	150	2812	573	4753	20.24
2002	6.85	7.04	6.94	0	31.70	135	2798	505	4666	18.89
2003	6.80	6.99	6.90	0	31.75	117	2778	431	4580	17.60
2004	6.77	6.95	6.87	0	31.81	82	2740	355	4468	16.35
2005	6.72	6.91	6.83	0	31.84	82	2714	319	4396	15.43
2006	6.68	6.87	6.79	0	31.86	74	2695	275	4318	14.68
2007	6.62	6.82	6.74	0	31.87	82	2702	266	4283	14.05
2008	6.57	6.78	6.70	0	31.90	80	2697	246	4254	14.37

Case 2

Immediate Improvement; Acceptable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST $MILLIONS
CURRENT	6.55	6.86	6.37	192	24.97	3234	8086	6697	11566	566.58
1989	7.78	7.97	7.78	0	31.30	27	3096	138	5290	36.75
1990	7.65	7.84	7.65	0	31.37	14	3014	103	5182	34.76
1991	7.53	7.71	7.53	0	31.41	10	2957	71	5091	32.53
1992	7.40	7.58	7.41	0	31.45	11	2897	51	4977	30.61
1993	7.30	7.49	7.32	0	31.48	15	2856	45	4907	25.70
1994	7.19	7.40	7.23	0	31.50	24	2863	44	4854	23.70
1995	7.13	7.33	7.17	0	31.55	24	2812	36	4761	22.47
1996	7.07	7.28	7.13	0	31.61	26	2771	35	4671	21.07
1997	7.02	7.22	7.09	0	31.65	17	2742	23	4583	19.49
1998	6.98	7.18	7.06	0	31.70	12	2707	20	4501	18.06
1999	6.91	7.12	7.00	0	31.73	20	2683	31	4432	17.20
2000	6.84	7.05	6.94	0	31.75	17	2677	29	4386	16.08
2001	6.76	6.97	6.87	0	31.76	9	2684	21	4356	15.76
2002	6.68	6.91	6.80	0	31.77	17	2696	25	4318	14.94
2003	6.62	6.84	6.74	0	31.78	22	2698	28	4275	14.18
2004	6.56	6.80	6.69	0	31.80	42	2677	49	4210	13.61
2005	6.51	6.74	6.64	0	31.84	66	2634	72	4138	13.12
2006	6.47	6.71	6.61	0	31.89	26	2574	31	4043	12.71
2007	6.40	6.65	6.55	0	31.91	71	2596	80	4042	12.29
2008	6.42	6.65	6.56	0	31.97	68	2600	76	4030	12.25

Case 3

Immediate Improvement; Desirable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST $MILLIONS
CURRENT	6.55	6.86	6.37	192	24.97	3234	8086	6697	11566	566.58
1989	8.44	8.52	8.47	0	33.49	16	100	121	403	10.46
1990	8.26	8.35	8.30	0	33.52	7	60	89	292	9.09
1991	8.10	8.19	8.14	0	33.54	4	32	60	188	7.32
1992	7.93	8.03	7.98	0	33.56	1	11	35	117	6.64
1993	7.81	7.92	7.87	0	33.56	0	10	23	84	2.15
1994	7.70	7.82	7.76	0	33.57	2	26	17	77	0.87
1995	7.59	7.72	7.67	0	33.57	0	19	10	57	0.41
1996	7.49	7.64	7.58	0	33.57	2	28	9	60	0.36
1997	7.39	7.54	7.49	0	33.57	1	34	4	59	0.29
1998	7.29	7.46	7.40	0	33.57	1	30	4	49	0.18
1999	7.18	7.37	7.31	0	33.57	1	22	4	35	0.19
2000	7.09	7.28	7.21	0	33.57	0	27	3	39	0.09
2001	6.98	7.18	7.12	0	33.57	0	12	3	24	0.10
2002	6.87	7.10	7.03	0	33.57	0	24	3	37	0.09
2003	6.78	7.01	6.94	0	33.57	0	11	2	21	0.08
2004	6.68	6.92	6.85	0	33.57	0	8	2	19	0.08
2005	6.58	6.84	6.76	0	33.57	2	8	3	17	0.06
2006	6.48	6.76	6.67	0	33.57	0	6	0	16	0.03
2007	6.37	6.66	6.59	0	33.57	30	133	30	143	0.14
2008	6.34	6.63	6.56	0	33.57	7	102	7	116	0.03

NMACR = NUMBER OF BRIDGES WITH A CONDITION RATING LESS THAN THE MINIMUM ALLOWABLE CONDITION RATING, "4"

