Review of Current Practices of Bridge Management at the State Level

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As part of a study to develop a bridge management system for the Indiana Department of Highways, a questionnaire survey was conducted to review the current practices of bridge management at the state level. It was found that most of the states have well-defined programs or procedures to set priorities on bridge rehabilitation or replacement programs. Study on bridge maintenance has just begun and only a few states, such as Pennsylvania, have established procedures to program bridge maintenance projects. The survey results were instructive in helping to understand how state highway agencies accomplish the allocation of funds to bridge projects. Many state agencies responded that they were not satisfied with their current bridge management procedures and expressed a need for a comprehensive bridge management system. Such a system might include steps that would estimate present and future needs, set priorities on projects, and determine optimal sets of bridge projects to use the limited funds effectively. The questionnaire survey revealed that the procedures currently used are mostly aimed at short-term programs.

In recent years there has been a growing concern about the safety of existing bridges. The Federal Highway Administration (FHWA) rated about 45 percent of the existing bridges in the United States as either functionally or structurally deficient *(1)*. In an effort to alleviate the nation's bridge safety problem, a federally mandated system for bridge inspection, evaluation, and reporting was established *(2)*. As a bridge-ranking index, FHWA developed the sufficiency rating, which ranges from 0 to 100 points. This index is computed using structural-condition ratings of bridge components and other information *(2)*. A bridge with a sufficiency rating less than 50 is eligible for federal funds for replacement. A bridge with a sufficiency rating between 50 and 80 is eligible for federal funds for rehabilitation. FHWA, however, provides flexibility to the states and other agencies to develop their own bridge selection procedures.

As part of a study to develop a bridge management system for the Indiana Department of Highways, a questionnaire survey was conducted to review the current practices of bridge management systems at the state level. Several states currently have developed formalized procedures to set priorities on bridges and an evaluation of these procedures is also presented in this paper. In addition, further research needs in the area of bridge management are identified.

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METHODOLOGY

Two approaches were used to review the current practices of bridge management systems at the state level: a literature search on bridge management procedures and a questionnaire survey. The questionnaire was sent to state highway agency bridge engineers of all 50 states, Washington, D.C., and Puerto Rico. It contained 13 questions. Some of them could be answered by a simple yes or no; others required the respondent to take time and write a few sentences of description. Many state highway agencies enclosed related material that reflected the urgent need for developing bridge management programs to use bridge funds effectively and efficiently.

ANALYSIS OF THE SURVEY RESULTS

Of the 52 questionnaires sent out in late April, 1986, a total of 44 were returned for analysis by July 15. Responses were well distributed to four geographical areas, as shown in Table 1. The survey indicated a need for a comprehensive bridge management system in 31 of the responding states. A summary of the survey results follows.

Inspection Procedures and Data Recording System

The first questions on the questionnaire were related to the level of compliance of state highway agencies in following FHWA's *Recording and Coding Guide for the Structure Inventory and Appraisal (SIA) of the Nation's Bridges (2)* to record information on bridges. Twenty-one states (48 percent) responded that they strictly follow the data recording system recommended by FHWA; whereas 20 states (45 percent) re-

TABLE 1 SURVEY RESPONSES

AASHTO Region	No. of States Responding	Total No. of States in Each Region
Region I (east)	11	13[a]
Region II (south)	11	12
Region III (central)	10	11
Region IV (west)	12	16[b]
Total	44	52

NOTE: Responses as of July 15, 1986.
[a]Including Washington, D.C., and Puerto Rico.
[b]Including Alaska and Hawaii.

sponded that they made some modifications to accommodate extra data requested by each state to meet their bridge management procedures. For instance, Iowa expanded the Structure Type Codes (3) to include several other types, whereas Michigan added a field to record paint condition and included a code for bridge railing. Texas also modified the content of the bridge data base so that more descriptive superstructure, substructure, and deck types of information could be recorded.

Three states, California, New York, and Pennsylvania, responded that they did not follow the basic structure of the SIA data-base format. California's Structures Maintenance System File *(4)* contains more complete data that characterize bridges. Detailed information is available on joint seals, barrier rails, abutments, piers, geological data, and so on. It also contains the damage history of bridges, including the category, date, and cost of remedial works. New York added a flagging procedure by which inspectors issue prompt notification to the appropriate authorities. Pennsylvania developed its own structure data base called the ***Structure Inventory Records System (SIRS) (5)*** and it has been used by PennDOT since 1982. The system's data base was expanded beyond the FHWA requirements.

