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A Modified Genetic Algorithm for solving uncertain Constrained Solid Travelling Salesman Problems ☆

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ABSTRACT

In this paper, a Modified Genetic Algorithm (MGA) is developed to solve Constrained Solid Travelling Salesman Problems (CSTSPs) in crisp, fuzzy, random, random-fuzzy, fuzzy-random and bi-random environments. In the proposed MGA, for the first time, a new 'probabilistic selection' technique and a 'comparison crossover' are used along with conventional random mutation. A Solid Travelling Salesman Problem (STSP) is a Travelling Salesman Problem (TSP) in which, at each station, there are a number of conveyances available to travel to another station. Thus STSP is a generalization of classical TSP and CSTSP is a STSP with constraints. In CSTSP, along each route, there may be some risk/discomfort in reaching the destination and the salesman desires to have the total risk/discomfort for the entire tour less than a desired value. Here we model the CSTSP with traveling costs and route risk/discomfort factors as crisp, fuzzy, random, random-fuzzy, fuzzy-random and bi-random in nature. A number of benchmark problems from standard data set, TSPLIB are tested against the existing Genetic Algorithm (with Roulette Wheel Selection (RWS), cyclic crossover and random mutation) and the proposed algorithm and hence the efficiency of the new algorithm is established. In this paper, CSTSPs are illustrated numerically by some empirical data using this algorithm. In each environment, some sensitivity studies due to different risk/discomfort factors and other system parameters are presented.

1. Introduction

The TSP was first formulated as a mathematical problem in 1930 and became increasingly popular after 1950. It is one of the most intensively studied problems in optimization even in recent years. A TSP is to find a possible tour along which a Travelling Salesman (TS) visits each city exactly once for a given list of cities and back to the starting city, so that total cost spent/distance covered is minimal. TSP is a well-known NP-hard combinatorial optimization problem (Lawler, Lenstra, Rinnooy Kan, & Shmoys, 1985). Different types of TSPs have been solved by researchers during last two decades. These are TSPs with time windows (Focacci, Lodi, & Milano, 2002), stochastic TSP (Chang, Wan, & Tooi, 2009), double TSP (Petersen & Madsen, 2009), asymmetric TSP (Majumder & Bhunia, 2011; Mestria, Ochi, & Martins, 2013), TSP with precedence constraints (Moon, Ki, Choi, & Seo, 2002; Rakke, Christiansen, Fagerholt, & Laportei, 2012), etc.

In TSP, it is assumed that a TS travels from one city to another using only one conveyance. But in real life, a set of conveyances may be available at each city. In that case, a TS has to design his/her tour for minimum cost maintaining the TSP conditions and using the suitable conveyances at different cities. This problem is called Solid Travelling Salesman Problem (STSP). Traveling cost from one city to another city depends on the types of conveyances, condition of roads, geographical areas, weather condition at the time of the travel, etc., so there always prevail some uncertainties/vagueness. For this reason it is better to model the costs by uncertain parameters as fuzzy, random, random-fuzzy, bi-random and fuzzy random values. To analyses the large scale/amount of data throughout a long time interval, we observe that the data values are fluctuating over a period of time/year/session etc. So, for the decision making problem, twofold random phenomena is well suited/realistic approach. Also since TS may use different conveyances to travel along different routes, there may be corresponding some risk/discomfort factors, which depend on the condition of roads, types and conditions of vehicles, law and order condition

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such as Terrorist/Maoist attack. Thus a TS must maintain a maximum risk/discomfort level at each step and also ensure a maximum total risk/discomfort factor for the entire trip. Such kind of constraint is called risk/discomfort factor constraint. This type of TSP is called Constrained Solid Travelling Salesman Problem (CSTSP). Till now, except Changdar, Maiti, and Maiti (2013), none has considered CSTSP.

The present problem is more complicated due to the uncertainty/impreciseness of the costs and risk/discomfort factors. As optimization of fuzzy objective is not well defined, it is very difficult to formulate it. We use fuzzy possibility and necessity based approaches (Changdar et al., 2013; Das & Maiti, 2013), Graded Mean Integration Value Method (GMIV) according to Chen and Hsieh (2000), Credibility measure using Dubois and Prade (1997) and Expected Value Method (EVM) by Liu and Liu [Liu and Liu, 2003] to represent and to solve the fuzzy CSTSP. For the random values of the costs and risk/discomfort factors, chance-constrained programming techniques, which were originally developed by Charnes and Cooper (1959) are implemented. For the bi-random costs and risk/discomfort factors, equilibrium chance constraints, according (Peng & Liu (2005, 2007)) are used. Similarly, for the random-fuzzy CSTSP, the approach of Katagiri (2013) and fuzzy random CSTSP uses Liu and Liu (2003) are utilized.

Soft Computing (SC) is an association of computing methodologies that include fuzzy logic, evolutionary computing and probabilistic computing. SC is a term originally coined by Zadeh (1994, 1998). A Genetic Algorithm (GA) is an optimization technique that is based on the evolution theory. It performs a random search having both exploitation and exploration. The first thing we must do in order to use a GA is to automatically build a set of solutions to the problem. In a TSP, every route that passes through all the cities is potentially a solution, although probably not the optimal one. Such randomly generated routes act as initial population of solutions for GA.