NSVA = NUMBER OF BRIDGES POSTED AT LESS THAN ACCEPTABLE

NSVD = NUMBER OF BRIDGES POSTED AT LESS THAN DESIRABLE

NLOSA = NUMBER OF BRIDGES WITH A LESS-THAN-ACCEPTABLE USER LEVEL OF SERVICE

NLOSD = NUMBER OF BRIDGES WITH A LESS-THAN-DESIRABLE USER LEVEL OF SERVICE

TABLE 4 BUDGET AND ACTION DISTRIBUTIONS UNDER LIMITED ANNUAL FUNDING ASSUMPTION CASES

Case 4

$60 million per year; Economical Improvement; Acceptable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	7173180.	7392432.	130	10560176.	124	34872832.	184	59998608.
1990	7954772.	3663459.	47	12058970.	56	36322064.	124	59999264.
1991	8643612.	1908895.	36	1811465.	30	47635296.	118	59999264.
1992	9322319.	1938865.	28	12117855.	40	36620368.	88	59999392.
1993	9889559.	4657745.	85	12569841.	153	32880992.	179	59998128.
1994	10469515.	6957076.	108	10213602.	133	32358832.	201	59999008.
1995	11612815.	2968343.	46	9063271.	113	36354160.	208	59998576.
1996	12628462.	4099982.	39	9698856.	93	33570240.	204	59997536.
1997	13653629.	3975055.	30	7931333.	93	34434608.	233	59994608.
1998	14691874.	4137818.	74	11128765.	213	30039472.	199	59997904.
1999	15705378.	4445545.	77	10904580.	186	28942688.	195	59998176.
2000	17092848.	5927847.	100	9070261.	152	27900880.	198	59991824.
2001	18676896.	5086611.	72	9603459.	165	26618128.	182	59985088.
2002	20147856.	5220128.	76	8055802.	140	26555120.	185	59978896.
2003	21793184.	4164303.	61	8918437.	116	25091904.	178	59967808.
2004	23187936.	5001723.	57	9531038.	136	22245520.	151	59966192.
2005	24911824.	2688282.	45	9176861.	107	23184640.	146	59961584.
2006	26402448.	4444083.	55	7722696.	105	21388224.	139	59957440.
2007	27864400.	4065553.	55	7433537.	106	20592096.	136	59955584.
2008	29184160.	3498459.	53	7296580.	107	19969536.	121	59948720.

Case 5

$60 million per year; Immediate Improvement; Acceptable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	7173180.	7392432.	130	10560176.	124	34872832.	184	59998608.
1990	7954772.	3663459.	47	12058970.	56	36322064.	124	59999264.
1991	8643612.	1908895.	36	1811465.	30	47635296.	118	59999264.
1992	9322319.	1938865.	28	12117855.	40	36620368.	88	59999392.
1993	9889559.	4657745.	85	12569841.	153	32880992.	179	59998128.
1994	10469515.	6957076.	108	10213602.	133	32358832.	201	59999008.
1995	11612815.	2968343.	46	9063271.	113	36354160.	208	59998576.
1996	12628462.	4099982.	39	9698856.	93	33570240.	204	59997536.
1997	13653629.	3975055.	30	7931333.	93	34434608.	233	59994608.
1998	14691874.	4137818.	74	11128765.	213	30039472.	199	59997904.
1999	15706162.	4581027.	76	10670266.	184	29040960.	196	59998400.
2000	17093984.	5931316.	101	9070261.	152	27898432.	198	59993984.
2001	18678144.	5086611.	72	9603459.	165	26688128.	182	59986336.
2002	20149104.	5220128.	76	8054486.	140	26555120.	185	59978832.
2003	21793744.	4164303.	61	8933127.	116	25075936.	178	59967088.
2004	23187872.	5099373.	58	9431856.	136	22245520.	151	59964608.
2005	24912672.	2688282.	45	9149842.	107	23210464.	146	59961248.
2006	26403616.	4444083.	55	7721380.	105	21388448.	139	59957520.
2007	27867136.	3950353.	54	7433151.	106	20701904.	137	59952528.
2008	29187792.	3498459.	53	7293958.	105	19970976.	121	59951168.

