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A stakeholder probability-based optimization approach for cost-effective bridge management under financial constraints

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ABSTRACT

Management of bridges under uncertainty is an important issue for stakeholders. The use of probabilistic approaches enables one to consider uncertainties in the structural deterioration, assessment, and maintenance processes. Combined with optimization techniques, it is possible to determine management strategies that simultaneously minimize failure, assessment, maintenance, and rehabilitation costs. Nevertheless, there is a strong need in developing practical and efficient frameworks that enable stakeholders to optimize future allocation of budgets for facilities under uncertain structural parameters. In particular, providing an approach that is in agreement with stakeholders constraints still remains a challenge. Moreover, the use of structural health monitoring (SHM) in future management frameworks, to update structural performance, still needs further development. The objective of this paper is threefold: (a) provide management strategies in agreement with fixed budgets, (b) provide management strategies that consider the time delay between the assessment and the intervention schedule, and (c) include information provided by SHM in the decision process and analyze the impact of monitoring strategies on the structural analysis accuracy. An event tree based approach is proposed to consider various uncertainties in the decision process. Optimal solutions are associated with multiple criteria such as minimum expected failure cost, minimum expected inspection/SHM/maintenance costs, maximum agreement of expected inspection/SHM/maintenance costs to available budgets, and maximum accuracy of monitoring results. The approach is illustrated on an existing highway bridge.

1. Introduction

The methodologies for optimization of structure management strategies have been largely investigated these last years [1–13]. There is indeed a strong need for decision making tools since bridges are aging and require higher maintenance costs whereas financial budgets remain constrained [14,13]. Current bridge performance-based assessment and prediction methodologies generally use probabilistic approaches to include both aleatory and epistemic uncertainties [15]. However, it is necessary to provide efficient concepts and methodologies that help stakeholders optimize their management strategies in a practical way. In addition, such approaches need to be based on accurate structural performance knowledge, which can be provided by SHM [16–22].

In most previous studies, optimal management solutions were determined by minimizing maintenance and failure costs and ensuring that an allowable threshold of performance is not reached during a specified time horizon. However, the purpose of a bridge owner can be different. The purpose is generally to determine optimal management strategies that ensure available budgets are used in the most efficient way. The interest can also be to consider the time delay between the assessment and the intervention schedule and plan when financial funds should be allocated for each bridge component (i.e., determine best future intervention times by anticipating future assessment results). In this context, the objective of this paper is to provide a stakeholder approach for optimization of bridge management strategies. Orcesi et al. [23] have proposed a multi-state based optimization framework using SHM information. They showed how to use strain monitoring data in structural performance updating and in the optimization of maintenance strategies.

In this paper, an event tree based approach is proposed to take into account uncertainties in the deterioration and decision processes at assessment times that can be associated with an in-depth inspection only (denoted μ_1) or an in-depth inspection followed by a monitoring program (denoted μ_2). Two management frameworks are identified and investigated herein to determine optimal management strategies from a stakeholder point of view. In the first framework (denoted F1), the histogram of assessment/maintenance cost (obtained with an event tree approach) is

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