Review of Recent Bridge Asset Management Systems

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Abstract: A number of transportation agencies throughout the world have adopted and implemented the bridge management system with advanced asset management decision-making capabilities. However, there are still significant room for improvement in the information and data upon which the bridge management systems are based, and on the results and decision-making that occurs based on the output of these systems. In order to address some of gaps in knowledge, the Federal Highway Administration (FHWA) of the U.S. Department of Transportation is initiating a Long-Term Bridge Performance (LTBP) program in 2006. In this paper, we will introduce the recent bridge management systems and the LTBP program in the States.

Keywords: Bridge Management System, Asset Management, Structural Health Monitoring

1. INTRODUCTION

Over the past decades, transportation agencies did their best to maintain and preserve highway structures, but plenty of funds were spent each year without benefit of a system to analyze all the engineering, economic, and business practice factors to support the best possible decisions. However recently, the use of Asset Management, which is the science of deciding when, where, and how to spend maintenance, preservation, and improvement resources in the most cost-effective way possible, has caused a revolution in the way that the transportation agencies manage highway structures. It also involves measuring performance so that good decisions can be repeated in the future and bad ones can be avoided [1].

The tools to perform Asset Management for bridges, which are called bridge management systems (BMSs), have been adopted by many transportation agencies in Japan, the United States and throughout the world to provide safety and a satisfactory level of bridge service. For example in the U.S., according to the Federal Highway Administration’s (FHWA) National Bridge Inventory (NBI), which contains information of more than 590,000 bridges, tunnels, and culverts located on public roads, it is indicated that the average age of the nation’s bridges is approximately 40 years (Fig. 1 [2]) and that more than 40% of them are either structurally deficient or functionally obsolete and in need of maintenance, repair, rehabilitation, improvement or replacement [3]. In addition, these numbers are likely to increase in coming years due to increased traffic demand, continued bridge aging and deterioration, and limited funds for rehabilitation and maintenance. This obviously is a very important reason why more effective BMS is required.

Although many transportation agencies have adopted and implemented BMSs with advanced asset management decision-making capabilities like the American Association of State Highway and Transportation Officials’ (AASHTO) AASHTOWare Pontis [4] or a similar system [5], there are still gaps in knowledge regarding how structures and materials perform and deteriorate over time, and how effective various maintenance, repair, or rehabilitation strategies really are for a given component or system. Besides, the materials being used for bridge construction today are changing rapidly and may be significantly different from conventional bridge materials, and the long-term experience with the performance of these materials is quite limited. As a result, although a number of transportation agencies practice bridge management, recent BMSs still have significant room for improvement.

In the U.S., with the passage of the Safe, Accountable, Flexible, Efficient Transportation Equity Act (SAFETEA-LU) in 2005, which authorizes the Federal surface transportation programs for highways, highway safety, and transit for the 5-year period 2005-2009, the FHWA is initiating the Long-Term Bridge Performance (LTBP) program in 2006. The LTBP program will provide some advances in the knowledge of how highway structures perform over the long time [2]. In this paper, the recent BMSs and the initial vision and goals of the LTBP program is introduced.

2. BRIDGE MANAGEMENT SYSTEMS

A bridge management system consists of formal procedures for analyzing bridge data for the purpose of predicting future bridge conditions, predicting maintenance and improvement needs, determining optimal policies, and recommending projects and schedules within budget and policy constraints. The AASHTO Guidelines for Bridge Management Systems [6] suggests that a BMS includes four basic components: data storage, deterioration and cost models, optimization models for analysis and updating functions.

2.1. Data storage

The database connected to the BMS stores data from periodic field inspections. Traditionally in the U.S., states have been required to monitor the condition of bridges to support the NBI which is maintained by the FHWA. According to the NBI, all bridge inventory components and, ultimately, the bridges receive integer numerical condition ratings from 0-9 based on a mostly visual comparison of the as-is structure with a presumed as-built state, as shown in Table 1 [7]. The ratings are intended to reflect general rather than local conditions. Sometimes
non-destructive tests are done by the inspectors to learn more about the condition of the bridge that cannot be decided during a visual inspection.

Information stored in the database is used as input into the modeling. The models are used to predict future conditions for each element and to perform analyses under different budget constraints to determine the impacts of carrying out different projects. The three primary types of models are deterioration model, cost model and optimization model.

