6th International Symposium on Advances in Science and Technology
SASTech
Malaysia | Kuala Lumpur
24 - 25 March, 2012
Scope of the Symposium
Organised by:
Khavaran Institute of Higher Education
Hosted by:
Geospatial Association of South East Asia

Investigate the Potential and Limitations of Meta-heuristics Algorithms Applied in Reservoir Operation Systems

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Paper Reference Number: 6-15-12-800
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Abstract

Nowadays, we are faced with the complex of process in water resource management. The complexity of water resources system makes the analysis of water resources investment alternatives difficult and complex. This leads to increase the application of systems analysis techniques.

Optimization makes it possible to do exact mathematical modeling in a process, so by applying mathematical programming methods we will be able to optimize our models. Recently approximation algorithms are developed to combine the basic principles of heuristic algorithms to reach an efficient method in feasible region. These methods are known as meta-heuristic methods. Evolutionary algorithms (EAs), Genetic Algorithm (GA), Ant Colony Optimization (ACO), Simulated Annealing (SA), Tabu Search (TS) and Artificial Neural Networks (ANN) are examples of these methods.

The mathematical programming has two main problems. Sometimes they consider local optima points as global optimum points, and each of the mentioned methods is used for certain issues.

In these studies the main focus is on developing tools to assist decision making and planning of water resources.

The tools of systems analysis are varied in their usefulness. The approach and appropriate techniques naturally vary from problem to problem. It depends on the characteristics, i.e., the objective, scope of planning, state of development of system, the space and time of planning process. Our goal in this paper is to explain some advantages and disadvantages of meta-heuristic methods like genetic algorithm and simulated annealing algorithm in planning, limitations, and applications. Furthermore, we aim to note some points to apply the most ideal of using the programming methods in water resources systems optimization.

Keyword: meta-heuristics, Optimal Reservoir Operation, Genetic algorithms, Simulated Annealing

1. Introduction

During the last decades, optimization and simulation models have been used widely in water resources systems planning and management. The main focus of studies was on developing tools to help decision making in water resources planning and development. In primitive developed models for water resources systems planning, the dominant emphasis was on deterministic simulation and linear optimization model. Since last decade, in recently developed models the major focus has been on developing stochastic simulation models to consider uncertainties and lack of clarity in systems, and also on meta-heuristic optimization to reduce computational problems. Optional procedure of mathematical optimization model is called heuristic method. The word "heuristic" is used to explain all step by step techniques and evaluating techniques in each step. In this method, local research can be done by set of logical, empirical or heuristic research rules. This method continues as long as it cannot find any better structure considering the evaluation criteria.

1.1. Meta-heuristic methods:

There have been many algorithms which are developed to solve complex optimization problems. These algorithms can be classified in exact mode and approximate mode. The exact algorithms guarantee an optimum solution in a period of time for each complex optimization problems. Still for complex optimization problems that are NP-Hard, there is no algorithm with polynomial time. Thus the exact methods in worst conditions may need time to exponential computation. This issue often takes long time of computation for practical objectives. Therefore, applying approximate methods have been noted more during the past 30 years.

During the last decades, set of approximate algorithms are developed, which are trying to combine basic principles of Heuristic methods to find a method for efficient search in feasible region. Nowadays, these methods are called meta-heuristic methods. Glover (1993) used the expression Meta-heuristic for the first time, while introducing Tabu search method as a meta-heuristic method. Meta-heuristic is a combination of two Latin words. Heuristic means "finding" and the suffix Meta means "beyond". Previously, meta-heuristic methods were called Modern Heuristic methods. There has been many definition of expression Meta-heuristic. According to Webster dictionary, its definition is "A top-level general strategy which guides other heuristics to search for feasible solutions in domains where the task is hard." Evolutionary algorithms (EAs) like Genetic Algorithm (GA), Ant Colony Optimization (ACO), Simulated Annealing (SA), Tabu Search (TS), and Artificial Neural Networks (ANN) are some samples of these methods.

