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Management of Reservoir Operation by Fuzzy Logic Decision Making

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Abstract
One of the basic issues in the construction management is decision making. When variables face uncertainty, for an instance in reservoir operation, fuzzy method is applicable for elite modeling. In this example it is possible to predict reservoir released water by fuzzy logic to achieve the optimal policy for long term use, based on net discharge, downstream demand and initial reservoir storage. As a case study, Dez dam reservoir in Iran is studied in this research. Results show desirable prediction by proper recognition of the problem and adequate elite modeling.

Keywords
Management, Fuzzy logic, Decision making

1. Introduction

Forever, mankind has attempted to build structures over rivers, in order to provide his water supply and necessary energy, and control the floodwater, which among them dams have had a significant role. Scientists have been constantly working on improving these structures and optimizing their utilization. Nowadays reservoir dam operation is one of the preferred issues in the water resources management field worldwide. Many methods for selecting the optimized operation solution have been innovated and presented which among them we can name linear programming, nonlinear programming, dynamic programming, and meta-heuristic programming.

As the variables affecting in the reservoir dam operation problem are confronted with many uncertainties (such as water entering the reservoir, the available amount of water in the reservoir, and downstream demand) using only optimizing methods which mostly have a crisp essence, even though they might theoretically seem efficient, but with a minor change in the inputs they are practically incompetent. What has been presented in this research is a combination of an optimization meta-heuristic method named Tabu search and a decision making method in uncertain conditions named fuzzy logic. In fact the optimized solutions attained through Tabu search, as precious experience, are the base of fuzzy model. In other words, Tabu search actually plays the role of an expert for fuzzy logic method.

2. Optimization Method

Optimization methods are divided into two groups: mathematical and meta-heuristic. One of the meta-heuristic methods is Tabu search (TS).

Tabu search is stabilized on neighborhood search but with avoiding being trapped in local optimums. The main idea of this method is in visiting regions that have not been searched recently. Therefore the method begins with an initial solution which is produced randomly and if a better solution, which isn't a tabu solution, is found the search process moves to it. This process is continued until the termination criterion is satisfied. According to the above, the main factors and concepts of this approach are as below (Consoli and Dowman, 2006; Cunha and Ribeiro, 2004; Glover, 2004; Glover, 1998).

2.1 Initial Solution

As in other heuristic methods, at the beginning of each problem, one initial solution is chosen randomly so that the search is started from that point. One advantage of TS is that it decreases the effect of the initial solution by intensification and diversification because theoretically, in large nonlinear problems, different initial solutions cause various local optimums.

2.2 Movement

Movement means transfer from the current solution to the next best point in the neighborhood which is not forbidden. The important point is that sometimes although the new solution is worse than the current global optimum and the current solution, still movement will be done (uphill climbing) with hope that local optimums are avoided and the whole space can be visited so that desirable solutions are found.

2.3 Tabu List

Best solutions of recent iterations are saved in a tabu list. The policy is to apply restriction to returning to visited areas and avoiding cycles and getting trapped in local optimums. Small lists let special areas to be searched more carefully (intensification) and larger lists let the process search wider spaces (diversification). Either all decision variables of solutions or one or more of the solution properties can be saved in the tabu list.

2.4 Aspiration Criteria

Sometimes according to the aspiration criteria, if an optimum is found in the neighborhood, although it has common properties with the solutions existing in the tabu list, its prohibition is ignored and it is chosen for continuing the process.

2.5 Termination Criteria

For stopping the approach from searching, different criteria can be applied such as maximum number of iterations; number of iterations done with no improves or finding a solution with a smaller objective function than the users defined value.

3. Fuzzy Logic

3.1 History and Definition

Fuzzy thinking develops an automatic flexible model versus the mathematical model that often presents difficulties in achieving adaption because of its degree of precision. However this is necessary to have a high degree of understanding about the process for designing an affective fuzzy model that adapts to changing conditions. On the other hand, fuzzy rules are constructed almost as spoken by an experienced operator.

From a mathematical viewpoint, fuzziness means multi valued and it comes from the Heisenberg Uncertainty Principle that deals with position and momentum. Lukasiewicz (Lukasiewicz, 1970; Resher, 1965) developed a three-valued absence and ambiguity.

