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Optimal Design of Water Distribution Networks Applying Pattern Search Algorithm with Fuzzy Parameters

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Abstract

Water distribution network optimization has been among the most significant issues that scientists have ever regarded it highly and have done their best to cut the expenses by taking hydraulic constraints into consideration. Accordingly, regardless of the uncertainty in the parameters of network design, optimization seems something unreal. Regarding the attempts made by other scientists to simulate the uncertainties in different systems; in this study, the Fuzzy method is used to model uncertainty in fuzzy uncertainty. Also, the Pattern Search of algorithm is used for optimizing water distribution network devices. By considering Friction coefficient in Darcy-Weisbach equation, a demand in nodes, and tank head as independent fuzzy parameters we can study cost variations, heads in nodes, velocity, and discharge pipes which are known as dependent fuzzy parameters.

Key words: Optimization, Fuzzy parameter, Pattern of search, Water distribution network

1 Introduction

Water networks optimization has been under research for about four decades, and notwithstanding a myriad of research studies carried out during this period, this subject, contrary to scientists' expectation is still a theory and is not practically employed by engineers dealing with designing distribution network projects. A reason to this can be scientists' neglection to selecting object function and optimization procedure. In all procedures conducted before, object function set for decreasing costs in constructing networks work under hydraulic constraints, and the most important thing in optimization was to earn total profit out of network and in this case, network could be designed at any time according to circumstances. Therefore, network uncertainty resulting from errors necessarily has to be considered as a future need. In this way, optimization can be put into practice. Concerning network designing, there are purposes that seem difficult to be fulfilled and it is because of model disability where there is uncertainty. Among the best procedures for applying uncertainty is fuzzy method. Although fuzzy method has been developed by Professor Zadeh for circa five decades and it is really applicable in engineering, it's not a long time that it has been applied in optimization. Goulter and Bocharat (1988) are pioneers of fuzzy method. They applied trapezoid membership functions for describing pressure deviation from desirable pressure in each node for designing an optimum network with the help of linear planning. Vamookride (1995) applied fuzzy functions with the help of dynamic planning for designing a convoluted networker [1.2.3].

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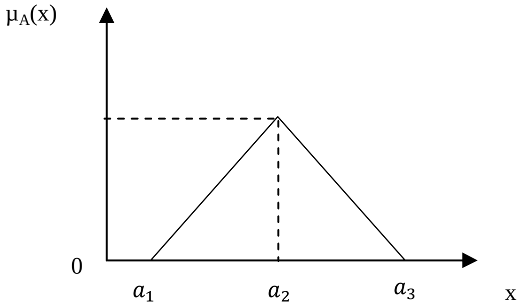
2 Uncertainly

Models of water distribution network are simulated models that are constructed for expanding water distribution networks into real networks. These models often involve certain and exact values and a large number of these internal parameters are described as a certain value. However, these certain parameters are a part of uncertain parameters. Uncertainty comes down to 3 groups. The first group characterized by measurement devices in which there are errors such as pump characteristics, tank head, pipes length and diagonal. The second group includes inexact information about a variety of parameters like nodes demand that differ by the passage of time and the third group which contains parameters that are simplified in real network[4,5,6,7].

Fuzzy procedure describes any changes in internal parameters by applying fuzzy membership functions in which statistical data are not needed. Parameters can be made fuzzy by using membership functions that are expressed as triangle, trapezoid, Gucci, and…. In these functions, value for membership function is calculated for each different α-cut [8, 9]. In the current research study, triangle membership function is applied (Fig 1), in which we can calculate membership function of fraction in pipes friction by considering 20% uncertainty and calculate tank head by considering half meter uncertainty and estimate demand on nods by considering 5% uncertainty.



