Enhancements of the Project Selection Module of the Indiana Bridge Management System

KUMARES C. SINHA
YONG ZHANG
Purdue University
ROBERT E. WOODS
Indiana Department of Transportation

ABSTRACT

The Indiana Bridge Management System (IBMS) was developed to organize, present and analyze information related to the maintenance and improvement of highway bridges. To recommend improvement alternatives, prepare cost estimates and optimize allocation of available funding, a large database containing information from bridge, road, and traffic inventories must be presented in an accessible and descriptive form. The IBMS has been in development for over a decade and the present paper discusses some of the enhancements made in the project selection module, including the revision of the agency cost model, the incorporation of a user cost model, and the updating of bridge condition transition probabilities. A graphical user interface was also incorporated for the IBMS to make interaction with data quick, easy and efficient. Whether viewing inventory or evaluating analysis results, presentation in chart, graph, and report format promotes good decision making. An example using the 1998 state bridge database is presented. An evaluation of the impact that budget levels have on the quality of the Indiana state bridge network is also included.

INTRODUCTION

The Indiana Bridge Management System (IBMS) is a project level system the core of which is the Project Selection Module. In this module, projects are selected using any one of the four submodules: decision tree (DTREE), life cycle cost analysis (COST), multi-criteria ranking (RANK) and optimization (OPT), depending upon the level of sophistication desired (Woods, 1994).

Decision Tree

The DTREE module is used to determine alternative repair and improvement activities based on traffic, highway class, bridge condition, and other bridge characteristics. There are four sets of inbuilt decision for four highway classes: NHS, Major STP, Minor STP and Local Roads. Depending on the bridge and traffic inventory data, the program first checks the functional adequacy of a bridge followed by its structural adequacy.
A Markovian process is used to predict expected bridge conditions in the absence of any improvement (Bulusu and Sinha, 1997). DTREE can recommend either structural

improvement or a functional improvement or a combination of functional and structural improvements or simply routine maintenance. A total of fifty possible improvement activities can be considered. DTREE also estimates the initial cost of every improvement activity recommended in future years. The most recent version of the bridge replacement cost estimation model uses the Cobb-Douglas production function (Vitale et al., 1996).

The Bayesian approach was incorporated for updating the transition probabilities of bridge elements. This approach helps to combine current information on transition probabilities with the new data from inspection. Prior transition probabilities, based on bridge inspectors' experience/opinion, were assumed to follow Dirichlet distribution. However, the observed field data were found to be represented by multinomial distribution (Bulusu and Sinha, 1997).

User Costs

User cost is primarily due to deficiencies of a bridge, which may cause load limits to be posted, restriction on clearance or even closure. This results in reduced traffic speed or detouring, thus increasing vehicle operating costs and travel time loss. User costs might be different for different stages of improvement. User costs before an improvement depend on current condition of a bridge. During the improvement work, it primarily depends on work zone traffic management strategies. Bridge traffic safety is separately considered in the traffic safety module (Sinha et al., 1989). The user cost analysis includes an estimation of vehicles to be detoured by highway class and by vehicle class. A detailed discussion is presented in Son and Sinha (1997).

Ranking

The RANK module determines project priorities. The priority of a project is estimated in terms of four factors: bridge safety, community impact, bridge physical condition, and project cost-effectiveness. Each of these factors is represented by a number of bridge attributes. Bridge safety index is computed in terms of clear deck width, vertical clearance, and inventory rating. Bridge physical condition involves remaining service life and ratings for deck, superstructure and substructure. There are eight disutility functions formulated in multiple stages using the Delphi iterative approach, and these have been revised and updated continuously to reflect the collective judgment and experiences of INDOT planners and engineers. The recent version of the IBMS provides greater flexibility in choosing the general format of a disutility function, as shown in Figure 1.

