

BRIDGE MANAGEMENT DECISION SUPPORT

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ABSTRACT

Bridge Management Systems (BMSs) are designed to assist the bridge manager in cost-effectively addressing the bridge infrastructure needs. Typical decision support include access and retrieval of bridge related information, assessment of bridge needs, evaluation and cost estimating of alternate strategies for inclusion in optimized capital and maintenance programs, network and project level forecasting, and trend analysis. This paper specifically focuses on major bridge related decisions managers face, at the network and project level, and the types of decision support needed for assuring appropriateness and cost-effectiveness of those decisions. It also discusses the data sources that can provide this decision support.

INTRODUCTION

Henry Ford made automobiles affordable and created an unprecedented need for expansion and improvement of roadway and bridge networks. As the automobile population grew, roadways were paved and bridges built. Depression era public works programs helped to meet much of this need, but most of that help ended with World War II. With all the growth, the U.S. never achieved a stable, steady-state bridge population. When these bridges became due for major preservation work, another major expansion program, the Interstate Highway Program, came along. That program replaced some of the worst bridges, added many new bridges and diverted our attention away from needed preservation work. Then, the country entered a new phase that it was not prepared to manage: the maturity of a highly diverse highway system. In its past enthusiasm to build and expand, timely maintenance of what was being built took a back seat to other local and national priorities. Deferred maintenance was thought of as a good way to stretch shrinking budgets. When attention was finally focused on bridge condition due to the catastrophic failure of some bridges (e.g., Point Pleasant, West Virginia), a sizeable portion of the bridge network needed substantial repairs.

The backlog of repair and replacement needs was large and new needs were also being identified with each new inspection and each improvement in the quality of

the inspections. It became obvious that a better job had to be done in managing bridge networks. New technologies were available to aid in the systematic collection and processing of bridge data: to store, analyze, summarize, and retrieve vast quantities of bridge information; and to organize that information in ways to improve the decision making abilities of bridge managers. The use of such technology has been called a "Bridge Management System."

Most bridge agencies have reasonable confidence in their knowledge of their bridges, but not the same level of confidence in their ability to decide what is most appropriate for those bridges at a given point in time or at specific times in the future. Consequently, many of these agencies have recognized their need for assistance in making bridge-related decisions. As a result, BMSs have been receiving considerable attention in this country within the last decade. While there can be many benefits to a BMS, the major benefit is comprehensive data based assistance to the bridge manager. To a large extent, the specific assistance a particular BMS provides is determined by its developing agency and operational users.

This paper identifies types of decision support, presents what many larger bridge management agencies in the U.S. and Canada consider the most important decision support capabilities, and recommends a group of critical decision support capabilities that should be part of a comprehensive BMS. Besides capabilities that should be incorporated, it also must be recognized that some capabilities should not be built into a BMS. One such capability is decision making. A BMS must never make decisions. This is a pitfall where BMS developers can easily stumble. The analytical processes can often fool the developer and the user into believing that the system knows best. Bridges cannot be managed without the practical, experienced and knowledgeable input from the Engineer/Manager. A practical way to help ensure that a BMS would not be used as a decision maker is to build in user adjustments at all the critical decision areas. A user adjustment would require the user to either accept the recommendation of the BMS or change it based on the user's knowledge. Without positive user action, the system should not be able to complete the analysis routine.

BRIDGE MANAGEMENT SYSTEM - BASIC COMPONENTS

Agencies responsible for bridges are very enthusiastic about the prospects for BMSs. The reason for this enthusiasm is that bridge managers understand and believe that the BMSs will significantly improve their ability to manage their bridges. Help can be provided by the simple automation of current bridge management procedures. This automation will enable managers to deal more effectively with many bridges, multiple competing needs and complicated issues. Besides the automation of current procedures, expanded and/or newly developed analysis procedures also will help the manager by providing information that was not available in the past.

