BRIDGE MANAGEMENT AT THE LOCAL GOVERNMENT LEVEL

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16. Abstract

The objective of this project is to provide local transportation officials with the information required to make sound decisions on the management of the bridges within their jurisdiction. Automated procedures are developed to prioritize the required maintenance, rehabilitation, or replacement (MR&R) within the district and present this information to the inventory manager. The automated procedure is intended to aid the transportation official in MR&R decisions, but not to be the final solution to every situation. In short, the program provides guidance.

This study investigated several existing bridge management programs, and attempted to apply these programs to a bridge management system (BMS) in a rural western environment. If an existing BMS could be modified to a rural environment, it was necessary to determine the extent of the necessary modifications and the computer resources required to implement the program; and if no existing BMS would be appropriate, develop a microcomputer-based bridge management program for the local and county bridge managers within Wyoming.

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DISCLAIMER

The data, methods, and findings presented herein are the sole responsibility of the Mountain Plains Consortium and the authors.

PREFACE

The need for rural bridge management is a growing concern for local transportation officials. It was our goal to examine existing methods of bridge management in relation to an applying such a method to a rural Wyoming environment using a microcomputer application. A computer program to utilize the existing database and prioritize recommended maintenance, rehabilitation, and replacement by a deficiency point system was developed.

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CHAPTER 1

INTRODUCTION

THE NEED FOR MANAGEMENT

A large percentage of the nation's bridges are more than 50 years old. These bridges were designed for less traffic, slower speeds, and lighter loads, and when combined with effects of deterioration, are increasingly in dire need of maintenance, rehabilitation, or replacement (MR&R). Although very few bridges on the interstate highway system fall into this group, a majority of county and local bridges do.

The fact that the majority of the nation's critical bridges are under the jurisdiction of local government agencies, where limited funds are available for these projects, only adds to the need for bridge management. An effective method of bridge management must be developed for the safety of the public and for sound financial planning at the local government level.

Public Safety

As the demands placed on the bridges within Wyoming continue to increase, the burden increases on state, county, and local officials to maintain the safest possible transportation systems. These officials understand that public safety is of the utmost concern and that careful assessment must be made to assure that the structures within their jurisdiction are in safe condition.

As the demands on these structures increase, so does the need for maintenance. Besides the effect weather has on the components of a bridge, traffic also plays an important role in the deterioration. The more demands on a structure, the more maintenance is required, and with the added maintenance the structure often receives increased use in volume and load, in a never-ending cycle.

The simplest or ideal solution to this problem is not the most practical. This solution would be to provide all required MR&R on the county's structures without concern for cost. Nationally, it would cost an estimated $50+ billion (Hudson, et al). In actuality there is only $2-3 billion annually available to address the MR&R problem of the nation's bridges. As this solution of providing all required MR&R is impractical, a method of scheduling the MR&R has to be developed to assist transportation officials in providing the safest structures possible with the funds available.

Financial Planning

To provide all the necessary MR&R on the State's bridges would require more funds than are currently available. A method should be developed to assist transportation officials in their decisions regarding the best use of existing funds. Many factors must be examined in scheduling MR&R funds, including but not limited to:

1. Maintaining the safest possible structures.
2. Improving public convenience.
3. Preserving the financial investment of the structure.
4. Providing efficient routes for emergency service vehicles.
5. Preventing traffic delays or disruptions that would increase user cost.
6. Providing economical routes for the transport of goods and services.
7. Correcting deficiencies within a reasonable time.

8. Allocating funds that best serve the long-range needs of the public.
9. Avoiding costly repairs through preventative maintenance.
10. Using engineering and maintenance personnel efficiently.
11. Using funding sources efficiently.
12. Minimizing life-cycle costs.

These issues may require that necessary MR&R be neglected on a particular structure until the time comes to replace the structure, or that MR&R be conducted on a structure that does not appear to require such attention.

OBJECTIVES OF RESEARCH

Initial Parameters

The objective of this project is to provide local transportation officials with the information required to make sound decisions on the management of the bridges within their jurisdiction. Automated procedures are developed to prioritize the required MR&R within the district and present this information to the inventory manager. The automated procedure is intended to aid the transportation official in MR&R decisions, but not to be the final solution to every situation. In short, the program provides guidance.

Several guidelines were established at the beginning of the research. These guidelines are:

1. Keep the same data format that the Wyoming Department of Transportation (WDT) is currently using. This eliminates the need for data conversion programs to translate data and the problems associated with translating data.

2. If an existing database can be adapted for use in rural Wyoming, it should be pursued within the limits of guideline #1.

3. The software developed should be able to run on a DOS-based operating system where data exchange can be by a convenient media (i.e. floppy disk).

Procedure of Research

The final procedure was to design software that utilized the INFORMIX database tables that the WDT currently is using. This database format was then expanded into a inventory routine similar to the dBASE software currently used by the Kansas Department of Transportation (KDOT) with the addition of a prioritizing routine to rank the structures beyond the NBIS sufficiency rating. This program was written in two phases. First, a program similar to the KDOT program BIS was developed. Second, the program was enhanced by adding a prioritizing routine. This prioritizing routine uses data items that are already present in the database in an algorithm to rank possible MR&R projects.

The scope of this work was limited to the implementation of these two phases as related to rural bridges in Wyoming. Other rural states with political, climatic, and demographic characteristics similar to Wyoming's will be able to adapt much of this work.

CHAPTER 2

REVIEW OF EXISTING LITERATURE

Of the nearly 574,000 bridges in the United States, nearly half were built before 1940. Of these 574,000 bridges, the Federal Highway Administration (FHWA) has rated approximately 45 percent as either functionally or structurally obsolete (Saito and Sinha), with more bridges joining this list each year as indicated by inspection reports. For a structure to be either structurally deficient or functionally obsolete it must have a Federal Sufficiency Rating less than 80.

A structurally deficient bridge is inadequate to carry legal loads, whether caused by obsolete design standards, structural deterioration, or waterway inadequacy. Bridge adequacy is determined by an on-site inspection, after which a condition rating and an appraisal rating are assigned. If a bridge has a condition rating of four or less for the deck, superstructure, substructure, culvert, or retaining wall, or an appraisal rating of two or less for the structure condition or waterway, it is considered structurally deficient.

A functionally obsolete bridge is one that is inadequate to properly accommodate the traffic due to inadequate clearances, roadway alignment, structure condition, or waterway adequacy. If a bridge has a appraisal rating of three or less for the deck geometry, underclearances, or approach roadway alignment, or an appraisal rating of three for the structural condition or waterway, it is considered functionally obsolete.

The FHWA sufficiency rating is computed using the structural-condition rating from the inspection reports of bridge components and other related information. This rating index is a number assigned to a bridge to determine its sufficiency for the demands placed on it. A scale from 0 to 100 is used. A rating of 100 represents an entirely sufficient structure (new structures are assigned 100), and the lower the number the more likely the bridge is in need of MR&R. The formula for determining the sufficiency rating is divided into four parts pertaining to the following structural attributes: structural adequacy and safety, serviceability and functional obsolescence, essentiality for public use, and special reductions. For further explanation of sufficiency rating, see Appendix A.

The federal government has set guidelines for federal funds in the case of replacement or rehabilitation based on the sufficiency rating. A sufficiency rating of less than 50 is eligible for replacement funds and a bridge with a sufficiency rating of 50 to 80 is eligible for rehabilitation funds (Saito and Sinha).

Of the 44 states that responded to a survey by Saito and Sinha (1986), the majority said there was a need for a comprehensive procedure in which decisions were made concerning bridge management[3]. Several states responded that they already had some sort of bridge management system (BMS) in operation. Of the states responding, 48 percent strictly followed the FHWA's "Recording and Coding Guide for the Structure Inventory and Appraisal (SIA) of the Nation's Bridges" to record information on bridges, and 45 percent followed SIA with modifications to accommodate extra data the state deemed important (Saito and Sinha). Wyoming is one state that has expanded upon the SIA fields.

Eight states already have BMS systems in operation: Indiana, Kansas, Michigan, Minnesota, New York, North Carolina, Pennsylvania, Virginia, and Wisconsin. Five of these programs are discussed in detail: North Carolina, Virginia, Kansas, and Pennsylvania, and Indiana.

Thirty-six percent of the responding states have or will have a priority-setting procedure. The majority of the states, however, do not assign numerical weights to the factors considered. Rather, weights are altered on a structure-to-structure basis. This strategy can lead to misleading results.

The type of factors that are considered in setting priorities for bridge MR&R are shown in Table 1. The table shows items that were reported by at least two states. It was noted that cost of improvement was often excluded from consideration in the priority-setting decision. As shown in the Table 1, 26 states considered cost whereas 18 states did not. The most common factors considered were structural strength, traffic safety, and locational importance. The structural strength factor includes such items as condition rating, appraisal rating, operating rating, and posted limit. The traffic safety factor consists of items such as deficient bridge deck width and vertical clearances.

Table 1. Attributes Used for Bridge Priority Setting at the State Level

State	1	2	3	4	5	6	7	8	9	10	11	12	13
AL		•	•	•	•	•	•	•		•			
AK		•	•	•	•	•	•	•		•			
AZ		•	•	•	•	•							
AR	•	•	•	•	•	•	•	•		•			
CA		•	•	•	•	•	•	•		•			
CO		•	•	•	•	•	•	•		•	•		
CT		•	•			•				•			
DC		•	•	•	•	•	•	•	•	•			
FL			•	•	•	•	•	•	•	•			
HI			•	•	•	•	•	•		•			
ID	•			•		•		•					
IL	•	•	•	•	•	•	•	•		•			
IN			•	•	•	•	•	•		•			
IA		•	•	•	•	•	•	•		•	•	•	
KS			•	•			•	•				•	•
KY	•	•	•	•	•	•	•	•		•			
LA	•	•	•	•	•		•			•			
ME		•	•	•	•	•	•	•		•			
MD			•	•	•	•		•					
MA	•		•	•	•			•		•			
MI			•	•	•					•			
MN		•	•	•	•	•	•	•					
MS		•	•	•	•	•	•	•		•			
MO				•	•		•	•					
MT	•					•				•			
NV	•	•	•	•	•	•	•	•		•			
NH		•	•	•	•	•	•	•		•			
NJ		•	•	•	•	•	•	•		•			
NY		•	•	•	•	•	•	•		•			
NC			•	•	•	•	•	•		•			
ND		•	•	•	•	•							
OH	•	•	•	•	•	•	•	•		•			
OK	•	•	•	•		•	•	•			•		
OR		•	•	•	•	•	•	•	•	•	•		
PA			•	•		•	•	•					
RI			•		•	•							
SC		•		•	•			•		•			
SD			•	•	•	•	•				•		•
TN			•	•		•	•	•		•			
TX		•	•	•				•					
VT			•	•	•	•		•		•			
VA			•	•				•		•			
WV			•	•	•	•	•	•		•			
WI		•	•		•			•					

NOTE: Attributes used: 1. Sufficiency Rating; 2. Cost of Improvements; 3. Structural strength; 4. Traffic safety because of functional deficiency; 5. Locational importance of bridges; 6. Estimated remaining service life; 7. Type of highway that the bridge serves; 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 record.

SOURCE: Saito, Mitsuru and Sinha, Kamares C., "Review of Current Practices of Bridge Management at the State Level", Transportation Research Record 1113, Transportation Research Board, 1987, p. 2.

