BRIDGIT BRIDGE MANAGEMENT SYSTEM SOFTWARE

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ABSTRACT

BRIDGIT is a micro-computer based bridge management system (BMS) being developed under NCHRP Project 12-28(2)A to meet the operational needs of state and local DOT bridge authorities as well as requirements being proposed by the Federal Highway Administration (FHWA).

The Phase I portion of the work has resulted in a software program named BRIDGIT. The system includes several modules that permit bridge agencies to store and modify inventory, inspection and maintenance information for bridges and culverts. An unlimited number of inventory data items can be created by the agency if desired. BRIDGIT also can produce a multi-period optimization analysis of the network or any subset of it to estimate and prioritize bridge improvement needs for both the constrained and unconstrained budget cases. Both costs to the agency as well as to users are included in the evaluation of feasible maintenance, rehabilitation and replacement options. The analysis also considers level of service goals for removing functional deficiencies due to geometric and load capacity deficiencies.

BRIDGIT provides routines to enable agencies to transfer information into the system from databases stored in other external systems. In addition, the system can automatically convert condition information uploaded from other systems, such as the NBIS (National Bridge Inventory System), to the condition rating format used in BRIDGIT.

Phase I of this project began in January 1992 and was completed in July of 1993. A second phase is in progress to develop some enhancements to the system and is scheduled for completion in early 1994.

PROJECT BACKGROUND

In 1985, NCHRP Project 12-28(2), Bridge Management Systems was initiated with the objective of developing a model form of effective bridge management at the network level. The specific project objectives were as follows:

- Develop methods to assess present and future needs of existing bridges;
- Establish guidelines for determining cost-effective alternatives both with and without financial constraints;
- Develop priority treatment of needs using generalized work activities (from posting and preventive maintenance through replacement);
- Provide flexibility to accommodate a variety of policy approaches;
- Provide flexibility to accommodate future expansion to the project level; and,
- Establish methods to ascertain standards of data reliability.

The project resulted in the identification of various modular elements required in a model bridge management system as well as the development of some of the engineering concepts necessary to operate such a system. The final phase of the project involved the development of an IBM PC-based computer program. Later testing and evaluation of the software by four state transportation departments identified several enhancements to the system which needed to be addressed before it could be accepted for use by state agencies.

Several research efforts in the areas of optimization, economic analysis, application of user costs, levels of service and deterioration models have been accomplished since the publishing of *NCHRP Report 300*,"Bridge Management Systems" and the development of the model BMS software. As a result, there was a need to review this information and to evaluate the possibility of incorporating applicable results into the BMS program. In addition, the initial system was not developed with any consideration for anticipated future requirements to be imposed by the Federal Highway Administration as part of its aim towards implementing Bridge Management Systems in all state transportation agencies by the year 1995.

The principal objectives of the current NCHRP Project 12-28(2)A, which began in January 1992, was to develop, validate and document a fully operational micro-computer based bridge management system software package that could be readily used by transportation agencies. The system is based on the conceptual design presented in *NCHRP Report 300* as well as the recommendations identified in the "Guidelines for Bridge Management Systems" which resulted from NCHRP Project 20-7, Task 46.

HARDWARE REQUIREMENTS

BRIDGIT is designed to operate as a single user system although a multi-user version is being developed as part of the Phase II portion of the project. It is assumed that a Local Area Network (LAN) will be used for the operating environment of the multi-user system.

The following is the recommended hardware configurations for operating BRIDGIT. The minimum configuration shown is designed to be a least cost system for smaller bridge agencies. The optimal configuration will provide better system performance as well as the capability to handle large bridge populations.

- Minimum Configuration
  - 80386 (Type DX) or 80386 (Type SX) based IBM PC or compatible
  - 3 MB RAM
  - 80 MB Hard Drive
  - 3½ inch Floppy Disk Drive, 1.44 MB
  - EGA or Hercules monochrome graphics card
  - EGA or Monochrome monitor
  - Keyboard and mouse
  - Dot matrix printer (for hard copy output)
  - DOS 5.0 or better
- Optimal Configuration
  - 80486 (Type SX) or 80486 (Type DX) based IBM PC or compatible
  - 8 MB RAM Memory to 32 MB RAM Memory
  - 80487 math co-processor (for 80486 Type SX CPU only)
  - Minimum 200 MB Hard Drive
  - 3½ inch Floppy Disk Drive, 1.44 MB
  - VGA or SVGA color graphics card
  - VGA or SVGA color monitor
  - Keyboard and mouse
  - Laser printer (for hard copy output)
  - DOS 5.0 or better

Hard Disk Capacity

The performance of a hard disk drive is determined by its average seek time and data transfer rate. Seek time, measured in milliseconds (MS), is the average time that a drive takes to manoeuvre the disk reading head to the start of the data block to be read. This seek time should be as brief as possible, preferably not exceeding 16 MS. The data transfer rate, measured in megabytes (MB) per second, should be higher for systems with large bridge populations; in the range of 1.2 MB/sec on average.

