Bridge Management System Software for Local Governments

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A software system was developed for a microcomputer to conduct bridge management system studies for local agency bridge systems. The software system was developed so that weighting factors and level-of-service goals were kept in separate data base files. This way, criteria could be easily changed without modifying the basic program. By evaluating one local county bridge system, it was demonstrated that microcomputers provided a good computing base for managing local bridge systems. The results of the bridge management system analysis showed excellent correlation with the independently developed bridge replacement program in that county. When differences occurred, they were justified when other factors were considered. A procedure was proposed for implementing a bridge management system at the local level. This approach encourages input from all involved parties in setting policy and level-of-service goals. Particular emphasis is placed on the importance of accurate and consistent bridge parameter data.

Although the need for improving the infrastructure at the local level is well documented, the tools available to local officials for optimally using allocated resources in infrastructure rehabilitation are limited. Local agency bridges are among the most expensive infrastructure items. Most bridge management systems (BMSs) in use today were developed for relatively large state bridge systems. They were also developed to use on relatively large computer systems. Unfortunately, these types of computer systems are not usually available to personnel at the local level. Therefore, the objective of this paper is to present the results of a study to develop a software package for microcomputers to implement a BMS and to present the results of a study for one county BMS.

BACKGROUND

The purpose of any BMS is to provide the means to systematically rank all bridges in a given bridge system. In its simplest form, most BMSs use a ranking formula of the form:

$$\text{Ranking} = \sum_{1} K_i f_i (a, b, c, \ldots) \qquad (1)$$

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where

K_i = Weighting factors,
$f_i (a,b,c,\ldots)$ = Priority ranking formulas, and
a,b,c = Bridge parameters.

A good summary of several BMSs developed recently can be found in the Federal Highway Administration's report on BMSs (*1*). Typically, the priority ranking formulas evaluate three to six different bridge functions. For example, the system developed for the North Carolina Department of Transportation has four priority ranking formulas (*2*). They measure bridge load capacity, deck width, vertical (over and under) clearances, and estimated remaining life. Other BMSs have priority rating functions measuring parameters such as sufficiency rating, structural and deck condition, and so on. (*3–5*).

The objective of all priority ranking formulas is to develop a number for each bridge on the system. Although these priority ranking formulas have various forms, their sensitivity to various bridge parameters can be shown to vary over a significant range. For example, the sufficiency rating has been shown to be very insensitive to average daily traffic (ADT). Thus, two identical bridges with vastly different traffic patterns would end up with identical priorities if only the sufficiency rating were considered.

The priority ranking formulas are functions of bridge parameters. For a BMS to be implemented, all bridge parameters must be collected for all bridges in the system. The implications of this statement will be discussed later in this paper. However, for the ranking formulas to properly rank the bridges in the system, all bridge parameters must be accurate and consistent.

The last terms discussed in the ranking formula are the weighting factors. These factors provide a means to give relative values to the importance delegated to the various ranking formulas. For example, if bridge deck width is an important local consideration, the weighting factor for deck width should be increased. In general, for most systems, bridge capacity has a fairly high priority consideration. In most situations, a low load capacity is also a good indicator that deck width and remaining life are also low. However, there are exceptions. In most systems, the sum of all weighting factors is equal to 100.

In conclusion, most BMSs develop a priority ranking for each bridge based on weighting factors, priority ranking formulas, and certain bridge parameters. The development of these systems is a series of compromises. If every conceivable bridge parameter is used in the priority ranking formulas, then each bridge parameter must be collected for every bridge in the system. If the number of bridges is large, this could become a significant effort. Even for smaller bridge systems, this approach could become an unwise use of resources. Because the objective of any BMS is to set priorities and get a relative ranking of the system bridges, a more logical approach is to minimize the number of key bridge parameters collected.

North Carolina BMS

To develop a BMS for local agencies, several existing BMSs were evaluated. The one selected for implementation was developed by Johnston and Zia (*2*) for the North Carolina Department of Transportation. It is based on setting level-of-service goals for three different bridge parameters. These are load capacity, deck width, and vertical clearances for traffic over or under the bridge, or both. These levels-of-service were defined as a function of road classification, ADT, and number of traffic lanes. Bridges are ranked based on the number of deficiency points (DP) assigned to each bridge.