2.2. Deterioration and cost models

Deterioration models predict the condition of bridge elements at any given point in the future. Most deteriora-

<table>
<thead>
<tr>
<th>Rating</th>
<th>Condition</th>
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<tbody>
<tr>
<td>N</td>
<td>Not applicable</td>
</tr>
<tr>
<td>9</td>
<td>Excellent condition</td>
</tr>
<tr>
<td>8</td>
<td>Very good condition – no problems noted</td>
</tr>
<tr>
<td>7</td>
<td>Good condition – some minor problems</td>
</tr>
<tr>
<td>6</td>
<td>Satisfactory condition – structural elements show some minor deterioration</td>
</tr>
<tr>
<td>5</td>
<td>Fair condition – all primary structural elements are sound but may have minor section loss, cracking, spalling, or scour</td>
</tr>
<tr>
<td>4</td>
<td>Poor condition – advanced section loss, deterioration, spalling, or scour</td>
</tr>
<tr>
<td>3</td>
<td>Serious condition – loss of section, deterioration, spalling, or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.</td>
</tr>
<tr>
<td>2</td>
<td>Critical condition – advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present, or scour may have removed substructure support. Unless closely monitored, it may be necessary to close the bridge until corrective action is taken.</td>
</tr>
<tr>
<td>1</td>
<td>“Imminent” failure condition – major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic, but corrective action may put back in light service.</td>
</tr>
<tr>
<td>0</td>
<td>Failed condition – out of service, beyond corrective action</td>
</tr>
</tbody>
</table>

Fig. 1. Construction year of bridges in Japan and in the United States [2].

Table 1. Condition rating [7].
tion models are patterned as a Markov process.

A BMS typically estimates two types of costs, so-called the improvement cost and the user cost. Improvement costs are estimated to determine the cost of a maintenance action to improve the condition of an element. The expected user cost savings for safety and serviceability improvements should also be estimated.

2.3. Optimization model

From the results of the deterioration and cost models, the optimization models determine the least-cost maintenance, repair and rehabilitation strategies for bridge elements using life-cycle cost analysis or some comparable procedure. Life cycle costing takes into account the maintenance performed on a bridge throughout its entire service life. The BMS also performs multi-year, network analysis. This capability allows analysis over all bridges in an agency's inventory to determine impacts of implementing or deferring repairs in the future.

The optimization routine also accounts for the desired level of service that a bridge should accommodate. The level of service pertains to the amount and type of traffic that a bridge serves.

A BMS may take either a top-down or bottom-up approach to optimization. The top-down approach first determines the desired goals for the entire network then selects the individual bridge projects based on those goals. The bottom-up approach determines the optimal action for each bridge then selects which projects will be completed based upon the network optimization. The top-down approach works quicker, since the individual projects are determined after the network goals are set. However, this optimization routine requires a large population to provide meaningful results. The bottom-up approach uses more computer time optimizing the individual bridge projects thus the process often proves cumbersome for large bridge populations.

2.4. Updating function

The BMS generates summaries and reports for planning and programming processes, and uses the information from actions taken to update the deterioration and cost models. Since most of the transition rates used in the deterioration models and improvement costs are based on initial estimates, the models need to be updated to make more reflective of actual conditions.

3. TYPICAL BRIDGE MANAGEMENT SYSTEM

A representative bridge management system is AASHTOWare Pontis, which is used by many transportation agencies, as shown in Fig. 2 [8], and other agencies have developed their own bridge management software. A review of the BMSs and their unique features are as follows.

3.1. Pontis

Pontis was originally developed in 1989 for the FHWA. It can assist agencies in allocating resources to protect existing infrastructure investments, ensure safety and maintain mobility. It stores inventory and inspection information about an agency's bridges, culverts and other structures, and provides a set of modeling and analysis tools to support project development, budgeting and program development. It helps an agency to formulate network-wide preservation and improvement policies for use in evaluating the needs of each structure in a network; and makes recommendations for what projects to include in an agency's capital plan. It also provides the capability to analyze the impact of different project alternatives on the performance of individual structures and on a network of structures. Agencies can use Pontis to define and schedule projects for individual structures or for groups of structures [9].

Agencies can choose to make use of all of the features of Pontis, or select portions of the software. For example, as shown in Fig. 2, some agencies use Pontis for inventory and inspection data management only; others use Pontis for modeling only.

![Fig. 2. Pontis licenses and applications in 2005 [8].](image-url)
3.2. BMS developed in Aomori, Japan

Aomori, which is located at the northern end of the main island in Japan, has many deteriorated bridges due to the severe winter climate. This fact will cause tremendously high cost for maintenance, repair and rehabilitation of the bridges in the future. Therefore, the Aomori Prefecture has decided to develop and implement the BMS to reduce the maintenance, repair, rehabilitation costs.

The developed BMS in Aomori, which is called Asset Management Support System for Bridges, consists of five steps. The first step is to establish the principal strategy of the bridge maintenance. The second step is to establish the individual strategy for each bridge considering those health conditions, roles in the road network, and particularities, namely selecting maintenance scenarios, then calculate life-cycle costs for each scenario. The third step is the long-term bridge maintenance planning for entire bridges by computing the total life-cycle cost for entire bridges and making adjustment of scenarios to get a uniform annual budget. The fourth step is the planning of maintenance, repair and rehabilitation works for the mid-term period. The final step is the reviewing of the entire management process [10, 11].

