Bridge Management Systems—State of the Art

A. M. SHIROLE, W. J. WINKLER, AND J. J. HILL

During the past decade, many agencies responsibile for bridges in the U.S. and abroad have been actively involved in the development of operating bridge management systems (BMSs). The Federal Highway Administration, American Association of State Highway and Transportation Officials, and Transportation Research Board have encouraged and supported such efforts. This paper presents an overview of major approaches to BMS development that have emerged during the past decade. It evaluates the role of differing needs, specific to different agencies, and the way in which they are addressed in developing customized bridge management systems. The paper reviews use of large mainframe as well as microcomputers for applications suitable for large and small agencies. Further, the paper presents some suggestions and insights about the future of the state-of-the-art of BMSs.

The information presented was compiled from available literature (1)(2)(5)(6)(8) and from results of a bridge management questionnaire summarized in Table 1.(10)

INTRODUCTION

During the past decade, agencies responsible for bridges have come to recognize the severity and enormity of problems associated with their bridge populations. As a result, significant efforts have been undertaken to analyze and find well-researched engineering solutions to these problems. Attention has also focused on finding better ways to manage all bridge-related activities in order to avoid similar problems in the future. Many agencies began developing comprehensive bridge management systems (BMSs) toward this goal.

Some states, such as Pennsylvania, North Carolina, and Indiana began developing their own BMSs. Others, in need of some assistance and guidance, have opted to wait and clearly understand ongoing efforts in development of BMSs. To provide an overview of these efforts, this paper reviews current practices, prevailing environments, and major approaches to BMS development. It also summarizes BMS-development activities in different agencies and highlights some primary features of those efforts. Further, the paper discusses BMS automation needs of small and large agencies and presents some helpful suggestions and insights with respect to the future of BMSs.

BRIDGE MANAGEMENT PRACTICES

Current attention toward developing BMSs should not be interpreted to mean that bridge-related activities were not managed in the past. Over their service life, some bridges were being managed better than others. As time passed, the numbers of bridges and their needs grew larger and larger. No longer could manual methods, "seat of the pants" type approaches, and use of only available resources satisfy these needs. Inadequacies of traditional management practices became obvious. The catastrophic bridge collapse at Point Pleasant, W. VA., in 1967 was the turning point in management of bridges in the U.S. Bridge inventory, inspection, rating, and posting programs were initiated, thus beginning a systematic approach to bridge management. As inspection practices improved, ability to assess bridge condition needs correspondingly improved. This improvement, coupled with rapidly deteriorating infrastructure condition, provided sufficient evidence to conclude that bridge condition needs far exceeded available resources and that comprehensive BMSs were needed.

As efforts to develop them began, the following inadequacies in current management practices became evident:

. Bridge data available from the Federal Structure Inventory and Appraisal (SI&A) forms represented a basic level that was not comprehensive enough for a desirable BMS.

. Most bridge management activity relied heavily on bridge condition while ignoring many other bridge needs.

. Current deterioration models were general in nature and not comprehensive enough to use for forecasting future bridge conditions. Further, load ratings were not included in deterioration models, rendering them ineffective in predicting remaining service life.

. Most bridge management practices pertained to project level decisions on a specific bridge. Network-level (a level of analysis that reviews and assesses groups of bridges) bridge management practices were either non-existent or essentially inadequate.

. Most bridge management activities were not based on sound economic analyses. Even when these analyses were done, user costs were usually not included or, if included, were not realistic.

. Bridge maintenance data are generally inadequate or non-existent.

. Systematic prioritization and optimization that could assure effective use of available fiscal and human resources, although needed, did not take place.

ENVIRONMENT FOR BMS DEVELOPMENT

Experiences of agencies that have undertaken BMS development clearly indicate that the development process and its success are very strongly impacted by the organizational environment in which the BMS is being developed.

The current BMS development environment typically has the following key characteristics:

. Bridge management decisions are made at different levels in each organization. For example, project-level decisions are being made at the operating level, while network-level programming decisions are being made at the planning level.

. BMS decisions will always be made by managers and not by any management systems. Managers do, however, need management systems assistance in making these decisions.

. Managers need decision-making assistance. Some of the areas involved are: ranking of needs, developing programs, predicting future conditions, etc.

. BMSs must include life-cycle-cost strategies. These are difficult to develop because existing maintenance data bases are inadequate to assist in these activities.

