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Evidential reasoning approach for bridge condition assessment ☆

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Abstract

Bridge condition assessment is usually conducted by bridge inspectors on the basis of visual inspections. This inevitably involves human being's subjective judgments and uncertainties. In order to model uncertainties associated with subjective assessments, this paper presents an evidential reasoning (ER) approach for bridge condition assessment. The ER approach has the following advantages over other approaches for bridge condition rating: (1) the relative importance of different bridge components and elements is incorporated into the model; (2) bridge condition ratings are treated as assessment grades rather than precise numerical values, which is more logical; (3) bridge element can be assessed to two adjacent assessment grades at the same time if it cannot be precisely assessed to only one assessment grade, each with a belief degree (probability, confidence) to show to what extent the element is assessed to the two different grades, respectively; (4) the overall assessment of a bridge is a distributed assessment, which provides a panoramic view about the bridge condition. A case study is provided to illustrate the implementation process of the ER approach for bridge condition assessment.

Keywords: Bridge condition rating; Evidential reasoning approach; Belief degree; Uncertainty

1. Introduction

In many countries bridge conditions are inspected and assessed periodically for the purposes of safety and maintenance. This is usually done by experienced or well-trained bridge inspectors, who are required to assign a numerical rating to each bridge element or component on the basis of visual inspections. Normally these ratings range between good/excellent condition and poor/failure condition, which requires imminent action (Bevc, Mahut, & Grefstad, 2001; Dunker & Rabbat, 1995; Frangopol, Kong, & Gharaibeh, 2001; Li, Shi, & Ososanya, 1996). Although such a traditional procedure is very popular and widely used, there are some problems with it.

First, the relative importance of bridge components and elements is not taken into consideration. As is known, bridge structures consist of components such as deck, superstructure, and substructure, which are composed of sub elements. Different components and elements play different roles in the structures and are therefore of different relative importance. They should not be treated equally.

Second, bridge condition ratings assigned by bridge inspectors to different elements are treated as precise numerical numbers, on the basis of which simple arithmetic operations are carried out. This study suggests that bridge condition ratings stand for assessment grades rather than precise numerical values (cardinal data). Different assessment grades should not be simply added together.

Third, uncertainties inherent in bridge inspectors' subjective ratings are ignored. Uncertainties associated with human being's subjective judgments are often inevitable. For instance, bridge inspectors sometimes may be unable to precisely assess a bridge element to one assessment

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grade. In this situation, uncertainties should be considered and the bridge inspectors should be allowed to assess the element to two adjacent assessment grades with different belief degrees.

Fourth, the overall assessment of condition of a bridge is too simplified to give a full description of the conditions of a bridge structure. Usually, bridge components and elements are seldom evaluated to the same grade. So, the final overall assessment should be a distribution, which gives a panoramic view about the conditions of a whole bridge structure. Based on such a distribution, an assessment grade can be generated and recommended.

Several projects and efforts have been made to improve bridge rating systems. For example, in order to reflect the relative importance of each component or element to bridge performance, the bridge management system (BMS) in New York State evaluates bridge conditions in terms of thirteen components. Each component is assigned a rating R_i on the scale of 1–7 during inspection and contributes to overall bridge rating R through a weight w_i, which varies from component to component and from one system to another. The overall bridge condition rating is given by (Testa & Yanev, 2002; Yanev, 1998)

$$R = \sum_{i=1}^{13} w_i R_i. \tag{1}$$

Melhem (1994) presented a fuzzy inference model for bridge condition rating, in which bridge condition ratings were given on a scale of 0–9 and were all considered as fuzzy numbers. The pairwise comparison matrix and eigenvector method were used to determine the priorities among bridge elements, and the fuzzy multiple attribute decision making technique was utilized to synthesize the ratings of bridge elements and to generate an overall assessment for each bridge component such as deck, superstructure and substructure. The overall assessment was also expressed by a fuzzy number, from which the overall rating based on the scale of 0–9 could be determined for each bridge component by using the principal of maximum membership grade.

Liang, Wu, and Liang (2001) built up a multiple layer fuzzy synthesis evaluation model for bridge damage assessment. In their model, a bridge structure was evaluated in terms of different bridge members using five grades defined as *nondamage*, *light damage*, *moderate damage*, *severe damage*, and *unfit for service*. In the first layer of the model, each damage item was evaluated using the five grades, but could only be evaluated to one of them. This was expressed by a vector. In the second layer of the model, the evaluation vectors for bridge members were synthesized with the weight vector of the bridge members, which produces a composite evaluation for the bridge under consideration. This composite evaluation was then normalized as an overall assessment for the damage of the bridge.

Li et al. (1996) presented a feasibility study on the use of neural networks in bridge condition evaluation. A neural network consisting of five subnets which are deck, superstructure, substructure, channel, and overall evaluation subset, was designed to simulate bridge evaluation process. The first four subsets were designed to evaluate the four major bridge components using nonlinear activation functions. The final subset was designed to reach a conclusion on the overall bridge performance using linear activation function.

Cattan and Mohammadi (1997) described an application of neural network systems in developing the relationship between subjective ratings and bridge parameters as well as the relationship between subjective and analytical structure analysis ratings.

Among the above improved bridge condition assessment approaches (a) the New York State model simply treats bridge condition ratings as cardinal data. (b) The fuzzy inference model views bridge condition ratings as fuzzy numbers and requires the condition ratings to meet the rule of addition operation on fuzzy numbers. (c) The multiple layer fuzzy synthesis evaluation model requires bridge experts or inspectors to assess every bridge element/item to only one assessment grade with 100% confidence. (d) The neural network models need significant numbers of bridge maintenance schemes to map the required relationships. All these approaches cannot model uncertainties associated with subjective ratings in an appropriate way and also cannot provide a full description of the overall assessment of a bridge structure.

This paper proposes and investigates an alternative approach for bridge condition assessment, in which the evidential reasoning (ER) methodology is used to model the uncertainties inherent in bridge subjective evaluation and to aggregate the assessments of bridge elements and components. The final overall assessment of a bridge is a distributed assessment, which offers a panorama of a bridge condition. The proposed approach can overcome the former mentioned drawbacks and is illustrated with a hypothetical case study.

2. The evidence theory

The evidence theory was developed by Dempster (1967) and extended and refined by Shafer (1976). The theory is related to the Bayesian probability theory in the sense that they both deal with subjective beliefs (i.e. probabilities). However, according to Shafer (1976), the evidence theory includes the Bayesian probability theory as a special case, the biggest difference being in that the former is able to deal with ignorance, while the latter is not and its subjective beliefs are also required to obey the probability rules.

The evidence theory has been widely applied in many areas such as artificial intelligence (AI), expert systems, pattern recognition, information fusion, database and knowledge discovery, multiple attribute decision analysis (MADA), audit risk assessment, etc. (Denoeux, 2000; Yang, 2001).