The Information System for Bridge Networks Condition Monitoring and Prediction

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ABSTRACT

This paper introduces an information system for estimating lifetime characteristics of elements of bridges and predicting the future conditions of networks of bridges. The Information System for Bridge Networks Condition Monitoring and Prediction was developed for the Roads and Traffic Authority of the state of New South Wales, Australia. The conceptual departure from the standard bridge management systems is the use of a novel stochastic process built out of the gamma process. The statistical model was designed for the estimation of infrastructure lifetime, based on the analysis of more than 15 years of bridge inspection data. The predictive curve provides a coherent mathematical model for conducting target level constrained and funding based maintenance optimization.

Keywords: Bridge Reliability, Gamma Process, Information Systems, Statistical Estimation, Structural Deterioration, Support System

INTRODUCTION

In the past two decades, a large effort went into the development of maintenance optimization systems for bridge management purposes. With road networks mostly completed and bridges aging, a systematic approach was needed in keeping the infrastructure maintained. Several systems have been developed, the most notable one being Pontis, a bridge management system (BMS) developed in the United States at the request of the U.S. Federal Highway Administration (FHWA). Pontis was developed via contracting to two consulting companies and in collaboration with six U.S. states. After a trial implementation in California and testing in several states, the system was adopted by the Association of American State Highway and Transportation officials (AASHTO) (Golabi & Sheppard, 1997). In 1991, the U.S. Congress mandated that state Departments of Transportation develop and implement comprehensive bridge management systems. Since the national bridge inventory was to be based on Pontis, many states elected to adopt it as their BMS.

Pontis was designed along the lines of Kamal Golabi’s proposal, and Golabi was asked to head the team that developed Pontis. In March
1988, at the suggestion of Bill Hyman of the Urban Institute, Kamal Golabi and Dan O’Connor, an official with the U.S. Federal Highway Administration, started a series of meetings to discuss the modeling and the optimization approach to bridge management that Golabi had been advocating for a number of years (Golabi & Sheppard, 1997). Golabi had developed a pavement management system for the State of Arizona to produce optimal maintenance policies for the 7,400-mile network of highways (Golabi, Kulkarni, & Way, 1982). At the heart of the system is a Markov decision model. In a similar approach, a Markov chain was made to drive the Pontis bridge management system (Golabi & Shepard, 1997; Thompson, Small, Johnson, & Marshall, 1998). In the Markov model of Pontis, the deterioration takes discrete states observed visually and the transitions from one state to the other are modeled with a Markov chain. The transition probabilities are determined from expert judgment and empirical observations. The Markov model formulation is appealing because it provides a framework that accounts for the uncertainty and the optimal policies can be obtained by solving simple programming problems (Thompson, Neumann, Miettinen, & Talvitie, 1987; van Winden & Dekker, 1998; Golabi & Pereira, 2003). However, a number of criticisms have been made against the usefulness of the model (Madanat, Mishalani, & Ibrahim, 1995; Frangopol, Kong, & Gharaibeh, 2001). Among the issues raised, the Markov chain has a restrictive stationarity assumption by which the time effect is not introduced effectively.

The Roads and Traffic Authority (RTA) of the Australian state of New South Wales manages more than 5000 bridges in its network. These bridges were built over the last 125 years using various materials and technology and for various loading standards. The structures are exposed to different environments and subject to different volumes of vehicle traffic. In order to manage these bridges and ensure their safety, the RTA has established a systematic condition rating procedure. Since 1992, the RTA has condition rated its bridge stock and recorded the data in its corporate Bridge Information System (BIS). A collaborative effort between the RTA and the University of Technology Sydney (UTS) was initiated to make full use of the condition rating information and capture the statistical behavior of the deterioration of the bridge elements in a mathematical model for assessment and prediction. In this article, we describe the approach, different from that of Pontis. After a review of all conceptual approaches and the analysis of data, we adopt an approach based on the use of a stochastic process we develop out of the gamma process for modeling deterioration. In recent years, researchers applied a stochastic process to the deterioration of civil infrastructure (van Noortwijk, 2009). A stochastic process such as the gamma process is an infinite collection of probability distributions, correlated in a manner suitable for modeling wear and degradation over time. The advantage of the gamma process is recognized and applied in many structural studies by van Noortwijk and co-authors (Pandey & van Noortwijk, 2004; van Noortwijk, Kallen, & Pandey, 2005; Pandey, Yuan, & van Noortwijk, 2007). We recognise the applicability of the stochastic process and use it in the problem. A system is developed as a research platform for the prediction of the condition of bridge elements, bridges and network of bridges and as a support system for the lifetime assessment and monitoring of assets. In the following sections we introduce the theoretical foundation of the predictive approach and the assessment and monitoring methodology and describe the associated software.

**STATISTICAL METHODOLOGY**

The Roads and Traffic Authority of the state of New South Wales is faced with the dual aspects of public safety and maintenance cost in the management of bridges and road structures within its jurisdiction. The interest is on predicting bridge element condition in a group of structures, predicting the future condition of a network of bridges and assessing the performance of a selection of bridges. An RTA bridge consists of
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