. Network-level bridge management decisions most often will require automation due to the size of data requirements and complexity of bridge decisions.

- Most managers are not familiar with mainframe computers although they are receptive to using microcomputers.
- User involvement during development is essential for success of any operating system.

MAJOR APPROACHES TO BMS DEVELOPMENT

Agencies involved in the BMS development process are inclined to adopt certain major approaches. These approaches provide the basis for development activities and also provide a logical methodology for decision-making.

For many agencies developing BMSs, basic objectives are similar. Consequently, the major approaches are also similar. Approaches, along with objectives, do differ in some BMS areas because of unique circumstances created by particular needs and available data.

Some common major approaches to BMS development activities are as follows:

- The first step has been a user survey to identify available and desired data, various report-needs and need for assistance in making decisions.
- Agencies have identified needs for decision support at the network and project levels. Typical network-level support is in terms of identifying, prioritizing, and predicting needs of a group of bridges. Typical project-level decision support is in terms of maintenance, repair, rehabilitation, or replacement decisions for individual bridges.
- Most emphasis to date has been on developing network-level decision support systems.
- Agencies developing BMSs systems have found it necessary to expand existing data bases to pick up data elements, such as vulnerability data not currently collected but essential for development of appropriate BMSs.
- BMSs are being developed in modular format, according to priority of their importance to the agencies.
- Basic network-level BMSs consist of the following core decision support modules: needs analysis, maintenance, rehab and replacement, work selection strategies, and development of capital and operating (maintenance) programs. The more comprehensive network-level BMSs consist of the basic BMS and certain other peripheral decision support modules. These may include prioritization, optimization, forecasting, estimating, and program monitoring.
- Basic project-level BMSs consist of the following core decision support modules: bridge-specific needs analysis and bridge-specific maintenance, rehab, and replacement work selection strategy. The more comprehensive project-level BMSs consist of the basic BMS and certain other peripheral decision-support modules, such as life-cycle analysis.
- Individuals involved with BMS development activities recognize that decisions will ultimately be made by managers, with the BMS providing necessary decision support. This is reflected in the manual override being built into most systems.

STATUS OF BMS DEVELOPMENT EFFORTS

The BMSs are in various stages of development in the United States and abroad. Most development efforts have been initiated by agencies responsible for large networks of bridges. The American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) have for some time encouraged development of BMSs.

Pennsylvania has been a leader in BMS development.(9) The Penn DOT effort began in 1984 and was implemented as an operational BMS in 1987. It integrated several data bases containing bridge data into one data base with approximately 400 data elements. This BMS includes a priority ranking procedure based upon minimum acceptable level and desirable level of service and the Federal Sufficiency Rating (FSR). It can provide cost estimating for maintenance/rehab/replace alternatives and is expected to have a future "what if" capability.

North Carolina has been also been active in BMS development.(3) It has a partially developed and implemented BMS, which began in 1983-84 with initial emphasis on maintenance management and is expected to be completed in 1991. This effort also utilizes a level-of-service concept to prioritize potential bridge projects. North Carolina's level-of-service concept includes load capacity, clear deck width, and vertical roadway under/over clearance.

Indiana started BMS development in 1987 and has partially completed and implemented its system.(4) Completion of a fully operational system is expected in 1992. Indiana's approach is similar to Pennsylvania and North Carolina in that it uses level of service to prioritize bridge work. In addition, it also evaluates bridge traffic safety. This approach enables Indiana to evaluate and account for bridge characteristics that may constitute hazards to traffic.

While Pennsylvania, North Carolina, and Indiana have pursued BMS development vigorously, BMSs are also being developed in other states, and in some provinces of Canada and abroad(7). There have been some concurrent efforts to create a generic BMS adaptable to specific needs of individual agencies. TABLE-I presents a brief summary of the status of these efforts.

AUTOMATING THE BMS

In concept, a BMS can be a manual system operable without use of a computer. In practice, agencies developing BMSs have recognized the need to automate their systems because of the size of their bridge networks and the complexities and inter-relationships among bridge-related decisions. User expectations play a decisive role in the selecting automating equipment for a BMS. Some considerations found by different agencies in selecting their computer equipment are as follows:

- Most agencies maintain their agency-wide data on either mainframe or mini-computers. There is a clear trend to have all transportation infrastructure information stored on the mainframe computer a state agency already has or is planning to acquire. Mainframe computers offer the most security, data storage capacity, speed, and potential for multi-terminal networking.

