PennDOT's BRIDGE MANAGEMENT DECISION SUPPORT PROCESS

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ABSTRACT

The purpose of this paper is to describe the capabilities of Pennsylvania's Bridge Management System (BMS) and how these capabilities support decision making within the Department of Transportation. The Pennsylvania Department of Transportation (PennDOT) has developed and implemented a comprehensive BMS. This system has been operational since December 1986. Pennsylvania's BMS can store a wide range of bridge inspection data. BMS also can analyze this data using individual subsystems to provide decision support for Department managers. A Bridge Rehabilitation and Replacement Subsystem provides cost estimating and prioritization of bridge improvement projects to support long range planning and programming decisions. A Bridge Maintenance Subsystem provides cost estimating and prioritization of bridge maintenance activities for assistance in developing annual maintenance programs. A Modeling Subsystem that uses deterioration curves for bridge condition and bridge load capacity enables Department managers to predict future bridge improvement needs using different funding scenarios. An Automated Permit Rating and Routing Subsystem is being developed to provide decision support in the load rating, routing and issuance of permits for overweight and oversize vehicles. Finally, a Reports Subsystem is available to provide both standardized and customized report generation capabilities for any subset of data in BMS.

BACKGROUND ON PennDOT's BRIDGE MANAGEMENT SYSTEM

Pennsylvania maintains a proactive approach to bridge inspection and bridge management, often implementing new systems or procedures before Federal requirements to do so. The early development of a BMS illustrates this proactive posture.

PennDOTs BMS was implemented in December 1986. This BMS is a powerful management tool that not only records and stores bridge inspection data for Pennsylvania's bridges but also enables Department managers to make key decisions concerning bridge inspection, maintenance, rehabilitation and replacement. BMS operates in a main frame environment and includes 17 on-line data screens and up to 400 data elements for every bridge. The system also can produce a wide range of reports including standard monthly statistics reports, standard menu driven reports, and customized, user generated reports.

Besides storing and recording bridge inspection information, BMS can automatically generate improvement costs, by bridge, for maintenance, rehabilitation and replacement needs. BMS also can prioritize bridges for capital and maintenance improvements. A unique feature of BMS is its modeling capability that enables the user to predict future bridge needs by programmatically degrading bridge condition and load carrying capacity over time.

Although BMS has been in production since December 1986, improvements and enhancements have occurred continuously. Completed BMS enhancements include new screens for fracture critical and underwater bridge inspection, sign structure and retaining wall inspection, as well as system integration with our Roadway Management System and our Project Inventory and Project Management Systems.

DEVELOPMENT AND IMPLEMENTATION OF BMS

The Department first investigated the feasibility of establishing a BMS in 1983. A Task Group composed of seven prominent engineers from both inside and outside the Department was commissioned to determine if the development of a BMS was feasible for Pennsylvania and, if so, to provide guidance and direction for developing such a system.

The Task Group conducted four, 1-day meetings during the Fall of 1983. The Group unanimously agreed that development of a BMS was feasible and urgently needed to assist in the management of Pennsylvania's bridges with the finite resources that were available. (Table I provides a summary of Pennsylvania bridges, associated deficiencies, and the costs to eliminate these deficiencies through rehabilitation or replacement projects.) In March 1984, the Task Group published a report of its findings and recommendations (*1*). In October 1984, a ten-member BMS Work Group began development of the engineering concepts and requirements for Pennsylvania's BMS. With strong management support and frequent interaction with both users and managers within the Department, the Work Group developed the concepts and the initial technical

TABLE I PENNSYLVANIA BRIDGE STATISTICS FOR HIGHWAY BRIDGES GREATER THAN 6 METERS (20 FEET) IN LENGTH

Bridge Owner	Number of Bridges	Deficient Bridges	Cost to Remove, Billion $
State	16,200	6,000	4.8
Local	6,800	3,300	1.2
Total	23,000	9,300	6.0

requirements documented in a report entitled *Engineering Concepts and Requirements for a Bridge Management System* (*2*). This report then served as the basis for a "Request for Proposal" to develop and install computer software for BMS on the Department's mainframe computer. On August 20, 1985, a software consultant was hired to provide development, testing, implementation and training of the new BMS software. The BMS Work Group worked side by side with the consultant throughout this effort to further refine the engineering concepts and requirements, to ensure that all requirements were met, and to provide needed coordination. On December 24, 1986, BMS was placed in full operational status statewide.

The entire BMS development effort is documented in a report published by the Work Group entitled, *The Pennsylvania Bridge Management System - Final Report* (*3*). A separate *BMS Coding Guide* was also prepared. The *BMS Coding Guide* has been revised several times over the years to reflect BMS enhancements and revisions that have occurred continuously since 1987. The most recent version of the *BMS Coding Guide* was prepared in 1993 (*4*).

