Applied Soft Computing 64 (2018) 126–137

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Forest road profile optimization using meta-heuristic techniques

Razieh Babapour [a], Ramin Naghdi [a], Ismael Ghajar [a,*], Zahra Mortazavi [b]

[a] Department ofForestry, Faculty of Natural Resources, University of Guilan, Sowmeh Sara, P.O. Box 1144, Iran
[b] Department ofComputer Engineering, Faculty of Artificial Intelligence, Al-Zahra University, Tehran, Iran

ARTICLE INFO

Article history:
Received 7 February 2017
Received in revised form 3 December 2017
Accepted 9 December 2017
Available online 15 December 2017

Keywords:
Forest road
Vertical alignment
Genetic algorithm
Particle swarm optimization

ABSTRACT

An optimal design of vertical alignment, considering the design constraints and costs is one of the most complicated problems of road planning and construction. The results of many linear, nonlinear and heuristic techniques that can enhance design ability to minimize the total cost of road construction using many different variables are well acknowledged. It is assumed that the genetic algorithm (GA) and Particle Swarm Optimization (PSO) can be efficiently applied for road vertical alignment allocation. This paper focuses on solving vertical alignment optimization problem using meta-heuristic algorithms. Two intelligent optimization tools of GA and PSO have been used to find a near optimal forest road profile, connecting specified endpoints considering restrictions associated with forest road profile design with cost evaluation. A number of setting parameters such as population size and crossing over and mutation rate in GA and also best group and particle's position in PSO were tested to search the global optimal answer. Results of optimization by GA and PSO approaches were compared with the common manual road profile drawing method. Results indicated that the GA and PSO could reduce earth work volume costs while designing more smoother and qualified alignment in comparison with the manual design. Results suggested that among the applied optimization methods, the GA was the most suitable one for this feature of the problem since it is able to save optimum position at better solutions with a reduced computed cost. From the cost point of view, it was cleared that optimizing the fixed length of road profile applying GA, with different population size, would be better for big numbers of control points but smoother for low numbers of control points.

1. Introduction

Developmentof the automated models for optimizing forest road's vertical alignments is one of the main goals of planners and designers before road construction. Applying these kinds of models entails formulating all effective costs, modifying applicable algorithms and working with geographical data. For achieving this aim the manual planning process is too slow, laborious, time-consuming and expensive for fairly large-scale areas, and solutions to these problems come without a guarantee of an optimal solution. In addition, it is nearly impossible to efficiently compare and analyze several potential plans developed using manual techniques [1]. Many mathematical models have been developed for optimizing road vertical alignments [2] using dynamic programming [3], linear programming [4], numerical research [5], enumeration [6] and Genetic Algorithm (GA) [7]. Due to random and global search nature, GA was the most adopted method of optimization. GA could seek among a huge number of answer generations to optimize fitness function (e.g. road vertical alignments to minimize total embankment cost). GA was initially proposed by Fraser [8], Fraser and Burnell [9], and Crosby[10] and popularized by John Holland [11] in 1975. As identified from the literature review, GA can successfully solve combinatorial optimization problems. Jha and Schonfeld [12,13], Jha and Maji [14] and Kang et al. [15] integrated genetic algorithms with GIS[1] for finding the optimum road alignments. While such integration allows using the real maps and data, it increases the computation time by increasing the number of entrances. Yang et al. [16] applied a GIS-based multi-objective optimization model to propose the acceptable highway alignment. The results indicated the ability of the proposed method in creating multiple trade-off solutions. Kim et al. [2] proposed a stepwise highway alignment optimization approach using genetic algorithms for improving computational efficiency and quality of solutions. They applied two different population sizes to develop a stepwise alignment optimization when employing genetic algorithm in suitably subdivided study areas. Their study resulted in that the proposed stepwise optimization gave more efficient

* Corresponding author.
E-mail address: i.ghajar@guilan.ac.ir (I. Ghajar).

[1] Geographic Information System

https://doi.org/10.1016/j.asoc.2017.12.015
1568-4946/

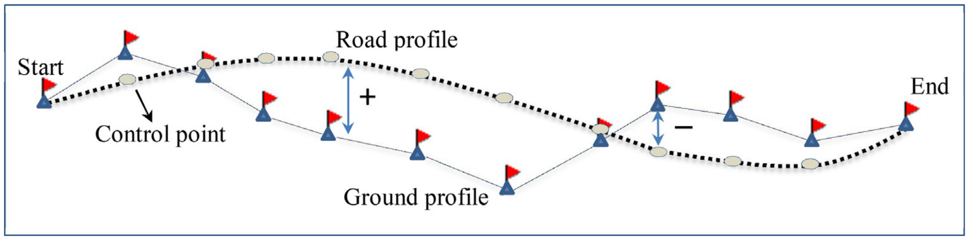

Fig. 1. Side view of ground profile and road profile.