- Decision-makers who would use a BMS for their decision-support prefer the simplicity and user-friendliness of microcomputers. This is because use of menu-driven programs, cursor-controlled operation, and intra-program windows simplify the use of a program. Needless to say, most potential BMS users lack the sophistication to use modern high-powered main-frame computers. Their familiarity with microcomputers has improved greatly in recent years.

- Based on software applications and design, the latest generation of microcomputers has reached a very competitive processing speed. Their ability to store, retrieve, and process data can be made adequate to accommodate even larger BMSs. It is recognized that very large data bases may reside more conveniently on a mainframe computer that could be networked to a microcomputer system to act as a hybrid. Networking micros is possible and cost-effective.

- Agencies have recognized that program construction and modification, as well as the use of menu-driven software, is more difficult on a mainframe and requires personnel well versed in the more complex operating languages of most mainframes. They have also realized that the many computer languages available for use on microcomputers (BASIC, C. Turbopascal, DBase, etc.) can make for a more flexible customized BMS. Further, report generation and graphics capabilities appear to be more readily available and useable with the microcomputers and accompanying color monitors.

Review of BMS development activities in the U. S. and abroad indicates a trend to rely on microcomputers in developing individual BMSs. This trend appears to be clearly justifiable on the basis of rapid improvements in microcomputer capabilities, in evidence so far and realistically expected to continue in the future.

STATE-OF-THE-ART OF FUTURE BMSs

BMS is an evolutionary process and the current state-of-the-art for BMSs is in very preliminary stages. For future BMSs to be truly effective operating decision-support systems, they must have the following features:

- A larger data base that would include bridge construction, inventory, inspection, maintenance, safety assurance (such as scour-related), planning, and programming information. This data base will typically reside on mainframe computers for large agencies (i.e., States) and on microcomputers for smaller agencies or as an interconnected version for joint use.

- The BMS structure will be in modular form, with each module packed with built-in sophisticated techniques, independently operable and subject to input data availability. These modules will use highly sophisticated methodology to provide better decision support. Data significantly impacting outcome of a decision will be clearly identified as decision-critical.

- The BMS will provide management and engineering support for the decision-maker and also allow for his/her manual override. The decision-maker will be able to reasonably predict, with help of the BMS, consequences of his/her decisions under various scenarios and will be able to run a sensitivity analysis to evaluate the impact of variations in underlying assumptions.

On the network-level, future BMSs will have the following specific capabilities(11):

- Needs Analysis: present as well as future program needs such as maintenance, rehabilitation, replacement.

- Program Selection and Coordination: capital and maintenanance programs under a variety of constraints.

- Program Effectiveness: monitoring and evaluating.

- Sensitivity Analysis: program effectiveness under a variety of assumptions and scenarios, e.g., level of funding and condition improvement of a network over a certain period.

- Report Generation: prompt and extensive sorting of available information.

On the project-level, future BMSs will have the following specific capabilities(11):

- Evaluation of current needs and prediction of future individual bridge needs: e.g., overlay in...years, painting...years.

- Prediction of remaining service life under a variety of scenarios: e.g., under varying levels of maintenance or repair.

TABLE 1. STATUS OF BMS EFFORTS

AGENCY	MAIN FEATURES AND STATUS
California	System being developed for FHWA, ranking "minimum acceptable" and "desirable" levels-of-service. Anticipated completion: 1992.
Florida	Ranking basis: level-of-service, system prioritizes repair/rehab needs. Anticipated completion: 1995.
Indiana	Ranking basis: level-of-service and bridge traffic safety. Anticipated completion: 1992.
Michigan	System to include network and project level analysis. Anticipated completion: 1993.
New Jersey	PC-based system to facilitate budget and resource allocations, project selection, and maintenance management. Anticipated completion: 1991.
New York	Prototype developed, ranking basis: structural condition, vulnerability, essentiality and serviceability. Anticipated completion: 1994.
North Carolina	Ranking basis: level-of-service, system partially implemented. Anticipated completion: 1991.
Pennsylvania	Ranking basis: level-of-service, large data base, provides cost estimation for repair/rehab/maintenance alternatives, operational.
Texas	System to assist forecasting maintenance and capital needs, project selection, and integrated planning. Anticipated completion: 1993.
Washington	Bridge deck management system operational, BMS will assist resource allocation and preventative maintenance planning, Anticipated completion: 1995.
Wisconsin	Life-cycle cost analysis and network optimization employed by system. System operational, continuing updates.
FHWA	DP-71 provides basis for network-level BMS development by states, identifies candidate elements for data base.
NCHRP	Report 300 published, Project 12-28(2) being completed, network and project-level BMS, identifies and details six BMS modules.
Ontario	Ranking basis: level-of-service, cost/benefit program now operational. Anticipated completion: 1993.
Manitoba	System to schedule work based on optimized cost and priority. Anticipated completion: 1991.
Denmark (Thailand)	Emphasis on bridge safety and optimal allocation of funds. Mostly complete and operational.
Finland	Ranking basis: level-of-service, network and project-level analysis planned. Anticipated completion: 1992.
Saudi Arabia	Emphasizes stochastic optimization and maintenance work scope selection. System operational.