1.2. Literature review:

Krikpattrick et al. (1983) suggested for the first time the basic technique formats of optimization for problems especially complex problems in an article called optimization by simulated annealing science. Kau et al. (2000) applied optimization method in watering planning by three

methods of interactive improvement, SA and GA. The results showed that simulation annealing method and genetic algorithm method will reach global optimum and iterative improvement method reaches to local optimum sometimes. Ahmad and Sarma (2004) presented a model for optimal operation from multipurpose reservoirs, the comparison between genetic algorithm and stochastic dynamic programming (SDP) showed the validity of the results. Hashemi et al. (2008) optimized the operation of multipurpose reservoir in Jiroft dam. Vasan and Raju (2009) declared that in order to plan efficiently in irrigation systems SA, GA can be used. Onur Hincal et al. (2011) studied on efficiency of genetic algorithm in optimization reservoir systems using real time, and they announced that genetic algorithm can be a good substitution for other traditional optimization techniques.

2. Reservoir operation model:

Large dams are usually designed, built and operate for several purposes. Water supply for urban, agricultural and industrial use, generating electrical energy (due to high performance, Maximize firm power ,Minimize energy shortages) and flood control and reducing its danger are main purposes of planning and operation reservoirs. Adjusting the river discharge for navigation, environmental purposes and controlling water quality in reservoir and in downstream river are other operational goals from reservoirs. Recreation, Fish and wildlife enhancement, Erosion and sedimentation control and also Combination of above are other purposes.

The general structure of a basic model, which is the base of many optimal reservoir operation models, is like as follows:

Minimize Z: Σ losst (Rt , Dt , St) (1)

Subject to:

$S_{t+1}=S_t - I_t - R_t - E_t - I_t$ (t=1, 2 ... n) (2)

$S_{min} \leq s_t \leq Cap$ (t=1, 2 ... n) (3)

$0 \leq R_t \leq R_{max,t}$ (t=1, 2 ... n) (4)

$S_t, E_t, L_t, R_t \geq 0$ (5)

Where: (Eqs. 1~5)

Cap: total capacity of the reservoir , St: storage at the beginning of month t , It: inflow to the reservoir during month t , Et: evaporated water , Lt : leakage from the reservoir , Smin: lower bound on the volume , Rmax,t : maximum allowable release and D: The constant demand. (From Karamouz, M .et al. (2003)).

In objective function the overall losses will be minimized during the operation. The variety of loss functions have been suggested for optimization reservoir operation, which are normally a function of water shortage to supply needs, and difference between water storage in reservoir and optimum storage in each month. The loss regarding to no needing is calculated by total amount of needed water systems with total amount of released water.

3. Genetic algorithm (GA):

Genetic algorithms are new generations of research methods and optimization. They are so popular because of their own simplicity, usefulness and power. The genetic algorithms are suitable for solving non-linear optimization problems with large number of complicated variable decisions in continues variable mode, and particularly in discrete mode.

The genetic algorithm is one of the adoptive learning techniques, which is able to model non-linear data. The first advantage of genetic algorithm is achieving to the global optimum instead of local optimum. Usually, they are not trapped in local optimum. It means most of the times we can trust the answer of algorithm, and it is possibly the best answer. This is because of applying stochastic transformative rules instead of certain transformative rules. To put it simply, any movement in each point is totally probabilistic, and it is not done by certainty. This issue is an important aspect of this method, and it prevents system to trap in local minimums. Of course the probability is in such a way that the movement toward object outweighs the movement toward the wrong answer. Furthermore, genetic algorithm is capable of working with numerical data, experimental data, and analytical functions. What's more, it can search the whole feasible region at the same time. The genetic algorithm is applied on the set of solutions rather a specific solution. The other plus point of this algorithm is that it can be applied for variety of problems without any changes.in fact, just about any question we need to represent different answers by chromosomes. The process by genetic algorithm will be done on chromosome's space not on solution space.

The MATLAB software is able to optimize the coded variables, since coding increases the speed of convergence. Although genetic algorithm is used to solve discrete optimization problems, similar methods like evolutionary strategies or simulated annealing algorithm exist that can be used in continues problems. They way to define and implement this algorithm is suitable to run in parallel or on multiprocessors easily.

But this algorithm just like other algorithms has its own disadvantages. Maybe the cost of its implementation in spite of its simplicity is the most significant disadvantage. Often, to solve problems generation of chromosomes are required, this may take a long time (especially when the population is large and the objective function is a complicated one).