Use of the Sufficiency Rating for Setting Priorities

The sufficiency rating is often used by state highway agencies for separating bridges into either the rehabilitation or replacement category to satisfy the federal funding requirement. However, in the actual priority-setting process at the state level, the sufficiency rating procedure plays a relatively minor role. Only 10 of the 44 states use sufficiency rating as a major factor. Thirty-two states use it as a minor factor and the remaining 2 states do not consider it as a priority-setting factor. One opinion is that the sufficiency rating is not able to account for the level of service of existing bridges *(6)*.

Factors Considered in Priority Setting

In the survey, 16 states (36 percent) responded that they have or will have priority-setting procedures. Several agencies replied that they have procedures to compute numerical points to develop a priority listing of bridges. These procedures are discussed in the second section of this paper. The majority of the 44 states, however, do not assign fixed numerical weights to the factors considered. Rather, weights are altered case by case. Other states, like Texas and North Dakota, do not consider numerical weighting systems useful because there are so many factors and they are too divergent to be quantified in a meaningful and satisfactory way.

Table 2 shows types of factors considered in setting priorities. It lists items that were cited at least by two states. For instance, in Nevada the first consideration is the sufficiency rating, followed by, in order of significance, cost, location, and traffic safety due to functional deficiency.

Cost of improvement is, however, often excluded from the priority-setting process. As shown in Table 2, while 26 states (59 percent) consider it as a factor, 18 states (41 percent) did not include it in preparing a list of bridge-improvement program rankings. The most accepted factors are structural strength, traffic safety, and locational importance. The structural-strength factor includes such information as condition rating, appraisal rating, operating rating, and posted load limit. The traffic safety factor consists of information such as deficient bridge deck width and vertical clearance. Other factors such as estimated service life, type of highway, average daily traffic (ADT), and detour length are used by many states, but some states completely exclude some of these factors from their priority-setting procedures. For instance, in Montana, only three factors are used in decision making: cost of improve-

TABLE 2 ATTRIBUTES USED FOR BRIDGE PRIORITY SETTING AT THE STATE LEVEL

State	1	2	3	4	5	6	7	8	9	10	11	12	13
Alabama		*	*	*	*	*	*	*		*			
Alaska		*	*	*	*	*	*	*		*			
Arizona		*	*	*	*			*					
Arkansas	*	*	*	*	*	*	*	*		*			
California		*	*	*	*	*	*	*		*			
Colorado		*	*	*	*	*	*	*		*	*		
Connecticut		*	*		*			*		*			
District of Columbia		*	*	*	*	*	*	*	*	*			
Florida			*	*	*	*	*	*	*	*			
Hawaii			*	*	*	*	*	*		*			
Idaho	*			*		*		*					
Illinois	*	*	*	*	*	*	*	*		*			
Indiana			*	*	*	*	*	*		*			
Iowa		*	*	*	*	*	*	*		*	*	*	
Kansas			*	*			*	*				*	*
Kentucky	*	*	*	*	*	*	*	*		*			
Louisiana	*	*	*	*	*		*			*			
Maine		*	*	*	*	*	*	*		*			
Maryland			*	*	*	*		*					
Massachusetts	*		*	*	*			*		*			
Michigan			*	*	*					*			
Minnesota		*	*	*	*	*	*	*					
Mississippi		*	*	*	*	*	*	*		*			
Missouri				*	*		*	*					
Montana	*					*				*			
Nevada	*	*	*	*	*	*	*	*		*			
New Hampshire		*	*	*	*	*	*	*		*			
New Jersey		*	*	*	*	*	*	*		*			
New York		*	*	*	*	*	*	*		*			
North Carolina			*	*	*	*	*	*		*			
North Dakota		*	*	*	*	*							
Ohio	*	*	*	*	*	*	*	*		*			
Oklahoma	*	*	*	*		*	*	*			*		
Oregon		*	*	*	*	*	*	*	*	*	*		
Pennsylvania			*	*		*	*	*					
Rhode Island			*		*	*							
South Carolina		*		*	*			*		*			
South Dakota			*	*	*	*	*				*		*
Tennessee			*	*			*	*		*			
Texas		*	*	*				*					
Vermont			*	*	*	*		*		*			
Virginia			*	*				*		*			
West Virginia			*	*	*	*	*	*		*			
Wisconsin		*	*		*			*					