For a convex (or concave) shaped disutility curve the equation governing it is given by:

$$U_i(x_i) = 100 \text{ if } x_i \le a_i$$

$$U_i(x_i) = -\frac{100b_i^\phi}{a_i^\phi - b_i^\phi} + \frac{100x_i^\phi}{a_i^\phi - b_i^\phi} \text{ if } a_i \le x_i \le b_i$$

$$U_i(x_i) = 0 \text{ if } x_i \ge b_i$$

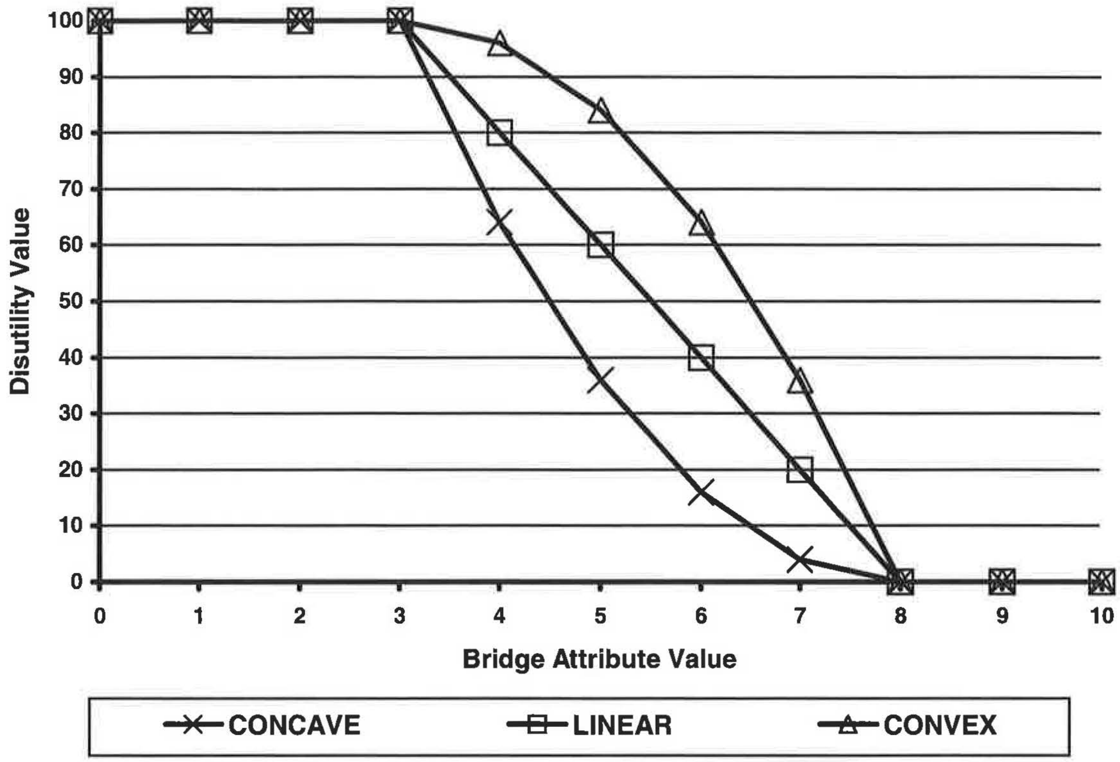

Figure 1: General format of a disutility function.

$\phi \geq 1$ for concave shapes
$\phi \leq 1$ for convex shapes

where

U_i = Distility function for i^{th} bridge attribute,
x_i = Value of the i^{th} bridge attribute,
a_i = Upper break point of i^{th} disutility curve,
b_i = Lower break point of i^{th} disutility curve,
ϕ = Degree of concavity (or convexity) of disutility curve.

Varying the value of ϕ will alter the appearance of the curve from a straight line ($\phi = 1$) to either a horizontal line or a vertical line. The priority of a project is determined by the difference between the disutility values 'with' and 'without' a proposed improvement activity.

Optimization

In the RANK module, projects are prioritized based on the change in total disutility values. However, the mix of projects may not be optimal due to budget constraints. An integer programming optimization technique was incorporated for multi-year optimal programming decisions. The objective is to maximize the difference between disutility values with and without the selected improvement activities subject to budget and other possible policy constraint (Vitale et al., 1996).