In spite of being new, fuzzy logic has been successful in many commercial areas: cement kiln operation (Holmblad and Oostergaard, 1982), camera and video recorders (Kosco, 1997), subway braking system (Yasunobu et al., 1983), cruise control systems (Holve et al., 1996; Boverie et al., 1993), traffic control (Krause et al., 1996), elevator control (Kim et al., 1996; Tobita et al., 1991), thickener operations (Santos et al., 1995).

3.2 Operation of a Fuzzy Logic Model

The model receives discrete input information and then maps this information into a series of fuzzy sets that explain the process of related input variables. This phase is called fuzzification. Then by the defined fuzzy rules inputs inference to outputs during the inference phase. Finally in the defuzzification stage, the fuzzy outputs map to the discrete output variables. On the other hand, steps of building a fuzzy logic controller are as follows.

3.2.1 Fuzzy Set Definition

The process starts by characterizing the universe of discourse for each I/E variable. In this article, terms such as high, medium and low are defined and standardized. For the fuzzy set shape, triangular and trapezoidal shapes were selected because they are very popular and produce reasonable interpolation results.

3.2.2 Rule Base Generation

In this step, the appropriate input states are linked to the appropriate output state by construction of two-dimensional grid of rules. If there are more than 2 variables, the most common approach is the use of multiple rules. For example if the rule is between 3 variables (such as this research) a 3D grid of rules can be constructed.

3.2.3 Inference

Many inference methods are available. Smith and Takagi (Kaufmann and Gupta, 1991) list ten methods. In this work, “Correlation-Product” method was selected. Also, all membership values are multiplied by an output fuzzy set.

3.2.4 Defuzzification

As with inference, Smith and Takagi (Smith and Takagi, 1993) list eight methods that in this research, the “Weighted-Average” method has been selected which is the easiest of all. In this method first the degree of belief in each set is multiplied in its average supermom; then the results are summed and divided into the sum of all DoBs (Degree of Belief).

4. Case Study

4.1 Description

As explained above, proper operation of fuzzy logic depends on the precious experience of the expert. In this article the optimized solutions of TS have been used as the experience which the fuzzy model is based on. In other words the combination of the TS optimization method and fuzzy system has been applied to predict what will occur in the future.

The problem worked on is the operation of dam reservoir. Solving this problem requires two independent algorithms; an optimizing algorithm which actually models the fundamentals of tabu search method and a simulating algorithm which simulates the reservoir in different circumstances. In order to originate the simulating algorithm the decision variable, objective function and constraints must be completely recognized and their mathematic relations precisely acknowledged.

4.2 Optimization

4.2.1 Decision Variables

The decision variable in the optimized dam reservoir operation can be the storage capacity in each sequential period (S_t) or the amount of water released in each period (R_t). In this article, the amount of water released in each period has been chosen as a decision variable.

4.2.2 Objective Function

In order to solve this problem it is possible to consider an objective function from variety of functions which here with the object of minimizing the deficiency, the following function has been considered:

$$Minimize\ \ O.F = \sum_{i=1}^{NT} \left[\frac{D_i - R_i}{D_{max}} \right]^2$$

D_i : The demand in each sequence for the i[th] decision variable

R_i : The release in each period for the i[th] decision variable

NT : The number of all the periods

$D_{\max}$: The maximum demand

4.2.3 Constraints

The most important constraint of this problem is the storage conjunction equation.

$$S_{t+1} = S_t + I_t - R_t - L_t$$

S_t : The storage capacity in the beginning of the t time period

I_t : The water inflow of the storage in the t time period

R_t : The released water in the t time period

L_t : Loss in t time period

Another constraint is caused by the storage capacity limit:

$$S_{min} \leq S_t \leq S_{max}$$

$S_{\min}, S_{\max}$: The minimum and maximum of the storage capacity

And the last constraint is the limit of water released from the storage:

$$R_{min} \leq R_t \leq R_{max}$$

$R_{\min}, R_{\max}$: The minimum and maximum of water released from the storage

There are different methods for applying the above constraints which the penalty factor method is the most common method:

$$F_p = F + \alpha_p \times \sum_{t=1}^{NT} CSV_t$$

F_p : Objective function with penalty
F : Original objective function
α_p : Penalty factor
CSV_t : Total amount of violation in t time period

The penalty factor amount should be adequate with the real objective function. It should not be very small because this will cause many calculations for finding the possible solution and for variation from the impossible answer. On the other hand, if it is very big, it will limit the search environment of the problem and isotropy to local optimized answers.

