California Bridge Health Index

A Diagnostic Tool To Maximize Bridge Longevity, Investment

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The California Department of Transportation (Caltrans) is responsible for 12,656 bridges with an estimated asset value of more than $35 billion. To manage the work performed on this vast inventory, Caltrans has developed a versatile diagnostic tool, the California Bridge Health Index.

The Health Index is a single-number assessment of a bridge's condition based on the bridge's economic worth, determined from an element-level inspection. The index makes it possible to ascertain the structural quality of a single bridge or a network of bridges and to make objective comparisons with other bridges or networks. Caltrans has discovered many management applications for the Bridge Health Index, including performance measurement, resource allocation, budget management, and choosing the best option for a bridge's preservation.

Caltrans has been involved since 1989 in the development and implementation of the Pontis Bridge Management System, a product of the American Association of State Highway and Transportation Officials (AASHTO). Pontis has introduced many enhancements to bridge maintenance and rehabilitation—most notably the element-level inspection, which provides a quick assessment of a bridge's condition by encapsulating the severity and the extent of any problems.

The availability of element-inspection information and the need to measure bridge condition accurately were key to the development of the California Bridge Health Index. Unlike the Federal Highway Administration's (FHWA's) Sufficiency Rating, the Health Index provides insight into the structural condition of a bridge without regard to the bridge's functional adequacy.

Inspection Standards

In December 1967, 46 people died in the collapse of the Silver Bridge in West Virginia. Since then, the federal government has monitored the condition of the nation's bridges, developing the National Bridge Inspection Standards and the National Bridge Inventory (NBI). The NBI contains information about every bridge on a public road—more than 575,000 bridges.

For more than 25 years, states have reported NBI inventory data annually, as required by the Federal Recording and Coding Guide. The Coding Guide defines 96 specific data describing a bridge's location, geometrics, age, traffic, load capacity, structural condition, and other relevant features.

Sufficiency Rating

The Coding Guide includes a procedure to calculate a bridge's Sufficiency Rating, which combines the functional and condition data in the NBI into a single number from 0 to 100. The federal government uses the Sufficiency Rating in allocating funds for the Highway Bridge Rehabilitation and Replacement (HBRR) Program and in determining eligibility criteria for bridge projects that use these funds.

Many perceive the Sufficiency Rating as representing the structural condition of a bridge—the lower the number, the worse the condition. However, the Sufficiency Rating combines data on function and condition and is not therefore an accurate tool for determining a bridge's condition.

As part of Caltrans bridge inspection program, engineers use an under-bridge inspection truck to inspect fracture-critical elements on a bridge over the Stockton Channel.

Functional Information

The NBI data that describe the service a bridge provides to a roadway often are termed functional data. These data describe the type of traffic carried by the bridge as well as the bridge's capacity in relation to traffic demand. A bridge that is not wide enough, high enough, or strong enough to meet traffic demand is functionally obsolete. The NBI data can identify functionally obsolete bridges.

Condition Information

The NBI records the structural condition of a bridge primarily through three items that represent major bridge components: the deck, the superstructure, and the substructure. The condition of these elements is assessed on a rating scale of 0 to 9, with 0 as the lowest or worst condition and 9 as the best.

These ratings provide information on the severity of a condition but do not identify or quantify the extent of the problem. The failure to identify or quantify the extent of a deficiency minimizes the effectiveness of NBI condition ratings in determining maintenance and rehabilitation needs.

NBI condition ratings also are vulnerable to subjective interpretation by bridge inspection staff. Since multiple distress symptoms may adversely affect the ratings that describe the general condition of a bridge, the inspection staff must decide which distress symptom most represents the bridge's general condition, introducing subjectivity into the ratings.

For example, a large bridge has many columns, only one of which is in poor condition. If the rest of the bridge is in good condition, what is the overall condition of the bridge? The NBI evaluation would dismiss the severity of a localized problem and report the bridge to be in good condition overall. However, if the localized problem condition spreads, at what point would it affect the bridge's overall condition? The NBI condition ratings do not account for this dilemma.

Close-up inspection of deteriorated bridge member.