The minimum recommended hard disk configuration is a storage capacity of 80 MB for a bridge inventory not exceeding 2000 bridges. A maximum configuration would require a 300 MB disk for a bridge inventory not exceeding 10,000.

Random Access Memory

BRIDGIT is designed to utilize any available "extended" memory, resulting in increased data processing speed. Eight to 32 megabytes of Random Access Memory (RAM) should be incorporated into the BRIDGIT computer hardware. Although a math co-processor improves the speed of most optimization analysis routines, in most cases additional RAM memory has a greater impact on improving overall program performance and would therefore be a better investment choice.

SOFTWARE INCORPORATED IN BRIDGIT

The following software packages were used in the development of the BRIDGIT program and have been incorporated in the compiled source code. Therefore, purchase of these packages is not necessary to operate BRIDGIT unless it is desirable to modify the source code in the future:

Database Management Software (DBMS) - FoxPro

FoxPro 2.5 (Copyright © Microsoft Corporation) is the primary software language used to develop BRIDGIT. It is a fully relational fourth generation database language. Upcoming versions of FoxPro will include capabilities to operate in a variety of other operating systems such as Windows, Unix and Apple Macintosh.

Text Report Generation Software - Foxfire

To permit users to create and generate reports in a user friendly manner, Foxfire 1.02 (Copyright © Micromega Systems Inc.) was incorporated into BRIDGIT. This package enables users to define simple as well as complex filtering expressions to produce customized reports.

Graphics Development Software - dGE Graphics

To provide visual representation of database information, BRIDGIT provides several on-screen as well as hard copy graphs. To accomplish this, a graphics applications package called dGE Graphics 5.0 (Copyright © Bits per Second & Pinnacle Publishing) was used. This package produces user-friendly and fast generating color graphics capable of outputting to a variety of dot matrix, laserjet and ink jet printers.

DESCRIPTION OF BRIDGIT SYSTEM FEATURES

This section provides a brief overview of BRIDGIT and details some of the key features included in the software. The main menu of BRIDGIT displays a pull-down menu which provides access to the following eight modules:

- System
- Inventory
- Inspection
- MR&R (Maintenance, Rehabilitation & Replacement)
- Analysis
- Models
- Other
- Reports

Navigation through the system is accomplished either through keyboard or mouse controlled functions.

Module 1: System

The System module contains routines to permit users to configure the system interface (screen colors, sizes, video modes) to suit personal preferences. It is also possible to use on-screen tools such as a calculator or calendar/diary.

Module 2: Inventory

The main menu of the Inventory module is shown in Figure 1. BRIDGIT provides a very flexible inventory database which allows agencies to create an unlimited number of data items to be recorded for each bridge or crossing in the network, as well as for individual spans, piers, abutments, joints and bearings of a bridge. For example, it may be desirable to keep track of the height, width and thickness of each pier of a bridge. This can be accomplished by creating three data items in the PIERS database. To track this information for each bridge pier, users must identify all the pier locations associated with a particular bridge (i.e., Pier 1, Pier 2, East Pier, West Pier, Temporary Pier in Span 1). BRIDGIT is supplied with a set of data items common to most agencies, including all FHWA mandated National Bridge Inventory (NBI) items.

The Bridge Definition Routine is used to define the physical make-up of each bridge or crossing in the network. Bridges may be divided into any number of *segments* permitting condition information to be reported for selective parts of a bridge. The various elements and protection systems which are comprised in each segment must also be defined. Bridge elements are categorized by deck, superstructure, pier, abutment, railing, joint and bearing groups. Protection systems are categorized by paints and overlays.

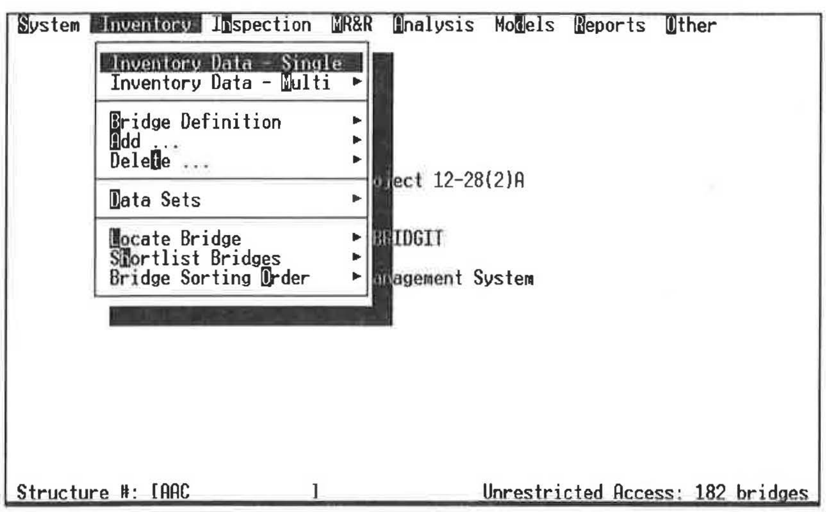

FIGURE 1 INVENTORY module main menu.