4.2.4 Numerical Example

The sample problem which is studied and solved in this research is Dez dam storage simple operation. This problem has been solved for a 5 year (60 month) period. As mentioned before the decision variable is the water released from the storage in each month. Therefore this problem has 60 decision variables. The available data regarding this problem is as follows:

S_1 =1430 mcm; $S_{\min}$ =830 mcm; $S_{\max}$ =3340 mcm
$R_{\min}$ =0 mcm; $R_{\max}$ =1000 mcm

The results of the optimized problem solution which include storage and release quantities for a 60 month period are shown in Table 1.

Table 1: Solution of Optimization

Month	Inflow	Demand	Release	Storage	Month	Inflow	Demand	Release	Storage
1	1,670	517	637	1,430	31	122	468	344	1,083
2	1,493	604	661	2,464	32	184	318	205	860
3	826	758	819	3,295	33	320	163	55	839
4	507	832	875	3,302	34	353	151	50	1,104
5	326	819	867	2,934	35	504	203	113	1,407
6	239	706	772	2,394	36	706	366	249	1,798
7	199	468	595	1,861	37	816	517	399	2,256
8	301	318	376	1,464	38	729	604	486	2,673
9	523	163	237	1,390	39	403	758	658	2,916
10	577	151	196	1,676	40	248	832	738	2,661
11	825	203	254	2,057	41	160	819	703	2,171
12	1,155	366	443	2,628	42	117	706	591	1,628
13	571	517	579	3,340	43	97	468	361	1,154
14	510	604	525	3,332	44	147	318	207	890
15	282	758	635	3,317	45	256	163	85	831
16	174	832	723	2,964	46	282	151	56	1,001
17	112	819	698	2,414	47	403	203	119	1,228

18	82	706	594	1,828	48	564	366	315	1,511
19	68	468	341	1,316	49	1,052	517	446	1,760
20	103	318	188	1,044	50	940	604	531	2,366
21	179	163	59	959	51	520	758	677	2,775
22	197	151	78	1,078	52	320	832	736	2,618
23	282	203	84	1,198	53	206	819	721	2,202
24	395	366	263	1,396	54	151	706	677	1,687
25	1,021	517	400	1,528	55	125	468	397	1,160
26	912	604	484	2,149	56	190	318	245	889
27	505	758	637	2,577	57	330	163	151	834
28	310	832	709	2,445	58	364	151	155	1,012
29	200	819	705	2,046	59	519	203	199	1,221
30	146	706	604	1,540	60	728	366	377	1,541

Note: *Inflow and Demand are input variables; Release is decision variable; Storage is state variable*

4.3 Fuzzification

In this article, the results from optimization which are based on past statistics are the base of forming the fuzzy model. In other words, the optimizing model plays the role of an expert in training fuzzy model and passing on its experience. For this purpose different fuzzy steps have been taken in the following order.

4.3.1 Fuzzy Sets Definition

According to the past data regarding the storage inflow and downstream demand, and also the optimization results of the amount of water in the storage and amount of water released, the fuzzy sets can be defined (in triangle and trapezium shapes). Therefore we have used the average and standard deviation for classifying the data in to three, low, medium and high groups. The results are displayed in Figures 1, 2 and 3.