NOTE: Attributes used for priority setting: 1. Sufficiency rating; 2. Cost of improvements; 3. Structural strength, including condition rating, appraisal rating, operating rating, and posted load limit; 4. Traffic safety because of functional deficiency; 5. Locational importance of bridges, including route for emergency vehicles and essentiality to nearby communities; 6. Estimated remaining service life; 7. Type of highway that a bridge serves, including functional classification and other highway classifications; 8. Average daily traffic; 9. Average daily traffic of heavy vehicle or percent truck; 10. Detour length; 11. Coordination with other construction projects; 12. Route/bridge continuity; and 13. Accident records related to bridges.

ment, estimated remaining service life, and detour length. The District of Columbia, Florida, and Oregon also consider the volume of truck traffic as a factor.

Part of a flow chart of the method for setting priorities on bridge replacement and rehabilitation projects used by the Louisiana Department of Transportation and Development is shown in Figure 1. This flow chart illustrates a general method used by many states to set priorities on bridge projects. The procedure resembles the successive subsetting method developed for Indiana (7) to set priorities for highway- and bridge-improvement projects.

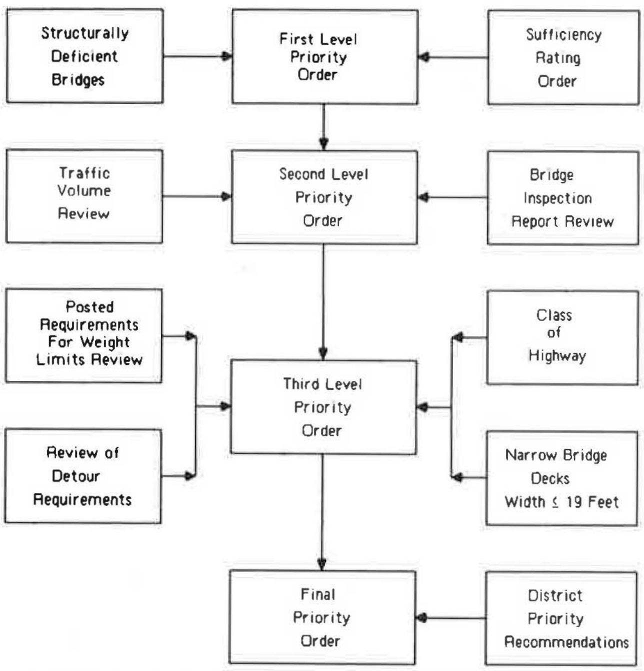

FIGURE 1 Part of the flow chart of the priority-setting method on bridge replacement and rehabilitation projects used by the Louisiana Department of Transportation and Development.

Distresses Versus Improvement Alternatives

The type and severity of bridge distresses will determine the type of improvement alternative. Careful identification of distresses is thus a critical element in bridge management systems. Furthermore, as condition ratings are widely used as an important factor in priority setting, the consistency in relative individual distresses to overall condition ratings must be maintained. Interviews with district bridge inspectors in Indiana demonstrated a high turnover rate for these engineers. Under such circumstances, the existence of guidelines for relationships between distresses, ratings, and improvement alternatives becomes significant for an effective bridge management system. The survey indicated that 19 states (42 percent) have such guidelines, whereas the remaining 25 states (58 percent) do not.

Several states mentioned the use of the maintenance and inspection guidelines published by AASHTO. Many states, however, publish their versions of the recording and coding guides in which detailed descriptions are provided for field inspectors to rate structural and functional deficiencies. For example, the guides prepared by North Dakota and Missouri contain highly detailed explanations concerning condition ratings. North Dakota's guidelines *(8)* contain comments on the relationship between condition ratings and actual distress levels, whereas Missouri's guidelines *(9)* provide specific items to watch while assigning certain ratings to structure components.

Bridge Project Programming Procedures

There can be two basic approaches to bridge project programming: a centralized approach and a decentralized approach. In the first case, district or regional offices select bridges to be considered for improvement and the central office and state bridge engineer set priorities on bridges. Selected bridge names are then sent to the state planning or programming office or both for actual programming. The majority of the states responding follow this general procedure. An example of the second group is California, where district planning offices are given the responsibility for setting priorities on bridge projects and programming. The programming process is, however, overseen by the California Transportation Committee.

