Available online at www.sciencedirect.com

ScienceDirect

International Journal of Pavement Research and Technology 9 (2016) 214–221

www.elsevier.com/locate/IJPRT

A decentralized multidistrict optimization framework for system-wide pavement maintenance resource allocation

J. Farhan *, T.F. Fwa

Department of Civil and Environmental Engineering, National University of Singapore, Singapore 119260, Singapore

Received 17 June 2015; received in revised form 2 May 2016; accepted 4 May 2016
Available online 27 May 2016

Abstract

Historically, pavement maintenance funds have been allocated based on a centralized programme development process. Such practice, though seemingly convenient, does not lead to optimal allocation of funds since districts generally have different priorities based on the state of development and condition of their respective road networks. This paper proposes a decentralized two-phased optimization framework for pavement maintenance fund allocation considering multiple objectives and cross-district trade-off at the network level. In the proposed two-phased analysis approach, Phase-I focuses on establishing the needs and funds requirements of individual districts given multiple performance targets or objectives, while a system-wide fund appropriation strategy is selected, in Phase-II, given budget and equity constraints across competing districts. The proposed approach is illustrated using a numerical example problem for appropriating funds to three districts. The results indicated that the proposed approach is not only able to evaluate the extent to which various performance targets are achieved at the central and district level, but also maintains equity in distribution of financial resources across districts.

Keywords: Pavement maintenance programming; Multiobjective; Multidistrict; Optimized resource allocation; Genetic algorithm; Dynamic programming

1. Introduction

System-wide pavement maintenance planning primarily involves programming decisions to determine financial needs and allocate financial resources over the entire network, with either short-term, medium-term or long term planning period. Resource allocation method generally varies country-wise predominantly on account of prevailing management structures in respective countries [13]. For example, some highway agencies employ a centralized programme development process. The eminent characteristic of this type of management approach is that the central office develops the programme and passes it down to district level units. In some agencies, the districts must follow the programme or explain any deviation, while in other agencies the districts may vary considerably from the central office list. Historical needs-based and formula-based appropriation approaches can be classified as centralized programme development process. The former approach is based on historical needs adjusted to take into consideration the inflation and special projects or other influences [2,14], while the latter allocates funds based on certain predetermined percentages and weights for each highway or district [3,12]. However, both of these approaches fail to account for inventory information, life cycle planning, predicted funding requirements, and the effectiveness of each dollar amount spent.

On the other hand, in the decentralized programme development process, funds are allocated to each district

* Corresponding author.
E-mail address: far.han@hotmail.com (J. Farhan).
Peer review under responsibility of Chinese Society of Pavement Engineering.

http://dx.doi.org/10.1016/j.ijprt.2016.05.003
1996-6814/

to develop their own programme within the available funds. An example of this programme is the performance based approach, which considers various pavement condition and performance aspects to optimally appropriate funds given predefined objectives at central level. Performance based approach, although superior to other approaches, inevitably involves multiple and conflicting performance objectives necessitating their simultaneous maximization or minimization while satisfying all the necessary constraints at central level. In the past literature, various performance based pavement resource allocation models have been proposed [11,17,5,15]. These models are either restricted to optimizing a single objective or they fail to incorporate maintenance needs/goals of each of the competing districts. The task of allocating funds across multiple districts is challenging since it requires negotiation between central and district level agencies, and the act of balancing amongst individual districts. This problem aggravates in situations where districts have different priorities keeping in view their state of development and condition of their respective road networks [6].

Thus, this paper proposes a decentralized two-phased optimization framework for pavement maintenance fund allocation across multiple districts. Phase-I of the approach represents the practice of having independent individual district management systems, each addressing operational and service objectives unique to itself. Phase-II incorporates Pareto optimal maintenance strategies from individual districts to perform central-level budget allocation analysis with a pre-determined set of objectives and constraints at central level. Phase-I Pareto optimal maintenance strategies from individual districts become the links for interaction with the central-level optimization analysis in Phase-II. The proposed framework not only evaluates the extent to which various performance targets are achieved at the central and district level, but also considers equity in distribution of resources across districts. This approach is demonstrated through an illustrative example.

2. Proposed two-phased analysis framework

The proposed approach is employed to account for various objectives of the central and district level agencies resulting in a practical decision support model for network-wide application. A two-phased analysis is performed with the first phase focusing on establishing the needs and funds requirements of the various regional agencies given multiple performance targets or objectives, while the second phase imposing the overall budget and equity constraints to arrive at the final budget allocation strategy. The proposed framework of the two-phased analysis approach is shown in Fig. 1.

Phase-I of the approach represents the prevailing practice, addressing operational and service objectives unique to each district with a common objective in minimizing maintenance costs, as in Fig. 1. The outcome of the analysis in Phase-I will be a family of Pareto optimal solutions, which offers a convenient basis for performing the cross-district trade-off analysis in Phase-II.

Given the attributes of Pareto optimal maintenance strategies of each district, from Phase-I, an optimal central-level budget allocation analysis is performed in Phase-II. The inputs of this phase consists of: (1) performance and cost attributes of Pareto optimal strategies, (2) a known overall amount of maintenance budget available for the entire pavement network, and (3) predetermined network-level objectives for the optimization analysis. The attributes of the Pareto optimal maintenance strategies, from each of the districts, create a connection between the district and central-level optimization analyses. Given any maintenance budget, this connection relays information, pertaining to pavement performance or condition, between the two phases described earlier. Since optimization is involved in the two phases, Genetic algorithm [9] is selected as the optimization tool for Phase-I analysis and dynamic programming [4] for Phase-II optimization analysis in this paper.

3. Pavement maintenance budget allocation model

The framework explained in the preceding section is illustrated using a highway network system divided into three districts. The mathematical formulation of the optimization models for the pavement management systems in three districts and that for the overall highway system are presented in this section. Although the proposed framework is equally applicable to maintenance and rehabilitation activities, this paper only considers maintenance.

3.1. Phase-I: district level budget allocation model

Since a decentralized management structure is proposed, districts develop their own pavement maintenance strategies in this phase of the analysis. The Pavement Condition Index (PCI), which is an ASTM standard for the pavement condition assessment [1], is used to represent pavement condition. PCI values are assigned to distresses on a scale from 0 to 100 based on distress type, density and severity, and range from 100 for a perfect pavement condition to 0 for the worst condition. The PCI of any pavement section j is determined using the following equation:

$$PCI_j = 100 - (TDV)_j \quad (1)$$

where TDV is the total deduct value equal to the sum of individual deduct values (DV) for each distress present in the pavement section, computed based on the standardized procedure published in ASTM [1].

In order to develop mutually exclusive pavement maintenance strategies at district-level, a pavement maintenance model is formulated. For illustration purposes, the formulation consists of two objectives, namely minimization of the total pavement maintenance cost and maximization of the pavement network average PCI, and a constraint