Case 6

$100 million per year; Immediate Improvement; Acceptable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	6946043.	11109780.	130	15343713.	130	66598512.	262	99998032.
1990	7681723.	2381745.	45	10377024.	58	79557424.	206	99997904.
1991	8229275.	2155945.	41	13601678.	55	76009472.	231	99996368.
1992	8916991.	2323825.	30	11987707.	59	76768960.	209	99997472.
1993	9289178.	9580631.	111	22707456.	155	58420624.	269	99997888.
1994	9656729.	9072463.	128	15788903.	146	65479344.	325	99997424.
1995	10350127.	5832807.	80	27425872.	124	56389184.	245	99997984.
1996	11065676.	3921637.	69	38587664.	331	46420800.	231	99995776.
1997	11762377.	6529437.	77	13783308.	98	67922432.	308	99997536.
1998	12486888.	10483889.	154	26859616.	219	50169728.	315	99996112.
1999	13067825.	11787736.	103	28883424.	213	46255200.	303	99994176.
2000	13876480.	11585141.	104	13186708.	166	61344992.	420	99993312.
2001	14784690.	8459989.	85	15694221.	188	61054304.	346	99993184.
2002	15828223.	9645414.	89	13371290.	149	61147968.	375	99992880.
2003	16945616.	9578782.	82	16749520.	152	56722128.	328	99996032.
2004	17869712.	9900098.	81	14997986.	141	57222416.	294	99990208.
2005	18855072.	7214077.	64	21664480.	154	52252320.	262	99985936.
2006	19825280.	8429953.	65	17252240.	139	54472224.	233	99979696.
2007	20702672.	9355079.	70	21468608.	174	48450384.	217	99976736.
2008	21319888.	7352978.	61	22296240.	172	49004752.	193	99973856.

TABLE 4 (*continued on next page*)

TABLE 4 (*continued*)

Case 7

$200 million per year; Economical Improvement; Acceptable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	6709899.	11789666.	131	22398336.	159	159097504.	521	199995392.
1990	7296099.	2392983.	45	14409627.	116	175896848.	468	199995552.
1991	7620156.	2121576.	38	19328048.	127	170924512.	675	199994288.
1992	7985623.	2143363.	30	15820243.	110	174046672.	492	199995888.
1993	7878643.	13729639.	115	42733712.	152	135652624.	302	199994608.
1994	7964460.	11523774.	121	23220032.	157	157284672.	540	199992928.
1995	8073357.	10568107.	88	26431664.	115	154923488.	357	199996528.
1996	8361559.	9127456.	90	16696586.	114	165810768.	466	199996352.
1997	8575208.	9438775.	69	19682064.	118	162298848.	580	199994880.
1998	8741379.	18528768.	160	19893648.	170	152831456.	534	199995248.
1999	8552481.	24884720.	209	60796800.	141	105759920.	375	199993920.
2000	8410582.	31191472.	210	28469104.	157	131924320.	379	199995472.
2001	8312836.	30742800.	206	30772592.	160	130165920.	394	199996144.
2002	8335711.	24824784.	186	30311424.	137	136523536.	386	199995440.
2003	8281142.	22392272.	172	36800512.	146	132518944.	347	199992864.
2004	8188616.	21817072.	152	29636208.	114	140333680.	174	199995488.
2005	8287672.	21855936.	139	19040384.	91	150813872.	181	199997856.
2006	8201614.	23504464.	167	38609888.	185	129679168.	233	199995120.
2007	8294037.	9158743.	88	35185264.	189	147356768.	223	199994880.
2008	8024490.	22219072.	156	43408912.	135	126344688.	186	199997152.

Case 8

$200 million per year; Immediate Improvement; Acceptable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	6709899.	11789666.	131	22398336.	159	159097504.	521	199995392.
1990	7296099.	2392983.	45	14409627.	116	175896848.	468	199995552.
1991	7620156.	2121576.	38	19328048.	127	170924512.	675	199994288.
1992	7986176.	2116710.	27	15845869.	111	174046672.	492	199995424.
1993	7879054.	13729613.	114	42733712.	152	135652624.	302	199994992.
1994	7964282.	11520317.	122	23225552.	158	157284672.	540	199994816.
1995	8074061.	10563430.	86	26431664.	115	154926320.	357	199995472.
1996	8362215.	9122578.	88	16696586.	114	165814816.	466	199996176.
1997	8575537.	9449698.	71	19687408.	118	162281680.	581	199994320.
1998	8741046.	18564256.	163	19859680.	168	152830160.	533	199995136.
1999	8552056.	24890656.	211	60792752.	142	105759920.	375	199995376.
2000	8410084.	31191472.	210	28469104.	157	131924320.	379	199994976.
2001	8312114.	30749552.	207	30766400.	160	130165920.	394	199993904.
2002	8335513.	24815088.	185	30417024.	138	136427888.	385	199995504.
2003	8280881.	22393584.	172	38069920.	156	131291456.	341	199993840.
2004	8216700.	21923328.	153	29864896.	116	139988704.	188	199993616.
2005	8290277.	21847904.	140	23183520.	94	146676336.	170	199990032.
2006	8363047.	13549777.	114	39151840.	172	138932592.	241	199997248.
2007	8374266.	18031008.	131	32863488.	130	140724656.	196	199993408.
2008	8152120.	22298768.	159	43507568.	132	126037232.	198	199995680.