1: Triangle membership function

$$
\begin{cases}
\mu_A(x) = 0 & x \le a_1 \quad (1) \\
\mu_A(x) = \dfrac{x - a_1}{a_2 - a_1} & a_1 \le x \le a_2 \quad (2) \\
\mu_A(x) = \dfrac{x - a_3}{a_2 - a_3} & a_2 \le x \le a_3 \quad (3) \\
\mu_A(x) = 0 & x \ge a_3 \quad (4)
\end{cases}
$$

3 Optimization Model

In this article, external penalty function was used for combining constraints and object function, and Pattern Search algorithm was used for optimizing object function. Object function is as same as cost function and defined as equation 5.

$$\text{Min } C = \gamma \sum L_i D_i^e \quad (5)$$

In which C is total cost of pipes, Li and Di are pipe length and pipe diagonal respectively. γ and e are stable value that is achieved by the current price of pipes in market .

The constraints are either equal or unequal constraints. Equal constraints are as same as correlation in network nodes and unequal constraints are as equation 6 to 8.

$$D^{min} \le D_i \le D^{max} \quad (6)$$
$$H^{min} \le H_j \le H^{max} \quad (7)$$
$$V^{min} \le V_i \le V^{max} \quad (8)$$

In which D_i demonstrates pipes diameter, H_j shows pressure in nodes, and V_i is relative velocity in pipes [10, 11].

3.1 Pattern of search algorithm

The procedure of pattern of search algorithm is a sort of optimization that needn't information about object function gradient. Unlike conventional procedures that use higher derivations for finding optimal spot, this algorithm includes pattern, mesh polling and algorithm completion.

3.1.1 Pattern

A pattern comprises vectors in which pattern of search algorithm determines spots need consideration. The complex of vectors is dependent on the number (N) of object function variables. Actually, these vectors necessarily have to be a collection of positive base of R_N, in other words, there are 2 main procedures for determining pattern vectors: a) 2N procedure, b) NP1 procedure. In both procedures, N stands for the number of dependent variables. For instance, where object function involves three decision variables, there will be 6 vectors using 2N: [0 0 1], [0 1 0], [1 0 0], [0 -1 0], [0 0 -1], [-1 0 0], and where there are three decision variable there will be four vectors using NP1: [-1 -1 -1], [0 0 -1], [0 1 0], [1 0 0].

3.1.2 Mesh

In each phase, algorithm seeks spots by examining a collection named mesh in order to improve object function value. Indeed, Mash is achieved by multiplying vectors of search by a scalar known for mesh size and adding it to the current spot.

3.1.3 Polling

In each phase, algorithm calculates the spots on mesh in other words, calculates the value of object function. Where a complete polling is not used, algorithm stops as soon as arriving at a spot on mesh whose object function value is less than object function value of the current spot. If it occurs, calculation is successful and spot whose object function value was less will be employed in the next phase as a current spot. If algorithm fails to improve object function value, polling is unsuccessful and the present spot will be current spot in next phase. As long as calculation is done completely, algorithm examines object function value at all spots of mesh. Then it compares the lowest one with the current spot. Where the spot on mesh is less than current spot, polling is successful.

3.2 Algorithm halt criteria

A variety of criteria can be defined for optimization algorithm. These criteria can be the least size of mesh, the most number of calculation frequency of object function and alteration in value of function repeated twice on a row. Flowchart of (Figure 2) depicts how pattern of search algorithm works [12].

4 Procedure

4.1. Combination of optimization and uncertainty

In all steps, MATLAB was used.

4.1.1 Step one

Using network analysis through linear theory, friction coefficient of pipes was calculated regardless of uncertainty (normal value of friction coefficient in pipes means α-cut=1).

4.1.2 **Step two**

Using triangle fuzzy membership function(equations 1,2,3,4), and regarding 0.2 distances for α-cut, pipes friction coefficient, tank head, and demand was made fuzzy.

4.1.3 Step three

The relation between object function was determined like the equation (5).

The maximum and minimum need to be determined for constraints (the mentioned constraints in relation of 6, 7, 8) Constraints become non dimensional and combine with object function.