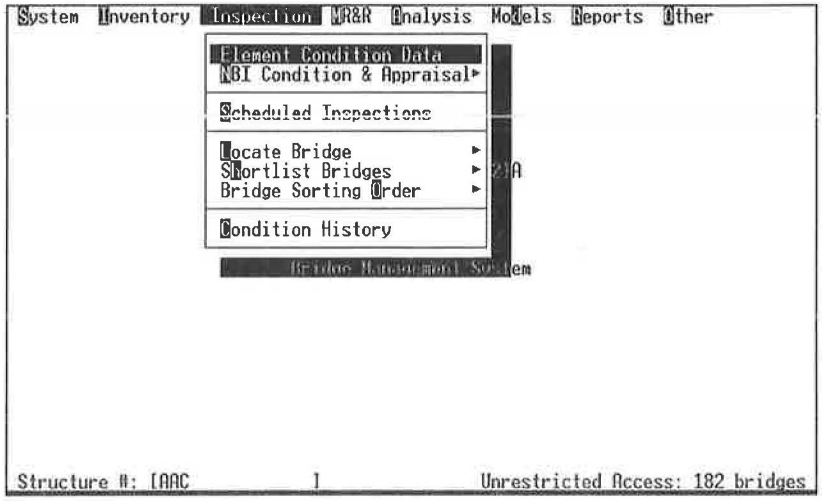

FIGURE 2 INSPECTION module main menu.

The Inventory Module also includes a routine for creating and selecting subsets (or shortlists) of the bridge network. This is useful for viewing or editing only selective inventory and inspection data as well as for performing an optimization analysis.

Module 3: Inspection

The main menu of the Inspection module is shown in Figure 2. This module permits agencies to view or edit inspection information for each bridge element or protection system as well as to view summarized historical data for the overall bridge population. Users are also able to store information concerning future routine and special inspections for a bridge.

BRIDGIT incorporates the same type of condition rating system used in the FHWA sponsored Pontis software (*1, 2*) to identify the nature and extent of deterioration of all bridge elements and protection systems in the network. Condition information to be input includes the quantities of element reported in each of the condition states defined for that element. Condition states for an element or protection system are described by types of physical as well as functional performance defects. Users may enter condition state quantity data by percentage of the total element quantity or by units of quantity (i.e., linear feet, square feet).

BRIDGIT also permits users to break down the reported condition state quantities into *portions*. For example, the deck element and protection system in the "East Approach" segment can be reported for groups of spans (i.e., Span 1, Spans 2 to 6). In this way, condition deficiencies in specific portions of a bridge segment can be identified.

Module 4: MR&R (Maintenance, Rehabilitation & Replacement)

The MR&R module provides the capability for agencies to plan, schedule and monitor multi-year work programs. Agencies will also be able to track historic work actions and related costs for individual bridges in the network. It is not intended that this module be used as a maintenance management system to report labor and material costs, however, it is possible to transfer information available in such systems into BRIDGIT.

Routines have been provided to:

- schedule and track MR&R Activities carried out by in-house as well as contracted forces;
- record a historical log of MR&R activities completed for each bridge in the network;
- provide a Project Cost Estimate routine to allow users to create detailed cost estimates for MR&R or improvement projects; and,
- maintain a standard list of MR&R Activities to be tracked.

Module 5: Analysis

The main menu of the Analysis module is shown in Figure 3. This is the most sophisticated module in BRIDGIT and draws on information stored within the Inventory module, Inspection module and Models module to produce optimized work plans for all or part of the bridge population, over a defined analysis horizon. Users may define the following parameters to be used in the optimization analysis:

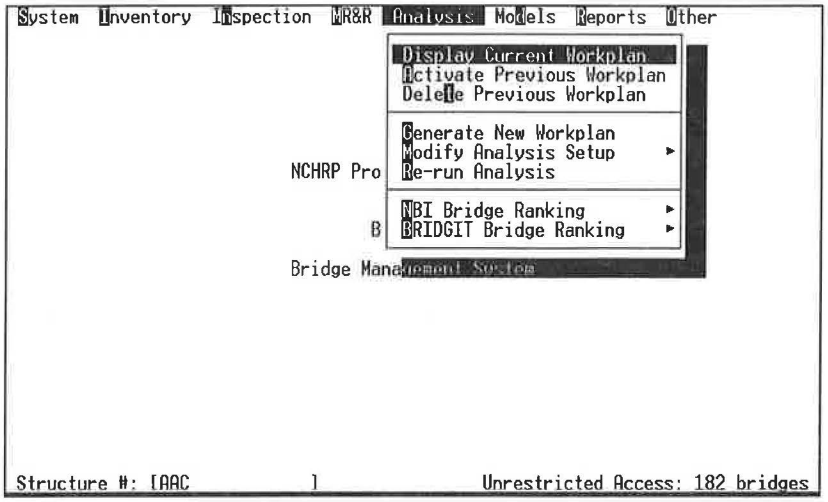

FIGURE 3 ANALYSIS module main menu.