The DP are calculated based on the following formula:

$$DP = CP + WP + VP + LP \quad (2)$$

where CP, WP, VP, and LP are need functions for load capacity, deck width, vertical over/under clearance, and estimated remaining life, respectively. The ranking formula for CP is:

$$CP = WC * (CG - SV) * (0.6*KA + 0.4*KD)/10 \quad (3)$$

where

$KA = (ADT^{.3})/12$,
$KD = DL * ADTO/(20*4000)$,
CG = Capacity goal (tons),
SV = Single vehicle posting (tons),
ADTO = ADT of over route,
DL = Detour length (mi), and
WC = Capacity weighting factor.

The ranking formula for WP is:

$$WP = WW * (WG - CDW) * ADTO/(3 * 4000) \quad (4)$$

where

WG = Width goal (ft),
CDW = Present clear deck width (ft),
ADTO = ADT of over route, and
WW = Deck width weighting factor.

For vertical clearances of the bridge, the ranking formula is broken into two components to account for traffic over and under the bridge. It is:

$$VP = VPU + VPO \quad (5)$$

where

$VPO = WV * (UG - VCLU) * ADTU/(2 * 4000)$,
$VPU = WV * (OG - VCLO) * ADTO/(2 * 4000)$,
UG = Underclearance goal (ft),
VCLU = Present vertical underclearance (ft),
ADTU = ADT of under route,
OG = Overclearance goal (ft),
VCLO = Present vertical overclearance (ft),
ADTO = ADT of over route, and
WV = Vertical clearance weighting factor.

The last component considered is the estimated remaining life for the bridge. This parameter is obtained from the formula:

$$LP = WL * [1 - (RL - 3)/12] \quad (6)$$

where RL is estimated remaining life (yr), and WL is remaining life weighting factor.

TABLE 1 LEVEL-OF-SERVICE GOALS

Highway Function Classification	ADT	Load Capacity (Tons)	Lane Width (ft)	Shoulder Width (ft)	Under Clearance (ft)	Over Clearance (ft)
Major collector	≤800	25.0	9	1	14	14
	≤2000	25.0	9	2	14	14
	≤4000	25.0	10	2	14	14
	>4000	25.0	10	3	14	14
Minor collector	≤800	16.0	9	1	14	14
	≤2000	16.0	9	2	14	14
	≤4000	16.0	10	2	14	14
	>4000	16.0	10	3	14	14
Minor collector	≤800	16.0	9	1	14	14
	≤2000	16.0	9	2	14	14
	≤4000	16.0	10	2	14	14
	>4000	16.0	10	3	14	14

Note: Deck width goal = Number of lanes * lane width + 2 * shoulder width.

For all components of the DP formula, the value for each component shall not be less than zero nor greater than the corresponding weighting factor. After looking at the ranking formulas, the DP formula is a function of eight bridge parameters, three service goals, and four weighting factors. These bridge parameters are usually available because they represent basic data describing the bridge. These ranking formulas can be easily manipulated to give DP per unit component deficiency. These can then be plotted, if desired, as a function of the appropriate bridge parameter.

The weighting factors are presented in Table 1. The service goals are presented in the FHWA report on Bridge Management Systems (*1*) and in the report by Johnston and Zia (*2*).

Once the DPs are calculated for each bridge, the bridges can be ranked in numerical order. There are several approaches to further optimize the use of limited bridge resources. Although more complicated, the incremental cost/benefit ratio can be used to determine the optimal replacement and rehabilitation projects for a system. This approach has some advantages for determining which projects are involved and the degree of rehabilitation and replacement needed so that the maximum benefits are obtained for a given budget. The primary disadvantage is that cost data are required for a relatively large number of alternatives.

