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An improved artificial bee colony algorithm for pavement resurfacing problem

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Abstract

Pavement resurfacing is a maintenance activity that is undertaken to enhance the service life of pavement. This pavement resurfacing activity involves laying a new layer of asphalt concrete over existing pavement after certain time. Due to engineering factors, economic variables and uncertainty in forecasting, the pavement resurfacing decision process is a complicated activity. Various optimization approaches currently used are simplified models for finding optimal frequency and resurfacing intensity within pavement maintenance framework. In this research, artificial bee colony algorithm is proposed to solve this pavement resurfacing optimization problem. This algorithm mimics the collective behaviour of bees while searching for nectar. In this approach, various scenarios are generated, optimality of each case is evaluated, and the information thus generated is used in subsequent evaluation until global optimality is reached. The effectiveness of proposed method is demonstrated through a numerical example. The solution obtained is similar to the exact solution reported in literature. The results indicate optimal resurfacing values can be obtained with little computational effort with proposed approach. The main advantage of proposed algorithm is removal of specification of trigger values for maintenance decision.

Keywords: Pavement; Resurfacing; Artificial bee colony; Life cycle cost; Optimization

1. Introduction

Under the combined action of traffic loading and climatic factors, the pavement deteriorates over a period of time. Beyond a certain level of deterioration, the pavement becomes unserviceable and the whole pavement has to be reconstructed. To avoid this expensive reconstruction process, maintenance activity like resurfacing is taken up. Camahan et al. [1] reported that resurfacing is less expensive treatment that decreases overall life cycle cost while increasing service life of pavement. Once the pavement is resurfaced, serviceability level increases to a certain extent. After this resurfacing, the deterioration process restarts and continues until next cycle of resurfacing. It is generally accepted that roughness of pavement is an indicator of pavement serviceability/pavement deterioration. Any increase in roughness leads to reduction in ride quality of pavement. Fig. 1 shows changes in pavement roughness with time. Due to simultaneous action of traffic and environment, the deterioration process (or roughness increase) is continuous and nonlinear in nature. Various trends like power form [2], polynomial form [3], and exponential form [4,5] have been used to describe this roughness progression. On the other hand, resurfacing activity leads to sudden drop in roughness level. This decision on pavement resurfacing is made by highway agencies based on network condition, budget constraints, and resources availability. Often engineer's experience, subjective judgement, and historical

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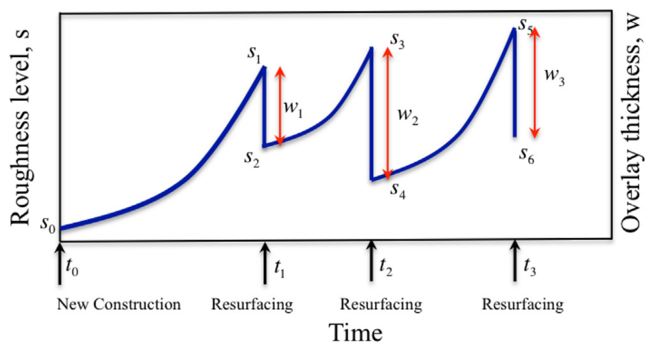

Fig. 1. Variation of pavement roughness during service life of pavement.

practice plays important role in this decision process [6]. This continuous increase in roughness and sudden drop in roughness results in a saw-tooth trend in pavement roughness during its service life. Exact shape/trajectory of this saw-tooth curve depends on traffic, climate, construction quality, and maintenance interventions [7].

Several optimization approaches have been proposed that aid in decision process of pavement resurfacing activity. These optimization approaches ranges from single pavement rehabilitation event in finite horizon to multiple pavement maintenance activities over infinite horizon [8–11]. Several researchers [10,12] have used deterministic approach while Pasupathy et al. [7] have used stochastic approach. Even though deterministic approach aids in arriving at exact solution for pavement resurfacing optimization problem, it deviates from real situation significantly [13].

In this research, Artificial Bee Colony (ABC) algorithm is used to solve this pavement resurfacing problem. The proposed methodology accommodates various factors like user costs, agency costs, inflation rate, interest rate, and achievable roughness levels during pavement resurfacing cycles. The frequency and thickness of resurfacing are obtained as solution while ensuring maximum cost effectiveness. Within ABC algorithm framework, various improvements like generation of multiple colonies (i.e. possible solutions), achieving global solution are proposed in this article. The main advantage of proposed ABC algorithm for pavement resurfacing problem is elimination of trigger roughness level specification beforehand.

This paper contains 6 sections of which this is first one. Section 2 presents a review of the relevant literature in pavement resurfacing optimization and ABC. Section 3 describes the model formulation used in optimization of pavement resurfacing. Section 4 describes the proposed solution procedure using ABC algorithm while a case study is presented in Section 5. Finally conclusions of the paper are presented in Section 6.

2. Literature review

Control theory has been used by various researchers to optimize pavement maintenance activities [8,14,15]. Control theory essentially assumes that pavement condition changes continuously over time. However, any maintenance activity leads to discontinuous pavement serviceability function. Pasupathy et al. [7] reported that control theory problems with discontinuous response is computationally interactable and is quite cumbersome. To handle this discontinuity issue, Tsunokawa and Schofer [16] suggested saw-tooth pavement roughness curve. In this approach, the saw-tooth curve is replaced by a continuous function that passes through the midpoints of the spikes and discrete resurfacing activity is replaced by continuous resurfacing rate. Thus, solution obtained using the approach proposed by Tsunokawa and Schofer [16] will yield approximate results. Tsunokawa et al. [17] proposed gradient search methods to obtain optimal pavement maintenance strategy. However, these gradient search methods have inherent disadvantage of getting trapped in local minima with wrong initial guess. Li and Madanat [10] used the concept of saw-tooth roughness profile to optimize the frequency and intensity of pavement resurfacing actions under steady-state conditions. They provided a simple, practical, and robust method that uses the concept of trigger roughness level which initiates resurfacing activity. The specification of predefined trigger roughness level essentially requires one to have prior information regarding optimality. Since this trigger roughness level is a part of optimization process, such an exercise might not be meaningful. If such an assumption has to be made, one has to resort to extensive parametric study before resorting to optimization. Ouyang and Madanat [12] proposed an analytical solution to the pavement resurfacing problem for a finite horizon using saw-tooth roughness curve. Sathaye and Madanat [18] extended this concept to multiple facility optimization problem. To obtain feasible solution, most of the work discussed above assume (i) optimization problem as deterministic, (ii) approximate discrete changes as continuous phenomenon, and (iii) certain functional form for deterioration function. Thus, solution obtained by these optimization approaches deviate from real situation significantly [13]. Under such circumstances, metaheuristic approaches have proved to be effective. The goal of present research is to apply one such metaheuristic optimization algorithm to solve this pavement resurfacing problem.

Bio-inspired metaheuristic algorithms are very popular for solving complex engineering problems. Ant colony optimization [19], genetic algorithm [20], particle swarm optimization [21], ABC algorithm [22] are some examples for such bio-inspired optimization algorithms. All these algorithms mimic the collective behaviour of insect/animal groups through complex interaction of individuals without supervision. These optimization approaches offer advantages like scalability, adaptation, speed, modularity and efficiency [23].

Karaboga [22] introduced ABC algorithm for solving multimodal, multi-dimensional numerical unconstrained optimization problem. This algorithm was inspired by the intelligent nectar foraging behaviour of honeybees in a colony. In a real bee colony, tasks like identification of poten-

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