4.1.4 Step four

Using Pattern Search algorithm procedure, object function of water distribution network is optimized by regarding α-cut for each distance (at beginning α-cut=0 is regarded).

4.1.5 Step five

Results achieved in step four are studied, for all diagonals, constraints need to be satisfied. Therefore sixth step is taken, otherwise seventh step is practiced.

4.1.6 Step six

Object function value is calculated for diagonals.

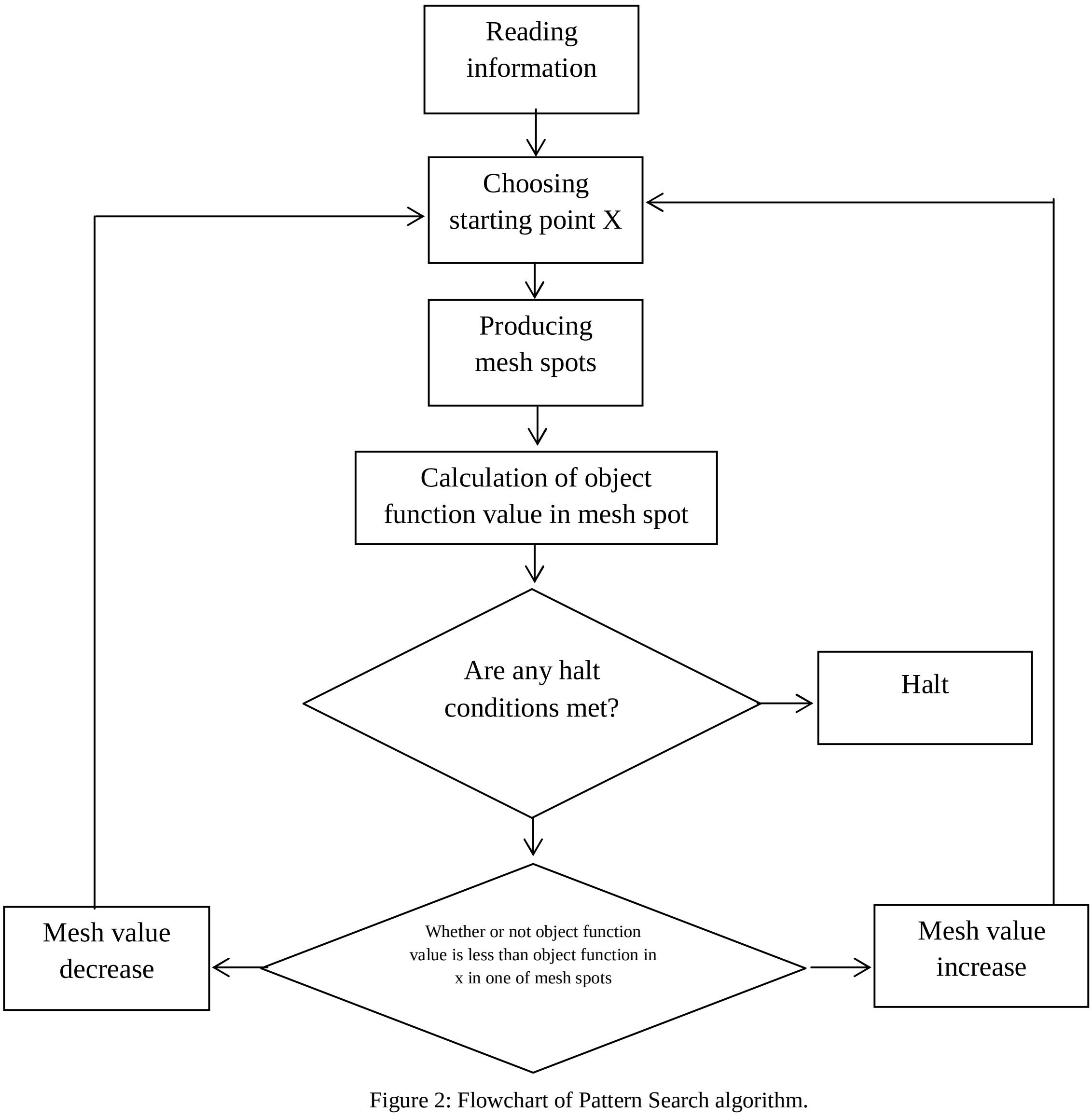


Figure 2: Flowchart of Pattern Search algorithm.

