BRIDGE MAINTENANCE DECISION-MAKING MODEL

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As bridge infrastructure continues to age and deteriorate, maintenance is essential for keeping the bridges in good condition. However, owners have limited funds, thus, they need to select the most suitable maintenance option at the right time to minimize the cost. With all the advancements in processes and tools used to manage the bridge infrastructure, many US States continue to report high numbers of structurally deficient bridges, one of which is California State Department of Transportation (Caltrans). The objective of this study is (1) identifying effective practices used by owners in bridge maintenance management and (2) developing a decision-making model to maintain the bridges, using Caltrans as a case study. To achieve this objective, the methodology of the study is divided into three steps: (1) a review of the current state of practice of bridge maintenance decision-making processes and bridge asset management strategies currently used by US Department of Transportations (DOTs) that had shown improvement in their bridge management strategies, (2) a conducted in-depth case study of the Caltrans maintenance decision-making practices, (3) based on both the review of literature and the data collected from the case study, a revised bridge maintenance decision-making process is developed and presented using a swim lane diagram. The proposed model builds on exiting DOTs’ effective practices and optimizes the selection of bridge maintenance decisions, including repair, rehabilitation, and replacement. The developed maintenance decision-making framework could potentially improve the effectiveness of bridge maintenance operations and help decision-makers effectively select and prioritize the bridge maintenance options.

Keywords: Interview, Deterioration, Replacement, Rehabilitation.

1 INTRODUCTION

Bridges are complex structures that require high financial investments during their entire life cycle, from bridge planning, design, construction, operation, and maintenance. According to the American Society of Engineers (ASCE), there are 614,387 bridges in the United States (ASCE 2017), with an average of 43 years old. Approximately four in ten or around 39% were constructed over 50 years ago, and 15% of these bridges are aged between 40 to 49 years. The standard for the lifetime of a highway bridge was set to 50 years. However, the bridge lifetime can be extended if the owner employs an adequate and timely maintenance cycle. With so many bridges reaching the end of their life cycle or becoming deficient, bridge management and maintenance needed become increasingly critical to ensure safe, reliable, and cost-effective operation.

There are many factors that lead to bridge deterioration. The existing bridges age, increasing traffic volume, weather, and low quality in construction and design processes; these factors are a
significant concern due to their massive impact on safety. The risk and consequences of bridge failure require owners and operators to maintain their bridge in good condition. In the United States, these actions have come to be classified as bridge preservation. Most bridge repair needs are identified through a regular bridge inspection program. Bridge inspectors will provide information, photos, details of existing bridge conditions. Next, if the bridges are identified as one where work is needed, more detail and information are required during a field visit by the inspector or the maintenance crew. The inspection report and bridge inventory data are the primary sources of information for an initial determination of a bridge's various maintenance and preservation needs. The cost of bridge maintenance could be one of the main factors for decision making because if the owner or agency plans ahead of time, it will need to plan a significant investment for them.

To make the bridge maintenance decisions, the bridge management agencies need to consider many factors, especially funds for rehabilitation and maintenance activities. Thus, the agency needs to be able to match such funds with which maintenance activities should be performed on which bridges in the network. However, to answer these questions, the bridge inspection should provide current and accurate information for the owner. In addition to deciding which maintenance and rehabilitation activities need to be performed, the agency must determine the frequency of maintenance and rehabilitation activities.

