ANALYSIS OF BRIDGE MANAGEMENT DATA IN NORTH CAROLINA

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ABSTRACT

An overview is presented of the North Carolina Bridge Management System. The system is based on economic evaluation considering agency and user costs, and 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 databases, analyses conducted and samples of 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 have been hampered by a lack of funds. This lack of funds has been aggravated by agency inability to justify the needs on a defendable 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's highway system contains about 14,300 bridges and about 3,200 culverts and large pipes. Of the bridges, about 14,000 are state-owned and 300 city-owned. Of the pipes and culverts, about 3,000 are state-owned and 200 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 (NCSU) 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:

- 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; and
- 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 on economic evaluation considering agency and user costs, and engineering evaluation considering minimum user and condition levels of service. By taking this approach, defendable 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 American Association of State Highway and Transportation Officials (AASHTO) Guidelines for Bridge Management Systems and the expectations of 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*).

DATABASES

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:

- Widespread network of users for some data entry;
- Anticipated growth of network users seeking information from the system;
- BMS development decisions and database sizes less controlled by hardware limitations;
- Database and software security;
- Access to databases that serve multiple unit users within NCDOT, not just the Bridge Maintenance Unit; and
- Anticipated future directions toward interaction with other databases 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 Databases, Application Programs, and Outputs. Currently, four databases 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 three; 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 database. The database 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 Database Records

The bridge inventory is an active database in which many bridge records are updated every day. 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. Therefore, record copies of each file are made at the end of each fiscal year. Although the record copies are critical historical resources for 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), and maintenance needs.

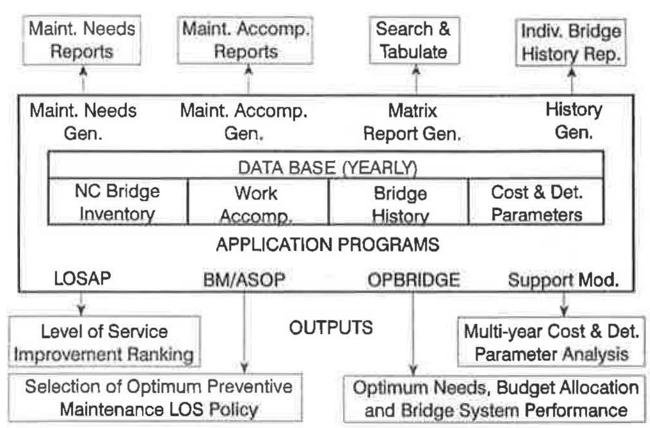

FIGURE 1 Elements of the North Carolina bridge management system.

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 a series of programs. Most act independently, while some produce outputs needed by other programs.

Report Generators

The databases are accessible for use by a broad range of 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 databases. Among these are individual bridge printouts of the inventory record for staff reference and inspector updating. The primary report generators are described below.

History Generator

The History Report Generator assembles a one sheet summary for each bridge (Figure 2). 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 (OP), posted load capacities (SV and TTST), ADT for the over and under routes (ADTO and ADTU), 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 database 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 database.

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 statewide averages, are part of each bridge record in the NCBI. The Maintenance Needs Report Generator program summarizes these 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), maintenance area and statewide. Resulting unit costs are summarized for each area and statewide for use in estimating costs associated with the maintenance needs backlog.

BRIDGE NO: 91119
COUNTY : WAKE
FACILITY : SR1912
FUN CLASS: LOCAL
SYSTEM : SECONDARY
STRNO : 0191200401190
FEATURE : NEWLIGHT CREEK

