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Optimal Cost Design of the Water Distribution Network Using the Meta-Heuristic Methods

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ORIGINAL ARTICLE

ABSTRACT: Today, optimal cost design of water distribution networks is one of the fundamental issues in water management plans. In recent years, high accuracy of meta-heuristic methods has gained attention of researchers. In this research, genetic algorithm and harmony search methods were used for optimal cost design of water distribution network in Kourtay village, Khoy. The results showed the significant ability of the methods, since the design costs were decreased by 8% and 10% using the genetic algorithm and harmony search algorithm, respectively. Furthermore, the Harmony search method was found more optimal and faster than the genetic algorithm.

Keywords: Economic Optimization, Genetic Algorithm, Harmony Search Algorithm, Water Distribution Network

INTRODUCTION

Inadequacy of healthy water in most parts of the world not only increases general disappointment, but also decreases health and welfare level of society. Hence, design of water distribution networks is one of the important issues in water management plans. However, regarding the high costs of water supply projects, it seems necessary to use the optimal methods (meta-heuristic methods) for designing water distribution networks with the lowest costs.

Algorithms that can provide the optimal responses in acceptable time interval are called Meta-heuristic algorithms. In recent years, these methods such as genetic algorithm were mostly used because of their high accuracy and speed.

Simpson et al. (1996) introduced genetic algorithm to optimize designed water distribution network. They used a simple algorithm with three operators: production, integration and mutation. The study showed that genetic algorithm is effective in finding optimal solutions to study networks.

Denedy et al. (1996) proposed an improved genetic algorithm to optimize pipeline networks. The results showed that the improved GA has better performance than the simple GA.

Montesinos et al. (1999) proposed another modified algorithm to optimal design of water distribution network. This modified genetic algorithm was tested to water supplies of NY and found the solution of achieving lowest cost in lower levels than previous genetic algorithm.

Geem (2009) applied the harmony search method for optimal designing of water distribution network in Hanowey, Vietnam. . This network was analyzed before by Fujiwara and Kang (1991).

In this research, the meta-heuristic methods namely, the harmony search method and genetic algorithm methods, are used to optimize water distribution network of Kourtay village, Khoy. The Epanet software is used to design and analyze the water distribution network, and optimal cost design of the network is done by HDNET and Optidesigner software for the harmony search and genetic algorithms, respectively.

MATERIAL AND METHODS

Hydraulic stimulation

Hydraulic loss due to friction in a pipe is shown as follow:

$$h_L = aq^b$$

where, h_L is hydraulic loss, q is the discharge, a is the resistance coefficient, and b is the current index.

Penalty equation: to follow hydraulic constraints, a penalty function was introduced. Penalty function prevents unpractical solutions and makes low dimensional pipes, unable to supply the needed pressure, to be discarded from the project. Low amount of penalty equation increases retardation, and in high penalty equation the error is ignorable.

Constraints in designing water distribution networks: pipelines are designed to determine the diameter, work pressure of pipes, pumping load in pumping stations, flow rate and water speed.

Diameter of pipes: in urban water distribution network design, increasing diameter of pipes decreases flow rate and consequently decreases pressure in pipe. In

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water distribution design, minimum of pipe diameters is 50 mm.

Pressure of nodes: pressure of nodes seems to be 14-40 meters, unless, aerator shower or pressure valves should be used and change diameter of pipes.

Flow speed limit: speed limit of water transmission pipes are usually 0.3 to 2 meters, and in terminal pipes this speed can be less than 0.3 m. Design of main lines of water distribution network is based on maximum speed limit of 2 m/s. Based on the standards of water industry of the country, the maximum speed limit for firefighting is 2.5 m/s.

Design discharge: in water distribution systems, water transmission lines are designed based on maximum daily usage condition and water distribution networks based on maximum hourly consumption. However, water distribution network should transform the needed water of consumers and supply it in the most consuming day, hour and hot weather conditions, and during the project.

Principles of design: to present an optimal design based on technical, engineering and economic principles, population of present and future is scrutinized to cover their need during project.

Project period: the period of project is one of the important parameters and design basics in hydraulic constructions. Regarding the number of affecting parameters in project period, there is no accurate math model to evaluate and select optimal project period. In this research, project period is according to circular number 4449.100 of Department of Energy in 1995.

Study area

The Selkede, Cavusgoli, and Kourtay villages are located 8 km from Khoy city in west Azerbaijan province, Iran. The villages are positioned by a wide road,. Due to the vicinity of villages, there is no clear boundary among them. Water of the villages is supplied by a wellin eastern part of Kourtay village and water is pumping to a reservoir at the top of the mountain. Table 1 shows the Demographics records for the villages since year 1996.