2 LITERATURE REVIEW

Bridge Maintenance is defined as the activity that is performed to keep the bridge structures in good condition within the limited budget. Furthermore, to ensure the continued safety of bridge users without waiting until the bridges are in a dangerous state for the users (FHWA 2012). Most of the DOTs' goals is to extend the bridges' service life and keep them in a good state at a minimum budget. Maintenance needs should be identified at the element level or during safety inspection by the bridge inspector and maintenance crews. Most DOTs have their standard list items of maintenance actions forms reported by inspectors or maintenance crews and performance reviewed by regional or central DOT staff. However, all records should include at least these three main actions: the maintenance needs, quantities, and priorities. Not all recommendations will be selected, it depends on the bridge rating condition and priority ranking needed. The maintenance needs are directed to maintenance crews, district-level contracts, or programming through the central DOT Office (NCHRP 2003). An unmet need can become a high priority. The priority will help in selecting the proper work and suitable for maintenance crews. If the size of the project is large, maintenance work can be done by outsourced contractors. It is evident, thus, that bridge maintenance decision making becomes the most important part of the bridge maintenance program process because it helps the bridge decision makers select the right tool at the right time and right place. The bridge owner might spend less money on maintenance and keep the bridge in a condition longer than the usual lifetime. However, to be able to make the right decision, the decision-maker should know the options of maintenance and cause of bridge deterioration.

**Bridge maintenance classifications.** There are six types: Bridge preservation, Preventative Maintenance, Responsive Maintenance, Rehabilitation or Major Maintenance, Bridge Replacement, and Routine or Minor Maintenance (AASHTO 2013).

**Inspection categories.** There are five inspection types as per FHWA (2018): initial inspection, routine inspection, in-depth inspection, damage inspection, and special inspection.

**Bridge inspection tools.** There are two groups: visual inspection and techniques inspection.
Influence decision factors. Several factors are influenced: nature and severity of the defect, effect of the repair method in bridge service life, and availability of funds (Rashidi et al. 2010).

Bridge Management System (BMS). BMS is mainly used to report the bridge inspection, rate conditions of bridges, provide the maintenance work needed, and respond to people involved. BMS can justify funding for bridge preventive maintenance, rehabilitation, and replacement. It could help politicians and the public understand where their taxes are being spent.

3 RESEARCH METHODOLOGY

The methodology that is applied to this study includes four steps. The first step includes reviewing the national bridge management literatures, 2) reviewing percentages of bridge deterioration in all states and selecting six states to benchmark effective bridge management programs, following the criteria shown in Table 1, using a swim lane diagram, 3) conducting a case study focusing on Caltrans's existing maintenance decision practices, including an interview with Caltrans as well as content analysis of maintenance program policy and manual, 4) synthesize the information from steps 1, 2, and 3 to develop a proposed data-driven maintenance decision model, considering the limitation of Caltrans to improve their bridge maintenance decisions, such as repair, rehabilitation, and replacement.

Table 1. State ranking, by number of structurally deficient bridges.

<table>
<thead>
<tr>
<th>State</th>
<th>Number of bridges</th>
<th>Number of structurally deficient bridges</th>
<th>Number of bridge with structurally deficient bridges as % of total inventory</th>
<th>Change in number of structurally deficient bridges</th>
<th>State ranking, by number of structurally deficient bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEORGIA</td>
<td>13,540</td>
<td>461</td>
<td>14.87%</td>
<td>-1.2%</td>
<td>34</td>
</tr>
<tr>
<td>ALABAMA</td>
<td>25,152</td>
<td>654</td>
<td>26.00%</td>
<td>-1.6%</td>
<td>89</td>
</tr>
<tr>
<td>NEW JERSEY</td>
<td>13,201</td>
<td>267</td>
<td>20.00%</td>
<td>-1.7%</td>
<td>71</td>
</tr>
<tr>
<td>MINNESOTA</td>
<td>13,540</td>
<td>631</td>
<td>46.99%</td>
<td>-1.6%</td>
<td>99</td>
</tr>
<tr>
<td>INDIANA</td>
<td>27,167</td>
<td>1,235</td>
<td>4.60%</td>
<td>-1.7%</td>
<td>61</td>
</tr>
<tr>
<td>MICHIGAN</td>
<td>14,245</td>
<td>1,025</td>
<td>7.10%</td>
<td>-1.5%</td>
<td>16</td>
</tr>
<tr>
<td>MARSHALL</td>
<td>17,610</td>
<td>1,094</td>
<td>6.23%</td>
<td>-1.7%</td>
<td>18</td>
</tr>
<tr>
<td>NORTH CAROLINA</td>
<td>18,407</td>
<td>1,714</td>
<td>9.33%</td>
<td>-1.6%</td>
<td>10</td>
</tr>
<tr>
<td>OKLAHOMA</td>
<td>23,138</td>
<td>2,262</td>
<td>10.17%</td>
<td>-1.5%</td>
<td>17</td>
</tr>
<tr>
<td>PENNSYLVANIA</td>
<td>22,977</td>
<td>2,728</td>
<td>10.99%</td>
<td>-1.6%</td>
<td>11</td>
</tr>
<tr>
<td>KENTUCKY</td>
<td>24,463</td>
<td>6,775</td>
<td>27.91%</td>
<td>-1.1%</td>
<td>2</td>
</tr>
<tr>
<td>CALIFORNIA</td>
<td>25,771</td>
<td>7,879</td>
<td>30.69%</td>
<td>-1.0%</td>
<td>2</td>
</tr>
</tbody>
</table>