4.1.7 Step seven

Achieved diagonals values are used as a new assumption and then the third step is taken.

4.1.8 Step eight

In step four, α-cut in distances of 0.2 is replaced for α-cut=0 and then we continue the steps to seven.

4.1.9 Step nine

With the help of achieved values in the sixth step, triangle fuzzy membership function is drawn for water distribution network. Following flowchart demonstrates combination of uncertainty with optimization (Figure 3).

Table 1: Information required at the nodes

Node No.	1	2	3	4	5	6	7
Demand(m^3/hr)	-1120	100	100	120	270	330	200
Ground height(m)	210	150	160	155	150	165	160

Tables 2, 3, 4 show friction coefficient, demand node, and tank head values for different α-cut (fuzzy independent parameter). Pipes costs for different α-cut (dependent fuzzy parameters) are shown in Table 5.

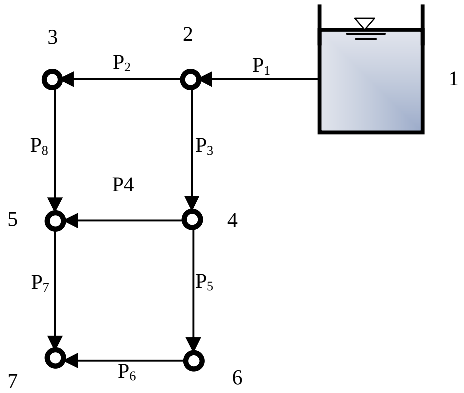


Figure 4: Structure of classic water distribution network

Table 2: Friction coefficient values for different α-cut

Pipe No.		1	2	3	4	5	6	7	8
α-cut=0	Min	0.014	0.016	0.015	0.016	0.015	0.021	0.017	0.014
	Max	0.021	0.024	0.02	0.024	0.023	0.031	0.026	0.022
α-cut=0.2	Min	0.015	0.017	0.015	0.017	0.016	0.022	0.018	0.015
	Max	0.020	0.024	0.021	0.023	0.022	0.023	0.025	0.021
α-cut=0.4	Min	0.015	0.018	0.016	0.017	0.017	0.023	0.019	0.016
	Max	0.019	0.023	0.021	0.022	0.021	0.029	0.024	0.020
α-cut=0.6	Min	0.016	0.019	0.017	0.018	0.017	0.024	0.0199	0.017
	Max	0.019	0.022	0.0198	0.021	0.020	0.028	0.023	0.0197
α-cut=0.8	Min	0.017	0198	0.018	0.019	0.018	0.025	0.021	0.017
	Max	0.018	0.021	0.019	0.021	0.0197	0.027	0.022	0.019
α-cut=1	Normal	0.017	0.021	0.018	0.0198	0.019	0.026	0.022	0.018

Table 3: Demand nodes values for different α-cut

Node No.		1	2	3	4	5	6	7
α-cut=0	Min	1064	95	95	114	256.5	313.5	190
	Max	1176	105	105	126	283.5	346.5	210
α-cut=0.2	Min	1075.2	96	96	115.2	259.2	316.8	192
	Max	1164.8	104	104	124.8	280.8	343.2	208
α-cut=0.4	Min	1086.4	97	97	116.4	261.9	320.1	194
	Max	1153.6	103	103	123.6	278.1	339.9	206
α-cut=0.6	Min	1097.6	98	98	117.6	264.6	323.4	196
	Max	1142.4	102	102	122.4	275.4	336.6	204
α-cut=0.8	Min	1108.8	99	99	118.8	267.3	326.7	198
	Max	1131.2	101	101	121.2	272.7	333.3	202
α-cut=1	Normal	1120	100	100	120	270	330	200