Data Requirements and Storage Capabilities of BMS

PennDOTs BMS contains 17 data information screens with provisions for up to 400 data elements for each bridge. All data required by the Federal Highway Administration (FHWA) are included plus additional data deemed necessary by the Department. Data are grouped by general data type and a coding manual provides detailed descriptions and codings for each data item. Table II provides a listing of all data screen names.

TABLE II SUMMARY OF BMS DATA SCREENS

Screen	Type of BMS Data
AA	General Data
AB	Features Intersected Data
AC	Structure Data
AD	Utility, Hydrology and Posting Data
AE	Inspection Data
AF	Proposed Improvement Data
AG	Repair and Painting Data
AH	Proposed Maintenance Data
AJ	Fracture Critical Data
AL	Narrative Data
AM	Condition Rating Data
AN	Completed Maintenance Data
AO	Planning, Programming and Budgeting Data
AR	State Roadway Data
AS	Sign Structure Data
AT	Retaining Wall Data
AW	Underwater Inspection Data

Data that resides in BMS can come from any of three sources: direct data entry via keyboard, such as bridge condition ratings; data generated through system calculations, such as improvement costs or priorities; and finally, data imported from other Department Management Systems, such as average daily traffic or program and budget status. BMS also exports bridge data to other Department Management Systems. The exchange of data between Department systems occurs automatically at either daily or weekly frequencies depending on data type. All Department Management Systems operate on a mainframe computer platform that simplifies the exchange of data between systems and offers instantaneous data access to all users via computer terminals in all of Pennsylvania's 67 counties. BMS currently exchanges data with the Project Inventory System, Project Management System and Roadway Management System. BMS also can store inspection data, on line, for the previous five inspections. Beyond that point, the oldest inspection data are archived on magnetic tape. All data are easily retrievable.

Data Analysis Capabilities and Decision Support

PennDOTs BMS includes the capability to analyze data in key areas and provide decision making tools to Department managers. The major data analysis capabilities of BMS are discussed in the following sections. A discussion of how these data analysis capabilities support decision making within the Department is also presented.

Bridge Rehabilitation and Replacement Subsystem of BMS

The Bridge Rehabilitation and Replacement Subsystem of BMS can prioritize bridges for capital improvements based on the degree to which each bridge is deficient in meeting public needs. Bridge deficiencies are evaluated in three general areas: level of service, bridge condition, and other related characteristics. A single deficiency rating is then computed for each bridge on a scale that ranges from 0 to 100.

Level of service deficiencies consider the bridge's load carrying capacity, bridge deck width, and vertical over and under clearances. Bridge data for each of these components are compared to established goals that vary depending on the functional classification of the bridge and traffic volumes. Deficiency points are assigned according to equations that relate actual data items to assigned goals for each bridge.

Deficiencies for bridge condition are based on an assessment of the individual condition ratings for the bridge deck, superstructure and substructure. For culverts, the overall culvert condition rating is used. Deficiency points are assigned based on table values that relate condition ratings to deficiencies. Other related characteristics that are also considered in determining deficiencies include: waterway adequacy, approach roadway alignment and remaining life of the bridge. Again, the appropriate data items are related to deficiency points using table comparisons.

Besides prioritizing bridge improvements, the Bridge Rehabilitation and Replacement Subsystem can automatically calculate bridge improvement costs. Costs are calculated by the system using the following data: proposed improvement code that is determined at the time of inspection, the deck area of the bridge, and unit cost tables stored and maintained in the system. Manual override of system generated costs is an available option for unique or unusual bridges.

Table III provides a summary of the general data required for the Bridge Rehabilitation and Replacement Subsystem of BMS. The Bridge Rehabilitation and Replacement Subsystem of BMS provides critical decision support for the development of the Department's Twelve Year Improvement Program. The Department maintains a rolling Twelve Year Improvement Program for highways and bridges that is updated every two years. BMS serves as the basis for selecting candidate bridge improvement projects by providing prioritized lists of needed improvements along with associated improvement costs.

TABLE III DATA USED FOR REHABILITATION AND REPLACEMENT SUBSYSTEM

Data Needed to Determine Deficiencies
Load Carrying Capacity
Clear Deck Width
Vertical Clearance on the Bridge
Vertical Clearance under the Bridge
Deck Condition Rating
Superstructure Condition Rating
Substructure Condition Rating
Culvert Condition Rating
Remaining Service Life
Approach Roadway Alignment Appraisal
Waterway Adequacy Appraisal
Average Daily Traffic
Detour Length
Data Needed to Estimate Costs
Proposed Improvement Type
Bridge Length
Bridge Width
Unit Costs for Improvements

Although BMS provides Department managers with an initial listing of candidate bridge projects, the ultimate selection of projects involves a rigorous planning and programming process that also includes extensive coordination with local and regional planning agencies, and public input solicited at several statewide public hearings. BMS also provides a means to help target fiscal resources to the various geographic areas of the state to ensure that all areas receive an equitable share of available funds. BMS simplifies the analysis of large amounts of data quickly and easily.