A simpler approach is to rank the bridges on the basis of a cost factor (CF) equal to:

$$CF = \text{Replacement costs (\$)/DPs} \quad (7)$$

The ranking of bridges subject to replacement can be made on the basis of this CF. It would then be prudent to select bridge replacement projects with low CFs. As with any numerical scheme, the user must use judgment and experience when selecting actual projects for a planning period.

In conclusion, the North Carolina approach to bridge management has several advantages over using a single parameter such as the sufficiency rating. This approach assigns DPs nearly directly proportional to ADT. Detour length is also strongly considered in the most heavily weighted factor, load capacity. An additional advantage is that levels of service can be assigned for each highway functional classification of the bridge. The sufficiency rating is assigned based on one standard for all highway function classifications.

Application to a Local Bridge System

Many local agencies have microcomputers available to personnel. Because the computing power of these microcomputers is more than adequate for the analysis of most local bridge systems, the North Carolina BMS was programmed into the microcomputer using the dBASE III Plus (TM) data base management system. This data base system was chosen because of its widespread use in many agencies.

To demonstrate the applicability of the data base system, microcomputer, and the North Carolina approach to bridge management, a bridge system of a local county was selected for evaluation. This county, in Kansas, is located near a growing major metropolitan area. However, many of the county bridges are on rural roads.

The following description is provided to give an idea of the status of the county bridge system evaluated. There are 114 bridges in the system. Several are trusses. However, the majority are simple span bridges made of steel and concrete. Of the 114 bridges, 6 were closed and were included in the totals. The highway function classifications are local roads, minor collectors, and major collectors. The county also has minor and major arterials, and Interstate roads, but bridges on these systems are not a part of the county system. There are 81 bridges on the local system, 6 on the minor collector system and 27 on the major collector system.

There are 9 bridges (6 closed) with an operating rating of between 5 and 9 tons. Eight bridges (6 closed) have an estimated remaining life of less than 5 yr. Forty-four bridges have an estimated remaining life of between 5 and 9 yr. Another 44 bridges have an estimated remaining life greater than 20 yr.

The last variable to be discussed is the ADT count. The ADT range for local road bridges is 0–1,200. Forty-seven local bridges have an ADT of less than 99. Twenty-two have an ADT of between 100 and 199, and 5 bridges have an ADT of between 200 and 299. The remaining local bridges have an ADT of greater than 300. For the 6 bridges on the minor collector system, the range of ADT was 51–3,340. In the traffic ranges previously described, the distribution of ADT was 2, 1, 1, and 2, respectively.

The ADT range for the bridges on the major collector system was 276–4,782. One bridge had an ADT of less than 300, 4 were in the range of 300–499, and 9 were in the range 500–999. Twenty-seven bridges on the major collector system had an ADT of greater than 1,000.

Although very few bridges were replaced during the past 10 yr, the system has several relatively new bridges with good operating ratings and conditions. As with most local systems, there are 6 bridges that have been closed because of poor condition and load condition. In addition, there are several bridges that have load capacity restrictions and are narrow.

In general, this county bridge system is typical of most systems. Some bridges are in excellent condition and others are in desperate need of repair. Overall, some local agencies have bridge systems that are in worse need of replacement and other agencies have bridge systems in better repair.

Fortunately, the local agency had previously developed a complete data base for its bridge system. A significant effort was expended to accurately complete this data base. Because all data were not required to conduct the bridge management study, a new data base was developed using a data base manager system that only contained those bridge parameters required to conduct the analysis.

WEIGHTING FACTORS AND LEVEL-OF-SERVICE GOALS

To improve the flexibility of the system, separate data base files were created for the weighting factors and the level-of-service goals. This way each parameter could be modified without changing the basic system. A dBASE program was written to conduct all numerical calculations and to index or rank each bridge. Because replacement costs were not available, the ranking was done on the DPs. Although the weighting factors were varied later in the study, the baseline weighting factors used in the analysis are those given as follows:

Function	*Weight*
Single vehicle load capacity	WC = 70
Clear bridge deck width	WW = 12
Vertical roadway under/over clearance	WV = 12
Estimated remaining life	WL = 6

The next step was to develop the level-of-service goals. Because of the nature of the data base system, any number of highway function classifications can be defined. For this study, service goals for three highway function classifications were defined. The selected service goals are presented in Table 1. In general, the goals are similar to those outlined in the North Carolina study. Deck width goal varied with ADT so bridges with wider decks would be found on more heavily travelled roads. Because many bridges are on narrow, lightly travelled roads, single lane bridges were permitted. The establishment of these service goals is very flexible. Because they were stored in a separate data base file, they could be easily changed without modification of the program.