In any BMS there are only three basic components: data, data analysis, and decision support. Another way of describing this, is: input (data that are necessary for the decision process), processing (the analysis routines to which the data are subjected), and output (the results of the analysis routines that will assist the user in making balanced bridge management decisions, i.e., reports and summaries). In the development of a BMS, these three components do not occur in the order presented. The first activity is the recognition of the areas of need for decision support. The second is the identification of the types of analysis to be used to obtain the desired decision support. The last is the identification and collection of essential data for these analyses. When BMS formulation and development were in their infancy, it was widely accepted that any BMS would never have sufficient information in its database to make decisions. The missing information is mostly intangibles, such as: political considerations, engineering experience and local needs. These and other intangibles are essential for the final decision. However, the proposed BMSs were recognized as being able to provide valuable assistance by organizing and analyzing the available bridge data. The decision making would be left to the Engineer/Manager.

One area that was often overlooked in the BMS planning stages was how difficult it is to produce deterioration rate estimates for groups of bridges. The experience in New York State confirms how difficult condition deterioration prediction can be. One can make reasonably good predictions of the network condition of an infrastructure group for the near future, but predictions for a particular bridge have not been so successful. The cost of bridge work is similarly difficult to predict. Even after bridge projects have been designed, there can be significant differences between the engineer's estimate and what the bidders submit. A

variation of plus or minus 10% is not uncommon. Therefore, we cannot and should not believe we can calculate precise benefit/cost data for various alternatives on one or many bridges. Thus, prioritization and optimization efforts have to be kept in the proper perspective. The quality and precision of the data that they rely on are insufficient to support sophisticated calculations.

COMPREHENSIVE BRIDGE MANAGEMENT - CAPABILITIES

Most dictionaries define comprehensive as "large in scope or content," or "marked by or showing extensive understanding in..." These two ways of defining the word "comprehensive" are subjective. Comprehensive bridge management also is subjective because it includes capabilities that are usually tied to the agency's needs. These needs are identified in the agency's goals, policies and standards. Therefore, what a particular BMS does for an agency is dependent on that agency's operational philosophies and the extent to which these philosophies are incorporated in the development of the system. A system exclusively developed for use by an agency will naturally be specifically tailored for that agency's goals, objectives, policies and procedures. A system developed for multiple agencies may not provide all the capabilities that each individual agency desires. The New York State Department of Transportation (NYSDOT) distributed a questionnaire to solicit information on the BMS development plans of major bridge management agencies. The results of that questionnaire (2) indicated that 37 (70 percent) of the responding agencies were anticipating adopting a system developed outside their agency. This shows that those agencies believe an externally developed system can support, or can be modified to support, their individual bridge management philosophies. BMSs, therefore, are likely to vary significantly in their construct and capabilities. Each system, however, should have some basic capabilities that are generally considered necessary for a comprehensive BMS. They are:

- Comprehensive bridge database and ease of access;
- Assessment ability for bridge condition, vulnerability and serviceability needs at the project and network level;
- Ranking/prioritization ability;
- Ability to develop and/or evaluate alternate work and program strategies based on cost effectiveness; and
- Ability to assess the effectiveness of decisions for optimal use of available resources.

In addition, a comprehensive BMS should provide the user with the ability to control various aspects of the program's operation and to "adjust" the results provided by the BMS, based upon the user's knowledge of unique or special considerations. These abilities are specifically focused on the user, not the system, as the decision maker. It is equally important to recognize that agencies are unique and their needs differ significantly. Consequently, a BMS without all the capabilities indicated above, although possibly viewed as not being comprehensive by many, may still satisfy all the needs of an individual agency.

BRIDGE MANAGEMENT DECISION SUPPORT

Bridge management decisions are related to either a group of bridges (Network Level Decision) or an individual bridge (Project Level Decision). Further, decisions at either level may include capital improvements and operating maintenance activities. The goal of a comprehensive BMS is to integrate these decision processes to attain the lowest possible and practical life cycle costs at the network and project level.

