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Optimum analysis of pavement maintenance using multi-objective genetic algorithms

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Abstract Road network expansion in Egypt is considered as a vital issue for the development of the country. This is done while upgrading current road networks to increase the safety and efficiency. A pavement management system (PMS) is a set of tools or methods that assist decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. A multi-objective optimization problem for pavement maintenance and rehabilitation strategies on network level is discussed in this paper. A two-objective optimization model considers minimum action costs and maximum condition for used road network. In the proposed approach, Markov-chain models are used for predicting the performance of road pavement and to calculate the expected decline at different periods of time. A genetic-algorithm-based procedure is developed for solving the multi-objective optimization problem. The model searched for the optimum maintenance actions at adequate time to be implemented on an appropriate pavement. Based on the computing results, the Pareto optimal solutions of the two-objective optimization functions are obtained. From the optimal solutions represented by cost and condition, a decision maker can easily obtain the information of the maintenance and rehabilitation planning with minimum action costs and maximum condition. The developed model has been implemented on a network of roads and showed its ability to derive the optimal solution.

Introduction

When pavement is in service, the traffic loads and environment would deteriorate it. Therefore, an amount of funds would be invested to maintain it in an adequate condition to perform its role. If available funds are sufficient, the pavement sections whose condition states are below minimum acceptable serviceability level will get maintenance and rehabilitation in time. However, lack of funding often limits timely repairs and rehabilitation of the pavement. Therefore, the decision making of

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pavement management is the problem on how to gain maximum condition with minimum costs [1]. In many real-life problems, objectives under consideration conflict with each other, and optimizing a particular solution with respect to a single objective can result in unacceptable results with respect to other objectives. A reasonable solution to a multi-objective problem is to investigate a set of solutions, each of which satisfies the objectives at an acceptable level without being dominated by any other solution [2].

While the selection and prioritization of roads can be considered a network-level decision, selection of repair methods for individual roads and their components can be considered as a project-level decision. In the literature, various systems have been developed to support either project-level or network-level decisions, and to a lesser extent, to support both of them. Despite both the network-level and project-level decisions being inter-related, most pavement management research has dealt with them as separate aspects, thus leading to neither being optimally decided. At the network-level, Fwa and Chan [3] developed a repair strategy of pavement considering two objectives for a network level over a planning horizon of 20 years. At the project level, on the other hand, Chikezie et al. [4] presented a project level pavement maintenance and rehabilitation programming problems, focus is mainly on selecting the repair method (e.g., 0: no action, 1: crack sealing, 2: pothole patching, and 3: rehabilitation for a selected road). In this case, details on the specific repair method, cost, and expected improvement are considered.

Over the year there have been successful applications and implementations of multi-objective optimization problems using genetic algorithms. Morcous and Lounis [5] presented an approach for programming maintenance alternatives for a network of infrastructure facilities. This approach uses genetic algorithm optimization techniques to resolve the computational complexity of the optimization problem and Markov chain performance prediction models to account for the uncertainty in infrastructure deterioration. The proposed approach was applied to schedule the maintenance activities of concrete bridge decks protected with asphaltic concrete overlay. Optimizing the resurfacing interventions on flexible pavements was proposed by Bosurgi and Trifiro [6]. The optimization problem was faced by programming a genetic algorithm that manages the decisional process on the basis of two indicators, referring respectively to the sideway force coefficient of pavement and to predicted accidents. In another work, Chootinan and Chen [7] introduced a multi-year pavement maintenance programming methodology that accounts for uncertainly in pavement deterioration. This is accomplished with the development of a simulation-based genetic algorithm approach that is capable of planning the maintenance activities over a multi-year planning period, they also considered the pavement distress deterioration model, but did not go beyond maintenance level.

Multi-objective evolutionary optimization algorithm aims at reducing overall substation cost and improving reliability was introduced by Yang and Chang [8]. Decision-varying Markov models relating the deterioration process with maintenance operations are proposed to predict the availability of individual component. In another work, the reliability-based optimization models for scheduling rehabilitation actions for flexible pavements are presented by Deshpande and Damnjanovic [9]. Three models are presented: minimizes the cost where the target reliability is set as a constraint; maximizes the cumulative life-cycle reliability where the budget is set as a constraint; and minimize cost and maximize reliability. Chikezie et al. [10], for example, developed a model that considers distress deterioration functions using genetic algorithms which invariably determines the warning levels for maintenance interventions. The developed model considers rehabilitation actions for the proposed work. Another example, Gao et al. [11] discussed how to efficiently and completely solve a bi-objective pavement maintenance and rehabilitation-scheduling problem, which aims at optimizing two objectives of pavement condition improvement and budget utilization in a simultaneous manner. A parametric method is suggested to solve the bi-objective pavement maintenance and rehabilitation-scheduling problem. They used a performance comparison between the widely used weighting method and the parametric method that clearly justifies the computational advantages of the parametric method. In another work, Marzouk et al. [12] introduced the developments made in a stochastic performance prediction model and optimization model as two major parts of an integrated pavement management system. Markov modeling is used to predict pavement condition with the use of pavement condition index (PCI). The genetic algorithm technique is adopted to build optimization model. Three objective functions are constructed for minimizing budgeted cost of maintenance and rehabilitation program, maximizing the quality of work performed, and maximizing the total percentage of the network area that will be under maintenance and rehabilitation (M&R). They also presented six types of maintenance and rehabilitation programs for achieving these objective functions. This model ensures that maintenance of road network is adjusted to the limits of budgeted cost with maintaining standard quality of performance.

The main objective of this paper is to develop an integrated pavement management system (PMS) that meets the conditions and specifications of Egyptian road networks. The proposed system aims at providing a technique for handling maintenance and rehabilitation programs as a major part in a decision support system at the network level. Other objectives of the study are: introducing a method for optimizing the maintenance and rehabilitation (M&R) decisions using multi-objective genetic algorithms in conjunction with Markov-chain model considering available budgeted cost and road network conditions using pavement condition index (PCI); and developing a computerized tool to facilitate the use of the proposed model. The output of the model is a set of planning strategies for the maintenance and repair throughout the planning horizon.

Component of a pavement management system (PMS) model

The main components of a generalized PMS that incorporates both project-level and network-level decisions are as follows:

- Detailed PMS models (time-dependent deterioration, repair cost, and repair-dependent improvement).
- PMS constraints (industry, governmental, political, user defined constraints, project, and network).
- PMS decision support module (user interface, condition assessment and optimization).