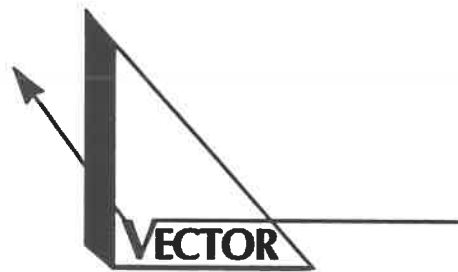


**INTEGRATING TRANSPORTATION MANAGEMENT
SYSTEMS INTO
TRANSPORTATION PLANNING AND OPERATIONS
NATIONAL CONFERENCE**

Proceedings



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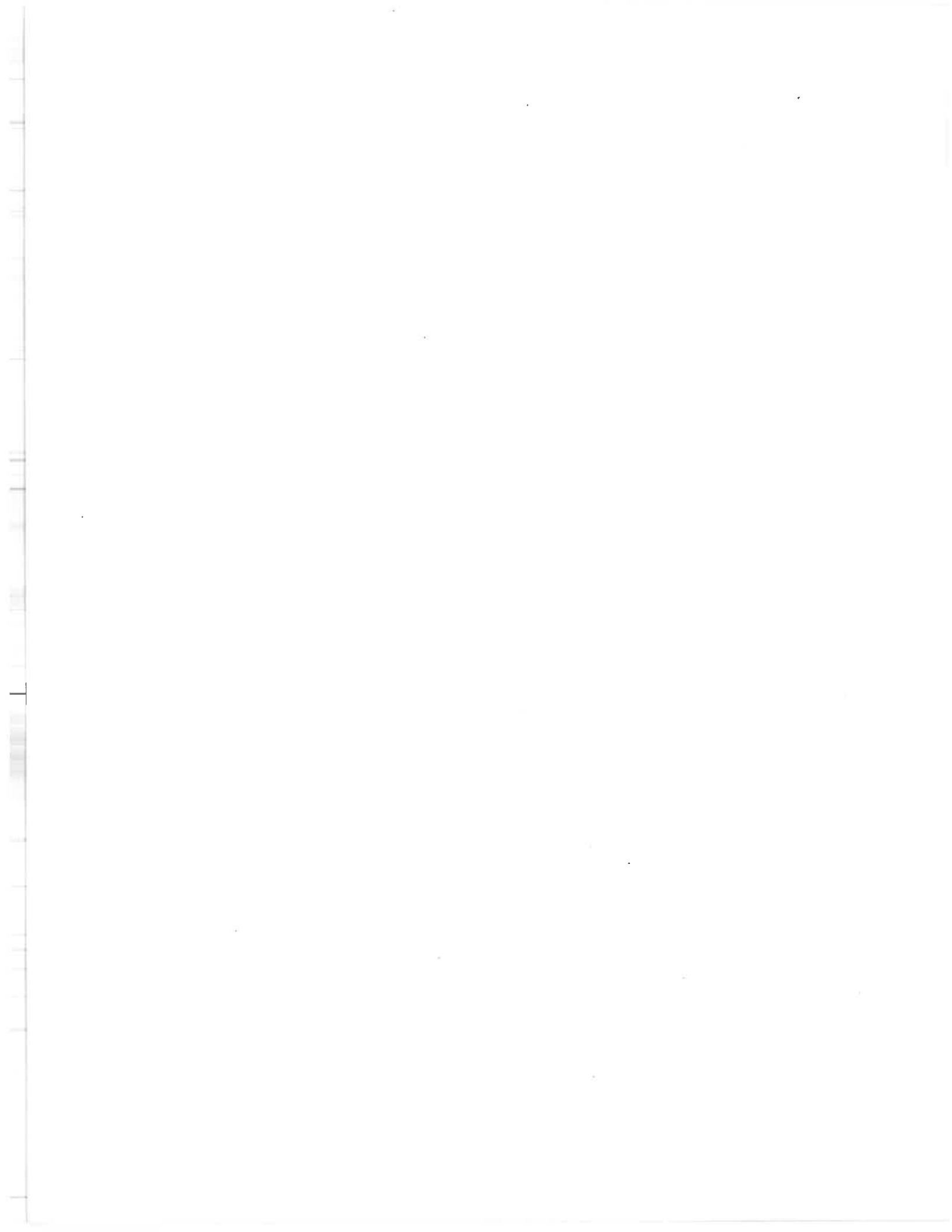


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BRIDGE MANAGEMENT BENEFITS UNDER REQUIREMENTS OF ISTEA

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Abstract: Bridge owning agencies have been reticent to implement Bridge Management Systems. However, experience in North Carolina, which has had an operational BMS meeting the new ISTEA requirements since 1988, indicates numerous benefits from such systems. An overview is presented of the North Carolina Bridge Management System. The system is based both in economic evaluation considering agency and user costs and in engineering evaluation considering minimum user and maintenance condition levels of service. The system seeks to reduce total costs to the ultimate owner, the user-taxpayer, while assuring essential minimum levels of condition and public service. Descriptions of data bases, analyses conducted, and samples of statewide results are included.

BACKGROUND AND OBJECTIVES

In the 1970's, the public became increasingly aware of the serious bridge deficiencies in the United States. However, efforts by the responsible federal, state, and local agencies to improve bridges has been hampered by a lack of funds. This lack of funds has been aggravated by agency inability to justify the needs on a defensible basis and legislative concerns about the absence of agency decision support systems to assist in determining best use of funds.

Nationwide efforts to improve in-service inspection and accumulate at least minimal data on a uniform basis were in place by 1980. However, the North Carolina Department of Transportation (NCDOT) Bridge Maintenance Unit determined that data alone was not enough to solve the fundamental problems. Furthermore, the initial federally mandated method of determining eligibility for improvement, the Sufficiency Rating, was not an adequate measure of a bridge in meeting public needs, particularly across all roadway functional classifications.

North Carolina contains about 14,300 bridges and about 3,200 culverts and large pipes. Of the bridges, about 14,000 are state-owned and 300 are city-owned. Of the pipes and culverts, about 3,000 are state-owned and 200 are city-owned. There are no county-owned bridges or roadways in the state. Thus, the NCDOT has responsibility for allocation of bridge funds to essentially all the roadway functional classifications within the state, except city streets, and must adequately balance the relative needs.