Case 9

$400 million per year; Economical Improvement; Acceptable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	6323224.	11782886.	132	31683040.	258	350166272.	1094	399955200.
1990	6607295.	2378051.	45	30067232.	266	360887296.	1401	399939840.
1991	6027956.	14010448.	185	45506160.	237	334431232.	1045	399975680.
1992	5397098.	13424122.	146	71831312.	246	248574896.	428	339227392.
1993	5818429.	5122591.	58	18286080.	95	77712784.	265	106939872.
1994	6149270.	5220405.	58	14561042.	84	67273568.	219	93204272.
1995	6095660.	15799279.	167	38008960.	235	119632576.	425	179536464.
1996	6029115.	18930224.	181	59773472.	234	117457840.	413	202190640.
1997	5889749.	21822064.	175	79304432.	244	123270864.	394	230287104.
1998	5687290.	17661408.	168	41492688.	253	143425120.	306	208266496.
1999	5748438.	15165728.	152	39782608.	208	78470384.	224	139167152.
2000	5673315.	18993840.	152	35496240.	187	92393840.	228	152557232.
2001	5938534.	14726123.	126	28356896.	187	67500784.	142	116522336.
2002	6150540.	13184694.	103	35706208.	156	65989616.	137	121031056.
2003	6228328.	14132374.	127	41956128.	210	76482688.	110	138799504.
2004	6389675.	13074331.	124	48164144.	226	50273408.	113	117901552.
2005	6516185.	12586960.	125	60093120.	241	52666448.	95	131862704.
2006	6541770.	15264622.	146	44425664.	217	50829344.	91	117061392.
2007	6592551.	12535110.	103	46600608.	207	57030096.	93	122758352.
2008	6780654.	11316391.	108	45037616.	230	21808768.	79	84943424.

Case 10

$400 million per year; Immediate Improvement; Acceptable Level of Service

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
1989	6323224.	11782886.	132	31683040.	258	350166272.	1094	399955200.
1990	6607295.	2378051.	45	30067232.	266	360887296.	1401	399939840.
1991	6181279.	13999616.	184	29858672.	172	349934848.	1119	399974400.
1992	5775728.	18185616.	155	68256000.	457	307747328.	1212	399964672.
1993	5171684.	17677488.	169	102411376.	566	274723584.	779	399984128.
1994	5108852.	6849685.	65	155090656.	334	133409488.	285	300458496.
1995	5335529.	15799279.	167	15914826.	104	55672000.	136	92721616.
1996	5402567.	18861088.	180	38523312.	138	56725168.	135	119512128.
1997	5348337.	21954864.	176	32516192.	143	115447712.	153	175267104.
1998	5467462.	17716208.	168	65136528.	183	72655552.	151	160975744.
1999	5745387.	14990720.	151	30094016.	136	52339968.	104	103170080.
2000	5773502.	18988224.	152	26981888.	135	56620192.	116	108363792.
2001	6025087.	14453172.	117	24382416.	130	61712912.	84	106573584.
2002	6117687.	13630078.	112	36077232.	132	66528960.	109	122353952.
2003	6236061.	12923740.	121	36154384.	169	79400304.	91	134714480.
2004	6348294.	13357929.	126	48078432.	203	40024400.	92	107809040.
2005	6543085.	13291592.	128	45931296.	215	43699296.	81	109465264.
2006	6649864.	14957370.	141	47621024.	195	39672768.	86	108901024.
2007	6850516.	12541474.	106	48790128.	197	39720256.	73	107902368.
2008	7117559.	11206768.	109	37687216.	208	22126368.	79	78137904.

TABLE 5 SYSTEM-LEVEL PERFORMANCE INDICATORS FOR LIMITED ANNUAL FUNDING ASSUMPTION CASES

Case 4

$60 million per year; Economical Improvement; Acceptable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST $MILLIONS
CURRENT	6.55	6.86	6.36	192	24.97	3234	8087	6695	11567	566.60
1989	6.48	6.82	6.33	72	25.20	3167	7911	6441	11364	437.13
1990	6.37	6.73	6.24	40	25.30	3100	7798	6342	11282	412.50
1991	6.25	6.64	6.14	18	25.37	3099	7699	6238	11175	364.28
1992	6.13	6.54	6.02	10	25.39	3143	7666	6187	11097	357.48
1993	6.07	6.48	5.98	10	25.52	3166	7586	6002	10951	366.92
1994	6.01	6.43	5.93	192	25.70	3216	7602	5826	10780	382.71
1995	5.94	6.37	5.88	427	25.83	3255	7580	5689	10610	428.82
1996	5.87	6.30	5.82	663	25.95	3324	7580	5575	10476	452.11
1997	5.81	6.24	5.77	847	26.11	3363	7567	5447	10327	513.63
1998	5.77	6.21	5.74	993	26.18	3446	7606	5304	10226	562.20
1999	5.72	6.17	5.71	1639	26.21	3518	7612	5186	10085	598.56
2000	5.67	6.13	5.68	2280	26.23	3561	7603	5087	9937	645.81
2001	5.62	6.08	5.65	2866	26.22	3608	7606	4990	9810	707.03
2002	5.57	6.03	5.61	3375	26.21	3642	7581	4892	9669	765.80
2003	5.51	5.97	5.56	3808	26.18	3694	7602	4826	9550	817.98
2004	5.45	5.91	5.51	4111	26.10	3762	7694	4788	9492	902.02
2005	5.38	5.84	5.46	4346	26.03	3859	7785	4789	9427	973.67
2006	5.32	5.77	5.41	4546	25.95	3937	7909	4781	9395	1067.01
2007	5.26	5.70	5.37	4780	25.85	4005	7970	4789	9344	1159.89
2008	5.20	5.64	5.32	5009	25.72	4087	8068	4811	9319	1258.68