Two states are currently in a state of transition concerning the authorization to program projects. In Florida, the programming procedure is being changed from a central office function to a district function. Procedures and policies were being developed as of July, 1986. On the other hand, in Ohio this programming task is now being sent back to the central office. The selection process based on need would eventually ignore the field district's geographical boundaries and base the selection almost entirely on sufficiency rating, but with some allowance for consideration of other factors.

Areas of Concern: Suggestions for Improvement

In answer to the question of whether any changes are necessary to improve the existing bridge management systems, 31 states (70 percent) responded that improvements are necessary. Thirteen of these 31 states expressed the need for a comprehensive bridge management system that would encompass maintenance, rehabilitation, and replacement of existing bridges. In 8 states, studies on bridge management systems were underway as of July, 1986. Texas has embarked on a research study on bridge management systems. In Pennsylvania, development of a comprehensive bridge management system has been underway since 1983 *(10)*. Figure 2 shows the structure of Pennsylvania's bridge management system. The resulting system will eventually be integrated into the roadway management system. Three states specifically mentioned that they would like to have a management system that could use the existing inventory data system effectively and systematically identify the most cost-effective choice for maintenance, rehabilitation, and replacement alternatives. Inclusion of cost data in the bridge management system is therefore considered to be essential by several states.

One state mentioned that a bridge management system is needed so that the political influence in the priority-setting task could be minimized to result in a more objective ranking of bridges. Where the priority-setting method is not specific, there would be more room for political maneuvers. Other concerns

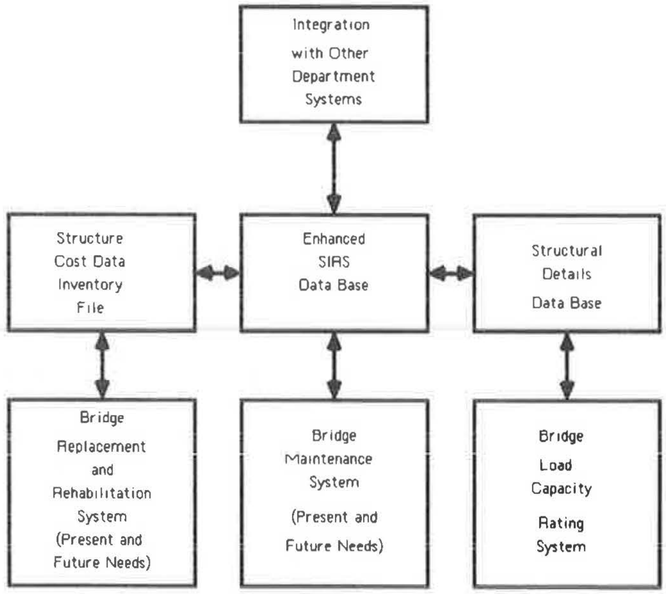

FIGURE 2 Flow diagram showing the basic parts of the Pennsylvania bridge management system.

expressed by two states might also apply to other states that are trying to develop a bridge management system. One important item is the commitment of top management in developing bridge management systems. The other concern is the availability of funds, time, and personnel. In Pennsylvania, for example, where a special group is devoted entirely to bridge management, the task of developing a comprehensive bridge management system may be easier. However, for many state highway agencies these two items may become a major hindrance.

Thirteen states (30 percent of the responding states) mentioned that their existing system is meeting the requirements for managing bridges in their jurisdictions. One reason for this is that these states have only a small number of deficient bridges and they can be adequately managed by subjective decisions. However, even some of these states believe that refinements to the existing system are needed.

SYSTEMATIC PRIORITY-SETTING PROCEDURES DEVELOPED BY STATE HIGHWAY AGENCIES

A critical element in a bridge management system is that of setting priorities on bridge-rehabilitation and replacement projects. Although a procedure for assessing present and future needs is required for long-term priority-setting and programming, the availability of an appropriate procedure is still scarce at present, as shown in Figure 3. In fact, 35 states (80 percent) do not have such a procedure readily available at present.

It was found that 7 of the 45 states had some kind of priority-setting procedures. These states are Kansas, Michigan, Minnesota, New York, North Carolina, Pennsylvania, and Wisconsin. The procedures used in North Carolina and Pennsylvania are based on a deficiency point procedure and the remaining procedures on a rating point procedure. Besides these states, Virginia responded that they use a deficiency point procedure, but the description was not available as of July 1986. In a deficiency point procedure, a set of acceptable and desirable levels of service is determined. Bridges that do not meet these criteria are given appropriate deficiency points. In a rating point procedure, certain points or relative weights are given to condition or appraisal ratings and other factors included in the consideration.

