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Original Research Paper

A comparative study on using meta-heuristic algorithms for road maintenance planning: Insights from field study in a developing country

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HIGHLIGHTS

- Proposed a meta-heuristic algorithm for the maintenance actions to maximize pavement performance and minimize maintenance cost.
- Single objective algorithms have failure in optimizing concurrently pavement performance and maintenance cost.
- Multi-objective algorithms performed better than the single objective algorithms.
- NSGAII algorithm performed better than MOPSO in terms of cost and pavement performance.

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ABSTRACT

Optimized road maintenance planning seeks for solutions that can minimize the life-cycle cost of a road network and concurrently maximize pavement condition. Aiming at proposing an optimal set of road maintenance solutions, robust meta-heuristic algorithms are used in research. Two main optimization techniques are applied including single-objective and multi-objective optimization. Genetic algorithms (GA), particle swarm optimization (PSO), and combination of genetic algorithm and particle swarm optimization (GAPSO) as single-objective techniques are used, while the non-domination sorting genetic algorithm II (NSGAII) and multi-objective particle swarm optimization (MOPSO) which are sufficient for solving computationally complex large-size optimization problems as multi-objective techniques are applied and compared. A real case study from the rural transportation network of Iran is employed to illustrate the sufficiency of the optimum algorithm. The formulation of the optimization model is carried out in such a way that a cost-effective maintenance strategy is reached by preserving the performance level of the road network at a desirable level. So, the objective functions are pavement performance maximization and maintenance cost minimization. It is concluded that multi-objective algorithms including non-domination sorting genetic algorithm II (NSGAII) and multi-objective particle swarm optimization performed better than the single objective algorithms due to the

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capability to balance between both objectives. And between multi-objective algorithms the NSGAII provides the optimum solution for the road maintenance planning.

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1. Introduction

Maintenance planning is a pronounced function of pavement management which involves a series of decisions on type, location, and time of maintenance actions that should be taken over the life span of the pavement in order to minimize the total maintenance cost and maximize pavement condition. So, the questions are which and when a segment should be maintained, and which maintenance action should be applied. Fig. 1 illustrates significance of executing maintenance actions on optimized preplanned time. The figure depicts the fact that if a maintenance action is not carried out on time, it might cost four times more in a short period of time afterwards.

Objective functions play a key role in providing an optimized maintenance plan. Various conflicting objectives have been applied to date such as minimum overall maintenance costs, maximum pavement condition or level-of-service, minimum safety hazards, maximum available resource utilization, and minimum disruption to traffic flows. Generally speaking, any maintenance policy planned with regard to only a single objective function may ignore or decline the importance of other objectives. For instance, a policy may minimize the total maintenance cost by sacrificing pavement condition or vice a versa. Multi-objective optimization is an appropriate tool to tackle such a problem through making a trade-off among different objective functions (Rose et al., 2010).

2. Background

Maintenance planning has been conventionally conducted employing single-objective optimization. The conventional single-objective optimization techniques such as linear programming, dynamic programming (Feighan et al., 1987) and integer programming (Fwa et al., 2000) have been widely utilized. Difficult modeling and formulation, and long computation time are the primary reasons that impose some limitations on using such models. This situation becomes inferior when multi-objectives are involved.

Different tools have been employed to perform optimization. Wang and Feng (1997) developed a network optimization model in order to maximize the pavement performance with the use of fuzzy systems. Ferreira et al. (2002a) developed a segment-linked optimization model called GENETIPAV-D using the genetic algorithm to reach the least discounted maintenance cost and rehabilitation strategy for various segments in a road network. In another study, the Ferreira et al. (2002b) applied a probabilistic approach to segment pavement link to carry out pavement management optimization. The probabilistic optimization planning approach has been also utilized by some researchers (Ferreira et al., 2002b; Abaza, 2005). This approach took advantage of a non-homogeneous discrete Markov chain to predict the future pavement conditions for a given pavement system. Kuhn (2010) deployed approximate dynamic programming in order to provide a maintenance plan for a large network of pavement. Jorge and Ferreira (2011) proposed a new maintenance optimization system called GENEPAV-HDM4 to integrate the pavement management system of the Municipality of Viseu, Portugal. Garza et al. (2011) developed a simpler and more useful network-level pavement maintenance optimization plan using the linear program method subjected to budget restrictions and the pavement performance thresholds. All the above-mentioned studies were conducted on the major roads. It seems that rural roads have not received enough attention by researchers. The multi-objective programming is a technique that can simultaneously satisfy more than one objective which may be more effective than a single-objective optimization model.

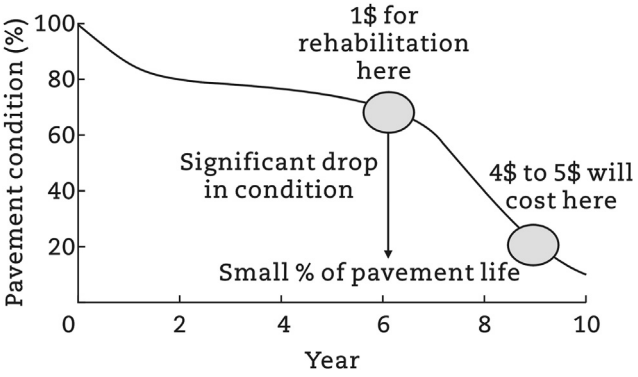

Fig. 1 – Pavement deterioration model.

3. Genetic algorithm

The genetic algorithm (GA) is a heuristic method that was first proposed by Holland which is inspired from the evolution of life in the real world (Holland, 1992) starting with randomly populating initial solutions. The solutions are evaluated and randomly mated based on their fitness using two operators called crossover and mutation. Then, offspring is produced as outcomes of mating process. The offspring is evaluated and replaced by the current solution with the lowest fitness. This procedure continues till the solutions converge or predetermined number of trials reach. The GA is an optimization tool for pavement maintenance programming

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