The principal purpose of a BMS is to provide properly analyzed information that will assist the user in selecting the best alternative action for a bridge or a network of bridges. Therefore, a BMS should present information to help the user coordinate bridge work activities, improve cost effectiveness of decisions and maximize benefits within constrained budgets.

The capabilities provided by a BMS for decision support are as many as the user and the bridge management agencies needs. Obviously, more appropriate capabilities can be included in the BMS when an agency is developing or controlling the development of that system rather than adopting a BMS developed by another agency. However, even in previously developed systems, a group of generally accepted basic core capabilities are included. Turner and Richardson (1) present data in terms of logical and practical groupings of data needs that are particularly useful when considering important decision support. The groupings are presented and described in Table I.

The NYSDOT is developing its own BMS. As part of the development process, the Department considered it important to identify those BMS capabilities that other transportation agencies deemed important for bridge management decision support. To satisfy this interest, questionnaires were sent to the Transportation Agency in the States, the District of Columbia, and several Canadian provinces. The results of the questionnaires provided a comprehensive list of desirable decision

support capabilities. The results are tabulated in Table II.

Table III identifies the information areas, analytical requirements and sources for each of these decision support capabilities for both network and project levels. It is evident from the first two columns in Tables III that two basic information sources are needed by all BMS decision support capabilities: 1) the root BMS database containing new and historic condition, inventory, work and cost data, and 2) the agency's goals, policies, standards and procedures. The first shows the need for basic data, while the second shows the basic reliance on the organization's operating philosophy.

A BMS has two other basic information needs. Resource availability (column 4 in Table III) controls the amount and type of work that can be done both within the agency and by contract, by establishing allocations. This availability is under the control of various legislative and other political entities. The needs analyses (column 3) are limited applications of the agency policies and standards to the bridge database to identify all potential problem instances. These are appropriate as an input because they are not subject to negotiation within the BMS. A bridge either meets agency standards or it does not. It is subject to a particular policy, or it is not. The program that the BMS process produces may or may not address these needs. These first four columns represent data inputs.

The last four columns in Tables III are examples of iterated outputs that require evaluation by the agency. These outputs describe the currently selected work program. If the agency is satisfied with the results, then the BMS process is complete. If the results are not satisfactory, then adjustments have to be made to the BMS parameters and a new program generated.

Table IV indicates the sources for the decision critical information and the processed information (outputs) that were shown as the columns in Tables III. As expected, BMS information is derived from data sources, while analysis inputs require data sources combined with models, criteria and analytical methods. Based upon the responses to a NYSDOT survey (2), the Turner and Richardson paper (1), and other sources, bridge management decision support is desirable in the areas of condition assessment and forecasting, program and budget development, monitoring and analysis, and vulnerability to failure. The bridge failure and deterioration groups referred to by Turner and Richardson clearly encompass the condition assessment, forecasting and vulnerability features identified as desirable by the NYSDOT survey results. Level of Service (functional obsolescence) is also a desirable and important consideration in program development

TABLE I GROUPINGS OF DATA NEEDS FOR BRIDGE MANAGEMENT DECISION SUPPORT

Prevent Bridge Failures	Data to prevent bridge failures are identified as data areas that affect the structural integrity of a bridge. These include condition, fracture critical, and scour data. These data, and other vulnerability data (i.e., hydraulics, earthquakes, collisions, overloads), can provide input to a decision support feature that would help the bridge manager in determining the urgency of structural integrity needs and help identify possible work strategies to address these needs. However, bridges identified as having such needs would very likely be "high priority" candidates and have few (if any) alternative actions.
Determine Functional Obsolescence	Data to determine functional obsolescence are data that help assess the ability of a bridge to function as it was originally designed. These data include information on bridge width, vertical clearance (on and over), load posting, and user costs (includes detour costs). These data can be used to determine the severity of functional deficiencies, identify the consequences of any deficiency, and help develop possible work strategies to address these needs.
Determine Maintenance Needs	Data to determine maintenance needs are directed at identifying the traditional operational needs of a bridge. This operational work is associated with minor condition corrective type work and preventive types of work that will arrest or reduce the rate of deterioration. These data can be used to identify maintenance need areas and to help identify and evaluate possible work strategies and work plans to address these needs.
Predict Bridge Deterioration*	Data to predict bridge deterioration are data relating to the condition of a bridge and its elements over time. These data include bridge condition data tracked over time and historical environmental information pertaining to the environment that those bridges were subjected to. Some of these data can be difficult to gather. These data are necessary to predict the future condition of bridges so all potential work strategies can be evaluated. This is a very difficult capability and that should be kept in mind when applying the results of any analysis.
Predict Bridge Costs*	Data to predict bridge related costs are data to enable the user to develop costs for all types of potential bridge work strategies. These data include the historical bid information pertaining to bridge and project costs, type of improvement work, and specific details for each bridge. These data are necessary to predict the cost of proposed work recognizing the difficulty with cost predictions in general.

