JOURNAL OF TRANSPORTATION
SYSTEMS ENGINEERING AND INFORMATION TECHNOLOGY
Volume 14, Issue 6, December 2014
Online English edition of the Chinese language journal

Cite this article as: J Transpn Sys Eng & IT, 2014, 14(6), 92−100.

RESEARCH PAPER

Managing Pavement Maintenance and Rehabilitation Projects under Budget Uncertainties

FAN (David)Wei*1 ,WANG Feng2

1. Department of Civil and Environmental Engineering, University of North Carolina at Charlotte, Charlotte 28223, USA
2. Department of Civil and Environmental Engineering, Jackson State University, Jackson 39217, USA

Abstract: A well-developed and maintained pavement management system (PMS) empowers a decision maker to select the best maintenance program, i.e., which maintenance treatment to use and where and when to apply it, so that a maximum utilization of available resources can be achieved. This paper addresses a decision making problem for managing pavement maintenance and rehabilitation projects under budget uncertainty (MPMRPBU). A stochastic linear programming model is formulated and solved for the MPMRPBU so that a set of candidate projects can be optimally selected from the highway network over a planning horizon. Numerical results are discussed based upon a pilot case study. Different optimization solutions based on deterministic optimization and stochastic programming approaches are discussed and compared. The effect of the budget constraint on the optimized solutions is investigated. The computational result indicates a high quality MPMRPBU solution using stochastic programming approach, suggesting that there is a potential that the algorithm can be used for real world applications.

Key words: traffic engineering; pavement management systems; decision making; pavement maintenance and rehabilitation; optimization; stochastic programming

1 Introduction

Pavement management systems (PMS) have long been used as the primary tool to support pavement maintenance and rehabilitation (M&R) activities. Deciding which road pavement sections should be included in the yearly M&R project list for a planning horizon of several years is one of the major functions of a PMS system. Pavement maintenance is defined as routine, preventive, or reactive maintenance activities which often include but are not limited to filling cracks, patching potholes, and other applicable treatments such as chip seal coat or slurry seal. Pavement rehabilitation generally refers to major maintenance actions that are intended to enhance the structural capacity of pavements, such as resurfacing (overlay), resurfacing with partial reconstruction (localized reconstruction), and complete reconstruction. Both pavement maintenance and rehabilitation are costly with pavement rehabilitation being more expensive. The stringent yearly M&R budgets available to the state Departments of Transportation (DOT's) usually cannot support every M&R need. A practical procedure that can optimally manage and improve DOT's pavement maintenance and rehabilitation project selection process can potentially save M&R cost and improve pavement condition for the agency [1].

The pavement management information system (PMIS) is the automated portion of the PMS used by the Texas Department of Transportation (TxDOT). The PMIS is a set of computer programs for storing, retrieving, analyzing, and reporting information to assist decision makers (i.e., state/district pavement maintenance engineers/managers in TxDOT) to make cost-effective decisions regarding the maintenance and rehabilitation of pavements[2,3]. The PMIS consists of two major components: (1) pavement data and information management; and (2) decision support provision. PMIS databases are populated with various kinds of pavement-related data, one of the most important of which is the pavement condition data that have been collected annually or biannually since 1985. The decision support component provides essential functions that assist decision makers to manage pavement M&R activities in a cost-effective manner. Generally the decision support system in a typical PMS assists decision-makers at two levels of pavement management that

Received date: Nov 12, 2012; Revised date: Oct 24, 2013; Accepted date: Apr 11, 2014
*Corresponding author. E-mail: wfan7@uncc.edu

DOI: 10.1016/S1570-6672(13)60145-2

are referred to as the network level and the project level [4,5]. Pavement management at the network level considers for the whole pavement network the development of an M&R budget plan, prioritization program and schedule of work over the analysis period while pavement management at the project level deals with engineering concerns for the actual implementation for an individual project. The network-level decision support can be further divided into programming level and project selection level [4]. At the programming level, budgets are established and general resource allocations are made over the entire network. The project selection level involves prioritization to identify which projects should be carried out in each year of the programming horizon. In recent years, considerable research efforts were made to tackle the PMS network level decision-making problem, both in the programming topic[6-10] and in the project selection topic[11,12].