• Level of Service Goals. In addition to evaluating bridge improvement actions due to condition related deficiencies, the optimization analysis also considers improvement actions to remove functional performance deficiencies. To accomplish the latter, agencies must define acceptable and desirable level of service goals for bridge deck width, vertical clearance and load capacity. In addition, the programming horizon (i.e., Immediately, 10 year, 20 year or "Only if Economical") in which these goals are to be satisfied must be input. BRIDGIT will select appropriate rehabilitation actions to remove all functional deficiencies within the defined time horizon providing sufficient funds have been budgeted.

• Available Annual Budgets. Users are required to identify the budgets available for each year of the analysis horizon of 20 years through an on-screen table. It is possible to define either the Total Annual Budget or multiple annual budgets portioned into Maintenance, Rehabilitation and Replacement amounts.

The optimization model performs an analysis in two steps. First, different life cycle activity profiles are developed for each bridge in the network, or selected shortlist, to estimate the present and future costs of various improvement options. Second, an optimization analysis is performed to prioritize needs and to select the most cost effective improvement options satisfying the defined constrained or unconstrained budget cases as well as the level of service goals.

Module 6: Models

The main menu of the Models module is shown in Figure 4. This module permits users to view or modify the various models and tables to be used in the optimization analysis. This enables a bridge agency to customize BRIDGIT to suit the uniqueness of its own bridge network and to identify its Maintenance, Rehabilitation and Replacement (MR&R) and Functional Improvement policies.

The following routines are included in the Models module:

Element & Protection System Models Routine

BRIDGIT allows an agency to create an unlimited number of bridge elements and protection systems. Elements are used to define the physical make-up of each bridge in the network and are categorized into seven groups:

- Decks
- Joints
- Railings
- Superstructure
- Bearings
- Piers
- Abutments

In addition, various types of paint and overlay protection systems may also be defined. The reason for distinguishing protection systems from elements is that the maintenance and replacement of protection systems are prioritized differently from elements. Protection systems do not influence the structural performance of a bridge.

BRIDGIT has been initially loaded with a set of 109 elements, 9 paint protection systems and 5 overlay

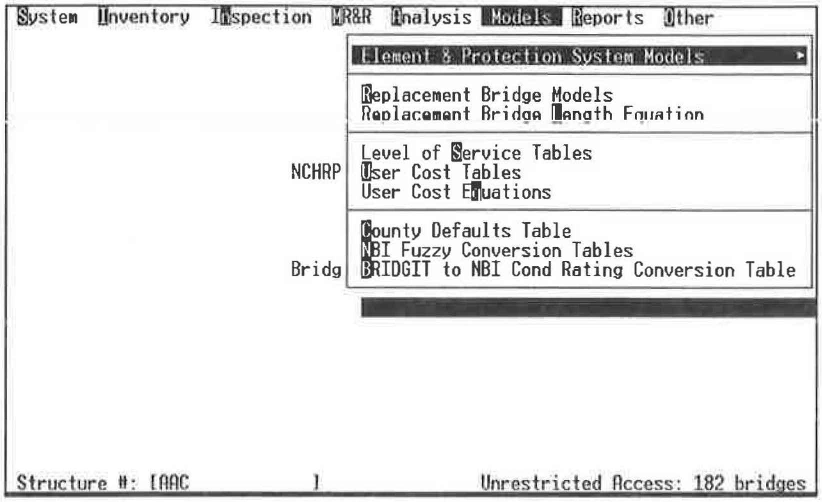

FIGURE 4 MODELS module main menu.

protection systems. Using these combinations, all of the 158 elements used in the FHWA sponsored Pontis software may be represented. While it will not be possible to delete any of these core system models, agencies can also create an unlimited number of additional models if desired.

The following information is required to define an element or protection system model:

- Identification & Units: To create an element or protection system model, users must provide a model name, identification number, the number of possible condition states and the units of quantity (i.e., linear feet of girder, square feet of deck, etc.) to be reported during inspection. In addition, a description of the element must be provided as well as a description of each condition state.
- Condition State Actions, Costs, Thresholds & A/M/U Factors: For each condition state, an improvement action and associated unit cost may be defined. (NOTE: BRIDGIT automatically considers the replacement and "Do-Nothing" alternatives for an element or protection system, therefore it is not necessary to define these actions). It is assumed that an improvement action will restore a condition state quantity to a State 1 level. BRIDGIT will use this information to calculate the costs associated with maintenance or rehabilitation of the element based on the quantities of element reported in each condition state during inspection. In addition, a Threshold Value must be defined to represent the maximum permissible quantity (in percentage) of an element which may be present in its worst condition state before a rehabilitation action should be triggered. This value will be used by BRIDGIT to determine the timing of certain condition improvement actions for an element or protection system.

