Span-Based Network Characterization for Bridge Management

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A methodology for a span-based approach to bridge network characterization is presented. Spans are organized and evaluated by using five distinguishing factors, namely, size, type of service, continuity, superstructure material, and design type. Emphasis is placed on making the methodology useful for a wide range of bridge management tasks. Network characterization is pursued through the aggregation of spans with similar characteristics into “span families.” The historical trends of various condition measures are evaluated for bridges, spans, and families of spans, and preliminary network-level trends are investigated. The methodology is applied for the case of the New York State Thruway bridge network. It is concluded that the decomposition of bridges into their constituent spans and the classification of spans into families provide a viable approach to the development of detailed condition prediction models.

The New York State Thruway Authority (NYSTA) and Rensselaer Polytechnic Institute (RPI) are cooperating to develop a bridge management system (BMS) for the authority’s inventory of 808 bridges. The computerized system will unite expert knowledge on deterioration processes and maintenance practices with available data and analytical methods to aid in bridge preservation decision making (1). The findings of the present study provide a framework for the more detailed development of the network-level analysis components of the authority’s BMS.

OBJECTIVES

It is the broad objective of the present study to develop a detailed approach to bridge network characterization. Specific objectives are to

- Develop an appropriate grouping of spans for use in network-level analysis, and
- Investigate historical network-level condition trends for bridges, spans, and families of spans.

Early products of this effort also serve to (a) establish the current status of the condition of the Thruway bridge network, (b) provide insight into the historical rate at which network condition has changed, and (c) provide input for the evaluation of the effectiveness of maintenance program initiatives.

BACKGROUND

The majority of Thruway bridges were built between 1954 and 1960. A diversity of sizes, designs, and materials exists. The most common type of structure is the simply supported composite I-beam, although many other types—such as built-up girders, continuous I-beams, trusses, box culverts, concrete frames, and concrete arches—are represented. Many bridges are composed of spans of more than one type. Across the network span lengths vary significantly, ranging from 6.1 m (20 ft) for ordinary box culverts or frames to 369.4 m (1,212 ft) for the main truss of the 4.8-km (3-mi) Tappan Zee Bridge.

The condition of each bridge is assessed at least biennially in accordance with the procedures developed by the New York State Department of Transportation, consistent with the National Bridge Inspection Standards (2). Inventory and inspection data, including element ratings and general recommendations for the bridge and selected components, are available for 1978 through 1992. For the purposes of the present study, the most recent inspection records for each bridge and span are used to represent the condition of the structure for a given year. This practice ensures that the entire bridge population is represented in the statistics calculated for each year.

In essence the 56 types of inspection ratings recorded during each inspection represent discrete assessments of aspects of bridge condition at different points in time. Although such information is useful for project-level analysis, condition must also be summarized to support network-level activities. This synthesis has typically been pursued through a weighted-average calculation methodology that combines the minimum ratings of 13 significant elements into a bridge condition rating (BCR) index (3). For the purposes of the present study a span condition rating (SCR) index was calculated by applying the same methodology to individual spans rather than to entire bridges.

SPAN CLASSIFICATION

Factors

The identification of factors suitable for classifying spans was achieved through extensive interaction between RPI and NYSTA personnel. In addition to the information obtained from studies documented in the literature, Thruway knowledge and experience were solicited through a series of questionnaires and discussion group meetings. Potential factors were screened with respect to (a) their influence on the rate of condition rating change, (b) their relevance to current maintenance decision-making practices, (c) the ability to quantify factors with the available data, and (d) interactions between factors. This screening process reduced the list of factors of interest to size, type of service, continuity, su-
perstructure material, and design type. The categories applicable to each factor are defined as presented in Table 1.

**Families**

Each span in the network is classified with respect to each of the five factors and is assigned to a “family” of spans with the same characteristics. There are 12,000 possible families defined by the combinations of categories listed in Table 1. However, the 3,372 spans in the Thruway inventory fall into only 116 families. Table 2 gives the 12 most populated families of Thruway bridges.

**NETWORK CHARACTERIZATION**

A meaningful characterization of bridge network condition is an important requirement for the development of optimization and other network-level analysis methodologies. Currently, the authority periodically reviews network condition to evaluate the efficacy of maintenance rehabilitation programs. For the purposes of the present study network characterization is pursued by dividing bridges into their component spans and then grouping individual spans with similar characteristics into span families. The historical trends of condition for various span families are examined, and the performances of the families are compared and contrasted with that of the network average. To enable evaluation of average condition trends from year to year, condition measures are determined for every bridge and span for every year of the analysis by using the most recent inspection records, which ensures that the entire bridge population is represented in the statistics for each year.

Figure 1 illustrates that historical average network condition trends are substantially similar regardless of whether the network is considered to be a population of 808 bridges (condition measured by BCR) or a population of 3,372 spans (condition measured by BCR).
TABLE 2 Sample NYSTA Span Families