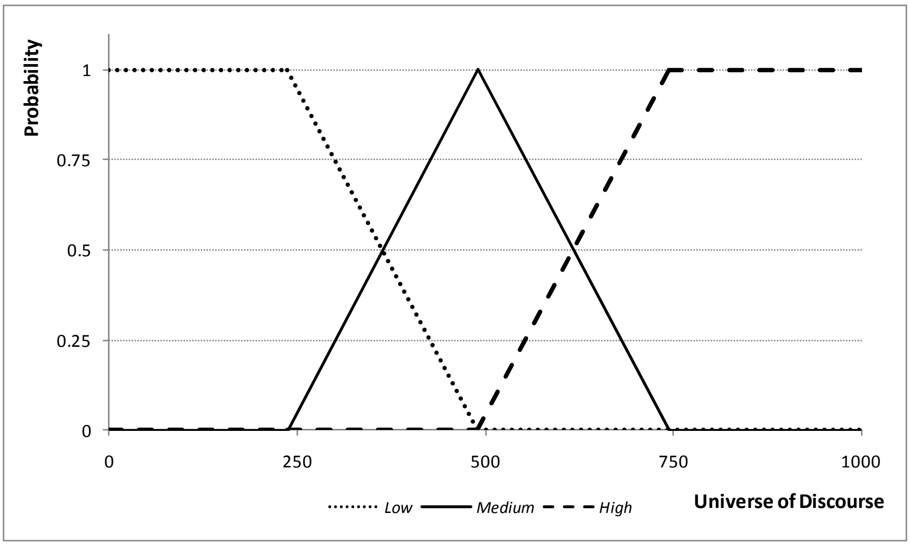

Figure 1: Fuzzy Set for Demand as Input Variable

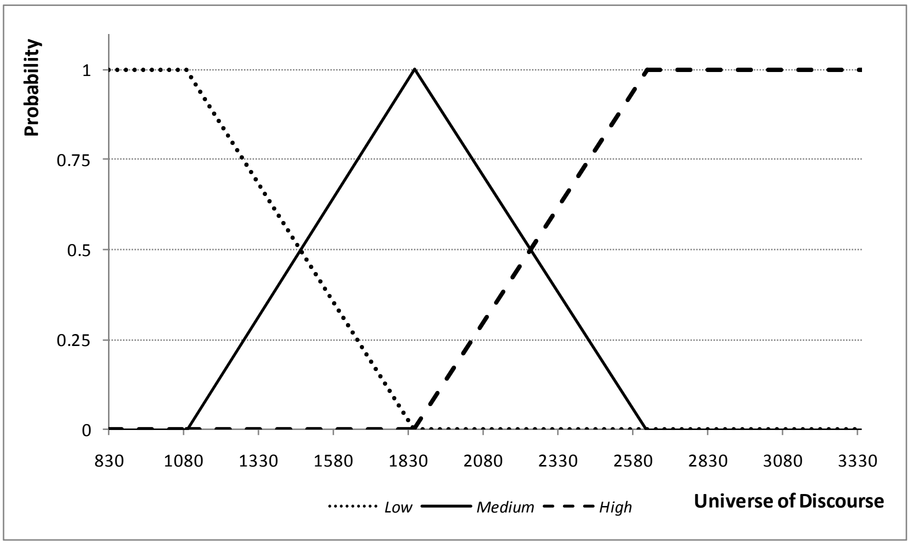

Figure 2: Fuzzy Set for Reservoir Water Storage as Input Variable

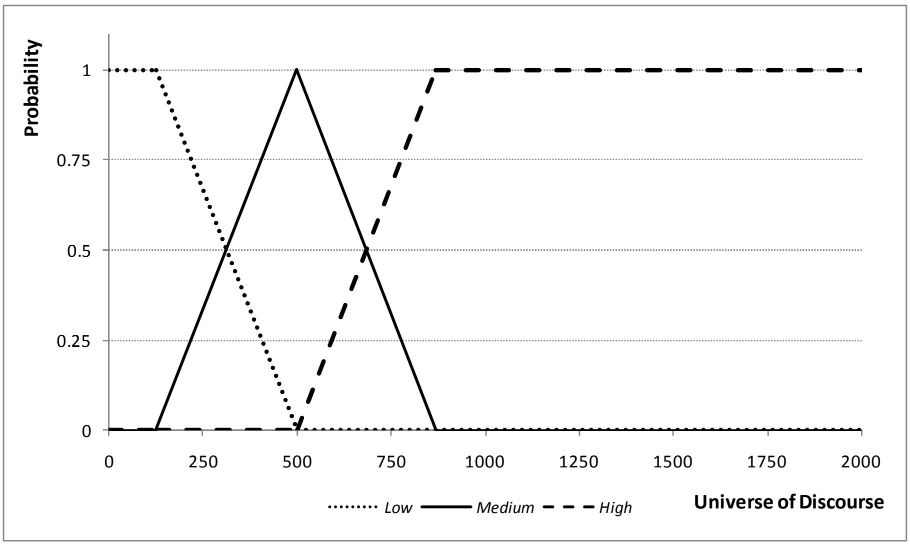

Figure 3: Fuzzy Set for Inflow as Input Variable

4.3.2 Fuzzy Rules

As the concept of the problem shows, the amount of water released (which is the state variable for the fuzzy problem) depends on the three input variables; inflow, downstream demand and the amount of water in the storage. Therefore a 3D grid of rules must be drawn.