The A/M/U Factor is an indicator which identifies whether a condition state is considered to be Acceptable, Marginally acceptable or Unacceptable as defined by the agency. For example, Condition State 1 usually represents a condition which would not require any remedial actions and is always considered to be acceptable. Condition State 2 may represent only a small amount of deterioration and would involve only preventive maintenance actions. It would also be considered acceptable. Condition State 3 may represent significant deterioration but with no loss of structural capacity or performance. It would be considered Marginally acceptable. In other words improvement actions will be performed only if sufficient funds are available. Condition state 4 may represent significant deterioration with loss of structural capacity or performance. This state would no doubt be considered unacceptable and would require rehabilitation action if the reported quantity of element exceeds the Threshold Value defined for the element.

- Maintenance Actions & Costs: Agencies may define preventive maintenance actions and costs associated with each condition state of an element or protection system. This information is used to calculate the annual routine maintenance costs for each bridge in the network.
- Element Deterioration Models: For each element and protection system, a deterioration model must be defined. It is necessary to specify the percentage quantity of element that will be present in each lower condition state (or worse) after a specified number of

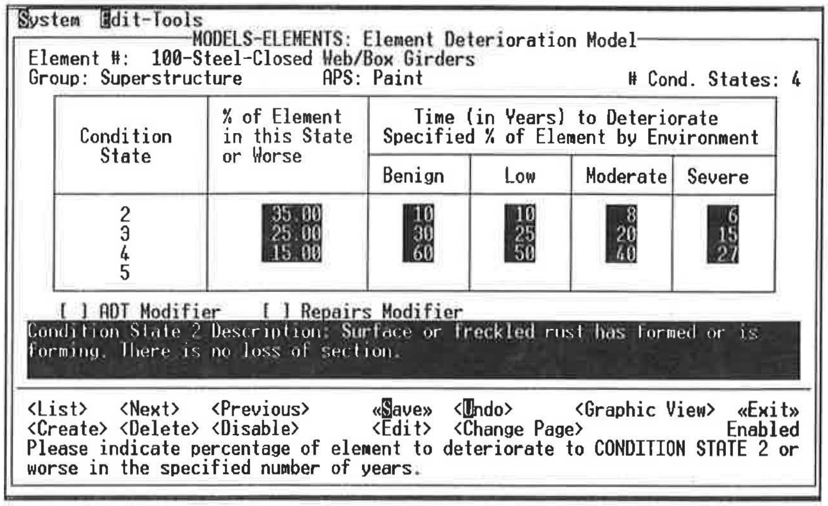

FIGURE 5 Deterioration model: steel open girders/stringers.

years. Figure 5 shows a sample deterioration model for a Steel Open Girders/Stringers element. For a moderate environment, 25% of the total quantity of element in an average bridge is expected to be in Condition State 3 or worse after 20 years. Stated another way, it will take 20 years for 25% of the element to deteriorate from Condition State 1 to Condition State 3 or worse. This type of information will be required for each condition state as well as for the four possible environment locations (Benign, Low, Moderate, Severe) that the element may be affected by.

For deck elements and overlay protection systems, it is also necessary to specify a factor to represent the increase in the rate of deterioration of an element due to the effects of average daily traffic and due to previous repairs. In the latter case, the development of life cycle costs for a bridge, BRIDGIT uses this factor to accelerate the deterioration of any deck elements or overlays that are reported to have been previously repaired.

The information defined for the model is used to calculate the quantity of element which will transition from a particular condition state to the next lower one, in any year. This is accomplished by employing the Markov Chain Process to calculate the transitional rates for each condition state of an element. The following assumptions have been made to adapt the Markovian model for application to BRIDGIT's bridge element deterioration models.

- Deterioration between states is a single step function. Therefore a quantity of element can only move to the next lower condition state in any year (i.e. state 1 to 2, 2 to 3, etc.).

- The transitional rate is not time dependent. Thus, the possibility of moving to a lower condition state is not a function of how long it has been in its current state.

The purpose of calculating the transitional rates is to project the quantities of a bridge element which will move to a lower condition state in a defined time horizon. This information is essential for estimating the deterioration of an element or protection system over time and the cost effectiveness of different MR&R improvement actions. Because little information is currently available to assist agencies in initially defining deterioration model parameters, BRIDGIT will be providing a routine for automatically updating the models from an analysis of historical inspection data. This feature is being developed as part of the Phase II portion of this project.