Description of Selected Priority Setting Procedures

A discussion of the procedures is presented below, with a summary of the attributes and factors used in the priority-setting procedures used by seven states. Their relative weights or point weights follow each state listing.

Kansas

In Kansas, two separate algorithms are used for priority setting: one for roads and one for bridges. The priority-ranking result-

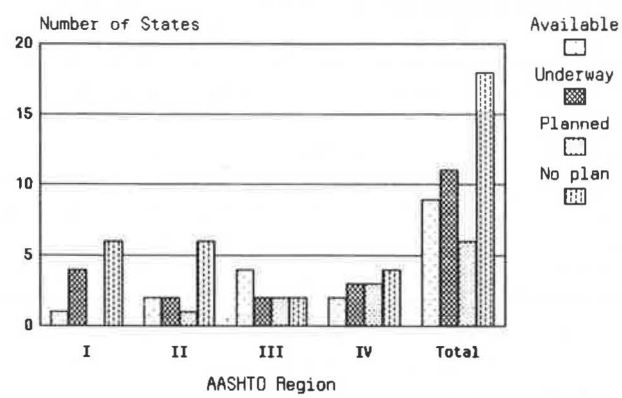

FIGURE 3 Development of a procedure for systematic programming of bridge replacement, rehabilitation, and maintenance.

ing from the use of these two algorithms is used to select projects for further consideration by the priority-optimization system. Three major factors are considered: traffic safety, structure strength, and structural condition. The major factor is the structural condition of a bridge, which represents 55 percent of the weight. The other two factors account for the remaining 45 percent of the weight. As roads and bridges are ranked together in this management system, a bridge adjustment factor is applied. The relative importance of bridges compared with roads is 0.53. Other factors are the functional class of roads, and the volume of traffic on or over the roads the bridges are serving. Accident rate and posted speed limit are also taken into account, but they affect final ratings only partially.

1. Basic attributes: (a) Horizontal clearance, 0.196; (b) Bridge roadway restriction, 0.088; (c) Deck condition, 0.232; (d) Structural condition, 0.314; (e) Operating rating, 0.170.

2. Adjustment factors: (a) Factors affecting all attributes: (i) Relative importance of bridges compared with roads, 0.53; (ii) Functional classification, 0.55 to 1.00; (iii) AADT, 0.381 to 1.000; (b) Factors affecting basic attributes (a) and (b): (i) Accident rate, 0.734 to 1.000; (ii) Posted speed limit, 0.191 to 1.000.

Michigan

Bridges requiring improvements are currently identified by the Critical Bridge Rating method, a numerical prioritization system. Three major factors are considered for determining critical bridge ratings: physical condition and traffic safety, financial capability of the highway authority, and importance of structure. The second of these is unique to this procedure and no other states responding to the survey included this factor in a set formula. In order for the two attributes to accurately represent improvement needs, the assessment of future needs must be carefully made. All three factors account for approximately the same weight in determining critical ratings. This method allows for the input of the selection committee, which consists of nine members. Committee members' opinions account for 27 points of the total 98 points. Committee members cast votes expressing their opinions on the seriousness of four attributes: (a) operating rating, (b) detour evaluation, (c) economic impact, and (d) functional classification performance evaluation.

1. Physical condition, total 35 point maximum: (a) Operating rating appraisal, 25 point maximum; (b) Traffic safety: (i) Bridge and approach features, 8 point maximum; (ii) Deck geometry, 2 point maximum.

2. Financial capability of highway authority, total 30 point maximum: (a) Total needs-funds ratio, 15 point maximum: (b) Total funds-structure cost ratio, 15 point maximum.

3. Importance of structure, total 33 point maximum; (a) Detour evaluation, 4.5 point maximum; (b) Traffic volume, 15 point maximum; (c) Economic impact evaluation, 9 point maximum; (d) Functional classification performance evaluation, 4.5 point maximum.

Minnesota

In Minnesota, two approaches are used to set replacement priorities for deficient bridges: one for bridges on the trunk highways, and one for those on non-trunk highways. All deficient bridges on the trunk highways are listed in priority order according to their rating computed by a formula that considers several attributes. No set formula is used for deficient bridges on non-trunk highways. In determining replacement priorities of bridges, a formula based on priority point values is used. Point values are assigned to the different items, which are grouped into three major areas: (a) structural adequacy, (b) serviceability and functional obsolescence, and (c) essentiality for public use. Percentages are then assigned to the sum of priority points in each consideration area: 50 percent for structural adequacy and safety, 25 percent for serviceability and functional obsolescence, and 25 percent for essentiality for public use.