Graphical User Interface

A graphical user interface (GUI) has been incorporated in IBMS to integrate the project selection module and the database management module and to link the combination with the report module. The interface was developed using Microsoft Visual Basic graphical capabilities. Data and results can be presented in several formats in the graphic interface, including tabular browser, tabular reports, pie charts, bar/column/line charts, and X–Y charts. Figure 2 shows the IBMS data browse window. This window guides the user to browse data in inventory, DTREE, COST, RANK and OPT modules. The data can be sorted by different options, bridge number, county, route number, district, and construction year. Pie charts can be generated to present the distribution of a single selected data field as a percentage or as the total number of bridges or projects. Bar, column, and line charts can be presented for up to two bridge attributes or data fields. X–Y charts can be used to display the relationship of a single parameter to time.

The graphs are classified into five categories: bridge inventory analysis, need assessment, utility analysis with RANK, optimal funding analysis, and bridge network quality analysis with OPT. Various options are available for the user to select for specific

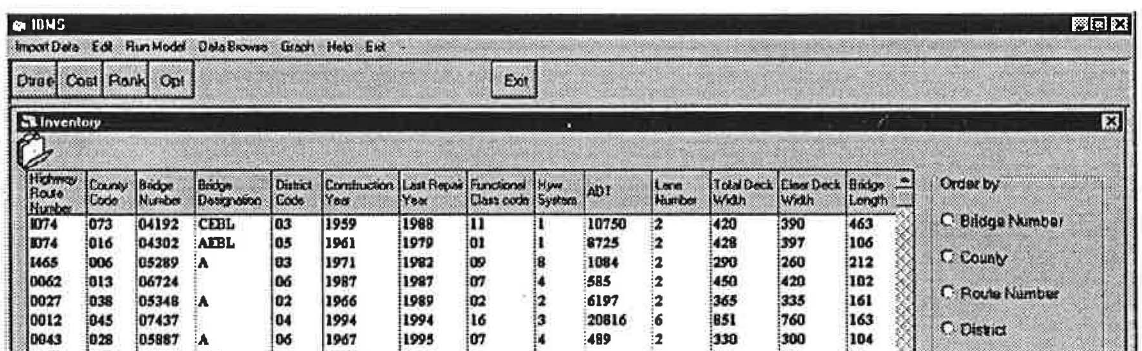

Figure 2: IBMS DATA browse window.

purposes. Data in graphs may be displayed by district, by road class, or when overall data, by year.

ANALYSIS OF RESULTS

In this section, an evaluation of improvement activities for the state bridge inventory is presented for the years 2000–2003.

Bridge Inventory Analysis

As of January 1998 Indiana had 17,871 state bridges at least 20 feet long. Bridge type, material composition, physical dimension, structural condition, geographic location, and the volume and type of daily traffic distinguish these bridges. In Figure 3 is given the distribution of the bridges by district. These bridges consisted of 2112 on NHS, 1872 on Major STP, 985 on Minor STP and 272 on Local Roads. The average age of bridges on NHS was 31 years, while the highest average age was 37, for bridges on Major STP. There was little variation in average age by district. The NHS road class contained largest mean deck area, while the Minor STP had the least. Superstructures were

