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Hybrid PSO and GA approach for optimizing surveyed asphalt pavement inspection units in massive network

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ABSTRACT

This study proposes an optimal arrangement of surveyed pavement inspection units (SIUs) for cost reduction, minimization of inspection errors and accuracy improvement of pavement network analysis. Inspection process requires surveying billions of distresses characteristics for different sections of a specific area. A comprehensive database is generally required for such pavement management system (PMS). A major concern with this type of data is lack of powerful methods for an effective analysis in a network level. A number of inspection units are surveyed with various sampling patterns for minimizing the cost and time of inspection. Analysis of large numbers of sections and inspection units is time consuming and needs high computation efforts. To address this issue, this paper focuses on developing efficient methods for decreasing complexity of the system. Accordingly, various combinations of the hybrid genetic algorithm (GA) and particle swarm optimization (PSO) are used for analyzing a typical pavement network. The numerical results confirm the ability of the proposed approach to optimize the arrangement of SIUs in network inspection error (NIE), computation time (CPU Time), number of SIUs (NSIUs), and convergence diagram for network, project and section management levels. The hybrid approaches result in an optimal solution in a short time with high accuracy for each section in a massive network. As a result, the inspection process can be performed with minimal costs.

1. Introduction

Road is among the essential global transportation infrastructures. One of the main components of these infrastructures is pavement. Pavement is deteriorated as a function of its type, severity, and density of distresses due to climate changing, traffic loads, and reduction in quality of the material. To deal with pavement deteriorations, actions such as covering it at a specific time are performed. In this connection, it is required to determine the accurate condition of pavement sections and select the optimal maintenance and rehabilitation (M&R) actions over a planning horizon. An optimal management is of great importance for cost minimization over a specified time period when modifying the pavement deterioration based on correct decisions [1]. These decisions are supported by an efficient system called as the management system (PMS). PMS is a valuable tool that has a collection of components, including data collection system, pavement condition monitoring, prediction models for determining the future condition, suitable assigning M&R actions to each section, and pavement sections prioritization based on M&R actions at network and project levels [2].

Transportation agencies apply pavement inspection process to gain detailed and duly information of the pavement conditions in a given network [3]. Pavement inspection process is a basic and important process in PMS for evaluating the real condition and selecting the right M&R actions. An inspection method consists of visual distress detection by inspectors through the field survey [4]. The pavement network is divided to various branches (for example, streets, parking lots, and roundabouts). Branches are the biggest part of pavement network in pavement management studies. Within the visual inspection process, branches are divided into sections and the sections into smaller units called “inspection units” or “sample units” [5].

Pavement inspection is generally a costly and time-consuming process that depends on the experience of the inspectors. The inspectors evaluate the survey necessity of the inspection units based on the inspection manual and the budget policies [6].

Surveying all inspection units with enormous data from pavement type, intensity, and density of distresses requires high efforts and

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proficiency, as well as substantial costs and time. Therefore, to achieve acceptable pavement condition, the inspection process is conducted by selecting a specific number of inspection units as surveyed inspection units (SIUs).

A composite indicator that considers multiple factors such as traffic, climate change, and characteristic changes of materials, is needed to assess pavement conditions. These indicators are proposed usually by the related agencies for selecting M&R strategies. Each of these facilities considers threshold values for distinguishing pavement sections [7].

Present serviceability index (PSI), international roughness index (IRI), pavement condition rating (PCR), pavement structural condition (PSC), present serviceability rating (PSR), pavement quality index (PQI), distress manifestation index (DMI), and the pavement condition index (PCI) are the most common pavement condition indicators [8]. As a more practical index among the others, PCI considers the characteristics of distresses, including type, severity, and extent in some works including Shahnazari et al. [1], Bianchini [7], Li et al. [9] and Moazami et al. [10].

Because PCI assessment of the sections is limited to the selection of few numbers of SIUs, it could not define the accurate pavement conditions. Besides, since surveying a large number of inspection units requires sufficient budget, execution of M&R actions faces with undesired delays. Thus, some efforts are required to optimize the arrangement of SIUs such as proposing a novel method that can simulate the inspection process and evaluate the acceptable accurate PCI in the sections. In this regard, evaluation of SIUs arrangement has been recently of interest for some researchers and agencies such as Department of Environment, Heritage and Local Government [11], Michigan Department of Transportation [12], Texas Transportation Institute [13], Oregon Department of Aviation [14], American Society of Testing and Materials (ASTM) [15], De la Garza et al. [16] and Mishalani et al. [17].

In ASTM D6433-11, a method is described for evaluation of SIUs arrangement wherein the allowable error in the calculation of PCI and the standard deviation are considered for PCI of inspection units in a given section. The arrangement of SIUs is determined using systematic random sampling [15]. The method proposed by ASTM does not provide an accurate estimation of PCI with the calculated number of SIUs; besides, it involves a high network inspection error (NIE). Therefore, this method faces with some limitations for selecting SIUs due to the additional excess time required for reducing the NIE as well as optimization of the SIUs arrangement.