1. Structural adequacy and safety, 50%: (a) Safe load appraisal rating, 20 point maximum; (b) ADT point, 6.5 point maximum; Category 1 total = $(a) \times (b)$.

2. Serviceability and functional obsolescence, 25%: (a) Deck geometry appraisal rating, 11 point maximum; (b) ADT, 6.5 point maximum; (c) Underclearance appraisal rating, 12 point maximum; (d) Water adequacy appraisal rating, 6 point maximum; (e) Approach roadway alignment appraisal rating, 6 point maximum; (f) Structural condition appraisal rating, 9 point maximum; (g) Type of bridge, 3.5 point maximum; (h) Age of structure, 4.0 point maximum; Category 2 total = $(a + b + c + d + e + f + g) \times h$.

3. Essentiality for public use, 25%: (a) Detour length, 11 point maximum; (b) ADT, 6.5 point maximum; (c) Road system designation, 6.5 point maximum; (d) Functional classification, 9 point maximum; (e) Bridge record for defense, on = 1, off = 0; Category 3 total = $a + b + c + d + e$.

New York

For priority rating of structures for rehabilitation or replacement, the New York State Department of Transportation computes a numerical value called RATE, which is derived by using the conditions of elements of a bridge and the volume of traffic using the bridge. The structural condition is the primary component and the traffic volume serves as a secondary component to compute a RATE value. The structural condition is first given a numerical value called Condition Rating, using the Department's structural-condition formula. Two formulas are used to compute RATEs for structures according to traffic volume.

Bridge elements considered: (a) Primary members, 10; (b) Abutments, 8; (c) Piers, 8; (d) Structural decks, 8; (e) Bridge seats, 6; (f) Bearings, 6; (g) Wingwalls, 5; (h) Backwalls, 5; (i) Secondary structural members, 5; (j) Joints (superstructure), 4; (k) Wearing surfaces and joints, 4; (l) Sidewalks and fascias, 2; (m) Curbs, 1.

North Carolina

North Carolina developed a bridge management system based on a concept of level of service in meeting public needs. Deficiency points are computed based on the magnitude of the

deficiency of certain attributes in relation to a set of acceptable and desirable minimum standards. Three characteristics of a bridge are considered: (a) single-load capacity, (b) clear bridge deck width, and (c) vertical roadway underclearance and overclearance. Their maximum point weights are shown in the table that follows. To these three characteristics, acceptable and desirable goals are set for functional classification and current ADT combinations. For instance, if a bridge is on a two-way arterial that carries between 801 and 2,000 in ADT, the acceptable clear deck width is 22 ft and the desirable deck width is 35 ft. Besides these three level-of-service characteristics, another characteristic, remaining service life, was included to compute the level of service deficiency points. A detailed description is given by Johnson et al. *(4)*.

1. Level-of-service attributes: (a) Single-vehicle load capacity, 70 point maximum; (b) Clear bridge deck width, 12 point maximum; (c) Vertical roadway underclearance or overclearance, 12 point maximum; (d) Estimated remaining life, 6 point maximum.
2. The formulas to determine these four deficiency points may be found elsewhere *(4)*.

Pennsylvania

The bridge management system of the Department of Transportation (PennDOT) is probably the most comprehensive program now available in the nation as of July 1986. The PennDOT priority-setting procedure incorporated North Carolina's level-of-service method and added structural condition information to overcome what can be a shortcoming of the North Carolina method.

Bridge deficiencies are evaluated in two categories, level of service and bridge condition, and these deficiency points are combined to obtain the total deficiency point, on a scale ranging from 0 to 100. The level-of-service criteria include three characteristics: (a) load capacity, (b) clear bridge deck width, and (c) vertical clearance. Deficiency points for bridge condition are computed using condition ratings. Bridge condition characteristics include superstructure, substructure, and bridge deck, as well as remaining service life. Maximum point weights of each characteristic are indicated as follows:

1. Level-of-service attributes, 75% at present: (a) Load capacity deficiency, 70 point maximum; (b) Deck width deficiency, 20 point maximum; (c) Vertical clearance deficiency, 10 point maximum.
2. Bridge condition deficiency (DPBC), 25% at present. (When the total bridge condition deficiency point becomes greater than 100, it is considered as 100.)
3. Total deficiency point = 0.75 (DPLS) + 0.25 (DPBC).
4. The formulas to determine these level-of-service and bridge condition deficiency points may be found elsewhere *(8)*.