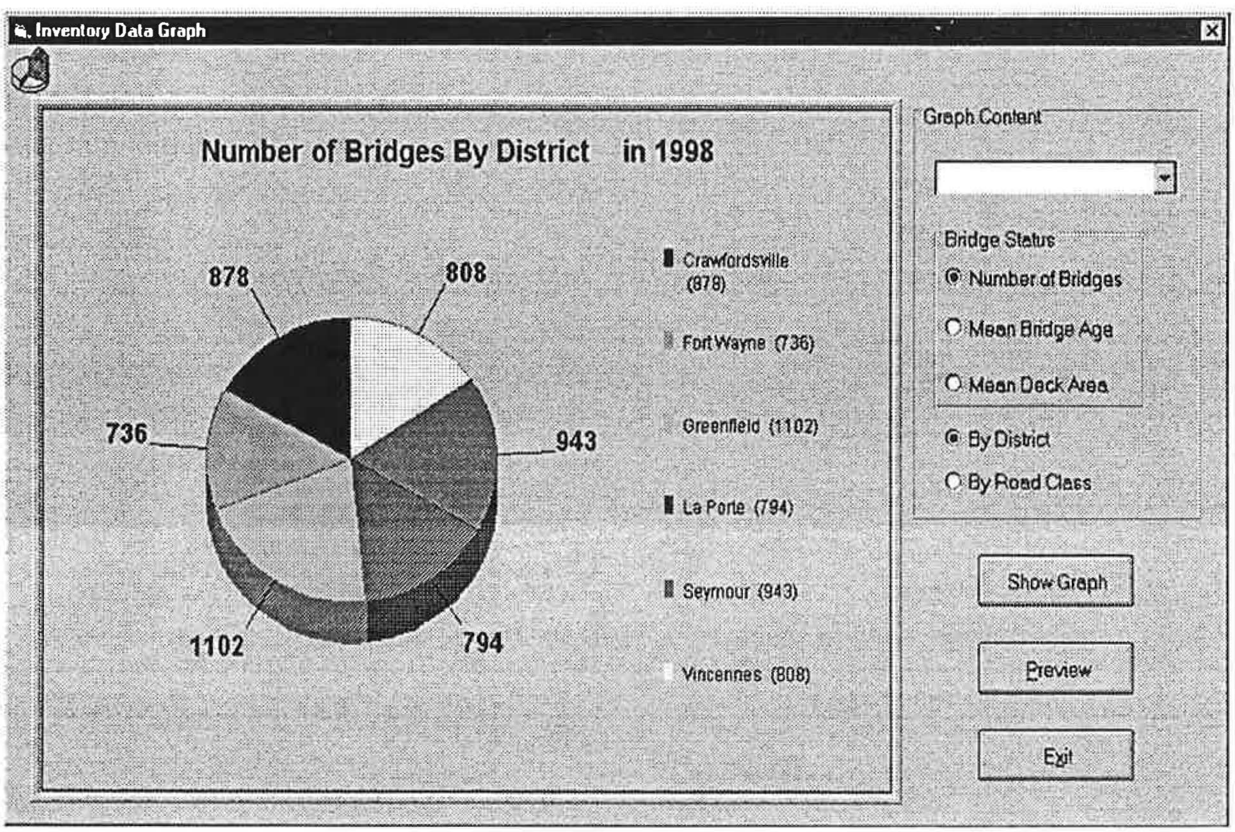

Figure 3: Distribution of state's bridges by district.

primarily constructed of three types of materials: concrete, steel, and prestressed concrete. The main types of construction were slab, multi-beam, truss, arch deck, and box beam.

Structural Condition of State Bridges

State bridges are grouped by condition levels. For clarity, NBI condition ratings less than or equal to 3 are identified as "serious". Similarly, condition ratings greater than 3 or equal to 7 are combined into the state indicated by "Good." "Satisfactory," "Fair," and "Poor" represent condition ratings of 6, 5, and 4, respectively. As an example, the 1998 deck condition data are summarized in Figure 4. The average deck condition was low compared to the superstructure and substructure condition. Furthermore, the NHS and Major STP road classes were in better structural condition than the Minor STP and local road classes.

Inventory Load Rating

The NHS road class had the largest percentage (65%) of bridges which could accommodate 35 tons or heavier vehicles and had the smallest percentage of bridges with inventory ratings of 15 tons or less. Bridges contained in the Local road class had almost the same percentage of bridges in the 35-ton and heavier categories. But in the 15-ton and