RANKING FORMULA

All these bridge management systems use a ranking formula of some form. According to Kurt, the ranking formula's simplest form is:

$$Ranking = \sum (K, f(a,b,c,\ldots)) \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where: K = weighting factors
f(a,b,c,...) = priority ranking formulae
a,b,c = bridge parameters

NORTH CAROLINA BMS

North Carolina has 17,300 bridges, with 97 percent being state-maintained, and about 65 percent qualifying for replacement (being either structurally deficient or functionally obsolete)(Hudson et al.). North Carolina's BMS developments have been based on the concept of level-of-service in meeting the public needs. Deficiency points are computed based on the magnitude of the deficiency of relative attributes in relation to acceptable minimum standards. Three characteristics are used (Kurt):

1. single-load capacity,
2. clear bridge deck width, and
3. vertical roadway underclearance and overclearance.

These levels-of-service characteristics were defined as functions of road classification, average daily traffic (ADT), and the number of lanes. Table 2 illustrates the level-of-service goals used by the North Carolina Department of Transportation (NCDOT).

Table 2. Level-of-Service Goals used in North Carolina Bridge Management.

Highway Function Classification	ADT	Single Vehicle Load Capacity (tons)	Lane Width (feet)	Shoulder Width (feet)	Vertical Clearance (feet)
Major Collector	≤800	25.0	9	1	14
	≤2000	25.0	9	2	14
	≤4000	25.0	10	2	14
	>4000	25.0	10	3	14
Minor Collector	≤800	16.0	9	1	14
	≤2000	16.0	9	2	14
	≤4000	16.0	10	2	14
	>4000	16.0	10	3	14

Note: Deck Width Goal = (Number of lanes * lane width) + (2 * shoulder width)

SOURCE: Kurt, Carl E., "Bridge Management System Software for Local Governments", Transportation Research Record 1184, Transportation Research Board, p 50, 1988.

The North Carolina BMS ranking formula for determining the deficiency points (DP) is:

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

where CP, WP, VP, and LP are need functions for load capacity, deck width, vertical over/under clearance, and estimated remaining life, respectively. Each value of CP, WP, VP, and LP is determined by functions related to elements of the bridge.

The ranking for load capacity (CP) is:

$$CP = WC\left(\frac{CG - SV}{10}\right)(0.6\ KA + 0.4\ KD) \quad \text{(3)}$$

where: $$KA = \frac{(ADTO)^{0.3}}{12} \quad \text{(4)}$$

$$KD = \left(\frac{DL}{20}\right)\left(\frac{ADTO}{4000}\right) \quad (5)$$

CG = level-of-service load capacity goal (tons: see Table 2)
SV = single vehicle posting (tons)
ADTO = average daily traffic of over route
DL = detour length (miles)
WC = capacity weighting factor

The variables are defined as: load capacity goal is the level-of-service goal that is desirable for the bridge; single vehicle posting is the maximum load capacity of a single vehicle; average daily traffic of over route is the ADT the bridge carries; and the detour length is the distance the ADT is rerouted if bridge is closed.

The ranking formula for deck width (WP) is:

$$WP = WW\left(\frac{WG - CDW}{3}\right)\left(\frac{ADTO}{4000}\right) \quad (6)$$

where: WG = level-of-service deck width goal (feet: see Table 2)
CDW = present clear deck width (feet)
WW = deck width weighting factor

The ranking formula for vertical clearance (VP) is in two components to account for traffic over and under the bridge:

$$VP = VPU + VPO \quad (7)$$

where:

$$VPU = WV\left(\frac{UG - VCLU}{2}\right)\left(\frac{ADTU}{4000}\right) \quad (8)$$

$$VPO = WV\left(\frac{OG - VCLO}{2}\right)\left(\frac{ADTO}{4000}\right) \quad (9)$$

UG = level-of-service underclearance goal (feet: see Table 2)
VCLU = present vertical underclearance (feet)
ADTU = ADT of under route
OG = level-of-service overclearance goal (feet: see Table 2)
VCLO = present vertical overclearance (feet)
ADTO = ADT of over route
WV = vertical clearance weighting factor

The variables are defined as: underclearance goal is the level-of-service clearance goal between the bridge and a route under the bridge; the present vertical underclearance is the existing clearance between lower route and bridge; the overclearance goal is the level-of-service clearance goal between the bridge deck and an overhead obstruction; and the present overclearance is the existing clearance between bridge deck and overhead obstruction.

The last component of North Carolina's ranking formula is the estimated life left for the bridge. The ranking formula for estimated remaining life (LP) is:

$$LP = WL \left[1 - \frac{(RL - 3)}{12} \right] \qquad (10)$$

where: RL = estimated remaining life (years)
WL = life weighting factor

The variable for estimated remaining life is an approximation of the useful life remaining based on general bridge condition. A remaining life of 15 years or more was selected as an indicator of a bridge in good overall condition. A bridge with less than three years of estimated life remaining was assigned the maximum deficiency points since the planning, funding, design, and construction processes require about three years.

The value for each component could not be less than zero or greater than the corresponding weighting factor. This method of computing the deficiency of a structure is easily done on a microcomputer; in this case it was programmed into a PC using the dBASE III Plus™ data management system.

To demonstrate the applicability of the data base system and North Carolina's bridge management approach, the bridge system of a local county was selected. Although North Carolina selected a county in western Kansas, located near a growing major metropolitan area, many of the bridges are in rural areas of the county (similar to areas of Wyoming). The demonstration area consisted 114 bridges (6 of which were closed to traffic) ranging from small, seldom-travelled bridges to Interstate bridges.

Because all data items were not required to conduct the bridge management study, a new database was created to contain only the data required for the analysis. In this example the program was loaded onto a 10MHz AT clone microcomputer. The system took less than 2 minutes to analyze. This included calculating the deficiency points for each structure and placing the structures in descending order.

A useful feature of this BMS system is the ability to tailor the weighting factors to meet the needs and requirements of a particular region. In the demonstration region, large farming equipment needs to cross the bridges. Hence, the deck width weighting factor was increased to accommodate this need. In areas where there are many tractor trailers on the road, the vertical clearance weighting factor may be increased.

A system similar to this one can easily be modified to meet the needs of a rural region like Wyoming.

VIRGINIA BMS

Virginia has proposed a ranking formula that combines the sufficiency rating and level-of-service concepts. The overall approach is similar to North Carolina's prioritizing approach, but utilizes Virginia's need functions (O'Conner and Hyman). These need functions were determined by considering the following bridge characteristics:

1. capacity (inventory rating),
2. clear deck bridge width,
3. vertical roadway under/overclearance, and
4. sufficiency (condition).

Also like North Carolina, these level-of-service characteristics are defined as functions of road classification, ADT, and number of lanes. Virginia also includes the sufficiency rating as computed by the NBIS equations in their computations.

The Virginia BMS ranking formula for the determination of deficiency points (DP)[5] is:

$$DP = CP + WP + VP + SP \quad \text{(11)}$$

where CP, WP, and VP are need functions for bridge capacity, width, and clearances respectively. SP is a function with the sufficiency rating. The range of values for DP is zero to 100.

The ranking formula for the bridge capacity (CP) is:

$$CP = WC \left(\frac{CG - IR}{5} \right) (0.6\ KA + 0.4\ KD) \quad \text{(12)}$$

where: WC = level-of-service load capacity weighting
CG = level-of-service load capacity goal (tons)
IR = inventory rating of bridges (tons)

$$KA = \frac{(ADTO)^{0.3}}{12} \quad \cdots\cdots\cdots (4)$$

$$KD = \left(\frac{DL}{20}\right)\left(\frac{ADTO}{4000}\right) \quad \cdots\cdots\cdots (5)$$

ADTO = average daily traffic of over route
DL = detour length (miles)

The variables are defined as: load capacity goal is the level-of-service goal that is desirable for the bridge; inventory rating is the load level that can safely utilize the bridge for an indefinite period; average daily traffic of over route is the ADT the bridge carries; and the detour length is the distance the ADT is rerouted if bridge is closed.

The equation for the clear bridge deck width (WP) is:

$$WP = WW\left(\frac{WG - CDW}{3}\right)\left(\frac{ADTO}{4000}\right) \quad \cdots\cdots\cdots (6)$$

where: WW = level-of-service width weighting
WG = level-of-service width goal (feet)
CDW = present clear deck width of bridge (feet)

The equation for the vertical under/overclearance (VP) is:

$$VP = VPU + VPO \quad \cdots\cdots\cdots (7)$$

where: $$VPU = WV\left(\frac{UG - VCLU}{2}\right)\left(\frac{ADTU}{4000}\right) \quad \cdots\cdots\cdots (8)$$

$$VPO = WV\left(\frac{OG - VCLO}{2}\right)\left(\frac{ADTO}{4000}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

WV = level-of-service vertical clearance weighting
GU = level-of-service underclearance goal (feet)
VCLU = existing vertical underclearance (feet)
ADTU = average daily traffic of under route
OG = overclearance goal (feet)
VCLO = existing vertical overclearance (feet)

The final segment of Virginia's priority ranking equation is the sufficiency priority (SP):

$$SP = WS\left(\frac{100 - SR}{100}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

where: WS = sufficiency weighting
SR = sufficiency rating of bridge

The sufficiency rating of bridge is the FHWA sufficiency rating discussed in Appendix A.

Three modifications that Virginia made to North Carolina's priority formula were the adjustment of the load capacity was changed from single vehicle to inventory rating, need function for load capacity was modified so bridges on lower classes of highway have a lower load rating, and the sufficiency rating was substituted for remaining life.

KANSAS BMS

Kansas has 24,915 bridges, most of which are owned by the Kansas Department of Transportation (KDOT), Kansas Turnpike Authority, and counties. Cities are responsible for bridges in the urban system. Counties and cities hire consultants for inspections, but the KDOT performs in-house inspections and ratings.

Existing System of Management

KDOT uses two different programs to determine the maintenance priority within the state, one for roads and one for bridges. The importance factor of bridges over roads is 0.53. This prioritizes maintenance projects for further consideration by a priority-optimization system.

Three factors are considered in the KDOT priority-optimization system:

1. traffic safety,
2. structural strength, and
3. structural condition of the bridge.

In weighting the factors, traffic safety structure strength equals 45% and structural condition equals 55%.

Other factors are considered in the final decision making process, including: the functional class of road, volume of traffic, posted speed, and accident rate.

Program BIS

The KDOT dBASE III program was obtained for evaluation. The software was written so that the user could perform all required bridge information tasks with a microcomputer. Tasks include:

1. Add structures into the inventory.
2. Delete a structure from the inventory.
3. Update structures that are already part of the inventory.
4. Review a structure in the inventory without changing any of the data.
5. Create reports for a single structure or multiple structures that are within set parameters.
6. Perform data conversion to or from an ASCII format.
7. Keep bookkeeping records, like previous users of the program.

These items are presented in a manner that makes data entry easy, and learning the program was relatively quick.

The only drawback to this program is that it does not prioritize MR&R into a format that can be used for planning and scheduling.

PENNSYLVANIA BMS

Pennsylvania Department of Transportation Structure Inventory Record System (SIRS) contains 22,500 bridges that are greater than 20 feet in length (Hudson et al.). An estimated 32 percent of these bridges are either structurally deficient or functionally obsolete.

Pennsylvania's approach to bridge management is not applicable to Wyoming for the most part. Their system is tailored specifically for the needs of Pennsylvania. An example of its uniqueness is its deficiency scale, where 100 is critical and 0 is no deficiency, just the opposite of the FHWA sufficiency scale. At present, Pennsylvania's approach is probably the most comprehensive BMS program in the nation (not including the FHWA program PONTIS). It uses a series of databases that require the power of a mainframe computer (IBM 3090). This program is a comprehensive system that:

1. integrates and utilizes data from the existing database structures inventory records system (SIRS) and other databases.,
2. enhances and expands SIRS database,
3. systematically evaluates the deficiencies and rehabilitation costs,
4. records maintenance and construction-cost history,
5. stores physical attributes for each bridge in the inventory, and
6. provides information for cost-effective management decisions.

For a further detailed report on Pennsylvania's BMS, see Appendix B.