DKMT: TM
HRMT: TM
SUMT: ST
SUTY: F-MB
SBMT: TM

AGE : 32
YRBT: 1957
YRRC: 84
RL : 24
FEDA: NFA-R

LENGTH : 51
DESIGN ADT : 120
DESIGN LOAD: OTHER
REPCOST : 153000
DL : 5

WG : 20
CG : 16.0
UG : 14.0
OG : 14.0
VCLO: 99.9

YR	DECK RAT. N123456789	EXP. ($00)	SUPER RAT. N123456789	EXP. ($00)	SUB RATING N123456789	EXP. ($00)	PAINT RAT. N123456789	EXP. ($00)	ADTO	ADTU	SV	OP	TT ST	SF	DP	RL	CDW	VCLU	C H N	C & R	R D C	A L N	W R A	S T C	AGE	YR
80	5	0	5	0	4	0		0	70	.	.	11	.	29	.	6	17.2	0.0	5	N	5	7	2	2	23	80
81	4	0	6	0	3	0		0	70	.	.	11	.	29	.	4	17.2	0.0	6	N	5	6	2	2	24	81
82	4	0	6	0	3	0		0	70	.	.	11	.	24	.	4	17.2	0.0	6	N	5	6	2	2	25	82
83	3	0	5	0	3	12	5	0	70	.	11	11	11	24	12	4	17.2	0.0	6	N	6	7	8	2	26	83
84	3	0	5	122	3	163	5	0	70	.	11	11	11	24	12	4	17.2	0.0	6	N	6	7	8	2	27	84
85	8	0	7	0	8	4	8	0	60	.	14	14	18	47	2	25	19.2	0.0	6	N	8	7	8	2	28	85
86	8	4	7	0	8	0	8	0	60	.	14	14	18	47	2	25	19.2	0.0	6	N	8	7	8	2	29	86
87	8	0	7	0	8	0	8	0	40	.	14	14	18	47	2	25	19.2	0.0	7	N	6	7	8	3	30	87
88	8	0	7	0	8	0	8	0	40	.	14	14	18	47	2	25	19.2	0.0	7	N	6	7	8	3	31	88
89	8	0	7	0	8	0	8	0	40	.	14	14	18	47	2	24	19.2	0.0	7	N	8	7	8	3	32	89

YR	<------ MAINTENANCE NEEDS (CODE,QUANTITY) ------> CDE	QUANT.	CDE	QUANT.	CDE	QUANT.	CDE	QUANT.	NO CD	TCOST ($00)	*	<---------- WORK DONE (CODE,QUANTITY) ----------> CDE	QUANT.	CDE	QUANT.	CDE	QUANT.	CDE	QUANT.	NO CD	TCOST ($00)	YR
80	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	80
81	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	81
82	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	82
83	479	500	474	80	493	40	492	20	4	35	*	493	60	0	0	0	0	0	0	1	12	83
84	479	500	474	80	493	40	492	20	4	48	*	493	744	492	479	0	0	0	0	2	285	84
85	0	0	0	0	0	0	0	0	0	0	*	493	20	0	0	0	0	0	0	1	4	85
86	0	0	0	0	0	0	0	0	0	0	*	565	101	0	0	0	0	0	0	1	4	86
87	556	25	0	0	0	0	0	0	1	2	*	0	0	0	0	0	0	0	0	0	0	87
88	556	25	0	0	0	0	0	0	1	2	*	0	0	0	0	0	0	0	0	0	0	88
89	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	89

FIGURE 2 Bridge history listing.

OPBRIDGE Program

The Optimum Bridge Budget Forecasting and Allocation System (OPBRIDGE) was developed (*3-7*) to determine the optimum improvement action and time for each bridge in the network under various level of service goals and funding constraints over an analysis horizon. Through input screens (Figure 3), 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 4. 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 5, 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 zero-one (0-1) integer-linear programming formulation, as shown in Figure 6. 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

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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  T U   MAINTENANCE   REHABILITATION   REPLACEMENT   TOTAL BUDGET
----  ---  -------------- -------------- -------------- ---------------
1993   %           10.            40.            50.      200000000.
1994   $     20000000.      60000000.     120000000.      200000000.
1995   T             .              .              .      200000000.
1996   T             .              .              .      200000000.
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 3 OPBRIDGE user input screen layout.

horizon. A variety of user options are incorporated to select sets of bridges for analysis and to summarize results. Examples of detailed bridge-by-bridge outputs are presented in Table I for several bridges—shown are the current and predicted conditions, and economic evaluations of alternatives leading to future actions and costs.