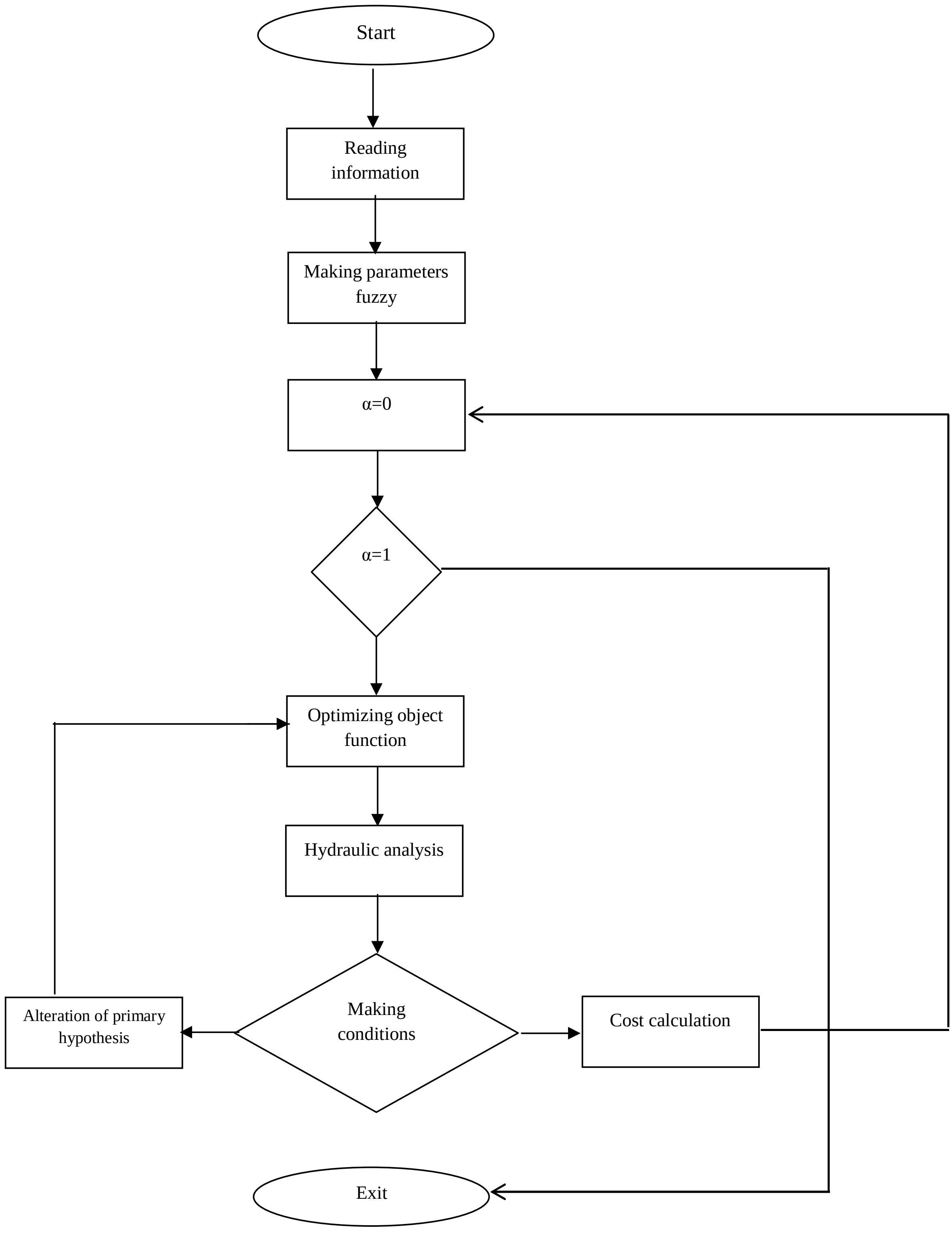


Figure 3: Flowchart of combination uncertainty and optimization

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α-cut=1	Normal	1120	100	100	120	270	330	200