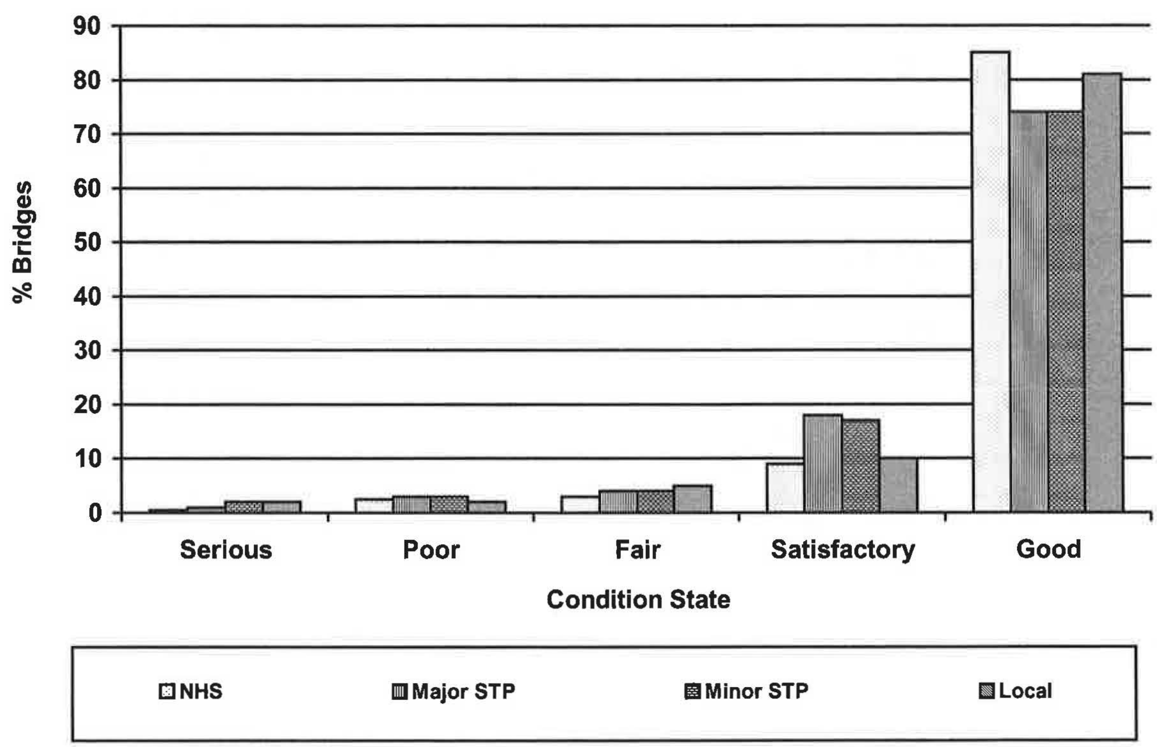

Figure 4: Deck condition by road class.

lower category, the Local road class had a much higher percentage (8%) than either the Major STP (2%) or the Minor STP (3%) road class.

Need Assessment for Bridges

DTREE determines the need based on largest cost and least cost. For each bridge in the inventory, DTREE recommends up to three alternative activities for each year, and these activities are sorted by project initial cost. In the year 2000, the need assessment indicated that 3,569 bridges would not require any improvements. This number dropped to 2,671 by the year 2003. The number of bridges requiring replacement averaged 150 from 2000 to 2003 for the least cost option. In 2000, 26 bridges would need superstructure replacement (including widening and raising superstructure) and this number increased to 46 in 2003, in the least cost option. In Table 1 is given the need assessment for the high cost option.

The difference from the least cost option is significant in the number of "strengthen superstructure" and superstructure replacement activities. The number of superstructure replacement activities increases from 26 in the least cost option to 383 in the high cost option. In the previous case, instead of DTREE recommending superstructure replacements, the less expensive "strengthen superstructure" activities were recommended. The number of bridge replacement activities also increased in the high cost option since DTREE selected bridge replacement instead of superstructure replacement for the same bridge.

Budget Requirements of Improvement Activities

Recommended improvement projects can be translated into funds required. Figure 5 shows the capital requirements of the bridge inventory assigned to the recommended projects from DTREE. For all improvement activities associated with the high cost option, the required expenditure in 2000 amounts to over $0.39 billion dollars. At present INDOT allocates about $60 million dollars per year to bridge improvement activities. There is a significant discrepancy between the budget requirements obtained by DTREE and the actual amount provided by INDOT. Even if it is considered that difference may have been exaggerated by the effect of estimation errors and deterioration rates used to predict the time progression of the NBI condition rating values, the gap between the need and the actual expenditure remains high.