4 RESULTS & ANALYSIS

Literature review is covered in previous section. Following steps were followed in the study:

4.1 Benchmarking the Existing DOT Processes

The idea of chosen benchmarking states based on the following criteria: 1) the states have the total number of bridges greater than 10,000 bridges (Table 1 above) or greater than 10,000,000 Square Feet by area, 2) determined top-ten states with more minor percentage change in the number of structurally deficient bridges between 2017-2018 and 2018-2019, 3) ranked by less percentage of structurally deficient bridges by area, and 4) ranked by less percentage of structurally deficient bridges by the number of the bridge. The six following states were selected: Texas, Virginia, Florida, North Carolina, Pennsylvania, and Georgia. Figure 1 is the example benchmarking the process from Texas. Based on the review of the six DOTs, they mostly have a similar framework for identifying and tracking maintenance needs and somewhat similar approaches to performance and priority measure. The main findings from each state: 1) inspector training program, 2) hiring a consultant/specialist for an inspection, 3) type of inspection tool, and 4) decision factors.
4.2 Analysis of Caltrans Case Study

Based on the review of various key bridge management Caltrans documents. The following themes are all integral in any maintenance-decision making process.

4.2.1 Content analysis of Caltrans documents

Caltrans began collecting element-level data in 1992 following the AASHTO Guide for Commonly Recognized Bridge Elements (FHWA 2005). After an inspection, an inspector's findings, including element-level condition assessments, photos, commentary, and recommendations, are entered into an electronic database for use throughout Caltrans. These findings populate a bridge inspection report used to convey the inspection results to the bridge owner and automatically generated priority lists for maintenance crews and bridge management engineers.

![Swimlane flowchart illustrating bridge maintenance process in Texas DOT.](image)

Figure 1. Swimlane flowchart illustrating bridge maintenance process in Texas DOT.

**Team involved.** Most bridge maintenance works in California are controlled by Structure Maintenance & Investigations (SM&I). SM&I is part of the Caltrans Division of Maintenance. The purpose of this department aims to ensure the safety of all structural bridges in state highway bridges and bridges owned by local government agencies. There are six offices. The executive office and structure investigation for North California, the office specialty investigations and bridge management, and the Structural Design and Analysis are all located in Sacramento. The structure investigation for South California is in Los Angeles. The toll bridge investigation is in Oakland. At present, all bridges in California are inspected through both routine and specialty investigations following the guideline by SM&I (Weykamp et al. 2009).

**Type of maintenance in Caltrans.** There are four categories of maintenance: 1) Routine maintenance is the repair of minor or major defects, 2) preventive maintenance includes crack sealing, deck sealing, deck overlay, joint projects, and bridge painting, 3) rehabilitation which will improve bridge elements to a near-new condition, 4) emergency maintenance is an immediate response to significant events.