Some of the maintenance activities included in Pennsylvania's current highway maintenance management system (HMMS) are general maintenance and betterments, or contract maintenance. The state wants to integrate the BMS with other department systems so common data can be easily updated on all databases.

Information gathered from bridge inspections is expected to be entered into the databases promptly after the inspection and maintenance activities that are coded 100 (100 for critical deficiency) will be flagged for further evaluation on MR&R. The following factors are considered:

1. the type of highway,
2. major traffic type (commercial, agricultural, industrial, or private), and
3. average Daily Traffic x Detour Length.

Most of the required data already exist in the state's SIRS database. The only items that were added were the maintenance activities and their respective urgency rankings.

INDIANA BMS

The Indiana Department of Transportation (IDOT) started developing its BMS in 1987 and has partially implemented the system. Its approach is similar to that taken by Pennsylvania and North Carolina in that it utilizes level-of-service goals to prioritize bridge rehabilitation and replacement projects. Like Kansas, it evaluates traffic safety. This enables IDOT to evaluate and account for conditions and characteristics in bridge design and maintenance that could pose a safety hazard to traffic.

FEDERAL HIGHWAY ADMINISTRATION PROGRAM PONTIS

Under the sponsorship of the FHWA, the program PONTIS was a joint venture of Optima Inc. and Cambridge Systematics. The objective was to develop a comprehensive, rigorous, yet flexible bridge management system at the network level. To insure that the program would be flexible and meet the needs of most any user, a Technical Advisory Committee (TAC) was organized to supervise the work. The TAC was comprised of representatives from the FHWA, the Transportation Research Board, and six states (California, Minnesota, North Carolina, Tennessee, Vermont, and Washington), many of which use bridge management systems within their states.

Initial Conditions

Two distinct sets of maintenance problems had to be addressed. These are generally classified as "improvements." The first set constituted typical MR&R items, which with time will further deteriorate and MR&R will be required. The second set included bridge elements that will not change with time. Examples include deck widening and raising the bridge to gain vertical clearance. The actions required by MR&R are generated through a dynamic model which incorporates the time-dependent variable with the state of the element. The model distinguishes between two actions that will produce the desired condition and compares the cost benefits of each action over time.

The designers of PONTIS found that, in addition to cost and budgetary issues, the principal objectives the planners and administrators are concerned with are the same factors listed in Chapter 1 as initial parameters.

The TAC created a list of bridge elements required to accurately define the MR&R for a given structure, including the possible condition of these elements, and the appropriate MR&R actions for each element condition (U.S. Department of Transportation, 1991b). This was an expansion of the NBIS data as set by the FHWA.

Objectives of PONTIS

Given the recommendations of the TAC and the initial parameters of bridge management, PONTIS was written to achieve the following tasks (U.S. Department of Transportation, 1991a):

1. Provide a systematic procedure for finding MR&R budget requirements.

2. Incorporate level-of-service goals in the assessment of bridge improvement needs and budget requirements.

3. Provide the capability to consider the entire bridge network to simultaneously arrive at optimal policies and recommendations for MR&R.

4. Retain the flexibility to address any subset of bridges.

5. Provide priority orders and sequencing for bridges in need of MR&R and improvement.

6. Coordinate MR&R planning decisions with future improvement decisions.

7. Consider the differing inspection and repair needs of the major structural components for bridges, as well as the differing needs of various types of bridges.

8. Allow updating of predictive probabilities as the necessary data becomes available over time.

9. Consider the immediate and future costs and benefits of the various courses of action and their effect on future conditions. In particular, the model would weigh the benefits of preventative maintenance versus costlier (but less frequent) corrective actions.

10. Allow sensitivity analyses of the recommended policies in terms of future conditions of the bridge network, and cost requirements.

11. Be flexible enough to accommodate different state-specific improvement, MR&R, and fiscal policy issues.

12. Provide a basis for short-term and long-term MR&R and improvement budget planning and resource allocation.

13. Provide a rigorous procedure and an analytical framework for incorporating expert engineering judgement in the model.

To achieve these tasks PONTIS was written in several modules that, when considered as a single program, effectively address the above issues and requirements.

Optimization Model

The goal for MR&R optimization is to determine the policy that minimizes the long-term MR&R costs of each element while maintaining the element in safe condition.

PONTIS recognizes that three important phenomena should be cataloged:

1. Bridge elements deteriorate, making transitions from one condition state to another.
2. Actions are taken on specific bridge elements, incurring a cost.
3. The action taken causes an improvement in element condition.

The MR&R optimization that PONTIS uses is a "steady state" condition. Network wide, any given state has elements passing into it due to the effects of deterioration or actions taken the previous year, and has elements passing out of it due to deterioration and actions taken in the following year. Simply put, for a given condition state, elements are continually entering and leaving this condition because of deterioration and actions taken.

Finally, three steps are taken in optimizing the MR&R. First, effects of deterioration are considered neglecting MR&R; second a steady-state probability is examined; and third a cost-benefit ratio for each action is computed. To determine the effects of deterioration on an element, a Markov chain procedure is employed. The steady-state probability implies that a process is in a given condition state and that a given action would be taken. A cost-benefit ratio permits optimization of the first two strategies and prioritizing the MR&R in a cost-effective manner. Mathematically, the cost-effective goal maximizes the benefits that each action provides. Benefits are defined as the cost savings resulting in performing the MR&R during the current year compared to allowing the structure to experience an additional year of deterioration, and performing the MR&R action at that time. The total cost is the cost to an agency to perform all the specified MR&R work on a bridge.

Review of the Software

In the review of the software, a primary drawback was immediately apparent: PONTIS uses a large amount of hard disk space. PONTIS executables use only about 6Mb of disk space; however, the databases that are required and generated can easily exceed disk capacity on conventional microcomputers (which was the case on the microcomputer that was immediately available to review the software). This drawback is minor and can be addressed with the purchase of suitable hardware. The recommended computer resources are outlined in Table 3.

Other drawbacks to PONTIS are: its databases may not be immediately compatible with the bridge inventory data already in use; the organization of data does not follow the existing NBIS data fields; and the menu system is complex and confusing for the new user.

The databases which the states' Departments of Transportation are currently using may not be compatible with PONTIS. This requires the data to be downloaded from the system in use to a format that PONTIS is able to translate.

The breakdown of required data items is not consistent with the existing NBIS data items that the states are currently required to follow. The new data fields expand upon the existing data items, increasing the number of element condition states from eight to 158 (including undefined elements).

Table 3. System Requirements to use PONTIS

	Equipment Recommended	Cost
Minimum Configuration	PC clone with 80386 processor 25 MHz 640k RAM 80287 Math co-processor 200 Mb 25 ms hard disk one floppy disk drive monochrome monitor MS DOS v3.3 or above	$3,500
Recommended Configuration	PC clone with 80386 processor 33 MHz 1.5 Mb RAM 80387 Math co-processor 2-200 Mb 15 ms hard disk drives one 3½" and one 5¼" disk drives VGA monitor MS DOS v3.3 or above Close-up telecomm. software QEMM memory management software PKZIP file compression software	$5,700

NOTE: These recommendations do not include the newer 486-50 MHz PC clones currently available.

At the time of this writing the prices for comparable systems are approximately 50 percent less than listed.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, PONTIS User's Manual, Washington D.C., December 31, 1991, p. 10.

Because PONTIS was written to be comprehensive and able to update itself, there are a number of menu items that create confusion for the new user. These menu items are difficult to trace through the program and the on-line help does not provide the necessary help for the user. Also, trying to correlate the NBIS data items to the newer PONTIS data items is not always an easy task.

PONTIS has benefits that should be noted. The program is able to separate elements into different condition ratings that require attention (examples: one bent, one girder, or square feet of deck). This allows for PONTIS to accurately describe the current condition of a structure.

Various implementations of PONTIS are outlined in Chapter 4, and advantages and disadvantages of such a large and refined system are detailed.

SUMMARY

Of the systems discussed, the systems developed by North Carolina and Virginia appear to have a "promising format" for application to Wyoming's local and county managers. The Kansas BIS program has a "promising format" for screen forms and report output. The BIS program also has a attractive feature for tracking previous users.

It would be ideal for Wyoming to be able to maintain the current databases, without the need to translate that data into another format, preventing the chance of incorrect data translation. To achieve this, a microcomputer-based program was written in INFORMIX 4GL to utilize the existing WDT data tables. The program records the previous user, like KDOT's BIS program, and incorporates a prioritization routine which is a expansion on the deficiency point methods of North Carolina and Virginia.

CHAPTER 3

SOFTWARE DESIGN AND PRIORITIZATION MODELING

INITIAL PARAMETERS OF THE SOFTWARE

The software design was governed by several parameters determined after the review of the existing software and project guidelines. These parameters dictated the language in which the program was written, the general organizational scheme and how the data transfer is achieved.

The INFORMIX database software was chosen as the fourth generation language (4GL) to write the program. This decision was due to the fact that the WDT already had the necessary database established in this format. Another deciding factor was that the INFORMIX 4GL software is readily available for both microcomputers (PC's) and the more powerful workstations used by the WDT. This allows for easier data transfer between the state and the counties, as the counties could use readily available microcomputers.

The general format of the program was determined to be one main program that would perform all aspects of bridge inventory and management functions. The program would have separate routines allowing the user to add, delete, review, or update the information within the databases. These routines are grouped into two modules, add/delete and review/update; the add/delete module is for the WDT Bridge Engineer or Project Engineer to add new structures or delete structures from the inventory. The review/update module is further broken down into three sub-routines: the update routine, for the local engineer to record the necessary information between the times that the WDT provides the data; the review routine, for administrators to manage the bridges within their jurisdiction; and the prioritize routine, to evaluate the MR&R needs of bridges within the database. The review/update routine generates reports for one structure or for a selected group of structures. Additional features include the bookkeeping of previous users, a descriptive on-line help to assist the user, and installed descriptions of the cryptic NBIS codes used in the defining of a structure.

The data exchange between the WDT and counties is a simple matter of mailing a computer disk, eliminating the need for modems and special communication lines. The INFORMIX 4GL includes a Utility program that allows an entire data table to be loaded to or from floppy disk for easy data transfer.

In the initial correspondence with Don Neuman, of Carbon County, and John Nelson, of Sweetwater County, it was suggested that the program include additional data fields for county use. These data fields need not correspond to NBIS or WDT data fields and the counties have the option whether or not the data is transmitted to the WDT. To accommodate this request, the separate data table for county data is linked to the state data through the structure number (the structure number is a four character string, i.e. bridge name, that uniquely identifies the bridge).

PROGRAM PHASE I - INVENTORY PROGRAM

In the initial phase of the project, an inventory program was written to allow the user to manipulate the databases as needed. The user would be able to add, delete, review, and modify the database similar to the dBASE program BIS currently used by KDOT.

Before writing the program, the required data tables were determined. Eight tables were required in Phase I and three additional tables in Phase II were required to store all necessary data. These tables are described in Table 4.

After the required tables were determined, the screen forms were created. The Structural Inventory and Appraisal Sheet (Federal Highway Administration) (Appendix C) was used as a guide in organizing the data into forms. The additional WDT data fields were then added in the order they appear in the existing data table. A total of 39 screen forms were required for the user interface.

Table 4. Database Tables Written into the WYO_BMS Bridge Management Program

Table	Description
* ADMINSTR	administrative data fields
* HYDRA	water and/or streamflow data fields
* INSPECT	inspection data fields
* LOADRAT	load rating data fields
* PHYSTR	physical structure data fields
COUNTY_FIELD	county specific data fields
DEFICIENCY	stores deficiency point calculation (Phase II)
EXPONENT	data table of exponential approximations (Phase II)
FIELD_HELP	explanations of numeric coding
PARAMETERS	stores display and prioritization parameters (Phase II)
USERDATA	records precious users of the program

* denotes a data table established in the WDT database

A small-scale program containing only four tables (adminstr, county, town, and userdata) was written to gain familiarity with the INFORMIX software. Once this program was operating properly the county and town tables were deleted and the program was expanded to include the other required tables.