Table 4: Tank head values for different α-cut

Head tank		
α-cut=0	Min	209.5
	Max	210.5
α-cut=0.2	Min	209.66
	Max	210.33
α-cut=0.4	Min	209.74
	Max	210.25
α-cut=0.6	Min	209.83
	Max	210.16
α-cut=0.8	Min	209.91
	Max	210.089
α-cut=1	Normal	210

Table 5: Pipes cost for different α-cut

Pipes cost ($)		
α-cut=0	Min	377000
	Max	518000
α-cut=0.2	Min	407000
	Max	508000
α-cut=0.4	Min	410000
	Max	478000
α-cut=0.6	Min	412000
	Max	460000
α-cut=0.8	Min	415000
	Max	450000
α-cut=1	Normal	420000

For example friction coefficient membership function for pipe 1 (Fig. 5), and pipe 8 (Fig. 6), demand membership function for node 1 (Fig. 7), and node 7 (Fig. 8), Tank head membership function (Fig. 9) are as below:

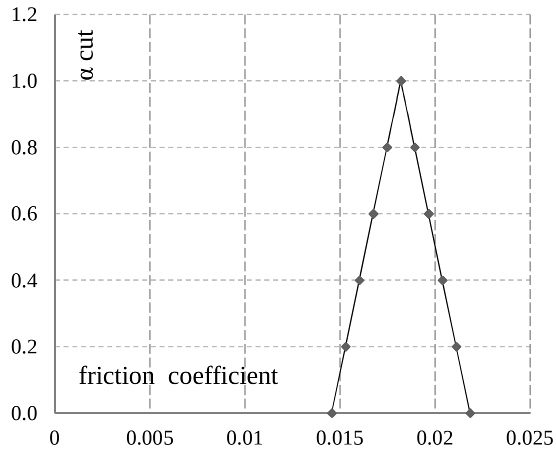

Figure 5: Pipe 1 friction coefficient fuzzy membership function

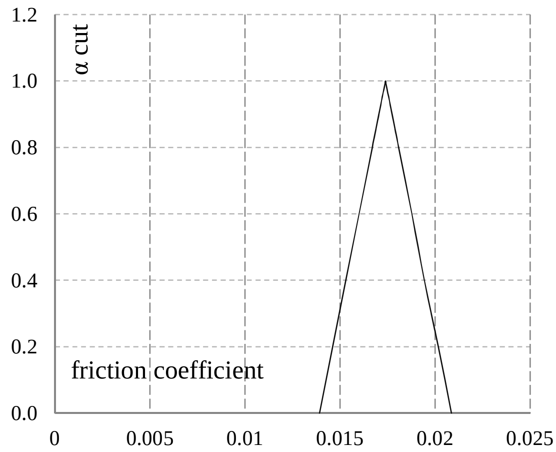

Figure 6: Pipe 8 friction coefficient fuzzy membership function

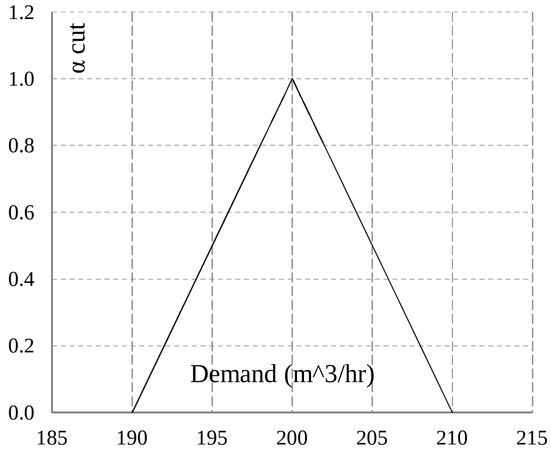

Figure 7: Node 1 demand fuzzy membership function

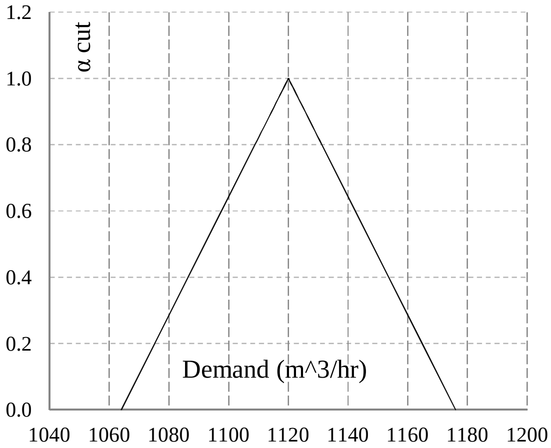

Figure 8: Node 7 demand fuzzy membership function