RESULTS

Although it is difficult to present the results of the analysis on the bridge system studied, some interesting observations could be made. The 114 bridges were analyzed using a 10 MHz AT clone microcomputer. To analyze the system completely took less than 2 min. This included calculation of all DPs and placing the bridge listings in descending order. Although most local agency bridge systems have less than 500 bridges, a microcomputer has more than sufficient computing power to handle the most sophisticated BMS.

For all bridges, the number of DPs for the entire system ranged from 0 to 72.7. Thirty-seven bridges had zero DPs. No bridge on the system had clearances less than the goals given in Table 1. Therefore, the maximum number of DPs was 88.

After the first analysis was complete, it was obvious that some bridges were not placed in the proper order. Upon review of the data, it became apparent that there were some errors in the data base. This illustrates the first observation. To use a BMS as a policy tool, it is imperative that a good, accurate data base of bridge parameters is available. If the bridge width of one bridge is missing, the ranking of that bridge will not be correct. Fortunately, the obvious errors are easy to spot. The subtle ones are much harder.

Because the weighting factor for load capacity was high, bridges with relatively high load capacity will obviously have small numbers of DPs. For bridges with relatively low load capacity values, bridges with high ADT had the higher number of DPs. The 10 bridges with the highest number of DPs were on the major collector system. The operating rating of these bridges varied between 5 and 16 tons. The ADT of the bridges varied between 496 and 4,782. The next 10 bridges were on the local or minor collector systems. The ADT of these bridges was generally lower.

Because the county had previously developed a comprehensive bridge replacement program, it was interesting to compare the results of the BMS and the independently developed replacement program. Except for specific instances, bridges with high numbers of DPs were scheduled for early replacement. Large discrepancies were observed in one or two instances, although there were good reasons for them in each case.

As discussed previously, all bridges in the county met the clearance goals for all highway function classifications. Therefore, the vertical clearance parameter did not provide useful information in the ranking process. For all bridges, no DPs were calculated for unsatisfactory vertical clearances.

Different weighting factors were considered. Variation of the vertical clearances' weighting factors was not considered for the reasons previously discussed. However, the load capacity weighting factor was reduced to 60 and the estimated remaining life weighting factor was increased to 16. After the analysis was complete, the results were compared. In general, the rankings were very similar with little change in relative rankings. However, two bridges changed their relative ranking approximately 10 to 15 positions.

IMPLEMENTATION FOR THE LOCAL AGENCY

What should be considered before a BMS is implemented at the local level? It would appear that the first step would be to get a commitment to the system from all persons responsible for selection of bridge replacement projects. This does not have to be a commitment to selection of bridge replacement projects based on the output of a "black box," but should be a commitment showing that the results from the BMS will be seriously considered as one important tool in the decision-making process. Because of the large amount of data required to implement a BMS, it is imperative that there be a commitment to the system.

The North Carolina system was used in this study. It was chosen because of its inherent flexibility and simplicity. Other BMSs could also be considered. However, the system selected should rank the bridges in a reasonable order with a minimum amount of data collection. Once the BMS has been selected, some interesting policymaking decisions can be made. It now becomes possible to set some long-term goals on the future configuration of the existing bridge system. For example, highway function classifications for the local agency road system can be defined. In some counties, a grid of high-capacity local roads at 3-mi intervals is being implemented. These roads will become major thoroughfares for the county and will have no posted bridges. In other cases, an existing system is working well and, with a stable environment, will not need to be changed.