Table 1. Rural population growth rate predicted by the geometric methods with analysis growth of the benefit conditions

No	Village	*1966*	Growth rate	*1976*	Growth rate	*1986*	Growth rate	*1996*	Growth rate	*2006*	Growth rate	*2011*	Growth rate	*2016*	Growth rate	*2021*	Growth rate	*2026*	Growth rate	*2031*
1	*Cavusgoli*	*280*	*2.96*	*375*	*4.72*	*595*	*-0.57*	*562*	*0.28*	*578*	*1.35*	*618*	*1.44*	*664*	*1.55*	*717*	*1.67*	*779*	*1.82*	*853*
2	*Selkede*	*442*	*2.74*	*579*	*2.76*	*760*	*0.63*	*870*	*0.63*	*979*	*1.40*	*1049*	*1.50*	*1131*	*1.62*	*1225*	*1.75*	*1336*	*1.91*	*1469*
3	*Kourtay*	*365*	*1.91*	*441*	*4.56*	*689*	*1.87*	*829*	*0.40*	*863*	*1.50*	*920*	*1.62*	*1007*	*1.75*	*1099*	*1.91*	*1208*	*2.10*	*1240*

Modeling and water distribution position

Water of the villages is provided from two wells, one of them is available and the other one will be drilled. The distance of the drilled well is 15 km from Cavusgoli village, 1.99 km from Cavusgoli village, and 2.065 km from Kourtay village.

For simulation, first required data including Autocad file of water distribution network and data about elements of regional water distribution network were gathered from West Azerbaijan Regional Water Authority. The data was then edited to provide input file for Epanet software. Designed network include 110 nodes, 117 pipes, one tank and one valve. To create the model, a file with BITMAP password was created to produce background of the Epanet file. IMPORT background of the Epanet file, nodes, pipes and tank were drawn, and then input data of the network, including diameter, stiffness, and length of pipes, consumed discharge and water balance of nodes, were entered and analyzed. In this case, the cost of used pipes (53.6, 63.8, 76.6, 6.8, 106.93, 136.6, 8.6 and 191.17 mm) is equal to 784543300.87 RIs.

To use created file in Optidesigner software, particular for genetic algorithm method, there is a need for a file with INP password, which should be measured after performance and opening file in this software and putting primary data, including unit cost, stiffness and diameter of pipes, pressure constraints of nodes, and velocity for pipes, and penalties, since the cost may decrease significantly but the constraints not be approved. Penalties are default in the program. There is no certain solution in selecting penalties. The error and trial method is used to achieve a practical solution. High amount of penalties create a better practical solution. After inputting primary data, the program is performed with repetition.The calculated cost of the pipes in this method is 726471000 RIs, which is 8 percent less than the calculated primary costs with Epanet software.

To create the file in HSNET software, particular for harmony search algorithm, an INP password file and DAT password file including diameter of pipes and their unit cost, and a PARA password file including minimum limit of each node and repetition of analyst are needed. Now, HSNET program is activated and INP file (created in Epanet program) is called and optimization is performed. The design cost calculated using the harmony search method is 703182000 RIs, which is 10% less than primary cost obtained using the Epanet software.

RESULTS AND DISCUSSION

Design of water distribution network for Kourtay village, Khoy, is done using the Epanet software, and cost optimization of the network is carried out using the genetic algorithm method with Optidesigner software and the harmony search method with HSNET software. The diameter of the pipes, flow pressure and velocity in pipes, and design cost are the outputs of the softwares. The results of the primary design is presented in Table 2 and 3.

According to Table 2, it is observed that the flow velocity is not in its range (0.3 to 2 m/s) in some pipes, low flow velocity creates sediments in the pipes and causes early failure and change of the pipes . To prevent velocity reduction, in the pipes, booster pump should be used.

However, high flow velocity increases pressure drop; therefore, there is a need to use pressure making facilities (pressure valves) in the network

Table 2. type of pipe (diameter mm) and flow velocity (m/s) in pipe for primary design

Pipe name	Pipe type	Velocity	Pipe name	Pipe type	Velocity	Pipe name	Pipe type	Velocity	Pipe name	Pipe type	Velocity
4	53.6	0.29	103	76.6	0.02	56	53.6	0.12	48	53.6	0.19
62	53.6	0.22	37	63.8	0.33	36	53.6	0.17	60	53.6	0.39
35	191.8	0.87	20	53.6	0.02	50	53.6	0.29	84	76.6	0.22
46	53.6	0.07	61	53.6	0.24	97	53.6	0.22	23	63.8	0.52
22	53.6	0.05	25	53.6	0.05	54	53.6	0.12	16	63.8	0.45
70	53.6	0.55	68	53.6	0.02	110	93.8	0.99	44	53.6	0.07
102	76.6	0.51	8	76.6	0.66	82	53.6	0.07	53	53.6	0.24
30	136.6	0.62	27	53.6	0.12	98	63.8	0.19	29	53.6	0.1
64	170.6	1	93	76.6	0.06	80	76.6	0.72	39	53.6	0.12
74	136.6	0.84	81	76.6	0.29	112	106.6	0.66	113	63.8	0.33
52	53.6	0.12	91	76.6	0.67	31	53.6	0.1	11	63.8	0.4
94	76.6	0.19	72	170.6	0.87	63	53.6	0.15	55	53.6	0.44