**Condition assessment rating of bridges.** Federal Highway Administration (FHWA) standards and guidelines require all states to report their bridge condition rating. Two inspection standard condition ratings are used in most state DOTs (FHWA 2012). The first is the National Bridge Inventory (NBI) database ratings which are used to generate condition ratings of major bridge components in the United States. The states collect it during the regular bridge inspection. It ranges from 0 to 9 and represents only the bridge elements' overall condition, specifically for deck, superstructure, and substructure (FHWA 1988). Core Element Inspection Conditions are used to rate the condition rating of the bridge element component. There are four condition states defined in AASHTO bridge element inspection manual. This system provides more information
on bridge inspection ratings. This assessment is the breakdown by the number of sub-elements, materials, and the units for quantities such as feet and each. Besides the NBI and Core Element, Caltrans developed a new performance measure which is called Health Index (H.I.), to prioritize the bridge needed. Currently, the most acknowledged performance measure based on current BMS elements is H.I., which ranges from 0% (worst condition) to 100% (the best condition). It indicates the condition distribution for the different elements on the bridge structure.

**Type of performance.** Caltrans uses a three-state performance measure that is good, fair, and poor to quantify the bridge deck area condition (Caltrans 2019). 1) Field maintenance crew, which is a bridge preventive maintenance that applies when bridges are in fair to good condition. 2) Major maintenance projects which is corrective and preventive maintenance that exceeds the scope of what field maintenance crew do. The bridges are in fair or a little below fair condition. 3) SHOPP Projects for the bridge that is ended of service life, more complex, and highly cost.

### 4.2.2 Interview with California Department of Transportation

The two interviews conducted were scheduled on December 18 and 23, 2019, at Caltrans District-7, Los Angeles, California. The first interview was with the Senior structural engineer at Structure Maintenance and Investigation in Head Office at Sacramento. This interview focuses more on the type of inspection tools, how data is collected, and the performance measure. The second interview was scheduled with the Asset Bridge Management team at District 7. This interview was focused on who conducts the inspection, who is involved in bridge maintenance processes, and the level of staffing involvement.

![Figure 2. Swinlane flowchart illustrating current bridge maintenance process in Caltrans.](image)

![Figure 3. Proposed bridge decision-making model for Caltrans.](image)

Interviewees think that bridge inspection tools used currently in Caltrans can be further improved. Improvement tools included the use of more bridge inspection technologies, such as
sensors. These will have the ability to carry a video camera, which could help the agency conduct inspections quickly, safely, and efficiently. They also mentioned about the current structural evaluation systems as it is considered only on major bridge components.

4.3 Proposed Caltrans Bridge Decision Making Model

Based on the findings from the interviews and the content analysis, the keys revisions made to Caltrans existing model was presented in Figure 2 and Figure 3. The inspection work is given to the district instead of ABME which will reduce time. There is no need to wait for ABME and the district inspector is more familiar with the area. The idea is borrowed from Florida DOT and North Carolina DOT, where the district inspector carries out the inspection. Condition assessment ratings and calculation cost of maintenance project are given the responsibility to district manager instead of delivered to SM&I. Peer review for the project's cost of over 4 million U.S. dollars is removed because the district manager and SM&I team have already reviewed the report and Maintenance recommendation. The selection maintenance method by the cost of over 4 million U.S. dollars has been removed. Instead, applying the H.I. as a criterion to select the maintenance option. Caltrans manual does not give much information on how they use H.I. or how it is used to categorize the bridge condition. Moreover, the interview data collection has no indication about using H.I.

5 CONCLUSION

The objective of this study was to critically evaluate and develop a proposed bridge maintenance decision-making process diagram for Caltrans. To develop the model, a thorough literature review, followed by benchmarking states was conducted. Then, interviews were schedule. The result of this analysis is mostly agreed with the current Caltrans bridge decision making model. However, some of the steps are modified into the proposed model. First, the inspection is given to the district inspector. Then, Health Index is added to the condition assessment rating. Following with the peer review is removed for the process. The benefit from the proposed model could help Caltrans in better working conditions. Thus, the SM&I team can distribute work to all districts to inspect bridges in each cycle. This will increase inspection productivity instead of just wait for SM&I team to do the inspection. There are many types of bridge inspection, this study was only limited to routine inspection.

References

FHWA, Bridge Management Experiences of California, Florida, and South Dakota, 2005.