The optimization methods developed for network programming of finding optimal M&R actions generally fall into one of the following two categories: (1) maximization of pavement conditions subject to M&R budget constraints; or (2) minimization of M&R cost subject to minimum requirements on road conditions. Since the network programming is normally conducted on a planning horizon of several years, the modeling of the transition of pavement conditions is needed. For the prediction of network pavement conditions over multiple time periods, the transitions of network pavement conditions are frequently modeled as Markovian chain processes, and accordingly the decision variables of the optimization models are just the Markovian transition probabilities which are associated with the designated M&R actions. In previous studies, the Markovian transition probabilities were applied in the current time period to either proportions[7,8,10] or aggregate lane miles[6] of pavements in different condition states in order to predict the pavement condition proportions or the lane miles in each of the condition states in the next time period.

The above studies in network programming can help a pavement engineer/manager know the proportion or aggregate lane miles out of the whole pavement network that are in need of a designated M&R treatment in each year of the planning horizon. Therefore with the help of network programming, pavement engineers can understand the pavement needs in the future years and can proactively conduct need analysis and budget planning for the pavement network. However, the information about the M&R needs for proportions and lane miles of the pavement network is far from detail enough to know whether or not a specific pavement section should receive an M&R treatment within the year's M&R project program. A PMS should also have the function of assisting the decision maker in selecting the best maintenance program, i.e., what maintenance treatment to be applied for which pavement section at what time, so that a maximum utilization of available resources can be achieved for the pavement network. This is what the network level project selection programming is all about.

A PMS should have a function routine to establish maintenance and rehabilitation priorities to support project-selection decision making. Clearly the quality of the prioritization directly influences the effectiveness of the available M&R budget, which in most cases, is deemed a prime goal of a decision maker. Currently the project selection process in the TxDOT PMIS is first to prescreen the "in need" pavement sections from the pavement network using an experience based decision tree, then calculate the cost and benefit associated with the pre-selected M&R treatment for each of the "in need" pavement sections, and then rank all the sections in descending order of cost-effectiveness ratios[2,3]. Finally the top sections with a total cumulative cost equal to the current year's allowable budget are selected for the year's M&R program. However, there are two flaws in using this project selection method: (1) the prescreening approach favors the most severely damaged pavement sections which accordingly have the highest priorities, and only the top sections on the list consume the budget of the whole pavement network while ignoring the needs of the other sections; and (2) it does not handle maintenance timing wisely because a less severely damaged section may have a low rank and is not taken care of in the current year, but the pavement section may deteriorate so badly in only a few years that a much more costly treatment would be needed. Just like in network programming, an optimization method could also be applied to the prioritization of M&R projects for the whole highway network over a planning horizon of multiple years. Decision variables could be dummy variables with values of either 1 or 0 indicating whether or not a pavement section would be selected and treated with a specific M&R action for a specific year in the planning horizon. Each decision variable is associated with a gain or improvement in pavement condition and a cost induced in the M&R treatment. The summation of the gains obtained from the decision variables for all pavement sections in the network comprises the total M&R effectiveness over the analysis years, and the summation of the treatment costs due to the decision variables for all pavement sections in the network constitutes the total M&R cost over the analysis years. To extend the experience gained in the studies in network-level programming, an optimal solution to a set of integer decision variables for the pavement sections in the network could be developed to meet annual M&R budget constraints and minimum requirements on pavement conditions, and to pursue to the highest degree maximization of the total network M&R effectiveness. Therefore, an integer linear programming (ILP) model could be constructed for the network-level project selection problem.