Since 1982, NCDOT staff and North Carolina State University researchers have gradually developed (1-9) the elements of a Bridge Management System (BMS) for use by the NCDOT Bridge Maintenance Unit. Two objectives, set at the inception of the research and development, are met by the North Carolina BMS:

1. The system has the capability to assess the optimum timing and selection among alternatives for maintenance, rehabilitation and replacement at the bridge level and to predict system-wide funding needs on an annual basis into the future.
2. The system has the capability to determine the optimum use of constrained budgets and to predict the resulting impact of inadequate budgets upon system-wide performance in terms of element condition deterioration, load capacity decline, and increasing user costs on an annual basis into the future.

Furthermore, the system is based both in economic evaluation considering agency and user costs and in engineering evaluation considering minimum user and condition levels of service. By taking this approach, defensible methodologies result since they seek to reduce total costs to the ultimate owner, the user-taxpayer, while assuring essential minimum levels of condition and public service. In accomplishing these and other objectives, the system also meets the more recently developed AASHTO Guidelines for Bridge Management Systems and the expectations of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). This paper provides an overview of the system, the analyses conducted, and samples of the types of results. Additional details are available in the various referenced reports and papers (1-9).

DATA BASES

The North Carolina BMS is designed as a mainframe system. Although this is partly because a centralized high speed mainframe is the primary hardware used within NCDOT, several other reasons have made this desirable for a large agency as follows:

1. Widespread network of users for some data entry;
2. Anticipated growth of network users seeking information from the system;
3. BMS development decisions and data base sizes less controlled by hardware limitations;
4. Data base and software security;
5. Access to databases that serve multiple unit users within NCDOT, not just the Bridge Maintenance Unit; and
6. Anticipated future directions toward interaction with other data bases such as Accident Reports and GIS, and the BMS role in larger Management Information, Planning and Decision Systems.

Figure 1 illustrates the relationships between the BMS Data Bases, Application Programs, and Outputs. Currently, four data bases are primarily utilized.

Bridge Inventory Records - The North Carolina Bridge Inventory (NCBI) contains the inspection data for all bridges, culverts and major pipes, about 17,500 records. Each record, with 273 items, is significantly expanded beyond the minimum National Bridge Inventory record requirement of 116 items. The added items include:

- Expanded descriptions of bridge components, materials, and features;
- Estimates of the quantities of maintenance needs under 40 work function codes with associated current unit costs;
- Condition ratings of about 40 elements of the bridge rather than 3; and
- Expanded location, dimension and general information.

Maintenance Work Accomplished Records - As maintenance is accomplished by crews, it is reported to a centralized Fiscal Cost and Work Accomplished data base. The data base actually serves many units within NCDOT but certain function codes are assigned to activities within the Bridge Maintenance Unit. About 40 function codes are used to describe bridge maintenance field activities. Data entered, subdivided by function code on each bridge, include the number of hours worked by each worker, the quantities of work accomplished, the equipment hours, and the materials expended. These quantities are extended through appropriate unit cost rates to obtain total costs.

Historical Data Base Records - The bridge inventory is a live data base in which many bridge records are updated every day. In order to preserve an understanding of how parameters change with time, it is important to retain a snapshot of the record periodically. Since the cycle for most inspections is two years, retaining a copy annually is adequate for most data. Similarly, data on work accomplished during each year should be saved for future analysis as needed. For this reason, record copies of each file are made at the end of each fiscal year. Although the record copies are critical historical resources for occasional future data extraction, the volume of data stored on many tapes is inconvenient for frequent use. Thus, a separate History database of key parameters is extracted and updated annually. The extracted data focus on items that would be useful in analyzing long-term trends such as condition ratings, load capacity, average daily traffic (ADT), maintenance needs, etc.

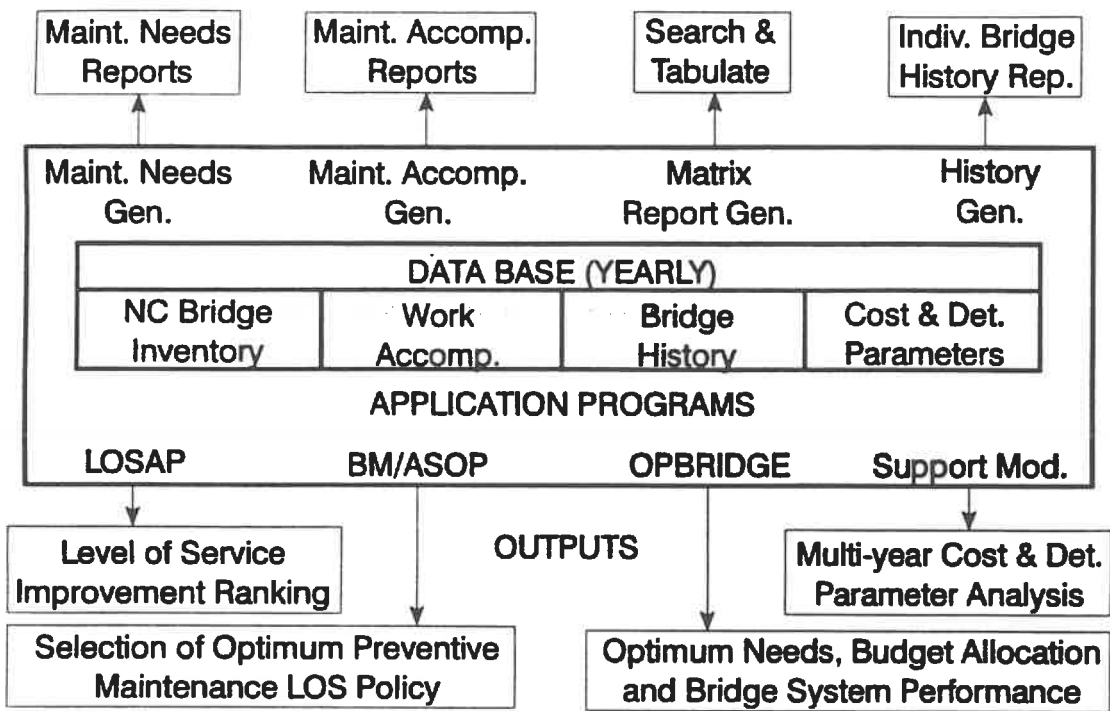


Figure 1. Elements of the North Carolina Bridge Management System

Cost and Parameter Data File - The main optimization program in the BMS, OPBRIDGE, which will be described later, requires certain data for its analysis beyond the bridge records in the NCBI. These data, which are determined by various support modules and other sources, are stored in the Cost and Parameter Data file. Example cost data include unit costs for rehabilitation, widening and various other improvements; unit costs for maintenance at various condition levels; vehicle operating costs; and bridge-related accident costs. Parameter data examples include element material deterioration rates, load capacity deterioration rates, ADT growth rates, percentages of vehicles detoured due to load capacity and vertical clearance deficiencies, and level of service goals for lane and shoulder width, number of lanes, vertical clearance, and load capacity.