Table 1: Need Assessment for High Cost Option

TYPE OF IMPROVEMENT ACTIVITY	YEAR			
	2000	2001	2002	2003
Do Nothing (may require routine maintenance)	3569	3340	2944	2671
Deck Rehabilitation	355	584	949	1159
Deck Replacement (including Widen Deck)	108	111	112	104
Deck & Superstructure Rehabilitation	70	64	76	112
Strengthen Superstructure (including Widen Deck)	6	6	6	6
Superstructure Replacement (including Widen Deck)	383	364	391	377
Bridge Replacement (including Widen Deck)	171	168	176	193

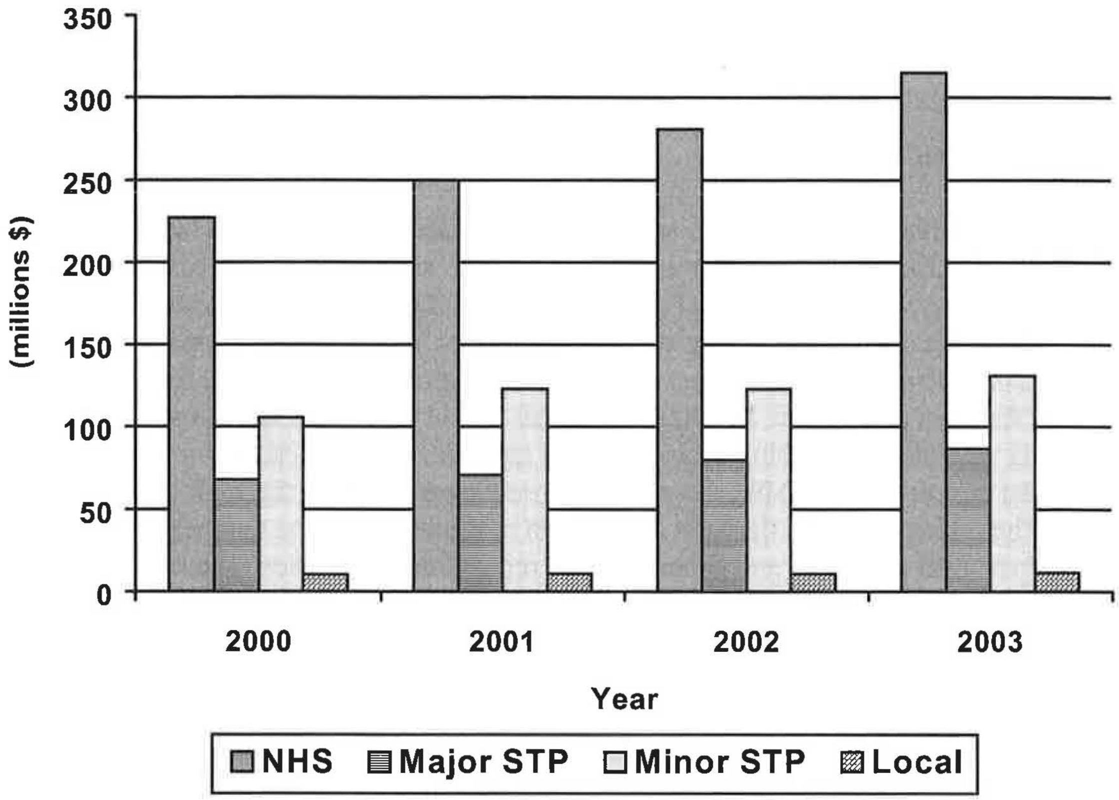

Figure 5: Budget requirements for state bridges.

Bridge Inventory Quality Assessment

The average network disutility associated with the state bridge inventory is presented in Figure 6 for the years 2000–2003. The top five curves provide the average network disutility value as an indication of the bridge inventory quality over the four-year period, in the absence of any improvement activities. The lowest curve indicates expected disutilities if the low option were implemented.