The first major problem occurred at this point in the project. The computer used to write the software had only 1Mb of RAM and memory problems started to appear. The 1Mb limitation did not allow enough space to run the operating system and INFORMIX run-time and store in memory the necessary data. A solution was sought that would allow the 1Mb machine to be used.

One solution attempted was to separate the program into two separate programs, one to add or delete structures and the other to review and modify existing structure data, however, this solution was not successful. A move to a computer with 3Mb of RAM solved the problem.

The report routine was written to produce reports to three different medias and four formats. A report can be generated in one of three ways. The default is to display the report to the monitor and the user has the choice of changing this to a printer or computer disk. Reports can be for a single structure or a number of structures. Single structure reports can be formatted like the Structures Inventory and Appraisal Sheet, or numerically by the NBIS item number (without the WDT-added data fields being included). Multiple structures are reported either by the entire inventory, or those structures that have sufficiency ratings within a specified range.

This program was then reviewed by engineers in Carbon and Sweetwater Counties while the algorithm for Phase II was being developed.

PROGRAM PHASE II - PRIORITIZING ROUTINE

The prioritizing routine, which could be considered the most important element of any bridge management program, is the focal point of this development. Several options could have been implemented in the prioritizing routine: the sufficiency rating equation could be considered alone, a formulation of a deficiency rating could be developed, a model representing deterioration over time could be developed, or a combination of a deficiency rating and deterioration model could be considered. Each of these options are discussed below.

Sufficiency Rating

The sufficiency rating, which was originally implemented to determine funding eligibility under the Highway Bridge Replacement and Rehabilitation Program (HBRRP) serves this intended purpose moderately well (U.S. Department of Transportation, 1989). However, as a priority ranking formula, the sufficiency rating has serious drawbacks. These drawbacks are mostly because the bridge sufficiency is determined on the basis of a single load capacity and deck width. This basis of comparison between bridges may not be appropriate for all the structures within a state district. With the heavy weights given to these factors, bridges that are relatively narrow and have a low load capacity would be assigned a low sufficiency rating, even though these bridges may be in good condition and adequate for the traffic they routinely carry.

Another shortcoming of the sufficiency rating when used for priority ranking is its insensitivity to certain key ranking factors. As an example, the traffic reduction factor "A" of the sufficiency rating formula is a function of the average daily traffic, detour length and $(S_1 + S_2)/85$. As shown in Figure 1, the sufficiency rating is plotted against the ADT for a varying $S_1 + S_2$ (sum of structural adequacy factor and serviceability factor), assuming a five-mile detour length. In most cases the sufficiency rating is insensitive to large changes in ADT, detour length. Consequently, the rating given to the structure would not distinguish one structure from another structure of equal physical condition but a drastically different traffic volume.

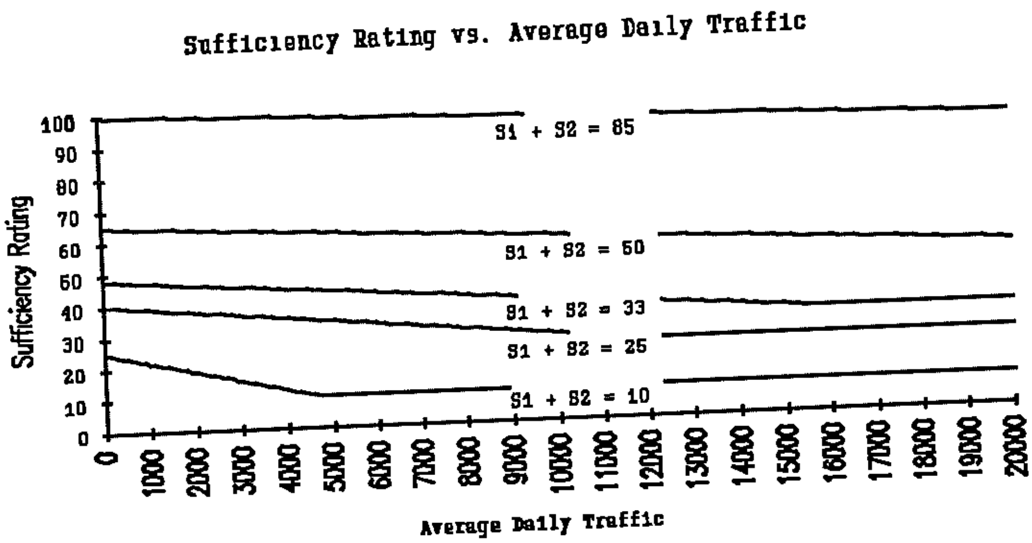

Figure 1. The Effect Traffic Count has on the Sufficiency Rating

Source: O'Conner, Daniel and Hyman, William, "Bridge Management System", Demonstration Project No. 71, Federal Highway Administration, U.S. Department of Transportation, October 1989, p. III-5.

If these drawbacks of the sufficiency rating as a prioritizing tool are not recognized, the local official could poorly direct financial resources to the wrong project at the wrong time. This method was eliminated from consideration in the prioritizing routine of the program due to these drawbacks.

Deficiency Rating

The deficiency rating as implemented by both North Carolina and Virginia to determine the priority of MR&R projects is a method of comparison by weighting certain bridge inventory data items. In contrast to the sufficiency rating, where a rating of 100 is a bridge in perfect condition, a deficiency rating of the same value would be a bridge in total collapse or disrepair. This reversal of rating designation could initially be confusing to the user of the program. However, the ability to rank projects by user-defined weighting factors can prove to be an asset in refining the program to a specific environment.

A drawback to this method of ranking the MR&R projects is that the equations defined by North Carolina and Virginia consider the bridge and its condition on a holistic basis. The individual elements or components and the effects of their deterioration are not considered. If a method of determining the deficiency rating for individual elements could be developed, this method of prioritizing bridge components is a viable method for implementation on the local government level.

Markov Chain Deterioration Method

The Markov chain approach as applied to bridge management is the probability of the bridge condition transition from one deterioration state to another. The probability of deterioration is presented in a probability matrix by which the present condition vector is multiplied.

The FHWA bridge rating system ranges from zero to nine, with nine being the best condition. The ten rating conditions are defined as ten states, each state representing a given condition. The bridge condition decreases over time without MR&R. The probability that the condition will change from state i to state j during a given period of time is denoted as $P_{i,j}$.

The transition probability matrix P is given by:

. . . . (14)

The state vector at time T is $S^{(T)}$, which can be derived by multiplying the initial state vector $S^{(0)}$ and the probability matrix P:

$$S^{(T)} = S^{(0)} * P * P * \cdots * P = S^{(0)} * P^{n} \quad \text{.............. (15)}$$

Therefore, a Markov chain is satisfied when both the current state vector and probability matrix are known. Because inspection reports give reference to the current condition of a bridge, the main problem in the Markov chain approach is the determination of the probability matrix.

The best method to determine the probability matrix is to have a historical database upon which to draw. This database should address a broad range of structure parameters: age, material type, structure type, condition, climatic conditions, traffic count, etc. The database should also contain probability matrices for different material types for the same bridge component. The more extensive the list of parameters used in the determination of the probability matrix, presumably the more accurate the results of the Markov chain. This data should also span several inspection cycles to establish the probability of state transition.

Currently, the historical database is not present for such a probability matrix to accurately predict the transition rate of components of a bridge. Without such a historical database, the probability matrix is determined by engineering judgement and the engineer must decide the rate that components deteriorate with time.

Final Decision for Prioritization Model

Of the three different methods described for prioritizing MR&R projects, the one most suitable to the rural environment in Wyoming is the deficiency point rating. The reasons to write the program with a deficiency point priority routine rather than one of the other two methods are: the sufficiency point method does not provide accurate enough data to make decisions on MR&R, and the Markov chain method requires additional databases which are not available.

The program was written to review the NBIS item 75 (Type of Work) for projects already determined to be urgent and compute deficiency points on a structure and element basis for the other structures within the database. In reviewing "item 75", the program puts the projects that are already defined as needing MR&R at the top of its priority list, and then lists possible projects based on the deficiency rating for the structures and structure elements independently. The parameters reviewed for structure and element deficiency point calculation are illustrated in Figure 3.

Structure Deficiency Point Calculation

The algorithms used for the calculation of deficiency points of the entire structure are similar to the equations used by the Virginia BMS program (U.S. Department of Transportation, 1989). However, it is recommended that the effect of truck traffic on the structure carry more weight than automobile traffic and detour length. The basis for this recommendation is that the total traffic count in a rural environment is generally not sufficient to influence the prioritization routine, and a bridge in advanced stages of disrepair can usually support the automobile traffic on the structure while it cannot support truck traffic. Detouring truck traffic is, in some cases, impractical or economically impossible.

The total deficiency points for a structure are the sum of four factors based on bridge data items—load capacity, vertical clearance, bridge deck width, and sufficiency rating— factored by the highway classification factor. The structure deficiency points are determined by the following equation:

$$DP_{structure} = \phi * (CP + WP + VP + SP) \quad \text{(16)}$$

where: $DP_{str.}$ = structure deficiency points
ϕ = highway classification factor
CP = load capacity deficiency points
VP = vertical clearance deficiency points
WP = deck width deficiency points
SP = sufficiency points

The highway classification is a predetermined factor within the database that adjusts the deficiency points according to the highway classification. The level-of-service goals are defined as the level-of-service goals of Virginia's BMS. The deficiency point equations are as follows.

The load capacity deficiency points are determined by:

$$CP = W_C \left(\frac{CG - IR}{CG}\right)^{n_1} (W_T\, KT + W_D\, KD) \quad \text{(17)}$$

where: W_C = load capacity weight factor
CG = level-of-service load capacity goal (tons)
IR = inventory rating (tons)

n_1 = load capacity importance factor
W_T = traffic weight
W_D = detour weight

$$W_T + W_D = 1.00 \quad \text{(18)}$$

$$KT = \frac{\left(\frac{ADT - ADTT}{MADT}\right)^{n_2} + \left(\frac{ADTT}{MADT}\right)^{n_3}}{A} \quad \text{(19)}$$

ADT = average daily traffic (vehicles per day)
ADTT = average daily truck traffic (trucks/day)
MADT = mean ADT over population (vehicles per day)
n_2 = automobile importance factor
n_3 = truck importance factor

$$A = \left[\left(\frac{ADT - ADTT}{MADT}\right)^{n_2} + \left(\frac{ADTT}{MADT}\right)^{n_3}\right]_{max} \quad \text{(20)}$$

$$KD = \frac{\left(\frac{ADTT}{MADT}\right)\left(\frac{DL}{MDL}\right)}{B} \quad \text{(21)}$$

DL = detour length (miles)
MDL = mean detour length over population (miles)

$$B = \left[\left(\frac{ADTT}{MADT}\right)\left(\frac{DL}{MDL}\right)\right]_{max} \qquad (22)$$

The vertical clearance deficiency points are determined by:

$$VP = \frac{VPO + VPU}{2} \qquad (23)$$

where: .... (24)

.... (25)

W_V = vertical clearance weight factor
VCGO = level-of-service vertical overclearance goal (feet)
VCO = present vertical overclearance (feet)
VCGU = level-of-service vertical underclearance goal (feet)
VCU = present vertical underclearance (feet)
n_4 = vertical clearance importance factor

$$C = \left[\left(\frac{ADTT}{MADT}\right)\right]_{max} \qquad (26)$$

The bridge deck width deficiency points are determined by:

$$WP = W_W \left(\frac{WG - CDW}{WG}\right)^{n_5} KT \quad (27)$$

where: W_W = deck width weight factor
WG = level-of-service deck width goal (feet)
CDW = present clear deck width of bridge (feet)
n_5 = deck width importance factor

The sufficiency points are inverse of the sufficiency rating on a scale from zero to 100 defined by:

$$SP = W_S \left(\frac{100 - SR}{100}\right) \quad (28)$$

where: W_S = sufficiency weight
SR = NBIS sufficiency rating

The weighting factors must satisfy:

$$W_C + W_V + W_W + W_S = 100 \quad (29)$$

In the event that a negative number is calculated by any of the deficiency point equations a value of zero is assigned to that particular equation. There also is a possibility that certain information would be missing from the database (for example, deck width) that would effect the deficiency points for that structure. In this case a flag is set that signals the user that the information to compute the deficiency points is incomplete and the resulting ranking should be scrutinized.