Replacement Bridge Models Routine

This routine permits the bridge agency to define standard Replacement Bridge models for different route classifications and for different ranges of span lengths. These models are used to develop the Replacement Life Cycle Activity Profiles (LCAPs) for each bridge in the network during the optimization analysis.

Level of Service Tables Routine

This routine permits agencies to view or modify the acceptable and desirable Level of Service goals for each of the parameters listed below. This information is recorded in a tabular format, classified by type of route.

- Load Capacity
- Vertical Clearance
- Bridge Clear Deck Width
- Number of Lanes

User Cost Tables Routine

This routine accesses and allows modification of the following information associated with the calculation of user costs for each MR&R alternative to be considered during the optimization analysis:

- Rate of increase of Average Daily Traffic (ADT) for different route classifications;
- Percent of vehicles detoured for different levels of bridge posting;
- Percent of dual axle trucks and truck-tractor semi trailers detoured for different ranges of vertical clearance;
- Estimated ADT for different road classifications;
- Estimated percent truck-traffic for different ADT's;
- Rate of load capacity reduction for different superstructure types in tons per year (assuming only routine maintenance is carried out);
- Unit accident costs;and,
- Vehicle operating cost tables (in $/mile) for vehicles weighing three tons or less, and vehicles weighing the maximum permissible vehicle load.

Also, the User Costs routine permits users to view the algorithms which are used by BRIDGIT to calculate accident costs and detour costs. The bridge agency can directly modify the constant values used in these formulas through tables. Modification of the formulas themselves may be accomplished by modifying the FoxPro source code.

Fuzzy Conversion Tables Routine

The Models Module also includes a routine containing Fuzzy Conversion Tables to be used to perform the following condition data conversions:

- Conversion of NBI condition ratings to BRIDGIT element condition states and estimated quantities;
- Conversion of any Agency defined condition ratings to BRIDGIT element condition states and estimated quantities; and,
- Conversion of BRIDGIT element condition states and reported quantities to NBI ratings for decks, superstructures, substructures and culverts.

Module 7: OTHER

This module is used to transfer information into and out of BRIDGIT from other systems as well as to provide tools for overall system administration. The following routines are included:

Import Data Routine

The Import Data routine is used to transfer information to system databases from the following external sources:

- NBIS ASCII File: This routine uploads data from an NBI ASCII file stored on a floppy disk, tape or a hard drive directory. It will not be possible to overwrite any existing information which has already been input into BRIDGIT. Therefore, this feature is intended to be used only to initially load data into the BMS.
- Other ASCII Files: This routine uploads data from a properly prepared ASCII file. It will be necessary for the agency to prepare the ASCII files with upload data in a prescribed ASCII file format. It may be desirable to upload to the BMS databases for the following reasons:
  - data is to be transferred from another existing bridge management system or from other information systems;
  - inspection results have been entered into an external data collection device or into a remote computer station and must be uploaded into BRIDGIT.

Export Data Routine

The Export Data routine is used to transfer information from BRIDGIT's databases to the following external sources:

- Create System Backup: This routine produces a backup of current BMS databases onto tape or hard disk directory, for data security or for future reference. Data files will be backed up in compressed format to minimize disk storage requirements.
- NBI ASCII File: This routine creates an ASCII file in the 400 character NBIS format specified by the FHWA, for any subset of the bridge network.
- Other ASCII Files: This routine creates an ASCII file for any set of BRIDGIT data items. This can be used to transfer data into other information systems used by the agency.

System Administration Routine

All the system administration functions necessary for managing BRIDGIT are found in the System Management routine. For security reasons, this routine is accessible only to the System Manager(s) who will be responsible for executing the following sub-routines:

- System Access: The access privileges of all system users is controlled by the System Access routine and are stored in an encrypted database. Through this sub-routine it is possible to assign a subset of the bridge network to individual users as well as to restrict access to specific BRIDGIT modules or routines.
- Database Maintenance: This sub-routine permits agencies to carry out maintenance of the hard disk to clean up data items marked for deletion and condense database file sizes.
- Data Validation : When data will be uploaded from external sources, important data irregularities may be present. The Data Integrity sub-routine cross checks all system databases to reconcile data contradictions that may exist in these databases after data has been imported into the system.
- Agency Setup: This sub-routine permits agencies to define several system setup parameters. These include a list of names and numbers of counties and districts associated with the agency as well as other items such as name of the agency, the date format to be used by the system, etc.

NBI Condition Data Transfer Routine

This routine allows an agency to convert NBI Condition Rating data items for superstructure, substructure, deck and culvert elements into the BRIDGIT condition rating system (condition states and quantities). This feature will facilitate initially producing condition information in the format required by BRIDGIT.

Module 8: REPORTS

BRIDGIT is capable of producing on-screen, ASCII and hardcopy output reports in either text or graphical format. Several pre-formatted reports are available for outputting inventory, condition, MR&R, models and analysis information. In addition a routine has been provided for created reports in a format which can be easily customized by the user.