Element-Level Inspection

To eliminate the subjectivity in the NBI condition ratings and to allow recommendations for specific action, FHWA's Demonstration Project No. 71 guided development of a new element-level inspection procedure. The effort culminated in the creation of the *CoRE-AASHTO Guide for Commonly Recognized Structural Elements*, often called the "CoRE Element Manual."

The CoRe Element Manual defines each element and the terms for associated condition states. FHWA has endorsed the manual, which is maintained by AASHTO.

The element-level inspection techniques differ from the NBI in several important ways. Most obvious is the more detailed breakdown of the bridge components. Instead of the NBI's single superstructure rating, element-level inspection requires individual condition assessments for girders, floor beams, pins, hangers, and so on. The element inspection techniques improved on the NBI by defining each element's condition state in precise engineering terms.

The inspection supplies the totals of each element and the numbers of the element in each condition state. With element-level inspection information, actions specific to the element type, the material makeup, the severity of the deterioration, and the quantity of the deterioration can be determined. Element-level inspection is arguably the single most significant accomplishment of bridge management system developments to date.

The more detailed element inspection information has enabled many improvements in bridge management and is the basis for the California Bridge Health Index.

New Performance Measure

The Sufficiency Rating did not meet California's need for a single number to measure the performance of maintenance and rehabilitation. Therefore Caltrans developed the California Bridge Health Index, a numerical rating of 0 to 100 that reflects element inspection data in relation to the asset value of a bridge or network of bridges.

The premise of the Health Index is that each bridge element has an initial asset value when new. An element may deteriorate to a lower condition state, reducing its asset value. With maintenance or rehabilitation, the condition of the element is likely to improve and the corresponding asset value to increase.

Field inspection can ascertain the element condition-state distribution at any point in time, or a deterioration model may predict it. Once the condition distribution is known, the current element value can be determined for all elements on the bridge. The Health Index for the bridge is the ratio of the current element value to the initial element value of all elements on the bridge (see sidebar below for the formulas). To apply the Health Index concept to a network of bridges, the entire network is treated as one large structure containing the summation of all element quantities and condition distributions within the network.

Calculating a Bridge's Health Index

Following are the formulas for the computation of the California Bridge Health Index:

$$HI = \left(\sum CEV / \sum TEV\right) * 100$$

$$TEV = TEQ * FC$$

$$CEV = \sum (QCS_i * WF_i) * FC$$

$$WF = [1 - (\text{Condition State \#} - 1)(1/\text{State Count} - 1)]$$

where

HI = Health Index;

CEV = current element value;

TEV = total element value;

TEQ = total element quantity;

FC = failure cost of element;

QCS = quantity in a condition state; and

WF = weighting factor for the condition state.

TABLE 1 Element Distribution for a Sample Bridge

Element Description	Units	Total Quantity	State 1	State 2	State 3	State 4	State 5	Unit Failure Cost (FC)
Concrete Deck	Sq. m	300			300			$600
Steel Girder	m	100	61	34	5			$3,500
RC Abutment	m	24	24					$7,700
RC Column	ea	4	4					$9,000
Joint Seal	m	24			24			$556

RC = reinforced concrete

Tables 1–3 present an application of the Health Index formulas to data from a sample bridge. The final calculation of the sample bridge's Health Index (HI) is as follows:

$$\begin{aligned} HI &= \left(\sum CEV / \sum TEV\right) * 100 \\ &= (\$622{,}300/\$764{,}144) * 100 \\ &= 81.4 \end{aligned}$$

Health Index Uses

The Health Index has had a positive impact on the management of bridges in California. The state uses the Health Index to allocate resources, to evaluate district bridge maintenance and rehabilitation, and to provide level-of-service indicators. California also is developing additional applications of Health Index concepts for evaluating annual budget strategies and the life-cycle performance of maintenance and rehabilitation.

Measuring Performance

Caltrans operates and maintains the state highway system through 12 regional district offices. Each district is responsible for the repair and rehabilitation of the highway system and its bridges to meet a required level of service. The level of service is a direct result of the available resources and the management strategies to preserve the system.

Figure 1 shows how the Bridge Health Index is used to judge the performance of each district's management strategies with the resources available. The goal is to have no more than 5 percent of the state's bridges with a Health Index below 80. The bridge management activities of districts that do not meet this goal are evaluated on their ability to make positive advances.