APPLICATION PROGRAMS AND EXAMPLE RESULTS

The BMS includes eight major application program and report generator groupings (Figure 1). Some are single, large (but modular) programs, such as OPBRIDGE, and others are actually a series of programs. Most act independently, while some produce outputs needed by other programs.

Report Generators

The data bases are accessible for use by a broad range of possible users in NCDOT. In this process, portions of data may be downloaded by some users into other generic software such as spreadsheets or statistical analysis packages, particularly SAS. For more routine use within the Bridge Maintenance Unit, several application programs have the objectives of searching, tabulating, and summarizing data from the data bases. Among these are individual bridge printouts of the inventory record for staff reference and inspector updating. However, the primary report generators can be grouped as follows:

History Generator - The History Report Generator assembles a one sheet summary for each bridge. One section of the data provided includes a listing of the current primary features of the bridge, materials, roadway information, etc. A second section tracks key inspection data on an annual basis since 1980. The data include condition ratings of the major components, appraisal ratings of various features, the operating rating, posted load capacities, ADT for the over and under routes, sufficiency rating and deficiency points. A third section tracks inspector estimated maintenance-need quantities and costs by function code as recorded annually since about 1983. The last section tracks the work-accomplished quantities and costs by function code on an annual basis since about 1983. This report allows the user to examine trends in maintenance needs, condition and strength deterioration, ADT, etc. and to determine the impact of maintenance efforts for individual bridges.

Matrix Manipulator & Report Generator - The Matrix/Report Generator program allows the user to search the NCBI data base for particular data, to search for groups of bridges within selected parameter ranges, to tabulate the numbers of bridges categorized into various parameter features, etc. This program is a revised version of the Federally-provided Report Generator Program. The modifications by NCSU and NCDOT allow the software to operate on the NCBI, which is expanded beyond the normal Federal NBI data base.

Maintenance Needs Generator - Maintenance needs for individual bridges are estimated under 40 work Function codes during each inspection. The data, including the function code, the quantities, and a unit cost based upon state-wide averages, are part of each bridge record in the NCBI. The Maintenance Needs Report Generator program summarizes this data by function code under several options including bridge-by-bridge, county, maintenance area, and statewide. The summaries allow the backlog of work to be monitored on both a quantity- and a cost-magnitude basis. The summary total, which always is greater than the available funds, and distribution by Maintenance Area have also traditionally been useful aids in apportioning available funds to the Maintenance Areas and in sizing the crews available in the Areas.

Maintenance Accomplished Generator - The Work Accomplished Report Generator summarizes the data by function code in monthly and cumulative year-to-date reports under several options including county (bridge-by-bridge), area, and statewide. Resulting unit costs are summarized for each area and statewide for use in estimating costs associated with the maintenance needs backlog.

OPBRIDGE

The Optimum Bridge Budget Forecasting and Allocation System (OPBRIDGE) was developed (3-7) to determine the optimum improvement action and time for each individual bridge in the network under various level of service goals and funding constraints over an analysis horizon.

Through input screens (Figure 2), a bridge manager enters the analysis horizon, minimum performance requirements, and policies as well as the granted budget, maximum allowable budget, or unlimited budget for each year in the horizon. A granted or limited budget can be entered either as a total available or as distributed by line item to maintenance, rehabilitation, and replacement activities. Upon execution, OPBRIDGE extracts data from the bridge database and the cost and parameter data file for analysis.

The analysis determines the economic viability of various maintenance, rehabilitation and replacement alternatives. Life cycle costing is used, and comparisons are based upon the equivalent uniform annual costs of each alternative versus the analysis year annual maintenance and user costs as shown in Figure 3. User costs accumulate from detours due to load capacity deficiencies, detours due to vertical clearance deficiencies, and accidents induced by width, alignment, and vertical clearance deficiencies.

Under unlimited funding, decisions are made as indicated in Figure 4, and all of the most economic alternatives can be selected. However, in limited funding cases, sufficient funds are not available to select all of the most economic alternatives. Thus, OPBRIDGE then optimizes decisions for every year in the analysis horizon under the budget constraint using a 0-1 integer-linear programming formulation, as shown in Figure 5.

At the end of every year in the analysis, OPBRIDGE ages bridges one year and predicts condition ratings, ADT, load capacity, etc. This allows the system to continue the analysis in the next year of the horizon. Finally, OPBRIDGE produces detailed bridge-by-bridge output showing current and expected future status, county-by-county output showing bridge-by-bridge and summary costs, and tabular and graphical output showing statewide (or subset) agency costs, user costs, and performance levels of the bridge system over the horizon. A variety of user options are incorporated to select sets of bridges for analysis and to summarize results.

Example tabular statewide results for a \$100 million, \$200 million, and Unlimited annual budgets over the next 20 years are shown in Table 1, 2, and 3. At \$100 million and \$200 million levels, the full budget is needed each year and the summary totals determined as optimal for maintenance, repair, rehabilitation and replacement are indicated in Tables 1a and 2a. If unlimited funds were somehow available (Table 3a), the economically justifiable backlog of about \$1.9 billion would be spent in the first year, resulting in an immediate increase in the inventory state and virtual elimination of user costs; this would be followed by an annual need averaging \$104 million in the 19 years thereafter. However, uniform budgeting is more realistic. Tables 1b, 2b, and 3b show the statewide summary of the predicted effect of these spending levels. By analyzing at various levels of funding and other options available using a "what if" approach, the results of various strategies can be evaluated, as summarized in Figures 6, 7, 8 and 9. At a level of \$250 million per year, Figure 6 shows that the full budget is not needed after the year 2004. At a budget level of \$200 million per year, significant improvements can be made over the next 20 years. At \$150 million, modest improvement can be expected. At \$100 million, some parameters are in a state of decline.