The Department's current Twelve Year Program for bridges includes more than 2,700 bridge rehabilitation and replacement projects. Since BMS was implemented in 1986, more than 1,000 bridge projects have been constructed or are now under construction. In addition,

many more bridge rehabilitation projects are included as part of highway restoration projects each year. BMS data are utilized to help select these bridge projects and to determine the most appropriate improvement type.

Bridge Maintenance Subsystem

The Bridge Maintenance Subsystem of BMS can rank bridges based on needed maintenance activities. It also can estimate costs for these bridge maintenance activities. A prioritization procedure has been developed which considers the effect of the most structurally critical maintenance activity need on the bridge and the individual bridge's impact on the road system. A maintenance deficiency rating is calculated by the system for each bridge on a scale of 0 to 100 with higher values suggesting higher maintenance needs. A menu of 76 bridge maintenance activities has been developed and stored in the system. These activities cover the full range of maintenance that can be done on a bridge using either Department Forces or a contractor. Bridge inspectors select needed maintenance activities for each bridge, estimate an approximate quantity of repair, and assign a relative priority to each maintenance activity identified. This process occurs at the end of each safety inspection and does not require a significant amount of additional time. With this additional information, the system can prioritize bridges based on maintenance needs and estimate costs. A list of all data required for the Maintenance Subsystem is included in Table IV. After each maintenance activity is completed, maintenance information is transferred from the maintenance needs in BMS to the completed maintenance activities where it serves as a historical record of completed work.

The Bridge Maintenance Subsystem provides decision support in the development of the Department's Annual Maintenance and Betterment Programs. These programs provide for all non-capital highway and bridge work. The work is done by either Department Forces or contractors. Bridge work includes any of the 76 bridge maintenance activities mentioned above and also small bridge replacements. Programs are developed on an annual basis, and BMS provides support through its needs estimating, prioritization, costing and tracking capabilities. Besides the various maintenance activities completed each year, about 100 small bridge replacements are included each year in this program.

TABLE IV DATA USED FOR MAINTENANCE SUBSYSTEM

Data Needed to Determine Deficiencies
Load Carrying Capacity
Deck Condition Rating
Superstructure Condition Rating
Substructure Condition Rating
Culvert Condition Rating
Remaining Service Life
Average Daily Traffic
Detour Length
Functional Classification
State Network
Priority of Maintenance Activity
Data Needed to Estimate Costs
Maintenance Activity
Bridge Length
Bridge Width
Estimated Quantity of Repair
Unit Costs for Maintenance Activity

Bridge Modeling Subsystem

The Bridge Modeling Subsystem of BMS provides a means to predict future bridge rehabilitation and replacement needs for Pennsylvania's bridges. The Modeling Subsystem enables the user to develop future estimates for deficiency ratings, sufficiency ratings, condition ratings, load capacities, and improvement costs. From these estimates, prioritized listings and associated costs can be developed. The Modeling Subsystem also considers the effects of inflation, traffic increases, and current or proposed spending levels.

Two basic deterioration models drive the Modeling Subsystem. These models allow for the deterioration over time of bridge condition ratings and bridge load carrying capacity that are the primary components used in the prioritization of bridges for rehabilitation and replacement. A method has also been developed which establishes new improvement codes for deteriorated bridges. These new improvement codes are then used to estimate future improvement costs. Table V provides a summary of the data used in the Modeling Subsystem.

The Modeling Subsystem provides decision support capability by allowing Department managers the opportunity to predict future bridge needs under many scenarios. This capability is useful, for example, in

TABLE V DATA USED FOR MODELING SUBSYSTEM

Data Needed to Determine Deficiencies
Future Load Carrying Capacity
Clear Deck Width
Vertical Clearance on the Bridge
Vertical Clearance under the Bridge
Future Deck Condition Rating
Future Superstructure Condition Rating
Future Substructure Condition Rating
Future Culvert Condition Rating
Future Remaining Service Life
Approach Roadway Alignment Appraisal
Waterway Adequacy Appraisal
Future Average Daily Traffic
Detour Length
Functional Classification
Data Needed to Estimate Costs
Future Improvement Type
Bridge Length
Bridge Width
Unit Costs for Improvements

determining the minimum annual expenditures that must be made to stay even with continuing bridge deterioration, or the minimum annual expenditures that must be made to eliminate all bridge deficiencies over several years. The Modeling Subsystem enables managers to ask "what if?" questions concerning all or any subset of the bridges in BMS. Of course, predicting future bridge needs is not an exact science, and the degree of accuracy of these predictions must always be carefully scrutinized and, in time, checked against historical records. Historical records also should be used to refine the prediction capabilities of the model. BMS has been storing historical records since its implementation in 1986, in anticipation of using this data for fine tuning.