Caltrans uses the Health Index as a performance measure. To convey the physical condition of a bridge to a layperson, Caltrans has developed a visual representation of the Health Index (Figure 2) using the condition-state definitions from the element-level inspection. The visual representation is used to define the levels of service for the maintenance and rehabilitation of bridges.

TABLE 2 Total Element Value of Sample Bridge

Element Description	Calculation	Resulting TEV
Concrete Deck	300 * 600	$180,000
Steel Girder	100 * 3500	$350,000
RC Abutment	24 * 7700	$184,800
RC Column	4 * 9000	$36,000
Joint Seal	24 * 556	$13,344
	Total (Σ TEV)	**$764,114**

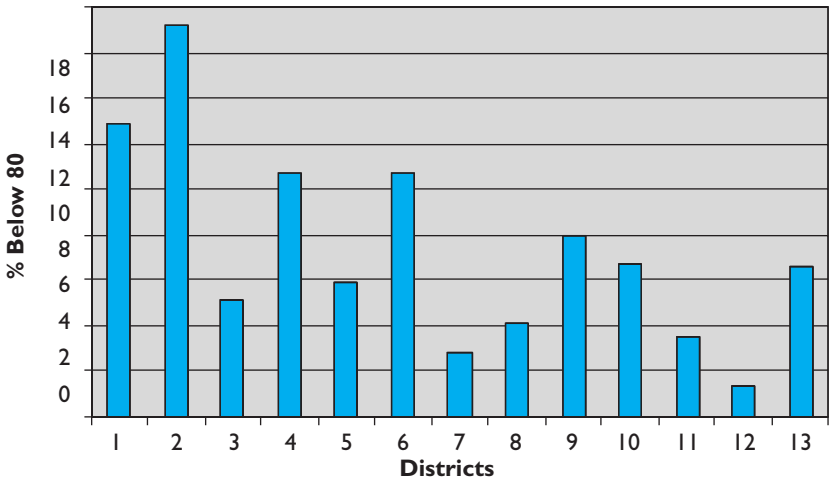
TEV = total element value; RC = reinforced concrete

TABLE 3 Current Element Value of Sample Bridge

Element Description	Calculation	Resulting CEV	Element Health
Concrete Deck	300 * 0.5 * 600	$90,000	50.00
Steel Girder	[(61 * 1.0)+(34 * 0.75)+(5 * 0.5)] * 3500	$311,500	89.00
RC Abutment	24 * 1.0 * 7700	$184,800	100.00
RC Column	4 * 1.0 * 9000	$36,000	100.00
Joint Seal	24 * 0.0 * 556	$0	00.00
	Total (Σ CEV)	**$622,300**	

CEV = current element value; RC = reinforced concrete

FIGURE 1 Percentage of bridges in each district with a Health Index below 80; District 13 represents the statewide average.



Data used to generate California Bridge Health Index involve careful measurements.

Allocating Resources

Caltrans has developed a formula for allocating resources to each district, based on the district's size, makeup, and the congestion of the bridges. If the bridges were all the same type, size, and condition, and subject to the same congestion, this baseline would be consistent for all districts. However, resource shortfalls, operating practices, and environmental issues cause differences in each district's network condition.

A district's network Health Index is used to adjust the allocation formula so that the base allocations increase proportionately for bridge inventories that have a poor network Health Index. This allocation procedure is under evaluation and is not accepted practice, however, it has assisted in the distribution of resources.

Budget Decision Making

Bridge managers often must evaluate the impact of several budget scenarios on the condition of a bridge network; this requires applying the Health Index concepts to future conditions. Most bridge management software programs predict actions based on modeling logic, selecting actions that meet the available budget. Budget constraints limit the number of actions that the management system software can select, reducing the Health Index for the network.

FIGURE 2 Visual representation of Health Index values.

