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Application of Water Cycle Algorithm to Stochastic Fractional Programming Problems

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ABSTRACT

This paper presents an application of water cycle algorithm (WCA) in solving stochastic programming problems. In particular, linear stochastic fractional programming problems are considered which are solved by WCA, and solutions are compared with particle swarm optimization, differential evolution, and whale optimization algorithm and the results from literature. The constraints are handled by converting constrained optimization problem into an unconstrained optimization problem using augmented Lagrange method. Further, a fractional stochastic transportation problem is examined as an application of the stochastic fractional programming problem. In terms of efficiency of algorithms and the ability to find optimal solutions, WCA gives highly significant results in comparison with the other metaheuristic algorithms and the quoted results in the literature, which demonstrates that WCA algorithm has 100% convergence in all the problems. Moreover, non-parametric hypothesis tests are performed and indicate that WCA presents better results as compared to the other algorithms.

KEYWORDS

Metaheuristic Algorithms, Stochastic Fractional Programming Problem, Stochastic Programming, Transportation Problem, Water Cycle Algorithm

1. INTRODUCTION

Stochastic programming deals with the condition where the parameters of the problem are uncertain or random e.g., future demands of goods depend on the market conditions; the transportation cost depends on the uncertain price of fuel, and crop yields typically depend on the weather conditions (Birge and Louveaux 2011). The uncertain parameters of the problem are considered as random variables that follows probability distribution (Rao 2019). To solve the stochastic programming problem, the idea is to convert a probabilistic problem into its equivalent deterministic form, and then the solutions are obtained by classical/ numerical techniques. Stochastic programming has been widely used in various areas of science and engineering. It has been applied to different real-

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time problems such as transportation (Yang and Feng 2007), finance (Carino et al. 1994), electrical generation capacity planning (Murphy et al. 1982), portfolio optimization (Abdelaziz et al. 2007), medical field (Ben and Masmoudi 2012, Punnakitikashem 2008), supply chain management (Fisher et al. 1997), social network (Wu and Küçükyavuz 2018), Risk Criterion (Riis and Schultz 2003). In this paper, stochastic fractional programming (SFP) problem is considered, which optimizes the ratio of two functions with some constraints. At least one of the parameters must be uncertain (or random) in nature, or some of the constraints can be in deterministic form. SFP problems have been applied to the business sector in different scenarios (e.g., cost v/s time, cost v/s profit, cost v/s volume). There are several classical and numerical techniques to solve the SFP problems (Charles and Dutta 2001, 2004, 2005, Charles et al. 2001). Mohamed (2017) proposed enhance adaptive differential evolution algorithm and Hadi et al. (2019) proposed LSHADE-SPA to solve high dimensional and complex optimization problems. In the last three decades, metaheuristic algorithms developed to solve the complex-computational, high-dimensional, non-differentiability, non-convexity problems. Basically, metaheuristic algorithms depend on the natural evolution and the algorithms are started with a randomly generated population. The most popular algorithms are Genetic Algorithm (GA) (Holland 1992), Particle Swarm Optimization (PSO) (Eberhart and Kennedy 1995), Differential Evolution (DE) (Das and Suganthan 2010), Ant Colony Optimization (ACO) (Dorigo and Birattari 2010), Teaching Learning Based Optimization (TLBO) (Rao 2016) etc. There are other several metaheuristic algorithms which are used to solve real-world applications such as energy efficiency in the IoT networks (Iwendi et al. 2020), early detection of diabetic retinopathy (Gadekallu et al. 2020), XGBoost classification model for intrusion detection (Bhattacharya, 2020), global optimization problems (Wu et al., 2020) etc. To solve the stochastic programming, Thangaraj et al. (2011) and Mohamed (2017) used DE algorithm and found the optimal solution.

Water Cycle Algorithm (WCA) was proposed by Eskandar et al. (2012), which is inspired by the natural water cycle and considers the flow of streams and rivers towards a sea. They compared the obtained results of WCA with other well-known metaheuristic algorithms (GA, Harmony search (HS), PSO, and DE). The obtained results manifested that WCA is an efficient and suitable algorithm to solve constrained optimization problems. WCA has been applied to different types of problems and presented significant results. Haddad et al. (2014) used WCA to solve the reservoir operation problem and stated that WCA has high reliability and efficiency. Sadollah et al. (2015) modified WCA in the evaporation rate for streams and rivers. Many researchers (Deihimi et al. 2016, Elkholy and Abd-Elkader 2019, Heidari et al. 2017) applied WCA to real-time problems and found to be the most efficient algorithm, due to its high capability of finding the optimal solutions.

To the best of our knowledge, WCA has not been applied to stochastic programming problems. Hence, in this study, the authors implemented WCA for solving SFP problems, as it uses a lower number of user-defined parameters and also presented a case study based on stochastic fractional programming problem. To handle constraints, several techniques have been developed with metaheuristic algorithms (Coello 2002, Mezura 2009). WCA handles the constraints with augmented Lagrangian method in which, constrained optimization problem is converted into an unconstrained optimization problem with some penalty to the objective function (Bahreininejad 2019). The results of WCA compared with the results of DE, PSO, WOA, and results from the literature (Charles and Dutta 2005). Also, a stochastic fractional transportation problem is considered with the real-world problem as an application of the SFP problem. Balaprakash et al. (2015) considered a vehicle routing problem with stochastic demands and customers and solved using an empirical estimation-based metaheuristic algorithm. Agrawal and Ganesh (2020) solved fuzzy fractional stochastic transportation problem in which the parameters are considered as fuzzy random variables which follow fuzzy exponential distribution. They also considered stochastic transportation problem in which the randomness and multichoice of parameters are taken simultaneously that are solved by classical approach (Agrawal and Ganesh 2020) .

The organization of this research paper is as follows: section 2 describes definition of SFP problem with mathematical model, section 3 presents methodology for solving the SFP problems. In