Case 5

$60 million per year; Immediate Improvement; Acceptable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST $MILLIONS
CURRENT	6.55	6.86	6.36	192	24.97	3234	8087	6695	11567	566.60
1989	6.48	6.82	6.33	72	25.20	3167	7911	6441	11364	437.13
1990	6.37	6.73	6.24	40	25.30	3100	7798	6342	11282	412.50
1991	6.25	6.64	6.14	18	25.37	3099	7699	6238	11175	364.28
1992	6.13	6.54	6.02	10	25.39	3143	7666	6187	11097	357.48
1993	6.07	6.48	5.98	10	25.52	3166	7586	6002	10951	366.92
1994	6.01	6.43	5.93	192	25.70	3216	7602	5826	10780	382.71
1995	5.94	6.37	5.88	427	25.83	3255	7580	5689	10610	428.82
1996	5.87	6.30	5.82	663	25.95	3324	7580	5575	10476	452.11
1997	5.81	6.24	5.77	847	26.11	3363	7567	5447	10327	513.63
1998	5.77	6.21	5.74	993	26.18	3446	7606	5304	10226	562.20
1999	5.72	6.17	5.71	1639	26.21	3517	7611	5185	10084	598.56
2000	5.67	6.13	5.68	2280	26.23	3560	7602	5086	9936	645.81
2001	5.62	6.08	5.65	2866	26.23	3607	7605	4989	9809	707.03
2002	5.57	6.03	5.61	3375	26.21	3641	7580	4891	9668	765.80
2003	5.51	5.97	5.56	3808	26.18	3693	7601	4825	9549	817.68
2004	5.45	5.91	5.51	4111	26.10	3761	7693	4787	9491	901.72
2005	5.38	5.84	5.46	4345	26.03	3859	7784	4790	9427	973.68
2006	5.32	5.77	5.41	4545	25.95	3937	7909	4782	9396	1067.04
2007	5.26	5.70	5.37	4780	25.86	4004	7969	4789	9344	1159.67
2008	5.21	5.64	5.32	5009	25.72	4086	8067	4811	9319	1258.54

Case 6

$100 million per year; Immediate Improvement; Acceptable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST $MILLIONS
CURRENT	6.54	6.87	6.36	193	24.97	3231	8085	6693	11567	566.56
1989	6.50	6.85	6.36	12	25.30	3099	7840	6362	11280	359.27
1990	6.41	6.78	6.28	2	25.47	3001	7659	6192	11113	272.59
1991	6.31	6.70	6.20	2	25.66	2934	7462	5977	10883	226.99
1992	6.22	6.63	6.12	2	25.81	2908	7331	5814	10671	206.07
1993	6.19	6.60	6.11	2	26.08	2815	7159	5505	10421	207.76
1994	6.18	6.57	6.11	63	26.44	2735	7006	5193	10123	212.59
1995	6.13	6.53	6.08	126	26.67	2700	6941	4965	9917	243.53
1996	6.11	6.51	6.07	232	26.82	2744	6915	4581	9634	250.87
1997	6.08	6.47	6.06	297	27.12	2693	6807	4350	9400	276.23
1998	6.10	6.48	6.09	372	27.41	2614	6697	4033	9164	335.73
1999	6.11	6.47	6.11	759	27.63	2603	6583	3843	8913	361.11
2000	6.14	6.49	6.16	1061	28.03	2446	6347	3573	8556	390.84
2001	6.16	6.50	6.19	1388	28.30	2346	6186	3339	8262	439.12
2002	6.17	6.49	6.22	1632	28.62	2192	5957	3098	7944	489.19
2003	6.18	6.49	6.24	1783	28.89	2094	5791	2896	7667	516.43
2004	6.17	6.48	6.25	1854	29.11	2048	5719	2763	7453	569.11
2005	6.17	6.46	6.26	1854	29.30	2018	5675	2640	7282	627.04
2006	6.15	6.43	6.25	1914	29.42	2025	5671	2586	7139	686.76
2007	6.14	6.41	6.25	1942	29.56	2006	5607	2506	6990	752.45
2008	6.12	6.39	6.24	2023	29.65	1985	5602	2433	6868	830.21