Bridge Automated Permit Routing and Analysis Subsystem

The Bridge Automated Permit Routing and Analysis Subsystem is a new subsystem of BMS that is currently under development and is anticipated to be implemented in about two years. This subsystem will replace the current permit system, which does only administrative functions. Permits are required for any oversize or overweight vehicles traveling through Pennsylvania. Each year the Department processes between 250,000 and 270,000 hauling permits, of which 12,000 are special hauling permits or superloads that require the review of a bridge engineer. The new subsystem will be completely automated. It will analyze individual bridges for load carrying capacity based on the actual axle weights and spacings of the permit vehicle. It also will check for vertical clearance and width restrictions based on vehicle size. Finally, it will evaluate and select travel routes, and issue the approved permit.

Three new data screens will be added to BMS to support the additional data requirements. Much of the new software will be installed on personal computers to simplify use by permit applicants, although data items will reside in BMS which is a mainframe system. Phone lines will connect the two. The primary benefits of this new subsystem will be rapid, consistent and responsive decision making by the Department in the review and issuance of hauling permits in Pennsylvania. This in turn will serve to increase productivity within the Department and within the trucking industry.

BMS Reporting Subsystem

A wide range of reporting capabilities has been included in BMS to access and use the extensive amount of data it contains. BMS can produce standard, menu driven reports; customized, user generated reports; and automatic monthly bridge statistics reports.

Standard menu driven reports are available in the Bridge Rehabilitation and Replacement Subsystem, the Maintenance Subsystem, the Modeling Subsystem, and they are anticipated to be available in the Automated Permit Rating and Routing Subsystem. These reports present the user with a menu of data and reporting options for each specific subsystem. The user selects from the menu of options and receives a report designed specifically for that subsystem. For example, the Bridge Rehabilitation and Replacement Subsystem will produce a report that displays candidate bridge projects in priority order with associated improvement costs. Other supporting data would be included as well. This reporting procedure is intended primarily for use by managers who have limited computer programming skills.

Customized, user generated reports require the user to be knowledgeable of computer programming languages; however, these reports offer the widest range of data reporting and manipulation for any subset of bridges in BMS. Some typical uses of this type of

reporting that have been used to support decision making in the Department include: screening bridges for scour vulnerability, screening bridges for seismic vulnerability, selection of bridge painting candidates, and bridge inspection scheduling including underwater inspections and crane inspections.

Automatic monthly bridge statistics reports serve to report, document, and monitor the number, condition, type, ownership, improvement needs, and costs of all bridges in BMS. These reports also serve as a basis to track trends or patterns that may be developing over time. For example, a comparison of monthly reports could be used to detect whether bridge maintenance needs have increased or decreased over the last five years on a statewide basis or within specific areas of the state. Department managers would then have a basis to consider changes to bridge maintenance program funding levels.

Future Enhancements

Although PennDOTs BMS has been in operation since December 1986, enhancements and improvements have taken place continuously. Major BMS enhancements are also planned including the implementation of the Automated Permit Rating and Routing Subsystem. The Department is also considering the development of optimization capabilities in BMS. An optimization model would provide additional decision support to Department managers by determining bridge improvements using life cycle cost analysis. Besides bridge improvement costs, the optimization model also would consider user costs and benefits based on traffic and accident data. Additional system integration that would enable BMS to exchange more information with other Department Management Systems is also planned. BMS integration is proposed for the Maintenance Operations and Resources Information System, the Accident Records System, and the proposed Geographic Information System. New technologies are also being considered for implementation in BMS. The use of hand held, computer pen pads for field entry of bridge inspection data would replace the current pencil and paper method used in the field. This technology would provide faster, more accurate data entry, since computer disks would be uploaded into BMS rather than entered via keyboard from field notes and forms. This in turn would provide Department managers with the most current bridge inspection information in the shortest period. Other technologies being considered include the use of data imaging that would allow certain paper documents such as bridge plans, sketches and diagrams to be scanned and stored in BMS. Also available are photo and video storage capabilities that would allow pertinent bridge information to be viewable at BMS computer terminals. This would allow Department managers a close up look at bridge problems and conditions.

CLOSING

All BMS capabilities, both present and future, will serve to support management decision making within the Department. These support capabilities are driven by the Department's primary objective of providing a safe, reliable and efficient network of highways and bridges.

REFERENCES

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