It is significant to note that predictions made by OPBRIDGE have proved to be reliable considering the numerous parameters involved. Analyses made in late 1988 (5,6), included prediction of expected performance over a 20 year horizon at several budget levels. Funding since that time has averaged about \$80 million annually. Results predicted for 1993 at the \$60 and \$100 million budget levels are re-tabulated in Table 4 along with the actual current 1993 average condition, load posting, and user cost states. The comparison, while not perfect, is very good considering that some prediction parameters are still being refined and many of the actions were programmed prior to availability of OPBRIDGE recommendations.

ANALYSIS HORIZON
 HORIZON ? (YEARS) 20
 FIRST-ANALYSIS YEAR ? 1993

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
 BYPASS BRIDGES WITH TIP \$ ALLOCATED ? Y

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 FOLLOWINGS 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	% \$		MAINTENANCE	REHABILITATION	REPLACEMENT	TOTAL BUDGET
	T	U				
1993	%		10.	40.	50.	200000000.
1994	\$		200000000.	600000000.	1200000000.	2000000000.
1995	T		.	.	.	2000000000.
1996	T		.	.	.	2000000000.
1997	U		.	.	.	.
----	-	
----	-	
2011	U		.	.	.	.
2012	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) N
 BY PRIMARY/SECONDARY/URBAN ? (Y/N) N
 GRAPHICAL OUTPUTS (BUDGETS AND PERFORMANCE) ? (Y/N) . . N
 BY FEDERAL/NON-FEDERAL AID ? (Y/N) N
 BY PRIMARY/SECONDARY/URBAN ? (Y/N) N
 COUNTY-BY-COUNTY OUTPUT ? (Y/N) Y
 UP TO WHAT YEAR ? 1993

CURRENT NEW-BRIDGE COST PARAMTERS
 UNIT COST ? (\$ / DECK AREA) 46.0
 FIXED COST ? (\$) 55000.
 DESIGN FEE ? (%) 12.0

Figure 2 OPBRIDGE User Input Screen Layout

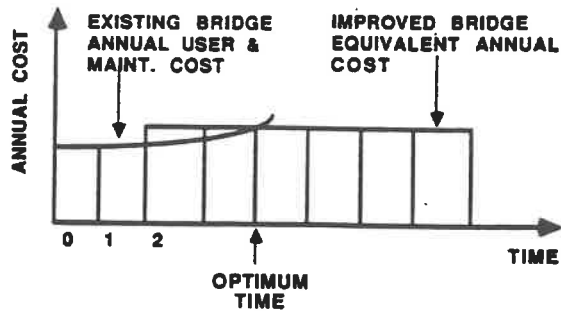


Figure 3 Optimum Time to Improve Bridge

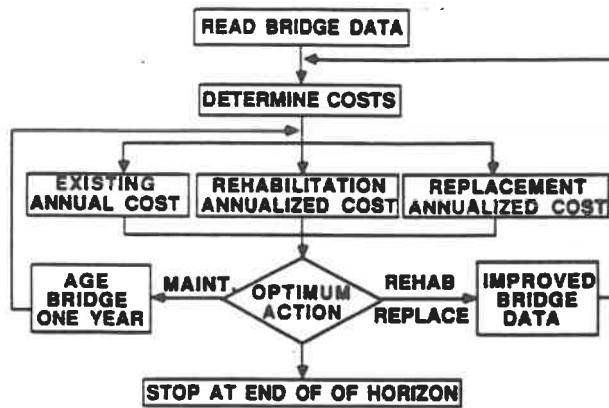


Figure 4 Selection of Most Economical Individual Action

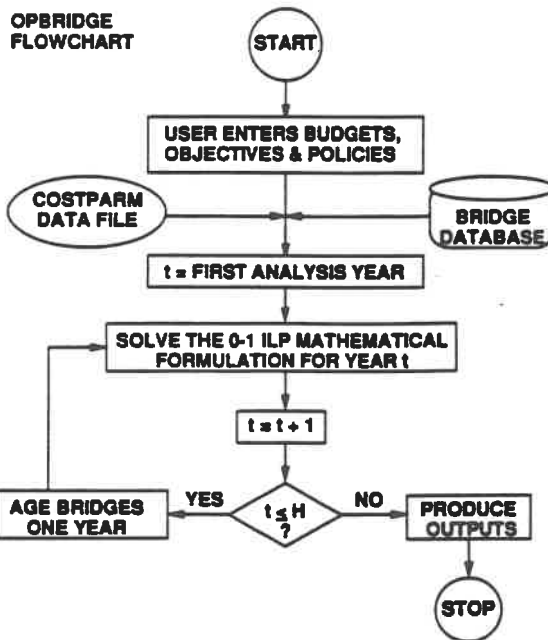


Figure 5 Optimum Action Selection Under Constraints

Table 1a Statewide Actions and Distributions at \$100 Million Annual Budget Level

YEAR	ROUTINE MAINT.	MAJOR MAINT.		REHABILITATIONS		REPLACEMENTS		TOTAL YEARLY BUDGET
	COST	COST	NO.	COST	NO.	COST	NO.	
1993	19265872.	12815856.	344	26425008.	413	41471824.	286	99978560.
1994	20982064.	7569433.	96	14394588.	185	57028160.	286	99974224.
1995	22763632.	9738558.	126	25387248.	283	42076672.	300	99966096.
1996	24086048.	7332152.	92	19084560.	204	49465264.	280	99968016.
1997	25566000.	7045491.	79	13836975.	176	53514640.	279	99963088.
1998	27351008.	5895587.	77	10745484.	123	55965840.	267	99957904.
1999	29186208.	9720569.	123	13447088.	174	47599648.	273	99953504.
2000	31008288.	14492007.	177	16238232.	209	38208944.	256	99947456.
2001	32842800.	15459012.	194	12692825.	187	38950784.	247	99945408.
2002	34559936.	10178527.	124	16760285.	264	38444368.	218	99943088.
2003	36897456.	11491971.	132	12795763.	175	38753776.	242	99938960.
2004	38513584.	12414712.	136	16006285.	169	33004960.	207	99939520.
2005	40195616.	17013824.	193	12366298.	150	30362736.	186	99938464.
2006	42255280.	16562084.	170	11750948.	129	29368208.	176	99936512.
2007	43871232.	17617952.	172	14849746.	172	23595776.	127	99934704.
2008	46117424.	12193857.	136	16623023.	184	25000592.	144	99934880.
2009	47472896.	10231030.	124	14088635.	134	28140400.	148	99932944.
2010	48555104.	12451549.	149	13880600.	129	25044176.	131	99931408.
2011	49863056.	8861315.	117	16801216.	151	24406624.	124	99932208.
2012	51285824.	12475509.	181	18144448.	212	18025600.	78	99931376.