TABLE 5 (*continued on next page*)

TABLE 5 (*continued*)

Case 7

$200 million per year; Economical Improvement; Acceptable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLCSA	NLOSD	USER COST $MILLIONS
CURRENT	6.54	6.87	6.36	193	24.97	3231	8085	6693	11567	566.56
1989	6.56	6.90	6.42	2	25.56	2948	7624	6119	11012	229.11
1990	6.52	6.88	6.40	0	26.01	2719	7221	5676	10544	167.54
1991	6.54	6.90	6.44	0	26.72	2420	6610	5015	9819	122.00
1992	6.51	6.88	6.44	0	27.17	2245	6221	4583	9290	99.14
1993	6.48	6.85	6.43	0	27.49	2110	5998	4251	8994	94.84
1994	6.53	6.87	6.48	0	28.05	1910	5642	3782	8460	78.73
1995	6.51	6.85	6.49	0	28.39	1777	5452	3450	8128	83.13
1996	6.52	6.86	6.52	0	28.80	1626	5198	3096	7708	72.12
1997	6.57	6.89	6.58	0	29.32	1442	4835	2684	7179	69.98
1998	6.64	6.94	6.68	0	29.85	1178	4482	2222	6714	88.09
1999	6.67	6.95	6.72	0	30.23	972	4274	1893	6380	68.60
2000	6.71	6.97	6.77	0	30.62	756	4048	1568	6052	75.64
2001	6.75	7.00	6.83	1	30.94	577	3793	1262	5702	77.88
2002	6.79	7.01	6.88	2	31.24	411	3531	990	5357	64.13
2003	6.81	7.02	6.91	2	31.50	286	3321	734	5035	52.16
2004	6.77	6.97	6.87	1	31.60	262	3326	642	4926	52.28
2005	6.73	6.92	6.84	0	31.67	244	3313	566	4813	46.62
2006	6.73	6.92	6.84	0	31.76	214	3254	483	4652	48.23
2007	6.72	6.91	6.84	0	31.82	186	3153	420	4489	52.19
2008	6.69	6.89	6.82	0	31.88	157	3105	350	4357	53.67

Case 8

$200 million per year; Immediate Improvement; Acceptable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLCSA	NLOSD	USER CUST $MILLIONS
CURRENT	6.54	6.87	6.36	193	24.97	3231	8085	6693	11567	566.56
1989	6.56	6.90	6.42	2	25.56	2948	7624	6119	11012	229.11
1990	6.52	6.88	6.40	0	26.01	2719	7221	5676	10544	167.54
1991	6.54	6.90	6.44	0	26.72	2420	6610	5015	9819	122.00
1992	6.51	6.88	6.44	0	27.17	2245	6221	4582	9289	99.14
1993	6.48	6.85	6.43	0	27.49	2110	5999	4250	8994	94.84
1994	6.53	6.87	6.48	0	28.05	1910	5643	3781	8460	78.74
1995	6.51	6.85	6.49	0	28.39	1777	5493	3449	8128	83.15
1996	6.52	6.86	6.52	0	28.80	1626	5199	3096	7708	72.13
1997	6.57	6.89	6.58	0	29.32	1442	4835	2683	7177	69.99
1998	6.64	6.94	6.68	0	29.84	1170	4483	2223	6715	88.10
1999	6.67	6.95	6.72	0	30.23	973	4275	1893	6382	68.61
2000	6.71	6.97	6.77	0	30.61	757	4049	1568	6054	75.65
2001	6.75	7.00	6.83	1	30.93	578	3794	1262	5703	77.89
2002	6.79	7.01	6.88	2	31.24	411	3532	989	5356	64.13
2003	6.81	7.02	6.91	2	31.49	285	3329	717	5029	50.32
2004	6.77	6.97	6.88	1	31.60	255	3320	617	4907	52.28
2005	6.73	6.92	6.84	0	31.67	241	3315	545	4801	46.77
2006	6.72	6.92	6.84	0	31.76	209	3259	460	4639	48.99
2007	6.69	6.89	6.81	0	31.82	175	3182	386	4500	49.96
2008	6.67	6.87	6.79	0	31.89	150	3126	319	4361	51.10

TABLE 5 (*continued on next page*)

TABLE 5 (*continued*)