Element Deficiency Point Calculation

In the deficiency rating for elements of the structure, the structure as a whole was broken down into the elements relating to components as shown in Table 5. These elements are the same elements that are currently in the inspection table of the WDT database and are already available in the Phase I development.

Table 5. Bridge Components and Elements of Each Component

Component	Element	Component	Element
Deck	deck	Culverts	barrel wingwalls cut-off walls
Superstructure	girders & beams floor beams stringers diaphragms truss - general truss - portal truss - brace bearing devices slices/connections alignment of members	Substructure	abut. wingwalls abut. backwalls abut. footings abut. seats abut. piling abut. berms pier caps pier column pier footing pier piling pier scour pile bents RC slope paving
Channel	channel (streambeds) embankment (fill) waterway bank protection embankment protection river control devises	Approach	general guardrail pavement shoulder embankment drainage slab vertical align.
Paint	railing superstructure substructure	Tunnel	general portals rock bolts

Several aspects of the bridge were considered in determining the algorithm for prioritizing the elements of the bridge: element rating, cost of MR&R, benefit ratio, classification of highway, owner of bridge, ADT, percent truck ADT, and detour length. It was decided that the element rating, ADT, and detour length were necessary for determining deficiency rating. The cost of MR&R and benefit ratio were eliminated from consideration due to the difficulty of estimating MR&R cost with the data available.

In formulating the algorithm for element deficiency points, a nonlinear equation was used to permit a higher emphasis on the elements in the worst condition. It was also decided to allow the local official to "fine tune" the parameters used to calculate the rating values. The official could set the exponents to unity (1.00) for linear proportioning. The deficiency point formula for an element is:

$$DP_{element} = \phi \left(\frac{R_C - R}{R_C}\right)^{n_6} (W_T\, KT + W_D\, KD) \quad \cdots\cdots\cdots\cdots\cdots \quad (30)$$

where: $DP_{element}$ = element deficiency points
ϕ = highway classification factor
R = element rating
R_C = critical element rating
n_6 = element importance exponential factor

The variables are defined as: highway classification factor is a scaling factor based on the classification of highway where the bridge is located; element rating is an element condition rating; critical element rating is the condition an element is in when it first receives MR&R consideration; and the element importance factor biases the deficiency point equation to elements that are critical to the structure and is independent of the condition of the element.

If a particular element is not present in a structure or the data is missing the related deficiency point will be null and not entered into the priority data table.

SUMMARY

An effective bridge management program for the local officials in Wyoming is the use of a microcomputer-based program written in INFORMIX 4GL that utilizes existing WDT data tables. It allows data transfer by computer disk, eliminating the need for an elaborate communication network.

The deficiency point method is suitable for implementation to prioritize MR&R projects using existing data. Possible projects are presented to the user in a three-phase display; structures that MR&R is already determined necessary (based on NBIS item 75), structures that have high deficiency points, and bridge elements with high deficiency points.

CHAPTER 4

METHODS OF BRIDGE MANAGEMENT

There are two immediate alternatives methods of bridge management on the local and county government level within Wyoming: to rely entirely on the WDT to make management decisions for all structures within the state, or to have the WDT manage structures that are classified as on-system and the local transportation officials manage off-system structures. Each alternative can further be refined as: using either PONTIS or WYO_BMS exclusively.

Each possibility provides bridge management, each with its strengths and weaknesses. PONTIS is better suited for larger inventories and specially trained operators, whereas WYO_BMS is more suited to the smaller inventories of a rural environment. The advantages and disadvantages of each possibility relative to a rural environment are discussed.

WDT MAINTAINS ENTIRE STATE INVENTORY

In a WDT maintained management program, the State Bridge Engineer would be responsible for the upkeep of the inventory and have the authority to schedule MR&R projects for any structure within the State. This network-level management scheme removes MR&R decisions from the counties and places the MR&R planning, scheduling, and coordinating with the WDT. A review of two possible network bridge management programs are discussed.

WDT Uses PONTIS Exclusively

For the WDT to use PONTIS exclusively for the entire state, the program must be used as a centralized bridge management system based in Cheyenne. This level of management, while providing adequate database size to utilize the advantages of PONTIS or another program with deterioration modeling, may not be the best solution for a rural environment or management at the local level. Advantages and disadvantages are outlined below.

Advantages:

1. At a state level, the number of bridges within the WDT inventory are sufficient to accurately portray deterioration modeling.

2. PONTIS is able to modify itself to more accurately portray deterioration effects on the inventory after each inspection cycle is completed and entered into the system.

3. The data in PONTIS may be linked to a Geographic Information Systems (GIS) through Bridge List files or Bridge Text files. Being able to link with GIS allows for graphical presentation of bridge information (examples: to color-code bridges according to condition or bridge currently scheduled for MR&R on maps).

4. Cost/benefit ratio for MR&R projects are computed for the current condition and one deterioration cycle. These cost/benefit ratios are then compared to illustrate to the most financially sound MR&R schedule to optimize resources.

5. The quantity of each element in a bridge can be defined and the condition state of the element need not be constant over the entire element. This allows for multiple conditions of an element to be present on a structure and more accurate portrayal of element condition.

6. PONTIS creates inspection sheets for any structure in the inventory with only the required elements of that structure on the sheet.

7. The WDT would need to train the bridge inspectors and a few operators on PONTIS, minimizing training costs.

Disadvantages:

1. The current WDT database would have to be translated into a format usable by PONTIS. The current WDT data fields are not 100 percent compatible with PONTIS data fields. WDT's expanded data fields may not have a direct counterpart in the PONTIS database and would either have to be deleted from the system or modified to fit within the PONTIS data structure.

2. The inspection condition ratings currently used are not the same as PONTIS condition ratings. The inspectors and program operators would have to be trained on the new condition ratings.

3. The MR&R costs are not constant across Wyoming and these differences in cost are not accurately portrayed within PONTIS cost/benefit calculations. Material transportation costs are one example of varying MR&R cost.

4. The WDT- and PONTIS-recommended MR&R may not be in the best interest of the county or local government. This recommendation would not consider political, economic, and demographic makeup of the local environment.

5. The financial burden for off-system structure MR&R is primarily the responsibility of the counties. With this responsibility, the counties should have an input on MR&R scheduling because they are more familiar with the financial state of their jurisdiction.

6. Some bridges may not be in the WDT database. This could be particularly true for older structures in remote rural areas that are not subjected to heavy traffic loads.

7. Hard disk space required for PONTIS and appropriate databases can exceed the limit of older microcomputers.

Additionally, some of the decisions affecting MR&R decisions that the WDT may not be able to answer are:

1. What are the expected demographic shifts in the district?
2. Do school buses use the bridge?
3. What is the importance of the bridge to recreational traffic?
4. What funds are available for MR&R projects?
5. What is the long-range goals of the county concerning bridge MR&R?
6. What is the size and strength of the local MR&R work force?

Weighing the advantages and disadvantages of network-level bridge management by the WDT using PONTIS, it does not seem like a viable solution for MR&R at the local level.

WDT Uses WYO_BMS Exclusively

Using WYO_BMS as a network-level bridge management program would utilize the centralized inventory in Cheyenne, and correspondence with counties by memos would be necessary. This level of management while using the existing INFORMIX database may again not be the best solution for a state network-level bridge management program. The advantages and disadvantages are outlined.

Advantages:

1. The current WDT database and condition rating system is used. This eliminates the need for data translators and the possible data conversion errors associated with translating data.

2. Using the existing databases eliminates the need to learn new element classifications and rating scale.

3. The hard disk storage space for WYO_BMS and appropriate databases is less than required by PONTIS. WYO_BMS can operate on most DOS-based microcomputers with a minimum of 2Mb RAM.

Disadvantages:

1. The WDT could benefit from deterioration modeling in scheduling MR&R projects. Deterioration modeling is not possible with WYO_BMS.

2. WYO_BMS has no cost/benefit ratio calculations to weigh advantages and disadvantages of MR&R options.

3. WYO_BMS is unable to incorporate outside information into the program. Many outside factors could influence the MR&R decisions.

A program like WYO_BMS is limited in it abilities and, when compared to PONTIS, is not the preferred choice for a state-level network bridge management system. While providing bridge management, WYO_BMS still lacks financial considerations which is a distinct advantage in managing large bridge inventories for MR&R prioritization.

STATE MAINTAINS ON-SYSTEM BRIDGES COUNTIES MAINTAIN OFF-SYSTEM BRIDGES

In a joint management system between the WDT and the counties, all matters of bridge inspection, recording, and MR&R scheduling are divided between WDT and counties. The WDT would manage on-system bridges within the guidelines of the FHWA using one of the previously mentioned management schemes. The counties would manage off-system bridges in a manner corresponding to and cooperating with the WDT. The responsibility for MR&R decisions of the off-system bridges are placed on the counties.

Three possible methods could be implemented: use PONTIS exclusively, use a combination of the two programs, or use WYO_BMS exclusively for management guidance.

Counties Use PONTIS Exclusively

The counties using PONTIS exclusively as a bridge management tool might find that it doesn't perform as well on a local level as it does on a network-level. PONTIS performs best when the inventory is large, so it does not seem a viable solution to a bridge management program in the intended rural environment. The advantages and disadvantages of using PONTIS with smaller inventories are outlined.

Advantages:

1. Deterioration modeling can be performed to predict the condition of elements if MR&R is not performed. Larger inventories could provide data for deterioration modeling, but deterioration modeling smaller inventories is limited.

2. Cost/benefit ratios can be performed to assist in MR&R scheduling. Again the size of the inventory effects the usefulness of cost/benefit ratios.

3. PONTIS is able to communicate with GIS systems or other compatible graphics software.

Disadvantages:

1. The number of bridges in a county inventory may not be adequate for a historical sampling of performance over time. A better solution would be to use the entire state inventory as a historical sampling which the counties would not have access to.

2. The current WDT database would have to be translated into a format useable by PONTIS, as described earlier. The current WDT data fields are not 100 percent compatible with PONTIS data fields, as described earlier.

3. Hard disk space required for PONTIS and the appropriate databases can exceed the limit of older microcomputers. Upgrading existing systems to use PONTIS may be too expensive for some counties.

4. The complexity and abilities of the program may exceed the needs of a local bridge manager.

5. There is no provision for MR&R overhead cost related to rural environments (for example, travel time for work force).

6. The condition ratings currently used are not the same as PONTIS condition ratings. This requires the users of PONTIS to learn a new rating system.

Larger counties or counties with large off-system inventories (150+ bridges) could manage PONTIS and it may be worth further investigation. In smaller inventory districts, PONTIS probably is more sophisticated than the counties actually need for successful bridge management.

Counties Use Combination of PONTIS and WYO_BMS

Using both PONTIS and WYO_BMS as part of a local bridge management program would allow the local official to have input from two sources to assist in MR&R scheduling. However, for many counties, using two computer programs for a local bridge management program would press the limits of financial, human, and computer resources. While users can compare the suggested MR&R output of the two programs, they may be given too much information to make sound MR&R decisions and would eventually rely on one program or the other for bridge management assistance. For this reason this possibility of bridge management was eliminated from further consideration.