Example tabular statewide results for a $200 million annual budget over the next 20 years are shown in Table II. The full budget is needed each year and the summary totals determined as optimal for maintenance, repair, rehabilitation and replacement are indicated. Table III shows the statewide summary of the predicted effect of this spending. 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 7, 8, and 9. If unlimited funds were somehow available, the economically justifiable backlog of almost $2 billion would be spent in the first year, resulting in an

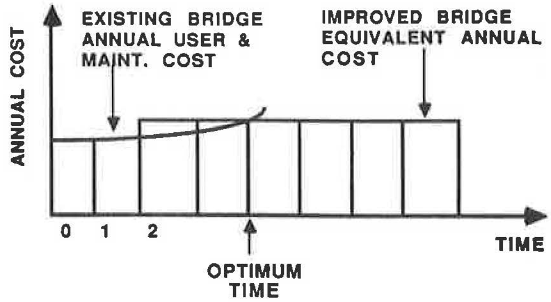

FIGURE 4 Optimum time to improve bridge.

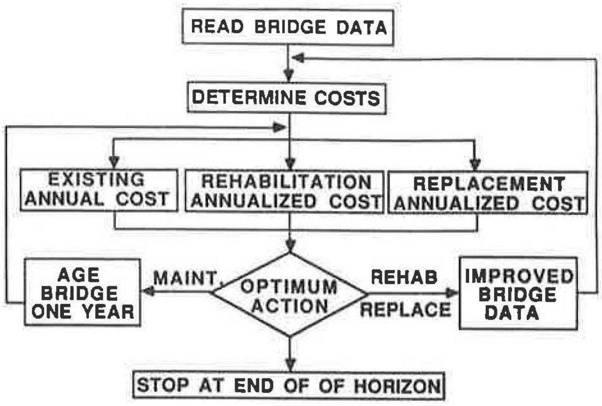

FIGURE 5 Selection of most economical individual action.

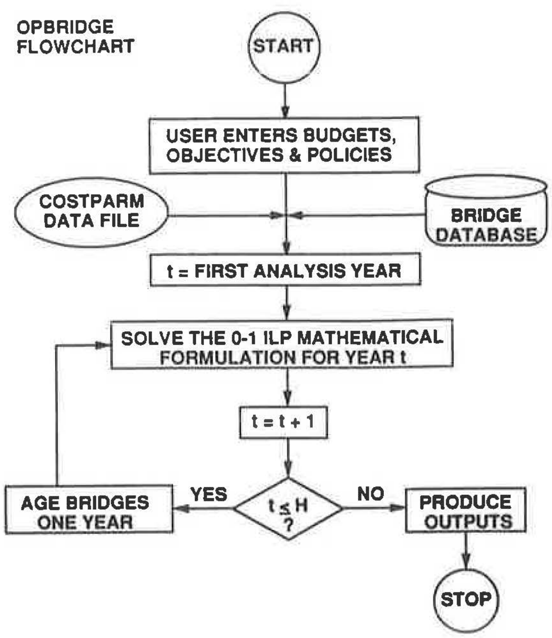

FIGURE 6 Optimum action selection under constraints.

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. 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 then has averaged about $80 million annually. Results predicted for 1993 at the $60 and $100 million budget levels are re-tabulated in Table IV 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 actions were programmed before availability of OPBRIDGE recommendations.

LOSAP Program

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. 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 Program

MAINTBRG (*2,9*) is focused at the problem of allocating funds to routine and preventive maintenance