<table>
<thead>
<tr>
<th>NO. OF SPANS</th>
<th>MATL</th>
<th>SERVICE TYPE</th>
<th>SIZE</th>
<th>CONTINUITY TYPE</th>
<th>DESIGN TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>819</td>
<td>steel</td>
<td>overpass</td>
<td>medium</td>
<td>simple</td>
<td>rolled beam</td>
</tr>
<tr>
<td>398</td>
<td>steel</td>
<td>overpass</td>
<td>small</td>
<td>simple</td>
<td>rolled beam</td>
</tr>
<tr>
<td>335</td>
<td>steel</td>
<td>thruway</td>
<td>medium</td>
<td>simple</td>
<td>rolled beam</td>
</tr>
<tr>
<td>172</td>
<td>steel</td>
<td>thruway</td>
<td>large (TZ)</td>
<td>simple</td>
<td>rolled beam</td>
</tr>
<tr>
<td>127</td>
<td>steel</td>
<td>thruway</td>
<td>large (NV)</td>
<td>simple</td>
<td>rolled beam</td>
</tr>
<tr>
<td>122</td>
<td>steel</td>
<td>overpass</td>
<td>medium</td>
<td>contin</td>
<td>rolled beam</td>
</tr>
<tr>
<td>109</td>
<td>steel</td>
<td>thruway</td>
<td>small</td>
<td>simple</td>
<td>rolled beam</td>
</tr>
<tr>
<td>101</td>
<td>steel</td>
<td>thruway</td>
<td>intermed</td>
<td>simple</td>
<td>rolled beam</td>
</tr>
<tr>
<td>82</td>
<td>steel</td>
<td>thruway</td>
<td>intermed</td>
<td>simple</td>
<td>plate girder</td>
</tr>
<tr>
<td>61</td>
<td>steel</td>
<td>thruway</td>
<td>intermed</td>
<td>cant/susp</td>
<td>plate girder</td>
</tr>
<tr>
<td>57</td>
<td>concr</td>
<td>thruway</td>
<td>small</td>
<td>other</td>
<td>box culvert</td>
</tr>
<tr>
<td>52</td>
<td>steel</td>
<td>thruway</td>
<td>medium</td>
<td>simple</td>
<td>plate girder</td>
</tr>
</tbody>
</table>

ILLUSTRATIVE EXAMPLE

Observations such as those described previously indicate considerable promise for improved development and use of network-level analysis tools such as deterioration modeling and treatment needs estimation. A simplified example illustrates this point. If simple linear regression models are developed for condition as a function of time, then the expression for the entire network is

$$\text{SCR}_{\text{network}} = 101.29 - 0.0484t \quad (r^2 = 0.86) \quad (1)$$

where $\text{SCR}_{\text{network}}$ is the mean span condition rating index for the network, and $t$ is the time, in years (1990, 1991, etc.). Similarly the expression for Family 105 is

$$\text{SCR}_{\text{Fam 105}} = 250.36 - 0.1237t \quad (r^2 = 0.88) \quad (2)$$

FIGURE 1 Historical average network condition trends.
where $SCRF_{105}$ is the mean span condition rating index for Family 105.

Although Equations 1 and 2 are extremely simplistic models, the slope terms reveal that the performance of Family 105 is significantly different from the network average performance. This difference has implications for predictions of future condition, treatment needs, budgeting, and so on. For example if Family 105's condition ($SCR_{105} = 3.96$) is actually decreasing at a rate of 0.1237 SCR points per year and the network "average" rate of 0.0484 SCR points per year is used to make a 10-year prediction, then the predicted average condition of Family 105 for year 2002 will be 3.48, while the actual condition will be 2.72. This overestimation of condition will most likely be associated with a considerable underestimation of the required funds. Thus a span-based approach to network characterization appears to provide a promising basis for improving network-level predictions, particularly as treatment types, performance, and costs are also expected to vary among span families.

**DISCUSSION OF RESULTS**

The illustrative example demonstrates the potential of the span-based approach to bridge network characterization. However this approach is not a completely sufficient prerequisite for analyzing historical network condition trends or projecting future needs. It is recognized that condition trends can vary significantly among components and elements (4,5), and it is thus essential to further decompose span families to investigate the performance of deck, superstructure, and substructure components. Historical condition trends for these components, as well as piers, wing walls, abutments and approaches, and numerous individual elements, were analyzed previously (4) and provide the basis for the development of more refined network-level condition models. To support project-level analysis information is synthesized on a span-by-span basis for individual bridge structures.

This decomposition and subsequent synthesis is consistent with the NYSTA BMS aim to provide a three-dimensional view of individual structures. In contrast to the traditional two-dimensional vertical cross-section view, the three-dimensional span-by-span view tracks the performance of individual members within each span. For example the condition and maintenance history of fascia and interior girders on a given span can be distinguished. The availability of such information supports more cost-effective decision making, because materials and design characteristics can vary between spans and condition and deterioration rates can vary both between spans and within the elements on a given span. The implications of expanded data requirements to support this approach are under study.

Figures 1 and 2 compare condition trends of the network and selected span families. It should be noted that although historical average network trends are substantially similar regardless of whether the network is considered a population of bridges (BCR) or a population of spans (SCR), the SCR could be considered a less conservative measure of aggregate condition than the BCR. The SCR for each span is generated from the minimum element ratings recorded on that span. In contrast the BCR is calculated from the minimum element ratings recorded on the structure, regardless of the span on which they occur. This method of calculation produces an index representative of the combined worst-case conditions on the bridge, but not necessarily of any individual span.

**SUMMARY AND CONCLUSIONS**

The major thrust of the study described here represents a departure from traditional bridge management practices. Whereas typical systems address the conditions of and needs for entire bridge structures, the present effort focused on individual bridge spans to provide a framework for a three-dimensional, span-by-span approach to bridge management. Spans were organized and evaluated by using five meaningful factors that affect deterioration, namely, size, type of service, continuity, superstructure material, and design type. Network characterization was pursued through the assessment of factor levels for each span in the network and
the aggregation of spans with similar characteristics into families. Historical condition trends for the network and selected span families were presented. It is concluded that the decomposition of bridges into their constituent spans and the classification of spans into families provide a viable approach to the development of detailed condition prediction models.

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REFERENCES


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