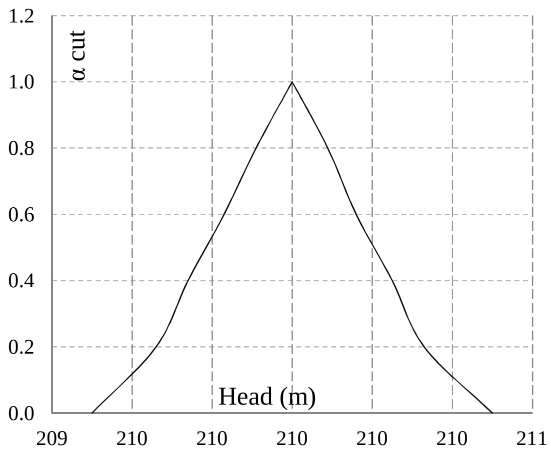

Figure 9: Tank head fuzzy membership function

Pipes costs for different α-cut (dependent fuzzy parameters) are shown in Figure 10.

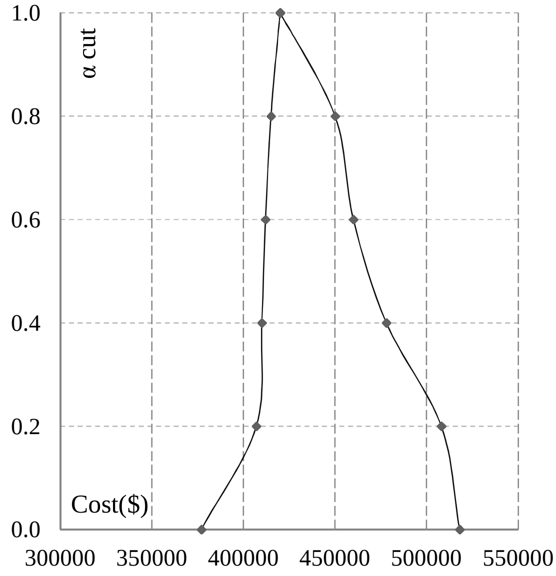

Figure 10: Depicts variation of network cost for each α-cut.

5 Conclusions

Uncertainty has been a part in water distribution network analysis and theory-based fuzzy procedure is an appropriate way for considering uncertainty in analyzing networks. Regarding friction coefficient as fuzzy, tank head and node demand are determined as uncertainty parameters (fuzzy independent parameters) where for each (α-cut) fuzzy membership function, the decrease value in heads, discharge, and velocity in pipes, which are all dependent fuzzy parameters, are changed. Additionally, applying independent fuzzy parameters in optimal designing of networks causes a variation in network cost- a dependent fuzzy parameter. Therefore, taking uncertainty into consideration is of paramount importance.

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