TABLE I SAMPLE DETAILED BRIDGE-BY-BRIDGE ANALYSIS PREDICTIONS OF STATES AND ACTIONS

BRIDGE NO. COUNTY FACILITY	DK SP SB	SPTY SUFF DPA	FC SY FA	RL DL TT	CG UG LENG	YR	AGE	ADT	SV	WG	CDW	VCLU	DK	SP	SB	**** EQUIV. UNIFORM ANNUAL COST (EUAC) AND OPTIMUM ACTION ***** USER COST $00	--- MN#1 -- COST $	--- MN#1 -- PROVID $	--- REP. --- COST $000	--- REP. --- EUAC $00	--- MN#2 -- COST $00	--- MN#2 -- EUAC $00	--- REH. --- COST $00	--- REH. --- EUAC $00
91070	ES	M-BM	LO	3	16.0	93	26	6600	21	26	28.0	99.9	5	6	3	1344	622	0	362	211	491	2977	690	2506
WAKE	ST	6.0	S	9	14.0	93	26	6600	34	26	54.0	99.9	9	9	9				CONDITION RATINGS				ACTION=REP.	
SR1615	TM	6.0	SR	25	76																			
91071	TM	M-BM	LO	15	16.0	93	31	13200	34	46	28.0	15.3	6	6	6	154	2487	2487	746	445	0	0	5003	445
WAKE	ST	71.0	P	4	14.0	93	31	13200	34	46	28.0	15.3	6	6	6				ECONOMICAL COMPARISON				ACTION=MN#1	
NC55	ST	12.0	FS	37	233																			
						100	38	14808	34	46	28.0	15.3	4	5	5	172	7046	0	746	445	0	0	5468	611
						100	38	14808	34	46	54.0	15.3	9	9	9				CONDITION RATINGS				ACTION=REP.	
91073	TM	M-BM	LO	21	16.0	93	24	3800	34	44	54.0	16.4	6	7	7	0	3649	3649	811	478	0	0	2167	388
WAKE	ST	77.0	P	3	14.0	93	24	3800	34	44	54.0	16.4	6	7	7				ECONOMICAL COMPARISON				ACTION=MN#1	
SR1002	RC	0.0	SR	37	262																			
						2	33	4395	34	46	54.0	16.4	4	6	7	0	11627	0	811	484	1887	324	2774	344
						2	33	4395	34	46	54.0	16.4	7	6	6				CONDITION RATINGS				ACTION=MN#2	
91074	TM	M-BM	LO	20	16.0	93	31	1200	34	22	24.0	14.2	5	5	7	133	1954	1954	381	219	922	367	1118	340
WAKE	PS	47.0	P	4	14.0	93	31	1200	34	22	24.0	14.2	5	5	7				ECONOMICAL COMPARISON				ACTION=MN#1	
SR1134	ST	0.0	SR	37	208																			
						95	33	1242	34	22	24.0	14.2	4	5	7	137	3434	0	381	219	976	381	1173	354
						95	33	1242	34	22	28.0	15.0	9	9	9				CONDITION RATINGS				ACTION=REP.	

TABLE II STATEWIDE ACTIONS AND DISTRIBUTIONS AT $200 MILLION ANNUAL BUDGET LEVEL

YEAR	ROUTINE MAINT. COST	MAJOR MAINT. COST	MAJOR MAINT. NO.	REHABILITATIONS COST	REHABILITATIONS NO.	REPLACEMENTS COST	REPLACEMENTS NO.	TOTAL YEARLY BUDGET
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.

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 that 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 Report 223* (*10*) and *NCHRP Report 273* (*11*) for roadway feature maintenance. The method provides a mechanism for combining alternative levels of service on multiple considerations (e.g., safety, preservation of investment) and for multiple elements (e.g., joints, rails, decks). In the system developed, bridge maintenance elements are evaluated using a zero to nine (0-to-9) rating, as in the Table V example. The rating also

TABLE III PREDICTIONS OF STATEWIDE AVERAGE PERFORMANCE AT $200 MILLION ANNUAL BUDGET LEVEL

END OF YEAR	AVERAGE CONDITION DECK	SUPER	SUB.	NMACR	AVG. SV POSTING	NSVA	NSVD	NLOSA	NLOSD	USER COST $MILLIONS
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,

NOTE : USER COST IS IN FUTURE (THEN-CURRENT) DOLLARS.