results than the existing methods and also improves the quality of solutions. Ichihara et al. [17] applied meta-heuristic methods for planning the optimum road vertical alignment considering the placement of control points. They used genetic algorithms to optimize the placement of control points while using dynamic programming to reduce earthwork cost by changing the longitudinal grade. Aruga et al. [18] applied GA and Tabu search (TS) in combination with linear programming to design a forest road profile with minimum construction and maintenance costs. Then they extended the model to optimize a forest road profile while changing heights at control points as well as the placement of control points considering the effect of the placement and the number of control points. They concluded that both GA and TS found good solutions within a reasonable time. Previous studies [19,20,18,17,12], have recognized that the genetic algorithm is efficient in optimizing highway alignments, due to its ability in testing better solutions among new iterations.

Considering mountainous forests and their highly needed earth work movement, which results in high costs when comparing to flat forests, ground shape needs special attention as one of the main constraints of designing road profile. Although a number of studies ignored ground shape's importance, some others [18,12,20,22] incorporated it in profile designing precisely.

Prediction measures of rock proportion as a constraint, prior to the road profile designing, by leading to more light excavation and less cost operation will help excavators to reduce the risks related to high excavation costs [23]. To achieve an efficient method for rock mass quality assessment, classification systems were gradually developed from the early stage [24,25,26], to the present stage with multiple factors and mathematical algorithms, like AHP[2] and OLR[3] [27], ANFIS[4] [28] and ANN[5] [29,30,31].

Swarm intelligence algorithms including Particle Swarm Optimization [32], Ant Colony [33], Cuckoo Search (CS) [34] and others [35] have been applied for optimization of NP-hard problems such as roads and highways design in recent years. Particle Swarm Optimization algorithm was first developed by Kennedy and Eberhart [36]. This algorithm is inspired by social behavior of bird and fishes and is based on a repeated process. Each particle is a feasible solution to the problem in the search space and each iteration leads to an update on the position of particles. Shafahi and Bagherian [32] applied a customized particle swarm optimization algorithm to search for a near-optimal highway alignment. The selected alignment met the constraints of highway design while minimizing total cost as the objective function. Their model used GIS maps to calculate right-of-way costs, earthwork costs, and any other spatial information and constraints. Their results were compared with the alignment found by traditional methods. In the highway development process, the first planning stage is that of selecting a corridor along which the highway is to pass. Angulo et al. [37] proposed a demand-based approach to provide a set of potential corridors. Their problem was formulated as a continuous location model to seek a set of optimal corridors with respect to the demand of potential users while satisfying budget constraints applying GIS. The method was tested using the PSO, two algorithms of the Simulated Annealing type and the Simplex Nedelmar method. Poole and Kotsialos [38] were concerned with the problem of macroscopic road traffic flow model calibration and verification. They applied ten various algorithms to solve the problem. Two sites in the United Kingdom had been used to test the models. Results indicated that PSO algorithm had proven to be more effective than others and provided the best results.

The paper presents a model for forest road vertical alignment optimization using PSO and GA, with several features and constraints. Also, the influence of the number of decision variables and road length on quality and cost of forest road profile was assessed using GA. At the end of work, the proposed alignment applying PSO and four scenarios of GA are compared with the common expert designed profile.

2. Material and methods

2.1. Study site

The study was carried out in a mountain temperate forest district covering approximately 1742 ha of Guilan province, northern Iran. The area is located between 48° 44′ 36"– 48° 49′ 58" of Longitude, and 37° 37′ 23" –37° 42′ 31" of latitude. The altitude ranges between 250 and 1150 m above sea level. A single lane forest road with 4.8 km length was assumed as a study site to test the applied road profile optimization methods. The detailed project information of this road segment was in access. According to the road project documents, there existed 273 control points along the road in where road grades were changing from each segment to neighbor ones (Fig. 1).

2.2. Methodology

The road profile optimization problem is to find an alignment that minimizes overall cost, subject to constraints. The forest road profile can be illustrated as follow:

Fixing start and end points in the study area and allowing the existing conditions of the study area changeable, find the best alignment among alternatives to optimize a specified objective function while considering needed structures and satisfying design and operational requirements [2].

This study applied MATLAB on a computer under Windows 2010, 32 bit, Intel Pentium Dual CPU with 2 GB RAM. The data were varied in side-slopes (0–55%). This provided a variety of cross-section types among the road stations to challenge the program in determining earthwork volumes. The thousands of feasible solutions were generated by changing alternative height at each control points at intervals of 0.1 m within 4.8 m above and below

[2] Analytical Hierarchy Process
[3] Ordinal Logistic Regression
[4] Adaptive Neuro-Fuzzy inference System
[5] Artificial Neural Network