The previously proposed methods face with some drawbacks such as lack of knowledge basis, lack of PCI in SIUs arrangement, need for low PCI spectrum, high sensitivity to the length of sections, and lack of tradeoff between number and place of SIUs. Accordingly, it is required to apply a method for optimization of SIUs arrangement.

To survey a pavement section, various sampling patterns are tested. Because such a process exponentially increases the computation time with the number of inspection units, a different method is needed for solving the present problem in acceptable time, cost, and inspection error.

To find an optimal arrangement of SIUs involves selection of an efficient sampling pattern with the optimum number of SIUs and the minimal section inspection error (SIE). The tradeoff between the NIE, inspection time, and the number of SIUs (NSIUs) is a complicated issue due to the computational complexity involved in such non-deterministic (NP-hard) problems.

Although the exact algorithms such as branch and bound method can produce global optima, they cannot solve NP-hard problems within the desired duration in problems with thousands of sections in the pavement network. Heuristics are another group of algorithms that provides semi-optimum solutions in an acceptable time. Therefore, to increase problem-solving speed, the artificial intelligence (AI) tools are rapidly developed and replaced with the classical methods in recent decades. Metaheuristics are particular AIs applied to achieve near-optimum solutions faster than previous methods [18].

In the recent two decades, several metaheuristics such as genetic algorithm (GA) and particle swarm optimization (PSO) have been implemented for solving various optimization problems because of their high efficiency for solving complex problems [19]. These methods,

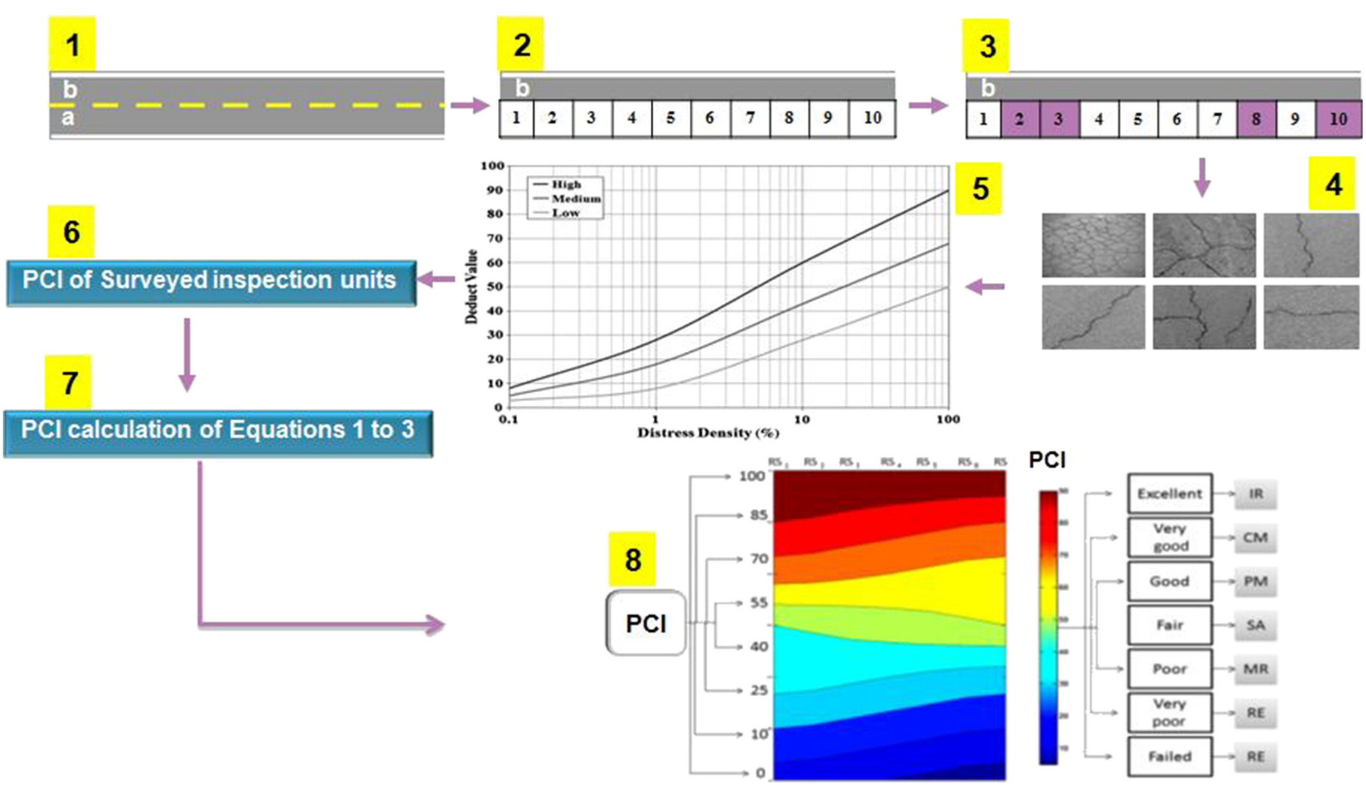

Fig. 1. A general framework for calculating the PCI of a section [27].