Case 9

$400 million per year; Economical Improvement; Acceptable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST $MILLIONS
CURRENT	6.54	6.87	6.36	193	24.97	3231	8085	6693	11567	566.56
1989	6.69	7.02	6.55	0	26.17	2639	7132	5542	10376	149.00
1990	6.86	7.18	6.77	0	27.62	1986	5879	4244	8880	83.32
1991	7.01	7.29	6.96	0	28.76	1467	4940	3258	7756	58.52
1992	7.03	7.29	6.99	0	29.16	1247	4607	2835	7291	50.41
1993	6.96	7.22	6.94	0	29.41	1161	4404	2636	7033	46.33
1994	6.89	7.15	6.88	0	29.61	1093	4286	2472	6837	41.78
1995	6.92	7.18	6.94	0	30.05	876	3962	2036	6435	38.41
1996	6.97	7.19	6.99	0	30.45	694	3685	1670	6062	34.60
1997	7.00	7.21	7.04	0	30.83	499	3435	1310	5702	32.40
1998	7.02	7.21	7.06	0	31.09	368	3233	1069	5423	28.28
1999	7.00	7.18	7.06	0	31.28	285	3117	879	5212	26.17
2000	6.98	7.16	7.05	0	31.45	202	2986	706	4996	22.95
2001	6.93	7.11	7.01	0	31.53	155	2935	587	4864	21.54
2002	6.88	7.06	6.97	0	31.60	123	2898	499	4756	19.98
2003	6.84	7.01	6.93	0	31.65	112	2880	423	4659	19.10
2004	6.80	6.98	6.89	0	31.70	91	2846	359	4559	17.63
2005	6.75	6.94	6.86	0	31.73	96	2825	329	4484	16.25
2006	6.71	6.90	6.82	0	31.76	87	2803	291	4405	15.58
2007	6.66	6.86	6.77	0	31.78	91	2805	267	4351	14.66
2008	6.61	6.82	6.73	0	31.82	104	2775	253	4289	14.61

Case 10

$400 million per year; Immediate Improvement; Acceptable Level of Service

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST $MILLIONS
CURRENT	6.54	6.87	6.36	193	24.97	3231	8085	6693	11567	566.56
1989	6.69	7.02	6.55	0	26.17	2639	7132	5542	10376	149.00
1990	6.86	7.18	6.77	0	27.62	1986	5879	4244	8880	83.32
1991	6.99	7.28	6.94	0	28.82	1474	4870	3212	7685	55.87
1992	7.21	7.44	7.18	0	30.25	716	3777	1690	6331	39.45
1993	7.36	7.55	7.36	0	31.17	178	3114	515	5405	31.57
1994	7.34	7.51	7.36	0	31.44	24	2943	44	4992	26.97
1995	7.26	7.44	7.29	0	31.50	14	2888	29	4886	26.04
1996	7.20	7.37	7.24	0	31.55	34	2858	44	4805	24.46
1997	7.15	7.32	7.20	0	31.61	28	2825	34	4699	22.69
1998	7.11	7.28	7.17	0	31.67	13	2759	21	4588	21.02
1999	7.04	7.21	7.11	0	31.70	19	2745	28	4511	20.25
2000	6.98	7.16	7.06	0	31.74	22	2706	33	4420	18.18
2001	6.91	7.09	6.99	0	31.75	20	2696	29	4361	17.35
2002	6.85	7.03	6.94	0	31.78	14	2695	19	4292	16.42
2003	6.79	6.97	6.89	0	31.80	15	2693	19	4233	15.56
2004	6.74	6.93	6.84	0	31.82	17	2671	25	4168	14.69
2005	6.68	6.88	6.80	0	31.84	30	2653	38	4115	14.04
2006	6.63	6.84	6.75	0	31.86	17	2625	27	4049	13.52
2007	6.57	6.79	6.70	0	31.88	26	2623	35	4008	12.75
2008	6.51	6.74	6.65	0	31.91	42	2596	49	3968	12.55

NMACR = NUMBER OF BRIDGES WITH A CONDITION RATING LESS THAN THE MINIMUM ALLOWABLE CONDITION RATING, "4"
NSVA = NUMBER OF BRIDGES POSTED AT LESS THAN ACCEPTABLE
NSVD = NUMBER OF BRIDGES POSTED AT LESS THAN DESIRABLE
NLOSA = NUMBER OF BRIDGES WITH A LESS-THAN-ACCEPTABLE USER LEVEL OF SERVICE
NLOSD = NUMBER OF BRIDGES WITH A LESS-THAN-DESIRABLE USER LEVEL OF SERVICE