Optimal Funding Analysis

The OPT module provides multi-year optimization of all feasible projects given by RANK, based on a specified budget. For a given budget level, IBMS can provide analysis on project allocation and funding allocation by road class and by district. The OPT module can formulate an optimal combination of projects that maximizes the total change of disutility values resulting from all feasible improvement activities. To measure the impact of budget levels on the bridge network, a network quality index is computed, as shown below:

$$NQI = 100 - \frac{\sum(0.667 * U_{safe} + 0.333 * U_{con}) * ADT}{\sum ADT}$$

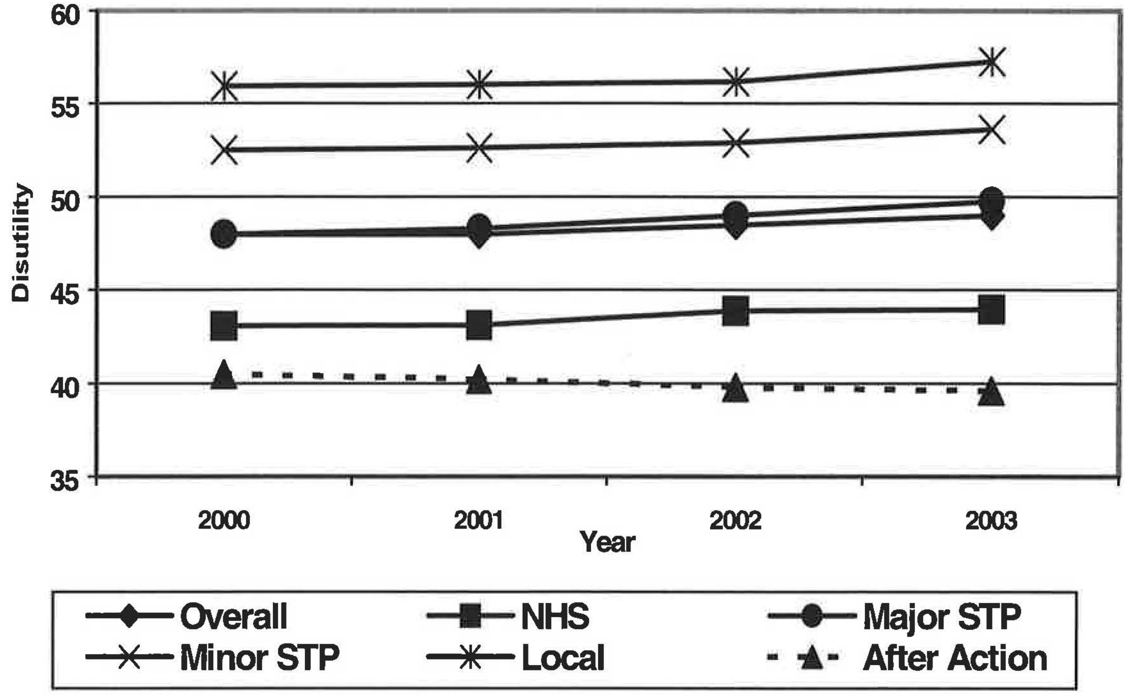

Figure 6: Mean disutility of state bridges (by road class).

where

NQI = Bridge network quality index
U_{safe} = Bridge safety disutility value
U_{con} = Bridge condition disutility value
ADT = Average daily traffic.

Figure 7 shows how the NQI changes from year 2000 to 2003 at three budget levels. When a $40 million dollar budget is considered, the NQI in year 2003 is 57. This value is slightly smaller than the NQI in the year 2000. If the budget is increased to $60 million, the NQI improves year by year. When the budget is up to $80 million, the NQI increases to 61 by year 2003. More NQI benefit is achieved by increasing the budget from $40 to $80 million. Further detailed analyses are conducted on funding allocation by district and by highway class (Zhang, 1998).