Table 1b Predictions of Statewide Average Performance at \$100 Million Annual Budget Level

END OF YEAR	AVERAGE CONDITION			NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST \$MILLIONS
	DECK	SUPER	SUB.							
CURRENT	6.27	6.63	6.03	330	25.86	2185	6948	5606	10643	245.34
1993	6.34	6.67	6.14	475	26.17	2185	6680	5202	10305	241.64
1994	6.32	6.65	6.15	615	26.44	2061	6441	4965	10052	239.60
1995	6.32	6.65	6.18	741	26.73	1999	6230	4701	9757	236.22
1996	6.30	6.63	6.18	847	26.98	2003	6101	4512	9481	230.98
1997	6.27	6.60	6.18	934	27.23	2023	6019	4338	9230	323.42
1998	6.23	6.56	6.16	1067	27.45	2071	5974	4202	8987	366.17
1999	6.21	6.53	6.16	1237	27.66	2055	5892	3984	8729	404.81
2000	6.20	6.51	6.17	1410	27.84	2029	5767	3782	8494	446.15
2001	6.18	6.49	6.17	1566	28.00	1995	5683	3584	8280	470.52
2002	6.16	6.47	6.17	1692	28.12	1987	5617	3422	8088	505.96
2003	6.14	6.44	6.17	1882	28.25	1954	5499	3250	7865	551.70
2004	6.10	6.41	6.15	2061	28.37	1941	5417	3113	7705	592.01
2005	6.07	6.37	6.14	2216	28.47	1913	5349	2984	7543	629.66
2006	6.04	6.33	6.11	2332	28.58	1873	5282	2854	7397	677.62
2007	6.00	6.29	6.08	2415	28.61	1885	5278	2794	7306	718.87
2008	5.97	6.25	6.06	2465	28.67	1873	5231	2713	7202	778.89
2009	5.93	6.21	6.04	2499	28.72	1886	5195	2666	7092	826.51
2010	5.89	6.17	6.01	2497	28.79	1852	5175	2589	7011	910.18
2011	5.85	6.13	5.98	2505	28.85	1853	5207	2550	6964	962.92
2012	5.82	6.09	5.95	2608	28.77	1929	5293	2578	6965	1023.26

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 2a Statewide Actions and Distributions at \$200 Million Annual Budget Level

YEAR	ROUTINE MAINT.	MAJOR MAINT.		REHABILITATIONS		REPLACEMENTS		TOTAL YEARLY BUDGET
	COST	COST	NO.	COST	NO.	COST	NO.	
1993	17675088.	31095104.	472	51170288.	596	100044064.	561	199984544.
1994	17928928.	14841812.	132	40421088.	228	126796096.	409	199987920.
1995	18488256.	19059200.	182	40025008.	276	122410832.	487	199983296.
1996	18684944.	25684048.	204	22444720.	211	133171872.	419	199985584.
1997	19043696.	15258803.	174	36156400.	209	129524080.	369	199982976.
1998	19122704.	13832032.	156	45771008.	151	121256224.	298	199981968.
1999	19249120.	14748202.	194	58056608.	260	107927056.	400	199980976.
2000	18741072.	23038128.	251	49990400.	232	108215840.	372	199985440.
2001	18410000.	24777472.	280	40327840.	233	116470320.	391	199985632.
2002	18210496.	18688288.	184	45478592.	316	117606896.	362	199984272.
2003	18258560.	15036579.	138.	42772864.	250	123914560.	385	199982560.
2004	17651216.	15007082.	131	41806288.	216	125525920.	341	199990496.
2005	16937936.	15182900.	164	48059488.	221	119813808.	271	199994128.
2006	16014172.	25610160.	211	36675520.	264	121695872.	167	199995712.
2007	15555273.	26399968.	265	46203408.	215	111838336.	121	199996976.
2008	15029438.	27940464.	222	49929520.	207	107088496.	198	199987904.
2009	15249769.	20617680.	177	31451488.	184	132677952.	212	199996880.
2010	14803074.	18921888.	202	43018000.	173	123254576.	166	199997536.
2011	14620932.	15244430.	174	50392288.	194	119737760.	137	199995408.
2012	14165187.	20434048.	283	59880912.	309	105501344.	281	199981488.

Table 2b Predictions of Statewide Average Performance at \$200 Million Annual Budget Level

END OF YEAR	AVERAGE CONDITION			NMACR	AVG. SV				NLOSA	NLOSD	USER COST \$MILLIONS
YEAR	DECK	SUPER	SUB.		POSTING	NSVA	NSVD				
CURRENT	6.27	6.63	6.03	330	25.86	2185	6948	5606	10643	245.34	
1993	6.49	6.79	6.31	274	26.64	1886	6424	4837	10014	229.39	
1994	6.53	6.82	6.37	249	26.98	1748	6135	4440	9608	213.11	
1995	6.60	6.88	6.48	224	27.54	1523	5733	4000	9110	201.12	
1996	6.63	6.90	6.55	158	28.10	1326	5377	3603	8674	241.16	
1997	6.65	6.91	6.59	135	28.46	1215	5152	3229	8297	252.72	
1998	6.62	6.89	6.60	118	28.73	1144	4931	2971	7983	210.83	
1999	6.66	6.91	6.66	93	29.13	1004	4632	2501	7547	200.29	
2000	6.69	6.93	6.72	78	29.53	844	4362	2148	7175	183.18	
2001	6.74	6.96	6.77	62	29.93	673	4107	1779	6807	169.01	
2002	6.79	7.00	6.85	61	30.27	537	3860	1487	6452	163.23	
2003	6.82	7.02	6.90	54	30.65	401	3558	1197	6060	154.66	
2004	6.83	7.04	6.94	40	30.96	300	3338	964	5747	142.57	
2005	6.84	7.04	6.95	28	31.17	221	3197	793	5493	112.28	
2006	6.82	7.02	6.94	23	31.30	182	3110	607	5306	107.87	
2007	6.79	6.99	6.92	11	31.38	146	3062	515	5188	59.08	
2008	6.77	6.98	6.91	4	31.53	112	2924	414	4990	49.42	
2009	6.75	6.96	6.90	2	31.71	92	2765	365	4793	41.61	
2010	6.71	6.92	6.87	1	31.80	77	2664	319	4650	30.69	
2011	6.66	6.89	6.84	0	31.89	88	2612	298	4542	24.17	
2012	6.70	6.92	6.87	0	32.06	64	2467	202	4292	19.94	