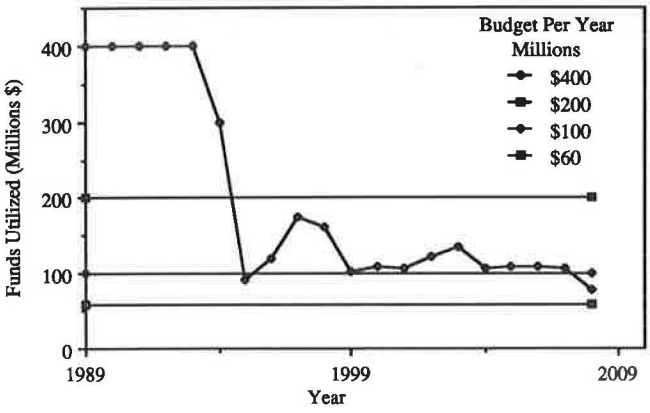

FIGURE 9 Funds of budget used per year.

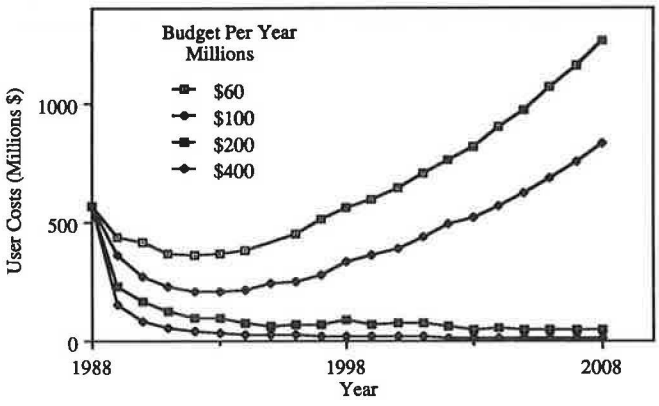

FIGURE 10 Budget impact on user costs.

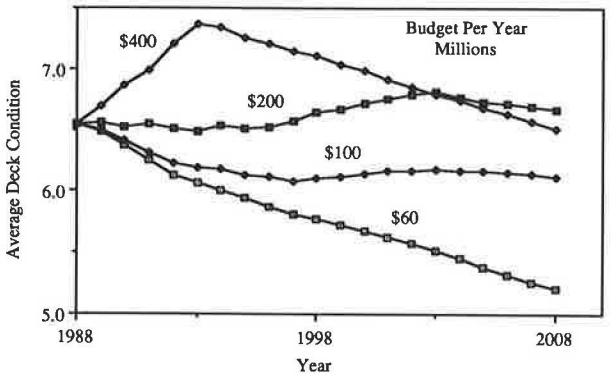

FIGURE 11 Budget impact on average deck condition.

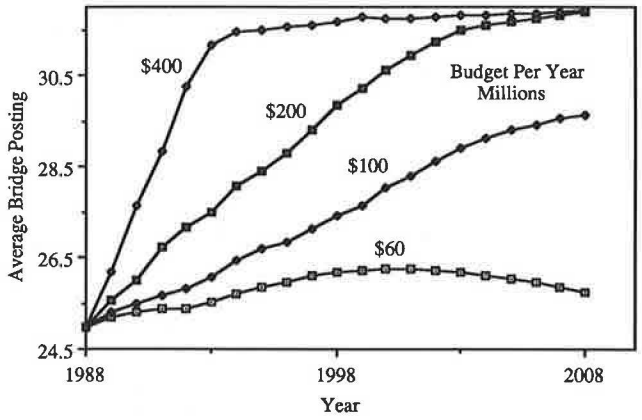

FIGURE 12 Budget impact on average bridge posting.

this reason, maximizing the EUAC reduction for improvement alternatives over routine maintenance is proposed for optimizing economic decisions at the system level.

5. A system-level optimization of bridge management decisions can be accomplished by 0–1 integer linear programming with multiple choice constraints.

6. The trial-and-error approach of OPBRIDGE allows managers to recognize the effect of their strategic user input on future budget needs and performance level of the bridge system. Revising user input is sometimes necessary to produce acceptable budgets and performance level.

7. The detailed bridge-by-bridge output provided by OPBRIDGE shows the status and actions recommended for first analysis year and major actions (replacement and rehabilitations) and their timings recommended thereafter for every bridge.

8. The tabular and graphical outputs provided by OPBRIDGE show funding needs or budget limits and the behavior of the state-wide, system-level performance indicators over the horizon. The outputs can be listed by federal- or non-federal-aid bridges and by state classification for primary, secondary, or urban system bridges.

9. The yearly county-by-county output provided by OPBRIDGE shows a list of bridges needing major actions (replacement and rehabilitation), cost of the major actions, and total funds needed for each county in the state. The total budget is also subdivided into federal-aid and state system funds. The county-by-county output is provided for each year up to the year (≤ horizon) specified by the user.

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