Condition State 1	Condition State 2	Condition State 3	Condition State 4	Condition State 5
				
Number of all bridges in Condition State 1	Number of all bridges in Condition State 2	Number of all bridges in Condition State 3	Number of all bridges in Condition State 4	Number of all bridges in Condition State 5
6771 (55.7%) BHI Range: 100	3422 (28.1%) BHI Range: 99–90	1016 (8.36%) BHI Range: 89–80	290 (2.38%) BHI Range: 79–70	641 (5.28%) BHI Range: <70

By evaluating the change in the network Health Index, it is possible to represent the future condition and the change in the value of the network as a whole based on any budget. The link that the Health Index provides between condition and asset value allows bridge managers to translate condition to dollar amounts.

Figure 3 graphs a budget-based Health Index for four sample funding levels over 10 years. Comparing the results for aggressive funding with those for minimal funding, a bridge manager can demonstrate the change in the Health Index over time based on the various budget options. The key feature of the Health Index is that a bridge manager can correlate bridge condition directly to asset value.

To demonstrate this concept, assume that the aggressive funding level shown in Figure 3 is $10 million per year and the minimal funding curve represents $1 million annually. If the overall asset value of the network is $30 billion and the percentage change in the Health Index between these two funding alternatives is 41 percent, then the reduction in asset value by opting for the minimal funding scenario is $12.3 billion over 10 years.

Therefore opting for the minimal funding plan would reduce expenditures by $90 million over 10 years, but would cost the agency $12.3 billion in asset value. AASHTO has recognized the value of the budget-based Health Index and has incorporated the concept into the current release of Pontis.

Measuring Improvement

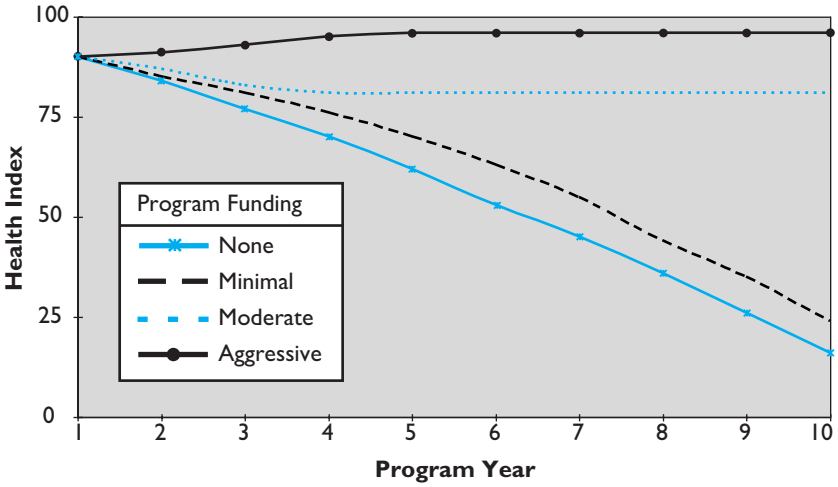
A primary goal of any bridge program is to maintain the condition of the structures by identifying the need for—and then performing—preservation. Often several options must be compared.

Bridge management software generally identifies preferred preservation actions based on benefit-cost analysis. The Health Index allows the bridge manager also to determine how the action would increase the asset value and extend the expected life of the bridge.

Figure 4 illustrates a sample Health Index over time that includes a major project in Program Year 5. The major action in Program Year 5 produces a dramatic increase in the Health Index—a 38 percent increase in asset value. The number of years it would take until the bridge reverts to the same Health Index before the remedial action is the extended life that action has provided to the bridge.

Any action or combination of actions has an initial cost and also a benefit measured by the change in asset value and the increase in life expectancy. Coupling economic optimization with the Health Index can provide the bridge manager with a picture of the cost, condition, and increased life expectancy of any project.

FIGURE 3 Budget-based Health Index for four funding levels over 10 years.



Proven Value

The California Bridge Health Index has proved effective in understanding the overall condition of a bridge or network of bridges. It has proved valuable in connecting desired levels of service with the performance and the allocation of resources for bridge maintenance and rehabilitation.

Moreover, with sophisticated bridge management system software such as Pontis, predicting a bridge's future Health Index based on ongoing deterioration—with or without maintenance actions—is no longer a complex task. This benefit of relating physical condition to asset value promises to make the Bridge Health Index an integral part of bridge management, not only in California but worldwide.

FIGURE 4 Health Index for a bridge over 14 years, showing increased life due to a major project in Program Year 5.