Counties Use WYO_BMS Exclusively

The counties using WYO_BMS exclusively as a bridge management tool will find that inventory size does not influence its performance. WYO_BMS is equally capable of performing bridge management on small and large bridge inventories. The only effect larger inventories have on WYO_BMS is increased time for prioritization computation. The advantages and disadvantages will be discussed further.

Advantages:

1. Designed for a rural/local environment with relatively few bridges in the inventory.

2. Uses the existing WDT database, which is familiar to the user.

3. The hard disk storage requirements are less than those of PONTIS.

4. The prioritizing routine uses a deficiency point method for entire structures and structure elements.

5. A smaller, less complex program allows for ease of use.

6. Users can fine tune the program to suit the needs and requirements of their counties.

7. The necessary software is relatively inexpensive and is able to run on most microcomputers having over 2Mb of RAM.

Disadvantages:

1. Cost/benefit ratios are not possible.

2. Outside information can not be entered into the program in a matter that could effect the deficiency point rating.

3. The program is not directly compatible with other software.

In counties that are economically distressed or have a small bridge inventory, the WYO_BMS bridge management program is a viable solution to the problem of MR&R scheduling. It can run on older microcomputers (with at least 2Mb RAM) and the initial software is inexpensive. Running PONTIS may require purchasing a computer system (if current computer resources are inadequate).

SUMMARY

All management systems provide the user with additional insight on planning and scheduling MR&R projects. Each management system performs its management functions within parameters and goals set by the writers of the program.

In Wyoming, the choices of bridge management programs are limited to two choices, PONTIS and WYO_BMS. PONTIS is more suitable to larger inventories where deterioration and historical modeling can be utilized to their maximum potential.

WYO_BMS, while equally suitable for large or small inventories, was written with smaller rural inventories as its primary use.

CHAPTER 5

SUMMARY AND CONCLUSIONS

SUMMARY

The current need for MR&R on the nation's bridges far exceeds available funds, and a bridge management program needs to be implemented at every level of government. This is particularly true for rural bridge managers whose jurisdictions contain the majority of the bridges needing MR&R.

This study investigated several existing bridge management programs, and attempted to apply these programs to a BMS in a rural western environment. If an existing BMS could be modified to a rural environment, it was necessary to determine the extent of the necessary modifications and the computer resources required to implement the program; and if no existing BMS would be appropriate, develop a microcomputer-based bridge management program for the local and county bridge managers within Wyoming.

Many of the existing BMS were written for the specific state in which the program is used, or the computer resources of the sponsoring DOT. In review, the majority of the existing BMS were found to be:

1. network-level bridge management tools for extensive inventories, not smaller rural inventories,

2. written for larger populations and traffic counts not found on rural roads,

3. written for mainframe computers or workstations, or

4. inventory tools with no MR&R prioritization capabilities.

These existing management programs do not meet the requirements of a rural management program.

Of the management systems reviewed, the program PONTIS is the most promising of all network-level bridge management programs available. It is a comprehensive management program that inventories, prioritizes, creates inspection reports forms, and can communicate to GIS-based programs. However, PONTIS is more sophisticated than needed for smaller inventories, and not suitable for economically distressed districts without the adequate human and computer resources. In response to the drawbacks of PONTIS and other existing BMS programs, it was determined that a bridge management program had to be written to solve rural bridge management problems. The WYO_BMS program can:

1. operate on a microcomputer platform,

2. maintain data for all bridges within a district's inventory,

3. add new bridges to or update existing bridges in the inventory,

4. transfer bridge data to or from the WDT by a convenient media,

5. calculate deficiency points for the entire structure and for the components and elements of the bridge, and

6. rationally prioritize the MR&R required to maintain the structures in a safe condition based upon the deficiency points.

The language chosen for the program was INFORMIX 4GL, the language used by WDT for existing bridge data.

The software was written to allow the user to add, delete, and modify bridge data, and prioritize the inventory to rank MR&R for the structure, components, and elements, based on current condition, automobile traffic, truck traffic, and detour length.

RECOMMENDATIONS

Within the State of Wyoming, it is recommended that two levels of bridge management be implemented as part of a total bridge management program. The WDT would manage the on-system bridges and the counties would manage the off-system bridges, with the method of management dependent upon the inventory size.

On-System Bridges

The on-system bridges in Wyoming are currently managed by the WDT. It is recommended that the WDT continues the management of these bridges using a comprehensive bridge management program.

For the WDT, with the size of the bridge inventory and the computer resources and trained staff at their disposal, PONTIS is recommended as the bridge management program. This has been chosen primarily for its ability to provide many of the functions required for a comprehensive network-level bridge management program: inventory management, deterioration modeling, and cost/benefit analysis.

Off-System Bridges

Three factors were considered in determining a method of bridge management for local and county governments: the inventory size, the current computer resources available, and the financial constraints of the county.

The size of the inventory could determine which management program would be most beneficial. If the inventory is large (150+ bridges) then PONTIS should be considered. Smaller inventories, which would not benefit from the deterioration modeling and cost/benefit analysis of PONTIS, are more suitable for the deficiency point prioritization of WYO_BMS.

Economic and financial limitations on some counties may determine which system the county selects.

AREAS OF FUTURE RESEARCH

The following research topics are suggested by the work presented here, but are beyond the scope of this study.

1. The deficiency point calculations of WYO_BMS are based on the condition rating and traffic. Expanding WYO_BMS to include economic aspects of bridge MR&R in a rural environment is suggested.

2. Study the importance factors used in deficiency point calculations of WYO_BMS. Results can be used by bridge managers in fine tuning WYO_BMS for their district.

3. Expand the knowledge base in deterioration modeling, examining parameters relevant to western states.

APPENDIX A

SUFFICIENCY RATING FORMULA

The sufficiency rating was an attempt by the FHWA to describe the current condition of a bridge based on four bridge parameters. This Appendix is included for those local officials that are not familiar with sufficiency rating calculations.

The sufficiency rating formula described herein is a method of evaluating data by calculating four separate factors to obtain a numeric value that indicates bridge sufficiency to remain in service. The result of this method is a percentage in which 100 percent would represent an entirely sufficient bridge and zero percent would represent an entirely insufficient or deficient bridge.

The sufficiency rating is the sum of numeric approximations for: structural adequacy and safety, serviceability and functional obsolescence, essentiality for public use, and special reductions.

The first factor, structural adequacy and safety (S_1), accounts for a maximum of 55 percent of the total sufficiency rating. The number indicated by the # mark are NBIS fields (i.e. #59). A brief field description is also given in parentheses.

a. Only the lowest of item 59, 60, or 62 applies.

If #59 (superstructure rating) or #60 (substructure rating) is	≤ 2 then	A = 55%
	= 3	B = 40%
	= 4	C = 25%
	= 5	D = 10%
If #59 and #60 = N and #62 (culvert rating) is	≤ 2 then	E = 55%
	= 3	F = 40%
	= 4	G = 25%
	= 5	H = 10%

b. Reduction for Load Capacity

(1) Calculate AIT (Adjusted Inventory Tonnage) as follows:

If first digit of #66 (Inventory Rating) = 1,
AIT = 2nd & 3rd digits x 1.56;

If first digit of #66 (inventory Rating) = 2,
AIT = 2nd & 3rd digits x 1.00;

If first digit of #66 (Inventory Rating) = 3,
AIT = 2nd & 3rd digits x 1.56;

If first digit of #66 (Inventory Rating) = 4,
AIT = 2nd & 3rd digits x 1.01;

If first digit of #66 (Inventory Rating) = 5,
AIT = 2nd & 3rd digits x 0.77;

If first digit of #66 (Inventory Rating) = 6,
AIT = 2nd & 3rd digits x 0.67;

If first digit of #66 (Inventory Rating) = 9,
AIT = 2nd & 3rd digits x 1.00;

(2) Calculate I using the following formula:

$$I = (36 - AIT)^{1.5} \times 0.2778$$

If $(36 - AIT) \le 0$ then $I = 0$

$$S_1 = 55 - (A+B+C+D+E+F+G+H+I)$$

S_1 shall not be less than 0% or greater than 55%

The second factor, serviceability and functional obsolescence (S_2), accounts for 30 percent of the total sufficiency rating

a. Rating Reductions (13% maximum)

If #58 (Deck Condition) is	≤ 3 then = 4 = 5	A = 5% A = 3% A = 1%
If #67 (Structural Eval.) is	≤ 3 then = 4 = 5	B = 4% B = 2% B = 1%
If #68 (Deck Geometry) is	≤ 3 then = 4 = 5	C = 4% C = 2% C = 1%
If #69 (Underclearance) is	≤ 3 then = 4 = 5	D = 4% D = 2% D = 1%
If #71 (Waterway Adequacy) is	≤ 3 then = 4 = 5	E = 4% E = 2% E = 1%
If #72 (Appr. Road Align.) is	≤ 3 then = 4 = 5	F = 4% F = 2% F = 1%

$J = A+B+C+D+E+F$

J shall not be less than 0% or greater than 13%

b. Width of Roadway Insufficiency (15% maximum)

Use the sections that apply:

(1) applies to all bridges;
(2) applies to 1-lane bridges only;
(3) applies to 2 or more lane bridges;
(4) applies to all <u>except</u> 1-lane bridges.

Also determine X and Y:

$$X = \frac{ADT(ITEM\ 29)}{NUMBER\ OF\ LANES\ (first\ two\ digits\ of\ item\ 28)}$$

$$Y = \frac{BRIDGE\ ROADWAY\ WIDTH\ (item\ 51)}{NUMBER\ OF\ LANES\ (first\ two\ digits\ of\ item\ 28)}$$

(1) When the last 2 digits of #43 (structure type) are not equal to 19 (culvert):

If (#51 + 2 ft.) < #32 (appr rdwy width) G = 5%

(2) For 1-lane bridges only:
If the first 2 digits of #28 are equal to 01 and

$Y < 14$	then	H = 15%
$14 \leq Y < 18$		$H = 15\left(\frac{18 - Y}{4}\right)\%$
$Y \geq 18$		H = 0%

(3) For 2 or more lane bridges. If these limits apply, do not continue to (4) as no lane width reductions are allowed.