BRIDGIT OPTIMIZATION ANALYSIS

The BRIDGIT optimization strategy is largely based on the methodology developed by North Carolina State University (*3,4,5*) for application to the needs of North Carolina Department of Transportation (NCDOT). As part of this effort, North Carolina State University has developed an analysis system named Optimum Bridge Budget Forecasting and Allocation System (OPBRIDGE) to support the bridge maintenance and improvement decision making process. The primary objectives of this software are to:

- Determine optimum use of funds at the bridge level considering both user costs and agency costs in life-cycle cost analyses;
- Predict optimum future funding needs;
- Determine optimum actions and uses of constrained funds; and,
- Predict performance of the bridge system under constrained funding.

OPBRIDGE considers Agency costs and User costs to determine the optimum improvement action and timing for each bridge in a network under various level-of-service goals and funding constraints over an analysis horizon. The optimization objective is to maximize reductions in equivalent uniform annual costs to the ultimate owner, the user-taxpayer.

At the end of each year of the analysis horizon, OPBRIDGE ages bridges one year and predicts condition ratings, Average Daily Traffic. etc. This allows the system to do the analysis for the following year. OPBRIDGE can produce detailed bridge-by-bridge output showing recommended current and future actions and tabular and graphical outputs showing future performance level of the bridge system over the horizon. Actions can be forced to assure that bridges are maintained to a minimum element condition level and/or to assure inclusion of bridges which do not meet user level-of-service needs. The optimization is at the bridge level for the entire bridge network or some designated subset of bridges.

The costing models used in BRIDGIT to develop LCAPs for different bridge improvement options incorporates several of the principals used in OPBRIDGE, however several modifications and enhancements were required to accommodate differences between the two systems. For example, there are seven groups of bridge elements and two groups of protection systems which must be considered in

BRIDGIT. OPBRIDGE only considers deck, superstructure and substructure groups. In addition, the condition rating system used in BRIDGIT requires that inspectors report the quantities of element or protection system in each condition state. The rating system used in OPBRIDGE is based on the NBI 0 to 9 scale.

The optimization model developed for BRIDGIT employs the same general optimization objectives as in OPBRIDGE but is unique in that it performs a multi-year analysis rather than a succession of single year analysis. This permits BRIDGIT to consider the option of delaying improvement actions to a later year where it would be more cost-effective. Therefore, if unlimited budgets are available, it is possible to determine the optimum period in which selected improvement alternatives should be scheduled rather than perform all actions in the first year.

Development of Life Cycle Activity Profiles

As part of the optimization analysis, BRIDGIT compares the cost-effectiveness of different improvement options between bridges by determining the present value of life cycle costs and benefits for each option. Costs in any year of the life cycle are calculated from the estimated user costs, annual routine maintenance costs as well as the costs of any bridge repair or improvement actions. The following sections describes each of these cost components in greater detail.

User Costs

BRIDGIT calculates user costs in each year of the LCAP based on projected future average daily traffic volumes to produce a total present value user cost. Two types of costs are incurred by users due to functional deficiencies of a bridge; accident costs and detour costs. Bridges having narrow deck width or low vertical clearance have a higher occurrence of accidents than bridges without these deficiencies. Bridges with low vertical clearance or insufficient load capacity will force a certain volume of truck traffic to be detoured to alternate routes, resulting in increased vehicle operating costs. As the volume of traffic increases, the number of accidents or detours will also increase.

Annual Routine Maintenance Costs

BRIDGIT will estimate the Total Present Value Cost associated with routine maintenance of a bridge over its service life. To calculate Routine Maintenance Costs for a bridge in any year of an LCAP, BRIDGIT will multiply the quantities of element or protection system reported in each condition state by the unit maintenance costs defined in the element or protection system model.

Bridge Repair & Improvement Costs

For any bridge, the initial costs of repair actions are determined by multiplying the unit improvement costs defined in the element and protection system models by the actual condition state quantities. The costs for bridge widening or replacement alternatives are calculated from information provided in the Bridge Replacement Models defined by the agency. To estimate bridge raising costs, BRIDGIT applies a user defined unit for each foot of vertical deficiency.

The various alternatives to be considered for economic analysis will be selected from knowledge based decision rules which will examine overall improvement strategies over the life-cycle of a bridge. BRIDGIT considers four possible improvement options for a bridge.

- Minor Repair to all bridge elements
- Major Repair to all bridge elements
- Rehabilitation (Major Repair and removal of all Functional Deficiencies)
- Replacement

For each of the above improvement alternatives, BRIDGIT calculates a Life Cycle Activity Profile for every bridge in the network or selected shortlist. The development of the LCAP's includes the costs associated with immediate as well as future improvement actions. BRIDGIT will project the future condition of elements and protection systems to calculate future improvement costs. BRIDGIT also projects future average daily traffic levels to determine future user costs. The LCAP models select feasible MR&R and functional improvement actions and determine the appropriate timing of such actions over the life cycle of each bridge.