Wisconsin

In Wisconsin, bridges requiring either rehabilitation or replacement are first selected based on condition appraisal and sufficiency ratings. A life-cycle cost model supplements the information of future improvement needs *(11)*. A priority list of bridges for replacement is developed by using the Rate Score. The rate score is obtained by subtracting from 100 the quotient of the sum of weighted appraisal rating points divided by the sum of weighted factors. The sum of weighted rating points is obtained by multiplying the point given to each item based on its condition appraisal by its weighting factor followed by the summation of all the products. The denominator is the summation of weighting factors, which is 118. The smaller the rating score, the worse the bridge condition. Indicated in the following list are the items considered in the priority-setting method. Each item is given points based on the 0 to 10 scale. As shown in the list, items related to structural adequacy and safety receive large weight compared with other items related to traffic safety or highway functional class.

Attributes considered (all attributes at 10 point maximum): (a) Superstructure condition rating, 25 point maximum; (b) Substructure condition rating, 25 point weight; (c) ADT in thousands, 13 point weight; (d) Horizontal or vertical alignment rating (the worst case of the two items is used), 8 point weight; (e) Roadway width or lateral underclearance (the worst case of the two items is used), 8 point weight; (f) Vertical clearance—over or under, 8 point weight; (g) Water adequacy appraisal, 6 point weight; (h) Functional class, 5 point weight; (i) Inventory rating and posted load limit, 20 point weight.

Evaluation of Selected Priority-Setting Procedures

An evaluation of the seven procedures was made based on two criteria. One is to examine whether weighting schemes embedded in the procedures accurately reflect decision makers' value systems in relation to the attributes and factors considered. The other is their ability to address properly the improvement needs of bridges.

Most of the seven procedures fully or partially incorporated the curvilinear nature of FHWA's bridge condition rating scheme. FHWA's SIA *(2)* condition and appraisal ratings show a non-linear relationship between ratings and levels of distresses encountered. A major break exists between rating scores 4 and 3 in terms of needed improvement activities. According to the SIA descriptions, rehabilitation needs significantly increase as the condition rating goes from 4 to 3. At rating 4, the structure is still in a marginal condition where potential exists for major rehabilitation. However, at rating 3, it is in poor condition where repair or rehabilitation is required. There is also a significant difference between ratings 3 and 2.

A similar argument can be made for other factors such as remaining service life and ADT factors. For example, the North Carolina method uses a straight-line function to compute deficiency points for the remaining service life beyond 3 years, whereas the Pennsylvania method uses a risk-averse, nonlinear function for the remaining service life beyond 5 years. It can be said that the concept used by PennDOT reflects how decision makers might feel about the importance of remaining service life in their decision making. In PennDOT's method, a decrease in the remaining service life closer to 5 years is considered significant, whereas the importance of the factor of

remaining service life becomes less as the remaining life becomes larger.

As for the second criterion, some priority-setting procedures need modification. For instance, in Minnesota's procedure, the structural appraisal rating earns less weight than the deck-geometry appraisal rating. The appropriateness of this weighting scheme can be questioned. A similar reversal of importance may take place in New York's procedure. Suppose that main structural members were rated 2 and the condition of piers was rated 5, or [rated in] generally fair condition. According to the current system, the weighted rating of the main structural members becomes 20 and that of the piers results in 40. If only these two elements were used, the condition rating of this bridge would be 3.33, which may mask the need for improvement of the structural members. North Carolina's level-of-service approach considers four attributes: single vehicle load capacity, clear bridge deck width, vertical roadway under/overclearance, and estimated remaining service life *(6)*. The method can be easily understood despite the elaborate formulas developed to compute deficiency points. However, dropping all condition-related information except the remaining service life may not be adequate to address structural needs for improvement. Furthermore, the selection of factors is dependent on the subjective judgment of the decision makers.

SUMMARY AND CONCLUSIONS

The questionnaire survey provided a state-of-the-art review of current practices in bridge management procedures used at the state level. It was found that most of the states have well-defined programs of procedures to set priorities on bridge rehabilitation or replacement programs. The study on bridge maintenance has just begun and only a few states, such as Pennsylvania, have established procedures to program bridge maintenance projects. The survey results were instructive in understanding how state highway agencies accomplish the allocation of funds to bridge projects.