- Available life-cycle strategies, their costs, and impact on required maintenance and life expectancy.

- Selection of appropriate work based upon a variety of criteria such as fiscal constraints, maximum detour lengths, etc.

- Engineering support for load rating, design, and drafting to ensure uniformity, consistency, and increased productivity.

CONCLUSION

The past decade has seen significant advances in development of bridge management systems to coordinate and improve management of all bridge-related activities. Some agencies have taken the lead, under constraints of the prevailing environment, and have developed their own bridge management systems while many others are in the process of developing them. BMS development has been summarized in this paper by focusing on major approaches taken by different agencies, status of their development activities as reported by them, and the state-of-the-art of automation relevant to BMS development. Current trends point to future BMSs being flexible, adaptable, user-friendly, and packed with built-in sophisticated techniques.

It must be noted that the purpose, comprehensiveness and capabilities of each BMS is solely determined by each developing agency.

REFERENCES

1. "National Cooperative Highway Research Program Report 300-Bridge Management Systems", Hudson, S. W., Carmichael, R. F., Moser, L. O., Hudson, W. R., Wilkes, W. J., Transportation Research Board, December, 1987.
2. "Bridge Management System: Concept Plan and Development Strategy", New York State Department of Transportation, Structures Division, October, 1989.
3. "North Carolina Bridge Management System, An Overview", Johnston, D. W., Chen, C., Nash, S. C., Research Paper for North Carolina Department of Transportation and Federal Highway Administration, January, 1987.
4. "The Development of Optimal Strategies for Maintenance, Rehabilitation and Replacement of Highway Bridges, Final Report Vol. 1: The Elements of the Indiana Bridge Management System", Sinha, K. C., Saito, M., Jiang, Y., Murthy, S., Tee, A. B., Bowman, M. D., Project No. C-36-73I, for Federal Highway Administration, August, 1988.
5. "Selection of Ideal Maintenance Strategies in a Network Level Bridge Management System", Harper, W. V., al-Salloum, A., al-Sayyari, S., al-Theneyan, S., Lam, J., Helm, C., for Transportation Research Board, January, 1990.
6. "Stochastic Optimization Subsystem of a Network Level Bridge Management System", Harper, W. V., Lam, J., al-Salloum, A., al-Sayyari, S., al-Theneyan, S., Ilves, G., Majidzadeh, K., for Transportation Research Board, January, 1990.
7. "Optimization of Bridge Management Appropriations With The Help of a Management System-Development of a Bridge Management System in Finland", Kahkonen, A., Marshall, A. R., Study obtained from Cambridge Systematics, Inc., 222 Third Street, Cambridge, Massachusetts 02142, (617) 354-0167.
8. "A Network Optimization System for Maintenance and Improvement of California's Bridges", Golabi, K., Thompson, P. D., Study obtained from Cambridge Systematics, Inc., 222 Third Street, Cambridge, Massachusetts 02142, (617) 354-0167.

9. "R. P. Project No. 84-28/28A, The Pennsylvania Bridge Management System Executive Summary, First Year, Prepared by Bridge Management Work Group, Bureau of Bridge and Roadway Technology, Commonwealth of Pennsylvania Department of Transportation, April, 1986.
10. "Bridge Management System-Survey", compiled by the New York State Department of Transportation, Structures Division, May, 1990.
11. "Present and Future of Bridge Management Systems", Shirole', A. M., Presented at The Engineering Foundations Conference on Managing America's Aging Bridges, November 14, 1989.