Procedia Engineering

Volume 143, 2016, Pages 666–673

Advances in Transportation Geotechnics 3 . The 3rd International Conference on Transportation Geotechnics (ICTG 2016)

Multiobjective Optimization of Maintenance Scheduling: Application to Slopes and Retaining Walls

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Abstract

This paper presents a computational framework for maintenance scheduling for road assets. This framework incorporates degradation and maintenance models along with optimization of maintenance strategies. Uncertainties inherit in the degradation process and effects of maintenance actions are addressed by considering model parameters as random variables and employing Monte Carlo simulation to estimate the future performance. The optimization involves the consideration of multiple objectives and the constraints satisfaction. The design variables are the type of maintenance actions and time of application. The objectives are the minimization of asset degradation and maintenance costs. The focus of experimental study is on slopes and retaining walls that are an integral part of many existing road networks. The obtained results demonstrate the validity and usefulness of the proposed framework. The presented framework can be generalized and applied to different types of infrastructure assets.

Keywords: maintenance scheduling, multiobjective optimization, evolutionary algorithms

1 Introduction

Most of the developed countries, where Portugal is included, have nowadays a fairly complete road network. These transportation infrastructures, composed of a set of elements that can be classified as bridges, road pavements, retaining walls, slopes and electronic equipments, are necessary to ensure good mobility conditions. The challenge today is to guarantee all security and mobility conditions of the road network under increasingly limited budgets. For this, appropriate tools are needed to help the management team to take the best decisions regarding the maintenance strategy to be implemented.

In order to accomplish this challenge, different tools are required to help the decisions makers. On the one hand, an accurate model is required to predict the assets degradation over time. On the other hand, a methodology able to quantify the effect of the different type

Selection and peer-review under responsibility of the Scientific Programme Committee of ICTG 2016

doi:10.1016/j.proeng.2016.06.095

of maintenance actions is needed. At the end, the best maintenance plan that guaranty all security and operational conditions, under the minimal possible cost have to be found.

With models for prediction of the assets degradation and effects of different maintenance actions, the problem of finding the best maintenance plan can be formulated as an optimization problem. In essence, the optimal maintenance planning addresses the two conflicting criteria: the performance of assets and the cost of maintenance. As a result, usually there is no single optimal solution but a set of solutions representing different trade-offs, known as the Pareto set [5]. This set can be approximated by performing multiobjective optimization. Evolutionary algorithms have proven effective in fulfilling this task [1].

This paper presents a computational framework to plan maintenance activities for road assets. This framework is validated through a case study consisting in maintenance planning for the slope and retaining wall belonging to a Portuguese highway network.

2 Computational Framework

2.1 Degradation Model

The degradation of road assets considered in this study is modeled by a continuous-time Markov process. The state space of the Markov process is defined by the condition indexes of the assets, $c \in \{1, 2, 3, 4, 5\}$, with 1 representing a very good condition and 5 referring to a very poor one. This is a classification system [6] that is currently used in Portugal. In the Markov process, the intensity matrix Q represents the rate of the process transitions between the states. Since it is assumed that, in each time interval, assets can only advance between adjacent states [3], the elements of $\boldsymbol{Q}$ are null except for the main diagonal and the diagonal above that as shown in (1).

$$\boldsymbol{Q} = \begin{bmatrix} -\theta_1 & \theta_1 & 0 & 0 & 0 \\ 0 & -\theta_2 & \theta_2 & 0 & 0 \\ 0 & 0 & -\theta_3 & \theta_3 & 0 \\ 0 & 0 & 0 & -\theta_4 & \theta_4 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{1}$$

The future state transitions are estimated on the basis of the intensity matrix. The elements of $\boldsymbol{Q}$ are calculated using a historical record of inspections. An initial estimate of the matrix $\boldsymbol{Q}$ is computed as:

$$\theta_i = q_{ij} = \frac{n_{ij}}{\sum \Delta t_i} \tag{2}$$

where $q_i j$ represents the transition rate between adjacent states, n_{ij} is the number of elements that moved from state i to state j and $\sum \Delta t_i$ is the sum of intervals between observations whose initial state is i. Subsequently, the initial Markov model is enhanced through an optimization process in order to improve the quality of fit. For more details on the process of building a Markov model an interested reader is kindly referred to [2].

2.2 Maintenance Model

The application of maintenance actions is intended to produce certain impacts on the given structure. Those impacts can be characterized by: (i) an improvement in the performance at the time of application, (ii) a delay in the degradation process for some period of time, and (iii) a reduction in the degradation rate for a period of time after application. The application