PROGRAM REQUIREMENTS

The IBMS runs on an IBM-compatible computer system. The most recent version was developed using IBM FORTRAN/2, GNU C, on Windows 95. The hardware requirements of the system are a 486 IBM-compatible computer with at least a 66 MHz processor, 16 MB of free memory (RAM), and 100 MB of hard disk space. The operating system required for running IBMS is WINDOWS 95/NT. It is a must as the most recent version of IBMS incorporates Graphical User Interface, which was written in Visual Basic 5.0. It is to be noted that WINDOWS 3.1 can be used for running DTREE, COST and RANK modules; however OPT requires a large memory usage, which should be

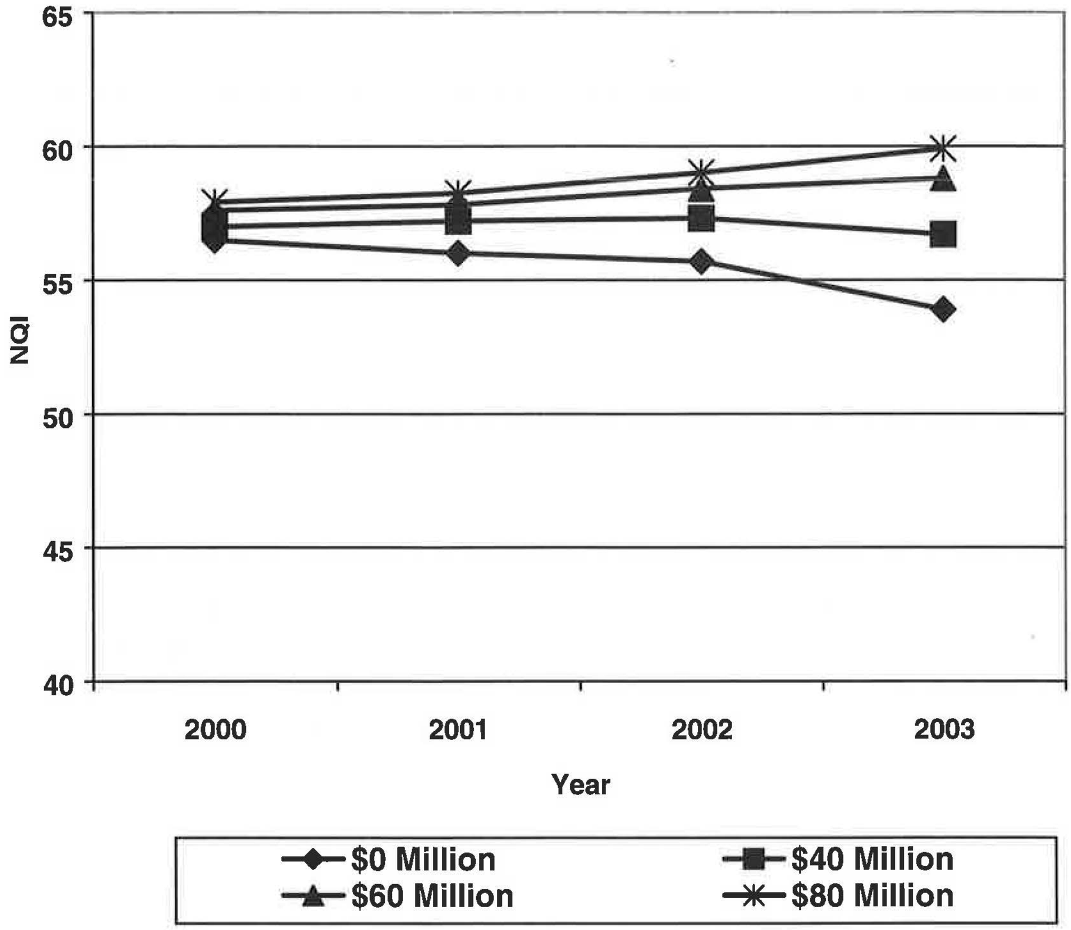

Figure 7: Mean bridge network quality index for different budget levels.

supported by DPMI. The IBMS can be installed using the installation disk either by typing setup at the prompt or by clicking the setup icon followed by selecting the IBMS install directory. The setup program will create the necessary directories and subdirectories and copy the files required to run the IBMS.

CONCLUSION

The IBMS was developed to organize, present and analyze information related to the repair and replacement of highway bridges in Indiana. It should be considered as a planning tool, not a final decision making mechanism. It is continuously being refined and enhanced as the operating environment is changed and new data are available.

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