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 3a Statewide Actions and Distributions at an Unlimited Annual Budget Level

YEAR	ROUTINE MAINT.	MAJOR MAINT.		REHABILITATIONS		REPLACEMENTS		TOTAL YEARLY BUDGET
	COST	COST	NO.	COST	NO.	COST	NO.	
1993	9579521.	44083968.	266	305282048.	1709	1526167040.	5120	1885112580.
1994	10577843.	17244848.	145	46476544.	119	86980944.	189	161280176.
1995	10782335.	19977744.	127	17436752.	103	62916672.	150	111113488.
1996	11033267.	10279552.	117	18825584.	93	57806400.	114	97944800.
1997	12338908.	10402650.	92	18549904.	76	80351488.	125	121642944.
1998	13199452.	7426329.	87	15055246.	52	46368160.	105	82049168.
1999	13197229.	18428384.	186	20664048.	116	51173360.	103	103463008.
2000	13047495.	21361968.	196	17717968.	99	67468128.	128	119595552.
2001	12904938.	18562160.	170	21654512.	99	70951616.	131	124073216.
2002	12707626.	18968672.	168	44309952.	188	64794048.	114	140780288.
2003	12809858.	14901430.	138	47386096.	149	39120064.	77	114217440.
2004	12548699.	14739682.	153	44619760.	143	29350000.	66	101258128.
2005	12875457.	17409168.	179	23550944.	117	54565120.	65	108400688.
2006	13123964.	15282807.	154	25530192.	131	36508224.	65	90445184.
2007	14085740.	17871120.	172	23596928.	141	85513744.	61	141067520.
2008	15047871.	13057712.	135	27094240.	163	19894064.	49	75093872.
2009	15390674.	13462325.	166	31240336.	119	21814016.	64	81907344.
2010	15644245.	11329504.	151	25386496.	132	32911616.	75	85271856.
2011	15796549.	9550293.	137	37136816.	176	20364624.	38	82848272.
2012	12932697.	96103456.	670	52274976.	250	37821840.	103	199132960.

Table 3b Predictions of Statewide Average Performance at an Unlimited Annual Budget Level

END OF YEAR	AVERAGE CONDITION			NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST \$MILLIONS
	DECK	SUPER	SUB.							
CURRENT	6.27	6.63	6.03	330	25.86	2185	6948	5606	10643	245.30
1993	7.67	7.90	7.70	0	31.63	24	2530	98	4825	21.43
1994	7.58	7.81	7.62	0	31.72	5	2427	59	4669	19.55
1995	7.48	7.71	7.54	0	31.79	4	2348	41	4541	16.89
1996	7.37	7.60	7.45	0	31.83	10	2295	39	4428	15.71
1997	7.28	7.52	7.38	0	31.87	8	2255	22	4317	14.74
1998	7.18	7.44	7.31	0	31.91	11	2206	16	4226	13.75
1999	7.12	7.37	7.26	0	31.94	6	2167	11	4143	13.26
2000	7.07	7.32	7.20	0	31.98	12	2124	15	4033	12.34
2001	7.01	7.25	7.15	0	32.01	10	2106	13	3939	11.40
2002	6.97	7.21	7.12	0	32.05	6	2069	9	3841	10.40
2003	6.90	7.14	7.06	0	32.07	6	2038	8	3777	9.66
2004	6.84	7.08	7.00	0	32.10	7	2020	9	3733	9.31
2005	6.77	7.01	6.93	0	32.11	9	2010	10	3686	8.85
2006	6.70	6.95	6.87	0	32.13	4	2010	6	3643	8.37
2007	6.63	6.88	6.80	0	32.14	8	2026	10	3608	8.08
2008	6.56	6.82	6.74	0	32.14	33	2015	35	3581	8.02
2009	6.48	6.75	6.67	0	32.18	40	1989	43	3530	7.85
2010	6.41	6.69	6.61	0	32.22	9	1948	12	3478	7.74
2011	6.33	6.63	6.55	0	32.21	52	1989	53	3494	7.66
2012	6.36	6.62	6.54	0	32.28	46	2035	47	3515	7.44