4. IMPACT OF BRIDGE MANAGEMENT SYSTEM

4.1. Preservation of bridges

Fig. 3 shows the ratio of damaged bridges to total bridges in each States [11]. It can be seen in the graph, the Pontis users have fewer bridges with damages than the Non-Pontis users do. It is anticipated that if the transportation agencies employ proper bridge management systems, they may be able to preserve their bridges in the long term. However as mentioned above, there is still room for improvement of current BMSs.

4.2. Accountability to the public

The bridge management system can offer users greater accountability by tracking what is bought with public funds, how spending decisions are made, and analyzing what has been accomplished. The recently-opened Carquinez Bridge in California provides a good example of how life-cycle concepts can be used to quantify the expected whole life costs. The use of life-cycle cost techniques proved valuable in helping the California Department of Transportation make the investment decision in the selection of the design type for the new Carquinez Bridge that were understandable to the public [11, 12].

<table>
<thead>
<tr>
<th>Program component</th>
<th>Sample size</th>
<th>Purpose</th>
<th>Information anticipated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term performance sample bridges</td>
<td>Large numbers</td>
<td>Long-term periodic inspection and evaluation</td>
<td>High-quality, quantitative performance data to support improved designs, improved predictive models, and better bridge management systems</td>
</tr>
<tr>
<td>Instrumented smart bridges</td>
<td>&lt; 100</td>
<td>Continuous monitoring of operational performance</td>
<td>Data about behavior under routine traffic conditions as well as rare, possibly extreme, events</td>
</tr>
<tr>
<td>Decommissioned bridges</td>
<td>As available</td>
<td>Forensic autopsies</td>
<td>Information about capacity, reliability, and failure modes of bridges that have deteriorated from corrosion, overloads, alkali-silicate reaction, fatigue, fracture, etc.</td>
</tr>
</tbody>
</table>

Fig. 3. Damaged bridge ratio in the U.S. [11].

Table 2. Preliminary plans for LTBP program components.
5. LTBP PROGRAM

5.1. Objective

The objective of the Long-Term Bridge Performance (LTBP) program is to collect, document, and make available high-quality quantitative performance data on a representative sample of bridges nationwide. Data will be collected through detailed inspections and evaluations, supplemented by a limited number of continuously monitored structures and forensic autopsies on decommissioned bridges. In the latter years of the program, the collected data will be analyzed to develop improved knowledge about bridge performance and degradation, better design methods and performance predictive models, and advanced management decision making tools.

Specifically, the anticipation is that the LTBP program will provide a better understanding of bridge deterioration due to corrosion, fatigue, weather and exposure, and loads. The program will also provide information about the effectiveness of current maintenance and improvement strategies, and should lead to improving the operational performance of bridges with the potential to reduce congestion, delay, and crashes.

5.2. LTBP program components

The LTBP program will have three components of bridge monitoring and evaluation [2]. A preliminary description of these components of the LTBP program is shown in Table 2.

5.2.1. Periodically inspected bridges

The detailed inspections and periodic evaluations and testing on a representative sample of bridges throughout the U.S. will be included in order to monitor and measure their performance over an extended period of time. At the current time, it is envisioned that as many as 2,000 bridges will be included in the program, representing many structural types and materials, in a variety of conditions, exposures, and locations.

5.2.2. Instrumented bridges

Continuous monitoring of these bridges will be conducted using sensing technology to measure and record their performance characteristics under routine traffic conditions, and during and after rare or extreme events.

5.2.3. Decommissioned bridges

The detailed forensic autopsies of a number of bridges will be also included in the program, using some of the structures that are decommissioned by State transportation agencies. The interest is to collect actual performance data on deterioration, corrosion, other types of degradation, or effectiveness of various maintenance and improvement strategies typically used to repair or rehabilitate bridges.

The LTBP program will run for 20 years. It is anticipated that the resulting LTBP database will provide high quality, quantitative performance data for highway bridges that will support improved designs, improved deterioration and cost model, and better bridge management systems.

6. CONCLUSIONS

In this paper, the general components of bridge management systems, representative bridge management systems and a new project of the FHWA, which is called Long-Term Bridge Performance (LTBP) program, were introduced. The LTBP program will provide significant advances in the knowledge of how bridges perform over the long term. Based on the information which will be collected and analyzed over anticipated 20 years life of the program, the program will result in major improvements in materials and structures life-cycle models and cost analyses, development of performance-based specifications, and development of appropriate and quantifiable performance standards and measures.

REFERENCES