Once the highway function classifications have been determined, it is time to set service goals for each classification. It appears that at the local level, any BMS should be flexible enough to accommodate local priorities and needs. When truck traffic that supports the local economy requires relatively high vertical clearances, it becomes desirable to pay particular attention to the vertical clearance goals. In other locations, posted bridges have a severe impact on the local economy. In these situations, load capacity goals should be given additional consideration. In western Kansas, clear deck width is a particular concern at the local level because of the machinery used in the production of wheat.

The last decision-making process is the adjustment of the weighting factors. This step is very important and could be a significant driver of bridge rankings. From the studies made for the county system studied, changing the load capacity and estimated remaining life weighting factors by 10 percent did not change the relative order of most bridges in the system. However, several individual bridges changed by approximately 10 ranking positions. The selection of the highway function classifications, level-of-service goals, and weighting factors will have a significant impact on the configuration of the bridge system in the future. Therefore, it is important to have a consensus about long-term objectives of future bridge systems. If all interested parties have contributed to the process of setting service goals, the entire organization could be working toward a common objective. As long as the objective remains the total bridge system, input from technical staff, politicians, and users is important in the development of BMS goals. Once the goals and policymaking decisions are made, it becomes time to collect the hard data about the entire bridge system in its current state. If the BMS is to be effective, it is imperative that accurate, consistent, and reliable data be available for each bridge. These BMS systems are inflexible with respect to missing or inaccurate bridge properties.

Fortunately, all of the information required to use the North Carolina system is available from the Structural Inventory and Appraisal (SI&A) forms currently required for all bridges (*6*). Because all bridges on the local system must currently be inspected every 2 yr, up-to-date bridge parameters should be available. However, it is suggested that if these data are used they should be carefully reviewed for consistency and accuracy.

After all bridge parameters are inserted into a data base, the analysis of the data and calculation of the ranking parameters would take place. This project demonstrated that microcomputers have sufficient computing power for use with local bridge systems.

After the bridges are ranked for DPs, or some cost factor, actual projects can be selected. Although the ranking of the bridges with the BMS is an important tool in the project selection process, it should not be used blindly. Other considerations such as funding sources, availability of plans, construction schedules, and so on, are important.

At the conclusion of the analysis required by the implementation of a BMS, a logical, justifiable bridge replacement program should result. This program will be developed based on existing bridge parameters that fairly compare one project with all other bridges in the system.

The setting of highway function classifications, level-of-service goals, and weighting factors should not be set once and never reevaluated. Conditions and needs do change and a periodic review of these parameters is appropriate. However, they should not be changed indiscriminately. To adjust the service goals so that the relative ranking of a particular project is improved or changed, for example, would defeat the purpose for implementing a BMS.

CONCLUSIONS

Through the analysis of a typical county bridge system, it was shown that the computing power of microcomputers is more than adequate for operating BMSs. The BMS developed for North Carolina was chosen for implementation in this project. The software was developed using dBASE III Plus data base management system. With appropriate programming, separate data bases containing weighting factors and level-of-services goals were developed. This way criteria could be changed without modifying the ranking program. This approach improves software flexibility and friendliness.

The bridge parameters from one local county system were thoroughly analyzed using several ranking criteria. With the baseline criteria, the bridge ranking was compared with the actual replacement program developed independently by the county. In general, the two approaches to the development of a bridge replacement program agreed closely. Where differences occurred, they could be explained by taking other factors into consideration. The time required to develop a bridge replacement program with the use of a BMS was significantly less than that required for the manual selection process.

Based on the results of this study, microcomputers provide a very good base for BMSs. Although improved productivity could be used when a BMS is implemented, collection of bridge parameter data could become a major effort. If the data on the SI&A forms are accurate and up-to-date, this effort would be minimized. The reliability of the results are dependent on the quality of the bridge parameter data. These data must be accurate and consistent if reliable results are to be obtained. Although this project evaluated bridges, it could be modified to include the culvert systems of local agencies. In most areas there are more culverts on the local system than there are bridges.

Therefore, the potential for additional productivity gains while setting replacement priorities would be greater for culvert systems than it would be for bridges.

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