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,

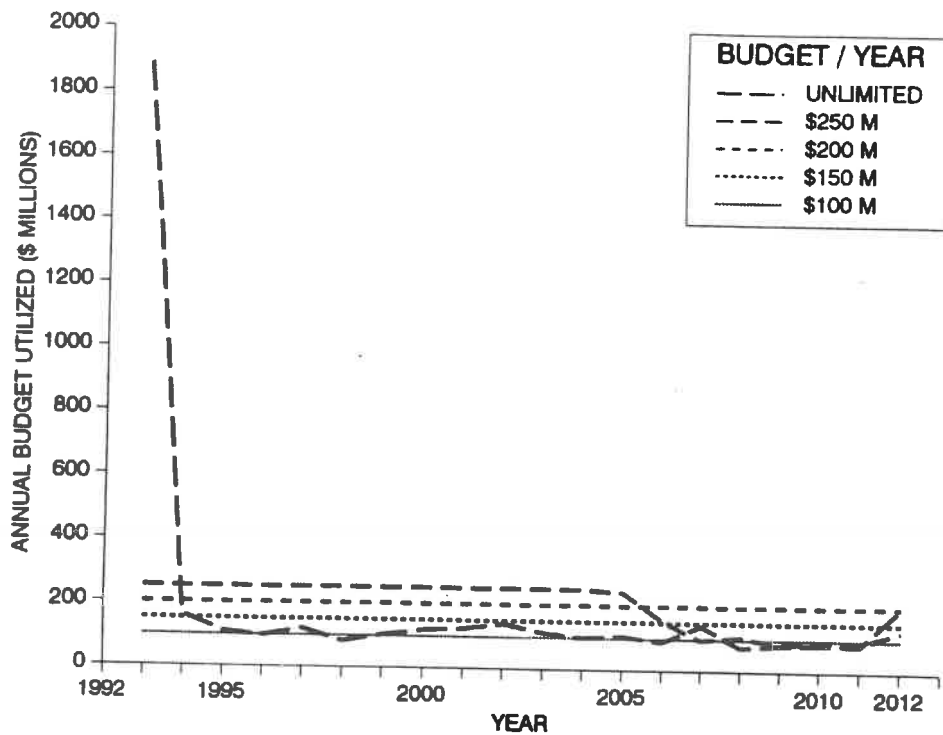


Figure 6 Budgets Utilized at Various Annual Budgets

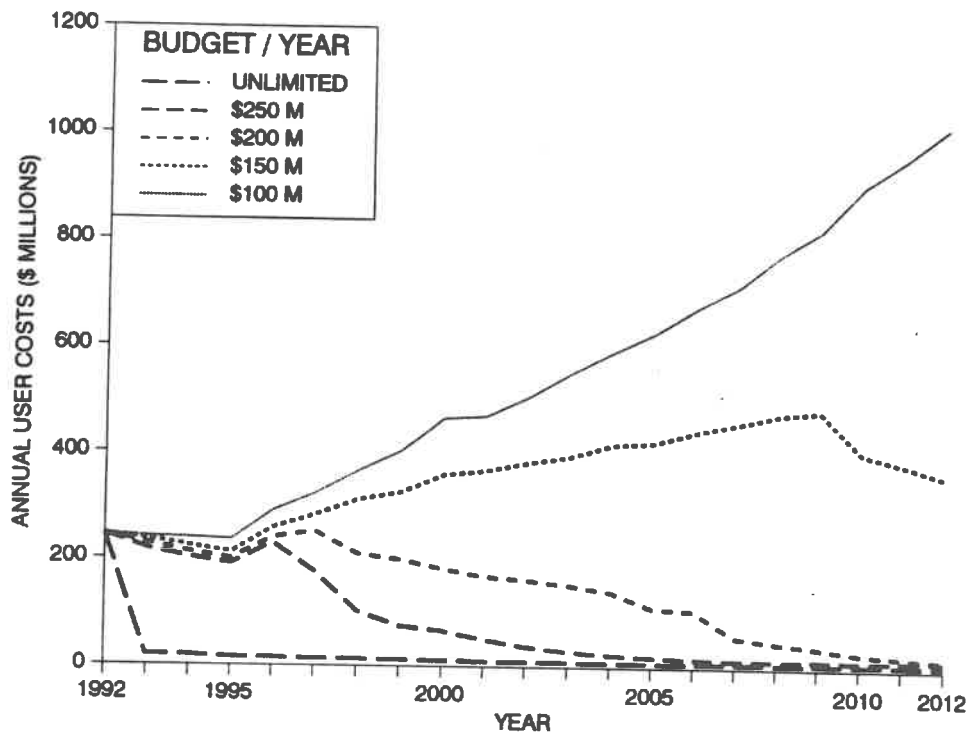


Figure 7 Predicted Users Costs at Various Annual Budgets

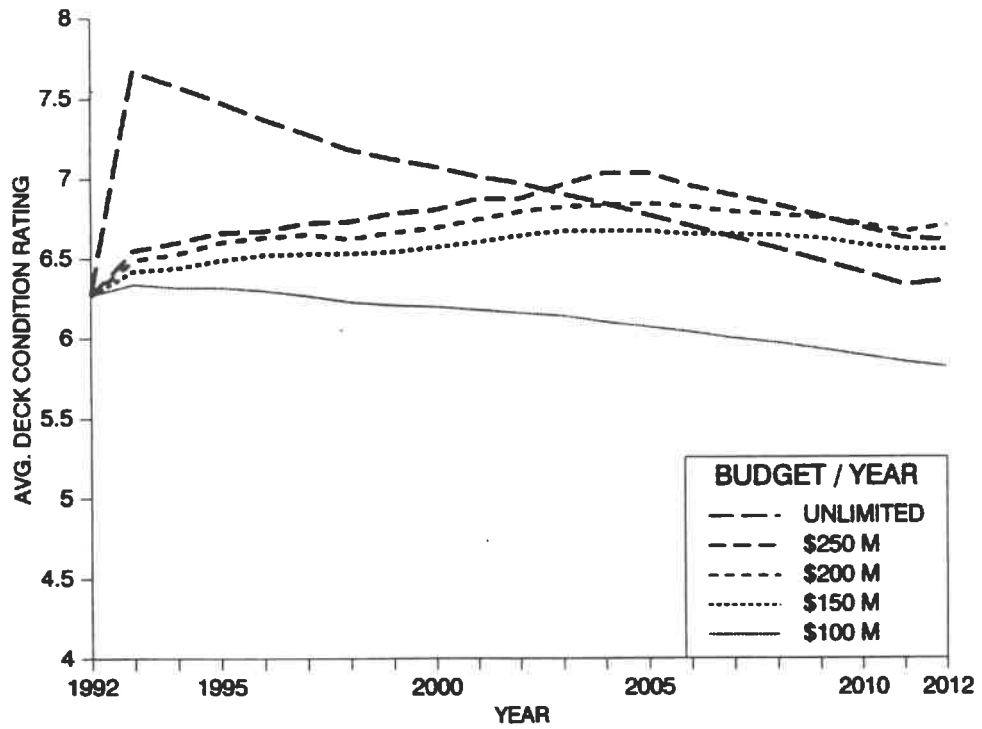


Figure 8 Predicted Average Deck Condition Rating at Various Annual Budgets

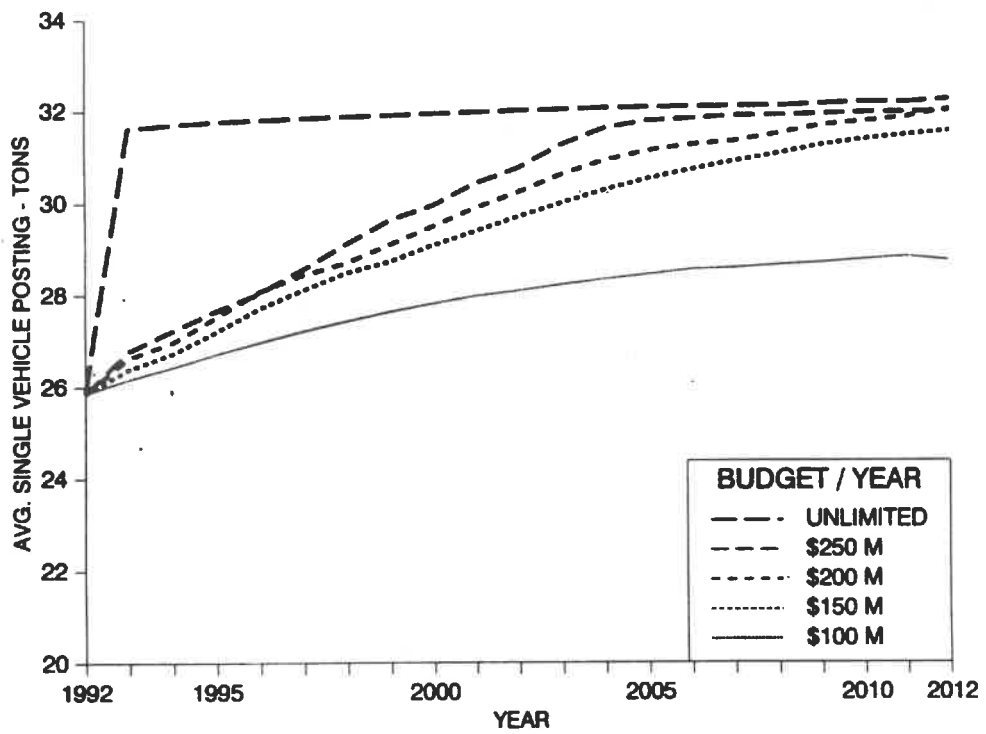


Figure 9 Predicted Average Single Vehicle Posting at Various Annual Budgets

Table 4 Comparison of 1988 Predictions to 1993 Current State

	Annual Budget (Millions)	1988 Actual	1993 Predicted	1993 Actual
Average Deck Condition	\$60	6.55	6.07	6.27
	\$100		6.19	
Average Superstructure Condition	\$60	6.86	6.48	6.63
	\$100		6.60	
Average Substructure Condition	\$60	6.36	5.98	6.03
	\$100		6.11	
Average Single Vehicle Posting (Tons)	\$60	24.97	25.52	25.86
	\$100		26.08	
Annual User Cost (\$ Millions)	\$60	566.60	366.92	245.30
	\$100		207.76	

LOSAP

The Level of Service Analysis and Prioritization (LOSAP) program was one of the first programs put in place to assist the decision making process (1). Although the ultimate goal of the BMS was a system like OPBRIDGE, neither the agency or user cost data, nor an understanding of the methodologies appropriate for that goal, were available in 1982 when the study began. Thus, LOSAP was developed as an empirical system of weighting factors to parallel the concept of user costs in evaluating bridges. Acceptable and desirable level of service goals for load capacity and geometry were established as minimum measures of bridges to remain in place and as new bridge objectives respectively. In order to rank bridges for improvement, deficiency points were calculated as functions of the deficiency magnitude and traffic volume. Ranked listings provided one line comparisons of bridges in columnar format. LOSAP proved to be a useful and easily understood tool to assist bridge decision-making; however, it now serves only as a point of reference as OPBRIDGE is implemented for more rigorous decision-making.

MAINTBRG

MAINTBRG (2,9) is focused at the problem of allocating funds to routine and preventive maintenance of bridges. The objective is to determine the optimum maintenance levels-of-service (L-O-S) that can be sustained under various levels of funding. A maintenance level of service is a condition state or threshold which triggers an appropriate maintenance activity. The MAINTBRG program was adapted by NCSU from the Algorithm for Selection of Optimal Policy (ASOP) originally developed in NCHRP Reports 223 and 273 for roadway feature maintenance.

The method provides a mechanism for combining alternative levels of service on multiple considerations (e.g., safety, preservation of investment, etc.) and for multiple elements (e.g., joints, rails, decks, etc.). In the system developed, bridge maintenance elements are evaluated using a 0-to-9 rating, similar to the FHWA Coding Guide rating for combined elements. The rating also corresponds to the maintenance levels-of-service where 3 - 7 are considered to be the normal range of the trigger options for maintenance activity and each has a expected normal improvement level. The program allows an agency to establish the relative values of different considerations and elements based on collective inputs from inspectors, field supervisors, maintenance engineers, legislators, bridge system users, etc. The optimization algorithm then assesses the optimal policy considering the maintenance funding constraints.