According to the average and standard deviation in different conditions, the rules have been defined as follows. As picturing a 3D grid of rules is not possible, this three dimensional grid is shown in three layers of two dimensional grids (Table 2). The quantities shown in the grid are actually the percentage of demand which must be released.

Table 2: 3D Grid of Fuzzy Rules

		Demand								
		Low			Medium			High		
Storage	High	80%	90%	100%	90%	95%	100%	90%	95%	100%
	Medium	65%	77%	85%	80%	88%	90%	85%	91%	95%
	Low	55%	60%	70%	70%	75%	80%	80%	85%	90%
		Low	Medium	High	Low	Medium	High	Low	Medium	High
		Inflow								

4.3.3 Inference and Defuzzification

To explain these two sections a numeric example is presented. It has been assumed that the following data is the input for decision making.

Demand = 450, Inflow =650, Storage =1280

According to the fuzzy sets, the following amounts are calculated as the different DoBs.

$$Demand = 450 \Rightarrow \ Low : 0.15,\ Medium : 0.85,\ High : 0.00$$
$$Inflow = 650 \ \Rightarrow \ Low : 0.00,\ Medium : 0.40,\ High : 0.60$$
$$Storage = 1280 \Rightarrow \ Low : 0.25,\ Medium : 0.75,\ High : 0.00$$

Now according to the fuzzy rules and based on the DoB amounts, inference and defuzzification occur as follows.

$$Q_{Demand=L} = 0.15\times[0.0\times(0.25\times55+0.75\times65+0.0\times80)+0.4\times(0.25\times60+0.75\times77+0.0\times90)+0.6\times(0.25\times70+0.75\times85+0.0\times100)]$$
$$Q_{Demand=M} = 0.85\times[0.0\times(0.25\times70+0.75\times80+0.0\times90)+0.4\times(0.25\times75+0.75\times88+0.0\times95)+0.6\times(0.25\times80+0.75\times90+0.0\times100)]$$
$$Q_{Demand=H} = 0.00\times[0.0\times(0.25\times80+0.75\times85+0.0\times90)+0.4\times(0.25\times85+0.75\times91+0.0\times95)+0.6\times(0.25\times90+0.75\times95+0.0\times100)]$$
$$P_{Demand=L} = 0.15\times[0.0\times(0.25+0.75+0.0)+0.4\times(0.25+0.75+0.0)+0.6\times(0.25+0.75+0.0)]$$
$$P_{Demand=M} = 0.85\times[0.0\times(0.25+0.75+0.0)+0.4\times(0.25+0.75+0.0)+0.6\times(0.25+0.75+0.0)]$$
$$P_{Demand=H} = 0.00\times[0.0\times(0.25+0.75+0.0)+0.4\times(0.25+0.75+0.0)+0.6\times(0.25+0.75+0.0)]$$

$$\%R/D = \frac{Q_{Demand=L} + Q_{Demand=M} + Q_{Demand=H}}{P_{Demand=L} + P_{Demand=M} + P_{Demand=H}} = \frac{11.68 + 73.44 + 0.00}{0.15 + 0.85 + 0.00} = 85.12\%$$

Release = 85.12%×Demand = 0.8512×450≈ 385

By calculating the release amount the predicting procedure comes to an end. The above numeric example was a sample for the suggested method in predicting the conditions in decision making where the conditions are uncertain. Thus, in any period by evaluating the present situation of the storage and its inputs and according to the downstream demand, simply and quickly the release in a way that the operation is optimized can be calculated even in long term and the total of deficiencies during the operation period is minimized.

5. Conclusion

In this research; a meta-heuristic optimizing method (Tabu search) was combined with a decision making method in uncertain conditions (fuzzy logic) to study the operation of dam storage. In fact, the optimizing model has the role of training the fuzzy model and passing on its experience to it; and as its manner is optimized therefore it will also optimize the fuzzy model treat. According to the results of this research, with the downstream demand, the storage input and the amount of water in the storage, after applying fuzzy model, we can finally calculate the amount of storage release in every timer period.

We can mention the following as the advantages of this method:

- This method is quite simple, quick and can simply be run by software.
- As in these kinds of problems uncertainty is high in the input variables, applying crisp optimizing methods, although seem theoretically logical, with a slight change in the problem input, the conditions change and are incompetent.

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