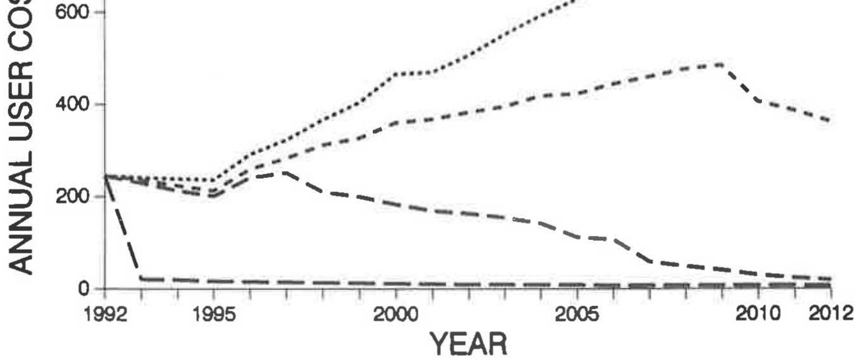

FIGURE 7 Predicted users Costs at various annual budgets.

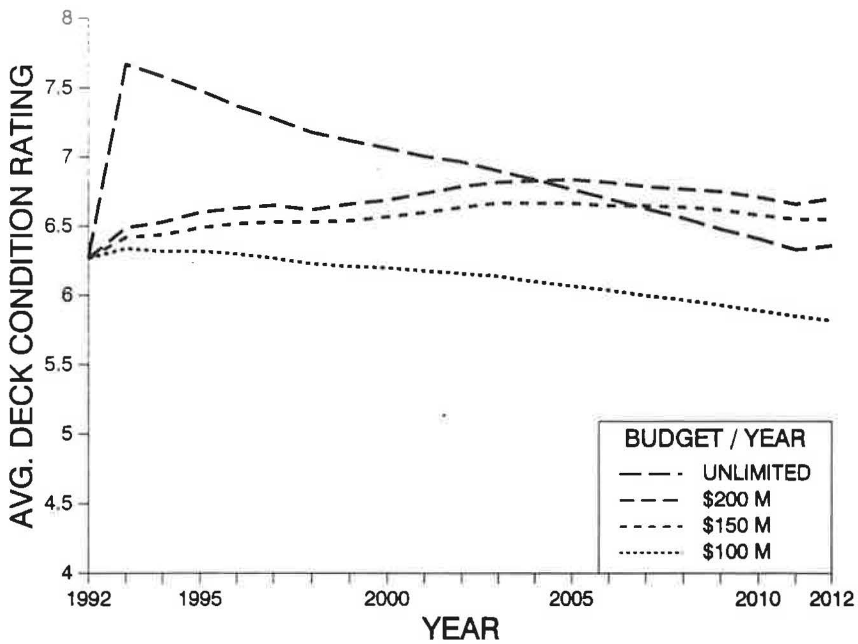

FIGURE 8 Predicted average deck condition rating at various annual budgets.

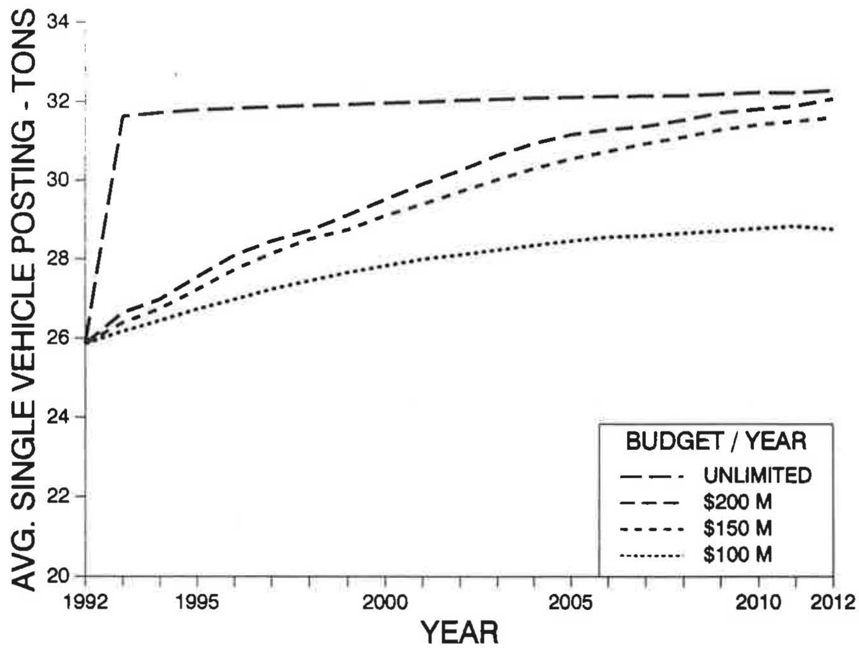

FIGURE 9 Predicted average single vehicle posting at various annual budgets.