As part of the optimization analysis, BRIDGIT compares the present value of costs associated with each of the feasible LCAP alternatives with the present value cost of the "Do-Nothing" LCAP. To develop this base case, it is assumed that no bridge improvement actions will be performed to the bridge during the optimization analysis horizon of 20 years. Two different scenarios can result from this assumption:

- Case 1 - Bridge Becomes Deficient During the Analysis Horizon: If at the beginning of the planning analysis horizon, a bridge has at least one key bridge element in deficient condition, the bridge could become totally unusable during the analysis horizon due to insufficient load capacity (i.e. load capacity is less than 3 tons). If this occurs, routine maintenance costs become zero and user costs due to vehicle detours become significant (depending on ADT and % truck traffic), thereby making the Do-Nothing Alternative undesirable.

At the end of the 20 year analysis horizon, the bridge will require either a major rehabilitation or replacement when either a Replacement Bridge LCAP or a Rehabilitation LCAP will be applied.

- Case 2 - Bridge Does Not Become Deficient During the Analysis Horizon: If at the end of the analysis horizon some key bridge element quantities are in either marginal or acceptable condition states, a Minor or Major Repair LCAP will be initiated.

BRIDGIT Optimization Analysis Model

The BRIDGIT Optimization Analysis Model will select optimal MR&R and functional performance improvement actions for each bridge in the network over a multi-year analysis horizon. In addition, the system considers both constrained and unconstrained budget cases. For the constrained budget case, users are also able to define budgets for maintenance, rehabilitation and replacement portions in any year of the analysis horizon.

BRIDGIT performs an optimization analysis over a horizon of 20 years. To minimize computational effort, this horizon is divided into 5 analysis periods; years 1 & 2, 3 to 5, 6 to 10, 11 to 15 and 16 to 20. At a representative year for each period, all bridges in the network are aged and the condition of bridge elements determined. BRIDGIT will evaluate the available annual budgets defined for that period by the user. If insufficient funds have been provided to match the selected MR&R needs, BRIDGIT will evaluate other lower cost MR&R alternatives using an incremental benefit/cost approach. Those with the highest Cost Effectiveness Indexes (CEI) are iteratively selected until the budget constraints are satisfied. Once optimization has been completed for a specific analysis period, BRIDGIT distributes the selected actions (in order of CEI) to each year in the period to expend the annual budgets previously specified by the user.

If the budget is unlimited, BRIDGIT selects the bridge alternatives with the highest CEI's, and allocates them to the period of the analysis horizon in which they should optimally be implemented.

The Cost Effectiveness Index is the rate of internal return between two alternatives. For each bridge improvement alternative being considered, BRIDGIT compares the Present Value Cost of agency and user life cycle costs, with the Present Value Cost of the Do-Nothing Alternative.

The calculation of the CEI for bridge i and improvement alternative j can be expressed as:

$$CEI(i,j) = \frac{PVDN(i) - PV(i,p,j) + IC(i,p,j)/(1+RRRR)^t}{IC(i,p,j)/(1+RRRR)^t}$$

where:

CEI(i,p,j)	=	Cost Effectiveness Index of alternative j in period p for bridge i;
PVDN(i)	=	Present Value Cost of the Do-Nothing alternative for bridge i;
PV(i,p,j)	=	Present Value Cost of improvement alternative j for bridge i calculated in period p;
RRRR	=	Real Required Rate of Return;
IC(i,p,j)	=	Initial Cost of alternative j in period p for bridge i incurred at the beginning of the representative year for period p;

For each bridge in the network, BRIDGIT determines the CEI's of all feasible alternatives to be considered in each period of the optimization analysis horizon. The alternative with the highest CEI over the analysis horizon is the optimal choice for that bridge.

The approach used in BRIDGIT regards the year when an improvement alternative is being considered as an additional variable within the optimization analysis and therefore evaluates the entire analysis horizon of 20 years as if it were one period. This permits alternatives in one analysis period to compete with others in a different period.

CONCLUSION

The Phase I portion of this NCHRP project was completed in July 1993. Work is continuing to develop enhancements to the system as part of a second project phase. Some of these enhancements will included expanding the system to permit operation in a multi-user environment with full network capabilities as well as a routine for automatically updating element deterioration models based on an analysis of historical inspection data. In addition, BRIDGIT will provide routines for developing bridge work plans and detailed cost estimates, permitting agencies to schedule and monitor MR&R work carried out by in-house forces or by contract.

A key objective of this project has been to develop a BMS which meets all of the requirements proposed by the FHWA in their rulemaking for bridge management systems. It is the intention of NCHRP to have the BRIDGIT system endorsed by the FHWA as a product that fully satisfies these requirements.

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