Sometimes, in order to solve a problem we have to wait for some days, and this issue can be mentioned as a disadvantage. Another problem is how to write a fitness function as the best

solution to the problem. If fitness function is not chosen properly, we will not be able to find a solution for the problem or we may solve another problem unintentionally. To select the appropriate fitness function, other parameters such as population, mutation rate, crossover, power and choice should be considered.

One of the challenges in genetic algorithm is premature convergence. To put it simply, the number of strong gens (but not optimal) may quickly overcome to the population, and cause the algorithm to convergence to a local optimum point. At the time that the population converges to a local optimum point (premature convergence) the ability of the algorithm to find a better solution disappears. In other words, if a genome that its distance is far from other genomes generation, and it appears very soon, it may cause limitation, and leads the solution to local optimum answers. It usually happens in small populations. Rank scaling method and tournament selection method can overcome this problem. In many optimization problems the artificial neural network and genetic algorithm work very well to find optimal variables. Furthermore, they can accelerate the forecasting process. The artificial neural network can be used as initial tools as modeling, and finally genetic algorithm can be used to optimize the artificial neural network.

Important points in genetic algorithm:

1-the initial population characteristics are very important to reach to the optimal answer.it means if the initial population is appropriate, we can get to the answer very soon. So sometimes instead of creating the initial population randomly, special conditions that apply to the initial population are used.

2-considering random parameters in the algorithm even if similar initial population is used may not result similar answers in different performances, and of course will be more tangible if different if we use different initial population.

4. Simulated Annealing algorithm (SA):

This algorithm just like genetic algorithm is appropriate for solving non-linear optimization problem with large number of variables, especially discrete ones. It can be used for continues variables too, and it is an appropriate tool to address the problems with continues answers. The simulated annealing algorithm can find acceptable answers because of focusing on local search, besides because of a random directed process in problems with many local optimums; it can pass the local optimum to reach the global optimum. Another especial advantage of this algorithm is the low consumption memory (in opposite of genetic algorithm), which is very high in addition simple implementation of this algorithm in comparison with other algorithms in the same class is another plus point. Moreover, this algorithm gives better answers in different problems like TSP, PSP. Its static and low cost structure is similar to steady state genetic algorithm.

The main disadvantages of this algorithm can be pointed to the following: Each time this algorithm only works on a point so it cannot provide a general form of the search space. It is absolutely without memory, and all the previous information obtained during the algorithm ignores no information saves about previous movements, so we are not able to use previous movements to choose new points. Thus the given answers do not depend on previous answers and it just depends

on its generator. To solve this problem we can combine methods with that, such as Tabu Search method which has memory (list of forbidden moves), also Faigle and Kern (1992) invented an especial algorithm called probabilistic TS as a Meta heuristic method to help simulated annealing algorithm. In this algorithm desperation is partly high and the convergence speed is partly low (for example the speed of this algorithm is lower than Tabu research algorithm.).To solve this problem researchers tried to combine this algorithm with meta heuristic algorithm Delport (1998) combined SA with evolutionary algorithms like GA to speed up the convergence and improve the quality of answers. Sullivan and Jacobson used Generalized Hill Climbing algorithms to combine SA and GA. Thus, it is proven that genetic Algorithm is suitable for addressing complicated discrete problems. This algorithm depends on initial value of the parameter, and if it is not chosen properly for initial temperature parameter it will probably trap in local optimum. Forecasting of initial value for problem parameters is impossible without benchmark. Although accepting weaker points to escape from local maximums helps a lot, in condition that the acceptance of these weaker points increases we may face improper results, and it will make more distance from global maximum.

5. Conclusions

The Meta heuristic methods are approximate and often non-deterministic (stochastic). The main purpose of meta-heuristic algorithms, in spite of heuristic algorithm is having efficient search in feasible region. They prevent the procedure of searching to trap in local optimum. Also the Meta heuristic algorithms do not depend on the problem type and it can be used widely to solve many optimization problems. The more developed Meta heuristic methods use the acquired information and experience during search process as a memory to guide the search toward the region with more possibility of finding the answers. Considering the optimal operation of multipurpose reservoirs in dams, we are facing nonlinear and stochastic problems in which, finding optimum answer is hard by using classic methods. The states above indicate the ability of Meta heuristic methods particularly genetic algorithm, and simulated annealing methods to solve these problems.

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