If the first 2 digits of #28 = 02 and Y ≥ 16, H = 0%
If the first 2 digits of #28 = 03 and Y ≥ 15, H = 0%
If the first 2 digits of #28 = 04 and Y ≥ 14, H = 0%
If the first 2 digits of #28 ≥ 05 and Y ≥ 12, H = 0%

(4) For all <u>except</u> 1-lane bridges:

If	$Y < 9$ and $X > 50$ then	H = 15%
	$Y < 9$ and $X \leq 50$	H = 7.5%
	$Y \geq 9$ and $X \leq 50$	H = 0%

If $50 < X \leq 125$ and

$Y < 10$	then	H = 15%

$10 \leq Y < 13$ $\quad H = 15\left(\frac{13 - Y}{3}\right)\%$

$Y \geq 13$ $\quad H = 0\%$

If $125 < X \leq 375$ and

$Y < 11$ then $\quad H = 15\%$

$11 \leq Y < 14$ $\quad H = 15\left(\frac{14 - Y}{3}\right)\%$

$Y \geq 14$ $\quad H = 0\%$

If $375 < X \leq 1350$ and

$Y < 12$ then $\quad H = 15\%$

$12 \leq Y < 16$ $\quad H = 15\left(\frac{16 - Y}{4}\right)\%$

$Y \geq 16$ $\quad H = 0\%$

If $X \geq 1350$ and

$Y < 15$ then $\quad H = 15\%$

$15 \leq Y < 16$ $\quad H = 15(16 - Y)\%$

$Y \geq 16$ $\quad H = 0\%$

c. Vertical Clearance Insufficiency - (2% maximum)

If #100 (Defense Highway Designation) > 0 and

#53 (Vertical Clearance of Deck) ≥ 1600 $\quad I = 0\%$
#53 < 1600 $\quad I = 2\%$

If #100 = 0 and

#53 ≥ 1400 $\quad I = 0\%$
#53 < 1400 $\quad I = 2\%$

$$S_2 = 30 - [J+(G+H)+I]$$

S_2 shall not be less than 0% or greater than 30%

The third factor, essentiality for public use (S_3), accounts for 15 percent of the sufficiency rating.

a. Determine:

$$K = \frac{S_1 + S_2}{85}$$

b. Calculate:

$$A = 15 \frac{ADT\ (item\ 28) \times DETOUR\ LENGTH\ (item\ 19)}{200{,}000\ K}$$

c. Defense Highway Designation:

If #100 > 0 then B = 2%
If #100 = 0 then B = 0%

$$S_3 = 15 - (A + B)$$

S_3 shall not be less than 0% or greater than 15%

The final factor, special reductions (S_4), are used only when the sum of the first three factors are equal to or greater than 50.

a. Detour Length Reduction

$$A = (DETOUR\ LENGTH)^4(5.205 \times 10^{-8})$$

"A" shall not be less than 0% or greater than 5%

b. If the 2nd and 3rd digits of #43 (structure Type, Main) are equal to 10, 12, 13, 14, 15, 16, or 17; then B = 5%

c. If 2 digits of #36 (Traffic Safety Features) = 0 C = 1%
If 3 digits of #36 = 0 C = 2%
If 4 digits of #36 = 0 C = 3%

$$S_4 = A+B+C$$

S_4 shall not be less than 0% or greater then 13%

Considering the four factors above the sufficiency rating for a bridge is:

$$Sufficiency\ Rating = S_1 + S_2 + S_3 - S_4$$

APPENDIX B

PENNSYLVANIA'S BMS

The State of Pennsylvania has developed a bridge management program that is probably the most comprehensive undertaken by a state department of transportation. Appendix B illustrates how in-depth this BMS is.

In the bridge management system used by the State of Pennsylvania, deficiencies are evaluated in three general categories:

1. level-of-service capabilities
2. bridge condition
3. other related characteristics

Deficiencies of the above characteristics are determined by the sum of eight need functions to get a total deficiency rating for the structure. The eight need functions include: load capacity (LCD), clear deck width (WD), vertical overclearance (VCOD), vertical underclearance (VCUD), bridge condition (SPD,SBD,BDD), remaining life (RLD), approach roadway alignment (AAD), and waterway adequacy (WAD). The bridge condition function is the sum of three condition equations representing bridge deck, superstructure, and substructure.

Weighting of the need functions are accomplished according to Table B1. Although in a totally deficient bridge it is possible to receive 285 points, the program limits the total deficiency points to 100 maximum. A deficiency rating of 100 for a structure can be obtained by a number of different methods dependent on bridge parameters.

Table B1. Development Breakdown of the Total Deficiency Rating of Pennsylvania's Bridge Management System

<table>
<tr><th rowspan="2">Deficiency Category</th><th rowspan="2">Maximum Deficiency Points in Category</th><th colspan="3">Limiting Conditions</th></tr>
<tr><th>(1),(2)</th><th>(3)</th><th>(4)</th></tr>
<tr><td>LCD</td><td>70</td><td>70</td><td rowspan="4">Σ≤80</td><td rowspan="10">Σxϕ≤100</td></tr>
<tr><td>BDD</td><td>50</td><td rowspan="3">Σ≤50</td></tr>
<tr><td>SPD</td><td>50</td></tr>
<tr><td>SBD</td><td>50</td></tr>
<tr><td>WD</td><td>15</td><td>15</td><td>15</td></tr>
<tr><td>VCOD</td><td>15</td><td>15</td><td>15</td></tr>
<tr><td>RLD</td><td>15</td><td>5</td><td>5</td></tr>
<tr><td>VCUD</td><td>10</td><td colspan="2" rowspan="2">Σ≤15</td></tr>
<tr><td>WAD</td><td>10</td></tr>
<tr><td>AAD</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>Maximum Totals</td><td>285</td><td>180</td><td>140</td><td>100</td></tr>
</table>

Source: O'Conner, Daniel S. and Hyman, William A., "Bridge Management Systems", Demonstration Project No. 71, Federal Highway Administration, U.S. Department of Transportation, October 1989, p III-17.

LOAD CAPACITY DEFICIENCY

The load capacity deficiency is a function of the rated load capacity, ADT, and detour length computed by:

. . . . (B1)

where: WLC = weighting for load capacity
RC = rated load capacity (HS vehicle), tons
CG_B = base value of the load capacity (HS vehicle)
TR = traffic ratio:

$$TR = \frac{ADT}{ADT_B} \quad (0.3 \leq TR \leq 2.0) \qquad \text{(B2)}$$

ADT = average daily traffic on bridge
ADT_B = base value, ADT (see Table B2)
DR = detour length ratio:

$$DR = \frac{DL}{DL_B} \quad (0.5 \leq DR \leq 2.0) \qquad \text{(B3)}$$

DL = detour length
DL_B = base value, detour length (see Table B2)

In equation B1 the values for the load capacity weighting and the constants K_0, K_1, K_2, K_3, and K_4 are 70, 0.044, 0.75, 0.25, 0.3, and 1.5 respectively. The base values are defined in Table B2.

Table B2. Base Values for Average Daily Traffic and Detour Length as per Highway Classification

Functional Classification	ADT_B	DL_B
Interstate	17,100	7.0
Arterial	8,600	10.2
Collector	1,670	9.3
Local	820	9.8

Source: O'Conner, Daniel S. and Hyman, William A., "Bridge Management System", Demonstration Project No. 71, Federal Highway Administration, U.S. Department of Transportation, October 1989, p III-18.

CLEAR DECK WIDTH DEFICIENCY

The clear deck width deficiency equation is a function of the clear deck width and the average daily traffic per lane. The clear deck width deficiency equation accounts for a maximum of 15 points in the total deficiency equation.

The width deficiency is computed by:

$$WD = WW K_{20} \; (TLR)^{K_{21}} \left(\frac{WG_M - CDW}{WG_M - W_{AM}} \right)^{K_9} \qquad \text{(B4)}$$

where: WW = weighting for width
CDW = clear deck width, feet
WG_M = width goal - minimum design, feet
W_{AM} = width - absolute minimum, feet
TLR = traffic per lane ratio

$$TLR = \frac{\frac{ADT}{n}}{ADTL_B} \; (0.25 \le TLR \le 2.25) \qquad \text{(B5)}$$

n = number of traffic lanes on bridge
$ADTL_B$ = base value, vpd/lane

In equation B4 the values for the width weighting and the constants K_9, K_{20}, and K_{21} are 15.0, 1.5, 2.0, and 0.5 respectively. The base values are defined in Table B3.

Table B3. Base Values for Deck Width, Absolute Minimum Width, and Vehicles per Lane as per Highway Classification

	Functional Classification	ADT	WG_M	W_{AM}	$ADTL_B$
Urban	Interstate	ALL	12n+4+10	11n	6,100
	Arterial	ALL	12n+4+8	10n	3,200
	Collector	ALL	10n+8+8	10n	810
	Local	ALL	10n+6+6	10n	390
Rural	Interstate	ALL		11n	6,100
	Arterial	ALL		11n	3,200
	Collector and Local Local	>750	11n+8+8	10n	810-collector
		400-750	10n+6+6	9n	
		50-399	10n+4+4	9n	390-local
		<50	10n+2+2	8n	

Source: O'Conner, Daniel S. and Hyman, William A., "Bridge Management System", Demonstration Project No. 71, Federal Highway Administration, U.S. Department of Transportation, October 1989, p II-7,8 and III-19.

VERTICAL OVER/UNDER CLEARANCE DEFICIENCY

The vertical clearance is broken down into equations for the overclearance and underclearance each having a maximum value. The maximums are 15 points for overclearance and 10 points for underclearance as determined by:

. . . . (B6)

. . . . (B7)

where: VCOD = vertical overclearance deficiency
VCUD = vertical underclearance deficiency
WVCO = weighting factor for overclearance (=15)
WVCU = weighting factor for underclearance (=10)
VCO = vertical overclearance, feet

VCU = vertical underclearance, feet
$VCOG_M$ = vertical overclearance goal - minimum design
$VCUG_M$ = vertical underclearance goal - minimum design
VCO_A = vertical overclearance - minimum acceptable
VCU_A = vertical underclearance - minimum acceptable

TR_O = traffic ratio on bridge: $TR_O = \frac{ADT}{ADT_B}$

ADT = average daily traffic on bridge
ADT_B = base value, ADT

TR_U = traffic ratio under bridge: $TR_U = \frac{ADTU}{ADTU_B}$

$ADTU$ = average daily traffic under bridge
$ADTU_B$ = base value, ADTU
K_{12} = constant 1.5

The base values are defined in Table B4.

Table B4. Base Values for Vertical Clearances as per Highway Classification

Functional Classification	VCO_A or VCU_A	$VCOG_M$ or $VCUG_M$	$VCOG_D$ or $VCUG_D$	K_{TO} or K_{TU}	ADT_B or $ADTU_B$
Interstate	14.50	16.50	16.50	2.5	17,100
Arterial	13.75	14.50	14.50	2.9	8,600
Collector	13.75	14.50	14.50	3.7	1,670
Local	13.75	14.50	14.50	4.3	820

Source: O'Conner, Daniel S. and Hyman, William A., "Bridge Management System", Demonstration Project No. 71, Federal Highway Administration, U.S. Department of Transportation, October 1989, p II-7,8 and III-19.

BRIDGE CONDITION DEFICIENCY

Bridge Condition Deficiency includes the condition assessment of three principal bridge components; the superstructure, substructure, and deck. The deficiency points for these components are based on the condition rating for each of these components derived by:

$$SPD = K_{SP}(WSP) \qquad \text{(B8)}$$

$$SBD = K_{SB}(WSB) \qquad \text{(B9)}$$

$$BDD = K_{BD}(WBD) \qquad \text{(B10)}$$

where: SPD = superstructure deficiency
SBD = substructure deficiency
BDD = bridge deck deficiency
WSP = weighting for superstructure condition (= 50)
WSB = weighting for substructure condition (= 50)
WBD = weighting for bridge deck condition (= 50)
K_{SP}, K_{SB}, K_{BD} = condition deficiency coefficients (Table B5)

Table B5. Condition Deficiency Coefficients

Condition Rating	K_{SP}	K_{SB}	K_{BD}
≤2	1.00	1.00	1.00
3	0.50	0.50	0.50
4	0.25	0.25	0.25
5	0.10	0.10	0.10
6	0.05	0.05	0.05
≥7	0.00	0.00	0.00

Source: O'Conner, Daniel S. and Hyman, William A., "Bridge Management System", Demonstration Project No. 71, Federal Highway Administration, U.S. Department of Transportation, October 1989, p III-21.