* Information in these groupings considered to be approximate.

TABLE II BRIDGE MANAGEMENT DECISION SUPPORT CAPABILITIES SELECTED BY TRANSPORTATION AGENCIES

Decision Support Capabilities	Selected by Responding Agencies* (%)
NETWORK LEVEL	
Analysis of Short/Long Term Capital & Operating Budgets Evaluate the effect of both long and short term capital and operating (maintenance) budgets and compare the results to agency goals and objectives.	79
Current Systemwide Assessment of Bridge Condition Provide bridge network assessment using the agency's condition methodology.	77
Forecasting Systemwide Assessment of Bridge Condition Project bridge network condition into the future using deterioration models.	75
Ability to Select the Most Prudent and Cost-Effective Mix of Capital/ Operating Improvements Based on Life-Cycle Costs Provide information on the advantages and disadvantages of alternative improvements.	75
Project Selection Select potential projects for inclusion in capital/operations program.	75
Program Development Develop a capital/operations program with capability to evaluate alternative "what if" scenarios.	74
Optimization of Improvement Action Evaluate advantages and disadvantages of improvement alternatives with ranking of individual projects.	68
Monitoring Bridge Improvement Program (Capital & Operating) Track the status of capital and operations programs.	60
Statewide Assessment of Bridge Service Restrictions Evaluate all bridges with respect to various levels of service for load carrying capacity, vertical clearance, and bridge width.	53
Vulnerability to Sudden Failure (scour, earthquake, etc.) Evaluate susceptibility of bridges to failure caused by scour, fatigue, earthquake, overload, collision impact, concrete/steel detail, etc., and analyze impact of alternative improvements.	43
Information Center Accessible to Others Availability of bridge data/information to others.	32
PROJECT LEVEL	
Definition of Individual Capital & Operating Needs Assessment of major needs (condition, vulnerability, serviceability and preservation) of individual bridges.	74
Prediction of Remaining Service Life of Improvements Identify remaining service life of a bridge using deterioration models and impacts of improvement activities.	55
Individual Project Cost Estimation: Capital and Operating Capital and operations cost estimates developed from component/element level data and associated costs for highway and utility work, construction inspection, etc.	51
Support for Structural Capacity Analysis (Load Rating) Analyze structural capacity of a bridge to produce load rating.	36
Project Design Support Develop project concepts, and structure design and detailing.	23