Many kinds of GA developed by the researchers such as Niched Pareto GA, Hybrid GA (HGA), and Adaptive GA (AGA), are available to get the optimal solutions in different research areas.

In the existing literature, many optimization methods, such as Simulated Annealing (SA) (Chiang & Russell, 1997), Tabu Search (TS) (Knoxl, 1989), Ant Colony System (ACS) (Bianchi, Dorigo, & Gambardella, 2002), Genetic Algorithm (GA) (Holland, 1975), and Particle Swarm Optimization (PSO) (Eberhart & Kennedy, 1995; Marinakis & Marinakii, 2010) are used for TSP problems. Recently Changdar et al. (2013) have solved CSTSP in fuzzy environment using ACO and GA.

In spite of the above developments in the area of TSP, there are some lacunas in the formulation of the problem and development of solution techniques. These are as follows:

- CSTSPs are more realistic TSPs. Except Changdar et al. (2013), none considered this type of problems. Moreover Changdar et al. (2013) formulated and solved the problem only in fuzzy environment and solve through four approaches possibility and necessity, GMIV, Credibility and EVM approaches. Here, CSTSPs are developed in several uncertain environments such as fuzzy, random, random-fuzzy, bi-random and fuzzy random.
- In the literature, different types of GA have been developed and used in solving several optimization problems including TSPs. Here for the first time, a new type of GA with 'probabilistic selection' and 'comparison crossover' is developed and used for solving CSTSPs in different uncertain environments.
- The new GA is tested with different data sets from TSPLIB and the efficiency of the proposed algorithm is established in terms of iteration/generation.
- Normally, in TSPs, only one route/path with minimum cost is presented. But, due to several problems, it may not be possible by a TS to follow the most minimum cost path. For this reason, here several alternatives near optimum paths for CSTSPs are presented.
- None presented the sensitivity studies for uncertain CSTSPs, which are available in the present investigation.

In this paper, some CSTSPs are formulated with different risk/discomfort factors for different conveyances and routes. A maximum total risk/discomfort is imposed on the entire tour in the form of a constraint. These models are developed with crisp, fuzzy, random, random-fuzzy, bi-random and fuzzy random costs and risk/discomfort factors. For the solution, a MGA is proposed using Boltzmann-probability distribution function, i.e. chromosomes are selected depending on the corresponding probabilistic values and a new parameter $\mathbf{P_s}$ (say **probability of selection**) is introduced. This selection procedure is called as 'probabilistic selection technique'. A virgin crossover technique, **'comparison crossover'** and usual random mutation are also implemented. The developed comparison crossover depends upon the basic requirement of total minimum travel cost. First, randomly selected two paths (say, parents) are modified. Then new paths (i.e. children) are created from the modified parents comparing the costs between the nodes (i.e. cities). The node with minimum cost is selected for this purpose. After crossover, random mutation is used for global optimum. The proposed algorithm is tested with standard data set from TSPLIB against the classical GA which is the combination of RWS, cyclic crossover and random mutation and hence the efficiency of the new algorithm is established. CSTSPs formulated in different environments are solved by both proposed MGA and classical GA for some empirical data set. Alternative near optimum paths along with optimum path are presented for each CSTSP. Some sensitivity analyses are performed due to different risk/discomfort factors and other system parameters.

This paper is organized as follows: In Section 2, we describe mathematical preliminaries. In Section 3, MGA is presented. Section 4 gives different kinds of CSTSP. Finally, we illustrate the above problems using some empirical data with discussion in Section 5. Last in Section 6, we conclude the paper with the scope of future development.

2. Mathematical preliminaries

2.1.A. Fuzzy possibility and necessity approach

Let $\tilde{a}$ and $\tilde{b}$ be two fuzzy numbers with membership functions $\mu_{\tilde{a}}(x)$ and $\mu_{\tilde{b}}(x)$ respectively. Then according to Zadeh (1994),

$$pos(\tilde{a} * \tilde{b}) = sup\{min(\mu_{\tilde{a}}(x), \mu_{\tilde{b}}(y)), x, y \in \Re, x * y\} \tag{1}$$

where the abbreviation *pos* represents possibility, $*$ is any one of the relations $>, <, =, \leqslant, \geqslant$ and $\Re$ represents set of real numbers.

$$\text{nes}\left(\tilde{a} * \tilde{b}\right) = 1 - pos\overline{\left(\tilde{a} * \tilde{b}\right)} \tag{2}$$

where the abbreviation nes represents necessity.

If $\tilde{a}, \tilde{b} \subseteq \Re$ and $\tilde{c} = f\left(\tilde{a}, \tilde{b}\right)$ where $f : \Re \times \Re \rightarrow \Re$ is a binary operation then membership function $\mu_{\tilde{c}}$ of $\tilde{c}$ is defined as

For each $z \in \Re$,

$$\mu_{\tilde{c}}(z) = sup\{min(\mu_{\tilde{a}}(x), \mu_{\tilde{b}}(y)), \quad x, y \in \Re \text{ and } z = f(x, y)\} \tag{3}$$