corresponds to the maintenance levels-of-service where three to seven (3-to-7) are considered to be the normal range of the trigger options for maintenance activity and each has an expected normal improvement level (Table VI). 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 funding constraints (Table VII).

TABLE IV COMPARISON OF 1988 PREDICTIONS TO 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	

TABLE V CONDITIONS AND LEVELS-OF-SERVICE FOR STANDARD DECK EXPANSION JOINTS

Condition L-O-S	Description	Consideration
9	Condition Rating 9 (Excellent Condition)	
8	Condition Rating 8 (Very Good Condition)	
7	Condition Rating 7 (Good Condition) - Presence of dirt and debris in the joints (>50% length affected).	Investment Preservation
6	Condition Rating 6 (Satisfactory Condition) - Presence of dirt and debris in the joints. Joint seal cracked and loose. Minor leakage.	Investment Preservation
5	Condition Rating 5 (Fair Condition) - Presence of dirt and debris. Joint seal cracked, loose, or partially missing. Joint seal leaking.	Investment Preservation
4	Condition Rating 4 (Poor Condition) - Presence of dirt and debris. Joint seal partially missing throughout the seal. Joint seal leaking to a large degree.	Investment Preservation
3	Condition Rating 3 (Serious Condition) - Joint seal is effectively missing.	Investment Preservation
2	Condition Rating 2	
1	Condition Rating 1	
0	Condition Rating 0	

TABLE VI EXAMPLE AVERAGE ELEMENT CONDITION RATING AFTER MAINTENANCE

Element	Condition Rating		Description of Typical Desirable Maintenance Work at Each Condition Rating
	Before	After	
Standard Deck Expansion Joints Function Code 576	7	7	No maintenance activity
	6	7	Reseal expansion joint
	5	7	Reseal expansion joint
	4	8	Complete expansion joint replacement
	3	8	Complete expansion joint replacement

TABLE VII EXAMPLE ELEMENT MAINTENANCE L-O-S RECOMMENDED BY MAINTBRG FOR VARIOUS ANNUAL BUDGET LEVELS

Bridge Maintenance Element (partial list)	Estimated Current L-O-S	Possible Selected Levels-of-Service at Each Budget Level (millions)				
		$A	$B	$C	$D	$E
Timber Deck	4	3	3	4	4	5
Steel Plank Deck	4	3	5	6	7	7
Concrete Rail	4	3	4	5	5	5
Timber Rail	5	3	4	4	5	5
Steel Rail	5	3	5	4	5	6
Compression Seal Expansion Joint	4	3	4	6	7	7
Standard Deck Expansion Joint	4	3	5	6	7	7
Steel Superstructure	4	3	4	6	7	6
P/S Concrete Superstructure	5	4	4	5	5	5
Timber Superstructure	4	3	5	6	7	7
Timber Substructure	4	3	3	4	4	4
Concrete Pile Substructure	4	4	6	6	7	7
Steel Pile Substructure	4	4	5	6	7	7
Paint System (Structural Steel)	3	3	4	5	6	6

Support Modules

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

- Estimates of the future Federal Highway Administration (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. Often 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 Database, but some analyze data from the NCBI or other sources to produce the desired outputs.

SUMMARY

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:

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

ACKNOWLEDGMENTS

The authors express their appreciation to the graduate research assistants at North Carolina State University and the staff members of the North Carolina Department of Transportation who have made contributions to the research and development resulting in the North Carolina Bridge Management System. The research at North Carolina State University was conducted in a series of projects supported by NCDOT and sometimes with the joint support of the FHWA. This support is gratefully acknowledged.

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