* Fifty-three Responding Agencies

TABLE III DECISION CRITICAL INFORMATION AREAS FOR NETWORK AND PROJECT LEVEL DECISION SUPPORT

	Information Sources				Processed Information			
	(1) Current & Historic Inspection, Inventory, Work & Cost Data	(2) Organizational Goals, Policies, Standards & Procedures	(3) Condition, Vulnerability & Serviceability Needs	(4) Resource Availability	(5) Program Cost Estimates	(6) Project Cost Estimates	(7) Forecast of Resulting Network Needs with/without Program	(8) Forecast of Resulting Project Needs with/without Program
NETWORK LEVEL								
Analysis of Short/Long Term Capital & Operating Budgets	X	X	X	X	X	X	X	X
Current Systemwide Assessment of Bridge Condition	X	X						
Forecasting Systemwide Assessment of Bridge Condition	X	X					X	
Ability to Select Cost-Effective Mix of Capital/Operating Improvements Based on Life-Cycle Costs	X	X	X					
Project Selection	X	X	X	X	X	X	X	X
Program Development	X	X	X	X	X	X	X	X
Optimization of Improvement Actions	X	X	X	X	X	X	X	X
Monitoring Bridge Improvement Program (Capital & Operating)	X	X			X	X		
Systemwide Assessment of Bridge Service Restrictions	X	X	X					
Vulnerability to Sudden Failure (scour, earthquake, etc.)	X	X	X					
Information Center Accessible to Others	X	X	X					
PROJECT LEVEL								
Definition of Capital & Operating Needs	X	X	X					
Prediction of Remaining Service Life of Improvements	X	X						X
Individual Project Cost Estimate: Capital and Operating	X	X				X		
Support for Structural Capacity Analysis (Load Rating)	X	X						
Project Design Support	X	X						

TABLE IV DATA SOURCES FOR DECISION CRITICAL INFORMATION

	DECISION CRITICAL DATA SOURCES											
	(1) Current & Historic Bridge Inspection and Inventory Data	(2) Current & Historic Work Cost Data (Capital & Operating)	(3) Vulnerability to Catastrophic Failure Data	(4) Serviceability Data	(5) Economic Indicator Data	(6) Deterioration/Improvement Model	(7) Cost Prediction Models	(8) Ranking/Prioritization Criteria	(9) Optimization Criteria	(10) Alternate Work Actions with Cost & Life Expectancy Estimates	(11) Service Life Models with/without Improvements	(12) External Agencies (i.e., FHWA & AASHTO)
INFORMATION SOURCES												
Current & Historic Inspection, Inventory, Work Histories, & Cost Data	X	X	X	X								
Organizational Goals, Policies, Standards, & Procedures	X	X	X	X	X	X	X	X	X	X	X	X
Condition, Vulnerability & Serviceability Needs	X		X	X								
Resource Availability												X
PROCESSED INFORMATION												
Program Cost Estimates	X	X	X	X	X	X	X	X	X	X	X	
Project Cost Estimates	X	X	X	X			X					
Forecast of Resulting Network Needs with/without Program	X		X	X		X					X	
Forecast of Resulting Project Needs with/without Program	X		X	X		X					X	

capability. Bridge costs are always a major part of program and budget development, monitoring, and analysis. These independent sources of information have been useful in providing a good understanding of which bridge management decision support capabilities are important.

Another major feature is the reporting capability. Without it, agencies would simply not be able to use the results of the BMS process. Reporting needs are individualized and vary from agency to agency as well as from time to time. It is equally important to note here that the basic conclusions reached in this paper are compatible with two previously released BMS documents. These documents are: American Association of State Highway and Transportation Officials' *Guidelines for Bridge Management Systems (3)* and *National Cooperative Highway Research Program Report 300, "Bridge Management Systems" (4)*. Therefore, the core of BMS decision support capabilities is essentially unaltered from the beginnings of bridge management conceptual development.

SUMMARY

There are many capabilities that should be included in a comprehensive BMS. These are dependent on the desires of the bridge management agency. These capabilities can be combined into major areas that represent core features of any BMS. These major network and project level core capabilities are

- bridge needs assessment,
- bridge needs forecasting,
- optimization, and
- report capability.

The following principles should be kept in mind throughout the development and use of any BMS:

- BMS's should be compatible with agency philosophies;
- Systems should provide user adjustments/decisions;
- Quality and precision of the data requirements for prioritization and optimization are insufficient to support complex routines, therefore, these efforts should be kept in proper perspective and expectations for these areas set at reasonable levels; and
- A BMS is a decision support tool, not a manager!

Considering all we know today, a more appropriate name for a BMS should be a "Bridge Management Decision Support System" (BMDSS).

REFERENCES

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