Although most of the states responding to the survey follow the guidelines of the federal SIA program, they modify and expand their data base to accommodate extra information for their use at the state management level. It was found that only ten (23 percent) of the 44 states use sufficiency rating as a major factor in setting priorities. Most state highway agencies use it to separate bridges into either the rehabilitation or replacement category to meet the federal funding requirement.

Relationships between distresses and improvement alternatives are not well established for bridge management compared with pavement management. Not many states have information on the relationship between the type and severity of bridge distresses and their improvement measures.

It was found that the responsibility of setting priorities on bridges and subsequent programming is mostly centralized. A list of bridges requiring rehabilitation or replacement is prepared by the district or region of a state. The central office then places priorities on bridges for future programming. A few states, like California and Florida, use a decentralized procedure and delegate the responsibility to their districts.

The majority of the state highway agencies (31 out of the 44 states) intend to improve the existing management procedures according to the questionnaire. Thirteen (42 percent) of these 31 states indicated the need for comprehensive bridge maintenance systems, preferably based on the existing data base. Some states also indicated that cost data should be incorporated into a bridge management system.

Of the 44 states, 7 have established procedures to set priorities on bridges by weighting factors with numerical values. A few modifications may be necessary to address the actual needs of bridges accurately. Many state agencies do not have formal priority-setting procedures to provide objective ratings of bridges. Some state highway agencies expressed their lack of confidence on such numerical weighting procedures. Some of the ambiguities of numerical weighting procedures, however, may be reduced by employing multi-attribute decision-making theories developed in the field of management science. Examples of the applications of these theories to bridge priority-setting problems are found in the literature *(12-14)*.

In conclusion, it can be said that many states are not satisfied with their current bridge management procedures and seek a comprehensive bridge management system. Such a system may include steps that would estimate present and future needs, set priorities on projects, and determine optimal sets of bridge projects to use the limited funds effectively. The questionnaire survey revealed that the currently used procedures are mostly aimed at short-term programs. A priority listing is made based on the data available at the time of programming, and projects are selected based on this information. One state, Wisconsin, was found to have a long-term bridge programming procedure in operation. Considering the fact that it takes several years to actually start constructing planned bridge projects because funds for preliminary engineering and bridge construction must be acquired, estimating the future condition of bridges is considered to be significant in bridge management systems.

Further Research Needs

The prime concerns at the state level at present are the development of a priority-setting procedure in which all the actors involved in the task of bridge management can have confidence, and that decisions made within a highway agency are consistent at all the levels of management concerned. Numerical weighting methods are one procedure that can be used to help decision makers stand on an objective and consistent decision-making platform. They should help develop a clear communication link between different levels of decision makers involved in bridge management. Current developments in the field of management science can be of help in developing such a method. It should be noted that such numerical methods are a supplement to, but not a substitute for, explicit evaluation of all relevant factors and consequences.

Efforts have been made by the state highway agencies to select factors to be considered in bridge management. Deficiency-point methods place a great deal of weight on level of service. Other rating point value methods use appraisal ratings as part of factors as well as condition ratings. However, it is believed that bridge rehabilitation or replacement decisions should be made by considering the physical condition of the structures as a major factor. Further research is needed to

simulate the dynamic nature of bridge conditions so that an accurate assessment of future bridge needs can be accomplished.

In order to make an accurate estimation of future bridge conditions, it is necessary to make accurate condition ratings of bridges. It was found from interviews with field bridge inspectors in Indiana that turnover rates of field inspectors, who form a significant part of a bridge management system, are high. To have a consistent evaluation of bridges, a set of appropriate inspection guidelines needs to be developed so that the quality of information provided for management decision making is improved. Condition ratings are somewhat subjective and imprecise. A procedure that translates various bridge characteristics into accurate condition ratings needs to be incorporated in a bridge management system.

Inclusion of appropriate cost data into a bridge management system is another critical area that requires further analysis. Currently, the FHWA requires each state highway agency to submit only unit structure costs, including superstructure and substructure costs, because of the variations expected in other cost items. At the state level, however, other costs such as approach and demolition costs need to be estimated. Owing to the nature of these cost items that are specific to construction sites, estimation is often made based on both previous experience and arbitrary guesswork. A more systematic approach is needed to estimate unit costs of major bridge items.

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