Table 3. Peer pressure of height (m) at each node for the original design

Node	pressure	Node	pressure	Node	pressure	Node	pressure	Node	pressure
NJ-90	34.97	NJ-53	32.59	NJ-38	32.08	NJ-97	29.91	NJ-84	29.19
NJ-32	43.67	NJ-36	42.78	NJ-73	27.64	NJ-91	29.41	NJ-72	27.56
NJ-99	31.45	NJ-41	33.26	NJ-48	34.3	NJ-57	26.43	NJ-27	41.02
NJ-13	24.02	NJ-30	30.16	NJ-83	26.17	NJ-110	38.18	NJ-86	43.05
NJ-89	30.2	NJ-65	31.92	NJ-55	37.04	NJ-21	41.25	NJ-80	28.04
NJ-47	38.08	NJ-100	26.61	NJ-23	39.94	NJ-75	41.23	NJ-103	41.86
NJ-104	37.6	NJ-67	28.94	NJ-106	26.68	NJ-85	28.07	NJ-62	35.37
NJ-107	13.76	NJ-5	44.13	NJ-35	35.28	NJ-15	31.03	NJ-19	24.41
NJ-17	39.81	N202-A	47.02	NJ-40	42.84	NJ-1	33.31	NJ-42	37.66

Based on the results, it’s seen that the pressure values at some nodes is outside its range (14-40 m). To solve this problem, there is a need for pressure valves (such as node 107) or pressure reducing valves (such as node 32, 202a).

In Table 4 and 5, type of pipe (diameter in mm) and peer pressure of height at each node obtained by the harmony method is presented . Based on the results of the Tables, the pressure values are in the range defined at the primary design.

Table 4. type of pipe (diameter in mm) for the harmony search method (HSNET)

Pipe name	Pipe type	Pipe name	Pipe type	Pipe name	Pipe type	Pipe name	Pipe type	Pipe name	Pipe type	Pipe name	Pipe type
4	53.6	19	53.6	37	53.6	10	53.6	50	53.6	21	53.6
62	53.6	73	93.8	20	53.6	41	53.6	97	63.8	45	53.6
35	106.6	92	53.6	61	53.6	24	53.6	54	53.6	76	136.6
46	53.6	104	53.6	25	53.6	42	53.6	110	63.8	47	53.6
22	53.6	108	53.6	68	170.6	34	170.6	82	53.6	15	76.6
70	170.6	6	53.6	8	76.6	71	170.6	98	53.6	100	63.8
102	63.8	85	53.6	27	53.6	29	53.6	80	93.8	79	93.8
30	136.6	48	53.6	93	53.6	39	53.6	112	93.8	14	53.6

Table 5. pressure (m) at each node for the harmony search method (HSNET)

Node	pressure	Node	pressure	Node	pressure	Node	pressure	Node	pressure
NJ-90	14.0647	NJ-50	28.4061	NJ-44	29.0342	NJ-41	25.3679	NJ-107	14.0179
NJ-32	34.8099	NJ-77	23.8031	NJ-84	29.3105	NJ-30	30.1849	NJ-17	30.8459
NJ-99	29.5071	NJ-31	35.7976	NJ-72	25.5002	NJ-65	22.4939	NJ-71	26.5923
NJ-13	24.2759	NJ-11	19.9393	NJ-27	32.385	NJ-100	25.9134	NJ-61	25.6381
NJ-89	30.1215	NJ-56	23.8049	NJ-51	23.9103	NJ-67	24.6967	NJ-87	30.7882
NJ-47	28.8277	NJ-79	28.9381	NJ-12	21.9192	NJ-5	21.2307	NJ-7	20.3624
NJ-104	28.7415	NJ-8	17.3471	NJ-59	25.6172	N202-A	23.2432	NJ-14	22.7641

Table 6. Type of pipe and flow velocity in pipe for the genetic algorithm method (Optidesigner)