Support Modules

The Support Modules (8) are a series of programs developed to generate data that are needed to periodically update the Cost and Parameter Data File which is used by OPBRIDGE or to develop cost data needed by MAINTBRG (9). Objectives of the modules are the following outputs:

- Future estimates of the FHWA Structures Cost Index;
- Deterioration analysis of major bridge components;
- Relationships for estimating replacement bridge length and maximum span;
- Relationships for replacement costs;
- Unit costs of rehabilitation by component, material and condition;
- Maintenance unit costs for major components by material type and condition;
- Current and future unit costs of work by function code; and
- Annual costs to achieve L-O-S for routine and preventive maintenance.

The Support Module routines are based in SAS. In many cases, standard statistical procedures are utilized such as various types of regression analysis. In other cases, particularly deterioration analysis, mathematical procedures have been derived. Most of these modules analyze data in the Historical Data Base; some analyze data from the NCBI or other sources to produce the desired outputs.

SUMMARY AND BENEFITS

The North Carolina DOT Bridge Management System has been gradually developed in stages since 1982. The various parts have been implemented for use by the Bridge Maintenance Unit. The approaches employed have not only aided NCDOT but they have served as a model for other system and criteria developers. The analysis results produced assist NCDOT in the funding request and decision making process for bridge maintenance and improvement. Key features of the North Carolina DOT Bridge Management System include the following:

1. A bridge inventory record significantly expanded beyond minimum FHWA requirements;
2. Detailed bridge maintenance needs reporting during the in-service inspections;
3. Detailed work-accomplished reporting during the maintenance process;
4. Economic assessment of alternatives for maintenance, rehabilitation and replacement;
5. Assessment based on both agency and user costs in conjunction with optional minimum level of service criteria;
6. Estimate of current backlog and prediction of optimum future needs for bridge maintenance and improvement; and
7. Prediction of future system performance under various levels of constrained funding.

The Bridge Management System is considered to be a decision assistance tool. Individual bridge situations may make other options, which may not be fully modeled by the system, a better choice. Thus, the BMS is considered to provide network level information for top level agency planning assistance and bridge-by-bridge information for review and decision assistance during the programming of operations and projects. The system has been beneficial by providing an understandable and defensible method of comparing options across the state. Gradually, funding levels are improving in response to the needs.

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