REMAINING LIFE DEFICIENCY

The remaining life deficiency is calculated as a function of the condition ratings for the superstructure, substructure, and deck given by:

$$RLD = (WL)\ (K_{16})\left\{1 - \frac{RL}{RL_B}\right\}^{K_{17}} \quad (0 \le RLD \le WL) \quad \ldots\ldots\ldots \text{(B11)}$$

where: WL = weighting for remaining life (= 5)
RL = estimated remaining life (Table B6)
RL_B = base value remaining life (= 15)
K_{16} = constant (= 1.837)
K_{17} = constant (= 1.5)

Table B6. Estimated Remaining Life Based on Sum of Condition Ratings for Superstructure, Substructure, and Bridge Deck

Sum of Rating	Remaining Life	Sum of Rating	Remaining Life	Sum of Rating	Remaining Life
27	50	21	27	15	10
26	46	20	26	14	8
25	42	19	23	13	7
24	38	18	20	12	6
23	34	17	17	11	5
22	30	16	14		

If any condition rating is 4 or less

Lowest Rating	Remaining Life	Lowest Rating	Remaining Life
4	10	2	1
3	5	0,1	0

Source: O'Conner, Daniel S. and Hyman, William A., "Bridge Management System", Demonstration Project No. 71, Federal Highway Administration, U.S. Department of Transportation, October 1989, p III-21.

APPROACH ROADWAY ALIGNMENT DEFICIENCY

The approach roadway alignment deficiency points are calculated by:

$$AAD = K_{AA}(WAA) \quad \text{(B11)}$$

where: WAA = weighting for roadway alignment (= 10)
K_{AA} = alignment coefficient base on appraisal rating (Table B7)

Table B7. Coefficients for Approach Roadway Alignment, Waterway Adequacy, and Weighting for Functional Class

Appraisal Rating	K_{AA}	Appraisal Rating	K_{WA}	Functional Class	ϕ
≤3	1.00	3	1.00	Interstate	1.00
4	0.50	4	0.50	Arterial	0.95
5	0.20	5	0.20	Collector	0.85
≥6	0.00	6	0.00	Local	0.75

Source: O'Conner, Daniel S. and Hyman, William A., "Bridge Management System", Demonstration Project No. 71, Federal Highway Administration, U.S. Department of Transportation, October 1989, p III-23.

WATERWAY ADEQUACY DEFICIENCY

The waterway adequacy deficiency points are calculated by:

$$WAD = K_{WA}(WWA) \quad \text{(B12)}$$

where: WWA = weighting for waterway adequacy (=10)
K_{WA} = waterway adequacy coefficient base on appraisal rating (Table B7)

WEIGHTING FACTOR FOR FUNCTIONAL CLASS

The final step in Pennsylvania's BMS is to factor the sum of the above equations according to the functional class of the highway that the bridge serves.

$$DP = \phi * \Sigma(LCD,\ WD,\ VCOD,\ VCUD,\ SPD,\ SBD,\ BDD,\ RLD,\ AAD,\ WAD)$$

APPENDIX C

STRUCTURAL INVENTORY & APPRAISAL SHEET

SOURCE: Kansas Department of Transportation, "Supplement Coding Guide for Bridge Inspection and Rating", November 1989, Appendix A.

Structure Inventory and Appraisal Form
National Bridge Inventory--Structure Inventory And Appraisal

DATE OF INSPECTION ___/___/___

(1) STATE NAME __________ CODE ________
(2) STATE HIGHWAY DEPARTMENT DISTRICT CODE ________
(3) COUNTY __________ CODE ________
(4) PLACE __________ CODE ________
(5) INVENTORY ROUTE (ON/UNDER) __________
(6) FEATURES INTERSECTED __________
(7) FACILITY CARRIED __________
(8) STRUCTURE NUMBER __________
(9) LOCATION __________
(10) INVENTORY ROUTE MIN VERT CLEAR ____ FT. ____ IN
(11) MILEPOINT ________
(16) LATITUDE ____ D. ____ M.
(17) LONGITUDE ____ D. ____ M.
(19) BYPASS, DETOUR LENGTH ________ MI.
(20) TOLL __________ CODE ________
(21) MAINTAIN __________ CODE ________
(22) OWNER __________ CODE ________
(26) FUNCTIONAL CLASS __________ CODE ________
(27) YEAR BUILT ________
(28) LANES ON STRUCTURE ____ UNDER STRUCTURE ________
(29) AVERAGE DAILY TRAFFIC ________
(30) YEAR OF ADT ________
(31) DESIGN LOAD __________ CODE ________
(32) APPROACH ROADWAY WIDTH (W/SHOULDERS) ________ FT.
(33) BRIDGE MEDIAN __________ CODE ________
(34) SKEW DEGREE ________ DEG.
(35) STRUCTURE FLARED CODE ________
(36) TRAFFIC SAFETY FEATURES CODE ________
(37) HISTORICAL SIGNIFICANCE CODE ________
(38) NAVIGATION CONTROL __________ CODE ________
(39) NAVIGATION VERTICAL CLEARANCE ________ FT.
(40) NAVIGATION HORIZONTAL CLEARANCE ________ FT.
(41) STRUCTURE OPEN, POSTED OR CLOSED CODE ________
DESCRIPTION __________
(42) TYPE OF SERVICE: ON __________ CODE ________
UNDER __________

Structure Inventory and Appraisal Form
sheet 2

(43) STRUCTURE TYPE MAIN: MATERIAL ______________
TYPE ______________ CODE ______

(44) STRUCTURE TYPE APPROACH: MATERIAL ______________
TYPE ______________ CODE ______

(45) NUMBER OF SPANS IN MAIN UNIT ______ CODE ______

(46) NUMBER OF APPROACH SPANS ______ CODE ______

(47) INVENTORY ROUTE TOTAL HORIZ CLEAR ______ FT.

(48) LENGTH OF MAXIMUM SPAN ______ FT.

(49) STRUCTURE LENGTH ______ FT.

(50) CURB OR SIDEWALK LEFT ______ RIGHT ______

(51) BRIDGE ROADWAY WIDTH CURB TO CURB ______ FT.

(52) DECK OUT TO OUT ______

(53) MIN VERT CLEAR OVER ROADWAY ______ FT.______ IN

(54) MIN VERT UNDERCLEAR REF ______ ______ FT.______ IN

(55) MIN LAT UNDERCLEAR RT REF ______ ______ FT.______ IN

(56) MIN LAT UNDERCLEAR LT REF ______ ______ FT.______ IN

(58) DECK CODE ______

(59) SUPERSTRUCTURE CODE ______

(60) SUBSTRUCTURE CODE ______

(61) CHANNEL & CHANNEL PROTECTION CODE ______

(62) CULVERTS CODE ______

(64) OPERATING RATING CODE ______

(66) INVENTORY RATING CODE ______

(67) STRUCTURAL EVALUATION CODE ______

(68) DECK GEOMETRY CODE ______

(69) UNDERCLEARANCES VERT & HORIZ CODE ______

(70) BRIDGE POSTING CODE ______

(71) WATERWAY ADEQUACY CODE ______

(72) APPROACH ROADWAY ALIGNMENT CODE ______

(75) TYPE OF WORK CODE ______

(76) LENGTH OF STRUCTURE IMPROVEMENT CODE ______

(90) INSPECTION DATE ____/____/____

(91) FREQUENCY ______ MO.
REASON ______________

(92) CRITICAL FEATURE INSPECTION:
A) FRACTURE CRITICAL DETAIL CODE ______ MO.
B) UNDERWATER INSPECTION CODE ______ MO.
C) OTHER SPECIAL INSPECTION CODE ______ MO.

Structure Inventory and Appraisal Form
sheet 3

(93) CRITICAL FEATURE INSPECTION DATE:
A) FRACTURE CRITICAL DETAIL ___/___
B) UNDERWATER INSPECTION ___/___
C) OTHER SPECIAL INSPECTION ___/___
(94) BRIDGE IMPROVEMENT COST $___,___
,000
(95) ROADWAY IMPROVEMENT COST $___,___
,000
(96) TOTAL PROJECT COST $___,___
,000
(97) YEAR OF IMPROVEMENT COST ESTIMATE 19/20 ____
(98) BORDER BRIDGE STATE CODE ________ SHARE ___%
(99) BORDER BRIDGE STRUCTURE NUMBER ____________
(100) DEFENSE HIGHWAY CODE ________
(101) PARALLEL STRUCTURE CODE ________
(102) DIRECTION OF TRAFFIC CODE ________
(103) TEMPORARY STRUCTURE CODE ________
(104) HIGHWAY SYSTEM CODE ________
(106) YEAR RECONSTRUCTED 19 ______
(107) DECK STRUCTURE TYPE CODE ________
(108) WEARING SURFACE / PROTECTIVE SYSTEM:
A) TYPE OF WEARING SURFACE CODE ________
B) TYPE OF MEMBRANE CODE ________
C) TYPE OF DECK PROTECTION CODE ________
(109) AVERAGE DAILY TRUCK TRAFFIC ________%
(110) DESIGNATED NATIONAL NETWORK CODE ________
(111) PIER PROTECTION CODE ________
(112) NBIS BRIDGE LENGTH CODE ________
(113) SCOUR CRITICAL BRIDGES ________
(114) FUTURE AVERAGE DAILY TRAFFIC ________
(115) YEAR OF FUTURE ADT 20 ______
(116) VERT-LIFT BRIDGE NAV MIN VERT CLEAR ________ FT.

APPENDIX D

WYO_BMS DEFICIENCY POINT PARAMETERS

The weighting and importance factors are user defined under the *Set-Up* routine within WYO_BMS. The choices made in the selection of these parameters affect the deficiency point calculation for the structure, components, and elements.

To assist the bridge manager in choosing these parameters the following figures were compiled. Figure D1 illustrates the effect that the selection of the exponent n has on the weighting of the bridge component or element. The equation used to demonstrate this is:

$$Weighting = Ratio^{n} \qquad \text{(D1)}$$

where Weighting = the ratio adjusted by exponent n

$$Ratio = \frac{A - X}{A}; \quad 0.0 \le Ratio \le 1.0 \qquad \text{(D2)}$$

A = level-of-service goal for bridge component or element
X = current condition of bridge component or element
n = importance factor

APPENDIX E

WYO_BMS SOURCE CODE AVAILABILITY

A copy of the Source Code for WYO_BMS can be obtained from the WDT or the University of Wyoming.

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APPENDIX F
BRIDGE MANAGEMENT IMPLEMENTATION GUIDELINES

For the Implementation of PONTIS.

1. Obtain copy of PONTIS.

2. Confirm that computer resources are adequate to run and maintain PONTIS.

3. Install PONTIS onto computer system in accordance with Chapter 2 of PONTIS User's Manual.

4. Train with the demo data package provided with the PONTIS software.

5. If existing bridge data is in a format not directly compatible with PONTIS, download existing INFORMIX bridge databases into an ASCII format. (In Wyoming, this step needs to be done.)

6. Modify the ASCII output from (5) in accordance with section 4.1.1 of PONTIS User's Manual. Load onto system.

7. Repeat (5) and (6) for each table within the INFORMIX database.

8. Train on PONTIS with familiar data.

9. If the database is corrupted during training the databases should be reinstalled on the system.

10. Train bridge inspectors on the new condition rating system used by PONTIS

11. Use PONTIS.

For the Implementation of WYO_BMS.

1. Obtain INFORMIX run-time license.

2. Obtain WYO_BMS.

3. Check computer resources for adequate RAM and storage space.

4. Install INFORMIX run-time and WYO_BMS on computer system. To install INFORMIX, follow instructions provided with the run-time. To install WYO_BMS, insert disk 1 into drive A: and enter

A:>INSTALL

Repeat for disk 2.

5. Run the WYO_BMS set-up program. To run the set-up program enter:

C:\INFORMIX\WYO_BMS>SETUP

6. Create a floppy disk backup of the *BRIDGE.DBS* directory. This is a copy of the empty data tables and system parameters.

7. Load ASCII format database information obtained from WDT using INFORMIX utility *DBLINK*.

8. Train users on the organization and use of WYO_BMS.

9. Reestablish the database after training is complete. Copy the back-up directory *BRIDGE.DBS* over the current *BRIDGE.DBS* directory and repeat step (7). This will eliminate any corrupted data entered during training.

10. Use WYO_BMS.

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