Pipe name	Pipe type	Velocity	Pipe name	Pipe type	Velocity	Pipe name	Pipe type	Velocity	Pipe name	Pipe type	Velocity
4	53.6	0.32	103	53.6	0.34	56	53.6	0.58	106	53.6	0.44
62	53.6	0.31	37	63.8	0.39	36	63.8	0.32	13	53.6	0.32
35	170.6	0.35	20	63.8	0.33	50	76.6	0.37	67	170.6	0.87
46	53.6	0.37	61	93.8	0.3	97	53.6	0.8	51	170.6	0.91
22	63.8	0.35	25	53.6	0.44	54	106.6	0.75	38	53.6	0.34
70	53.6	0.55	68	53.6	0.56	110	53.6	0.62	90	170.6	0.37
102	63.8	0.52	8	53.6	0.48	82	53.6	1.08	52	53.6	0.42
30	93.8	1.31	27	53.6	0.32	98	76.6	0.35	94	53.6	0.53
31	53.6	0.65	93	76.6	0.46	80	106.6	0.37	91	53.6	0.34
63	53.6	0.53	81	63.8	0.74	112	63.8	0.57	72	76.6	0.92

Table 6 shows the type of pipes (mm), and flow velocity (m/s) obtained by the genetic algorithm method (Optidesigner). It indicates that the flow velocity values in the pipes are in their range and there is no need for accessories or pipes with more diameters.

Table 7. pressure (m) at each node for the genetic algorithm method (Optidesigner)

Node	pressure	Node	pressure	Node	pressure	Node	pressure	Node	pressure	Node	pressure
NJ-90	28.71	NJ-53	23.19	NJ-38	32.08	NJ-97	27.16	NJ-61	30.5	NJ-107	14.1
NJ-32	37.72	NJ-36	35.47	NJ-73	24.83	NJ-91	20.27	NJ-87	35.55	NJ-77	23.76
NJ-99	28.64	NJ-41	26.16	NJ-48	27.2	NJ-57	25.18	NJ-7	20.22	NJ-5	37.87
NJ-13	24.4	NJ-30	29.97	NJ-83	26.02	NJ-110	31.09	NJ-44	29.03	NJ-54	25.21
NJ-89	30.2	NJ-65	22.25	NJ-55	30.8	NJ-21	34	NJ-84	29.02	NJ-35	28.19
NJ-47	31.84	NJ-100	22.61	NJ-23	32.64	NJ-75	34	NJ-72	25.59	NJ-29	29.11
NJ-104	31.65	NJ-67	24.82	NJ-106	26.68	NJ-85	33.99	NJ-27	35.06	NJ-15	28.07

Results of the Table 7 show that the pressure values are in their range and this is due to the fact that at the primary design stage, the pressure range was defined.

Table 8, 9 and 10 represent the total length of the intake pipe based on pipe type and its cost (RIs) using the primary design, genetic algorithm and harmony search method, respectively.

Table 8. Length of intake pipe and the cost (Epanet)

Length	8532.79	1247.42	2619.65	481.44	156.54	2117.07	417.71	1606.80	Cost= 784643
Diameter	53.6	63.8	76.6	93.8	106.6	136.6	170.6	191.8	

Table 9. Length of intake pipe and the cost (OPTIDESIGNER)

Length	8595.78	3004.76	1218.75	247.19	423.31	603.07	3086.6	Cost= 726471
Diameter	53.6	63.8	76.6	93.8	106.6	136.6	170.6	

Table 10. Length of intake pipe and the cost (HSNET)

Length	10809.0	1042.89	486.19	1112.9	159.25	1718.03	1834.2	17.06	Cost= 703182.3
Diameter	53.6	63.8	76.6	93.8	106.6	136.6	170.6	191.8	

Form these Tables it is seen that the harmony search method, with its hydraulic constraints, mostly uses low diameter pipes, therefore its design cost is less than two other methods. Generally, the harmony search method and genetic algorithm decrease the design cost by 10% and 8% respectively, compared to the original design. In harmony search method, repetition time before achieving optimal response is more than the genetic algorithm, but it ends more rapidly. Therefore, the Harmony search method is more applicable than the genetic algorithm method

CONCLUSION

This research evaluated efficiency and ability of two various meta-heuristic methods for optimal cost designing of water distribution network in Kourtay village, Khoy. Based on the results obtained, both of the methods have enough ability to decrease the design costs of water distribution networkIn general, the results of this study can be summarized as follow:

1. The design costs of the system were decreased by 10% and 8% using the harmony search method and genetic algorithm, respectively.
2. The Genetic algorithm and harmony search methods are efficient in minimizing the design cost of pipes of water distribution network in Kourtay village.
3. The Harmony search method gives more optimal and faster solution than the genetic algorithm method.

It is suggested to use other optimization methods in water distribution network designing in future works.

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