Water Resour Manage (2011) 25:2197–2218
DOI 10.1007/s11269-011-9802-5

Effect of Utility Function Curvature of Young's Bargaining Method on the Design of WDNs

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Received: 8 July 2010 / Accepted: 14 February 2011 /
Published online: 17 March 2011

Abstract The optimal design of a water distribution network is a simulation-optimization task that should consider conflicts between different groups of stakeholders directly or indirectly. Investors and consumers are two groups of stakeholders with conflicting goals. Young's bargaining method is a decision tool based on game theory that can help decision-makers to select one of the design alternatives by considering utilities of stakeholders. In this paper, the optimal design of two benchmark network problems (Two-loop and Hanoi networks) is considered with minimization of design cost and maximization of system efficiency, with respect to increasing hydraulic pressure. In this regard, decision alternatives are first determined by using a multi-objective, fast, messy genetic algorithm (MOFMGA).

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Young's bargaining method is then applied with different combinations of utility functions of stakeholders. Results show that the use of the same utility functions for both stakeholders improves 63.23% and 24.47% of investor goals and 79.08% and 45.69% of consumer goals compared to the worst possible alternatives in the Two-loop and Hanoi networks, respectively. Moreover, both investor and consumer goals improve 6.19% and 7.14% in the Two-loop and 22.73% and 6.07% in the Hanoi network using a more concave utility function whose emphasis is on stakeholder utility, respectively.

Keywords Water distribution network · Design · Conflict resolution · Young's bargaining method · MOFMGA

1 Introduction

In recent years, population growth, improvement in living standards which causes to increase consumption, migration to urban regions, limitation of water resources, and conflicts among decision-making groups are important reasons for optimal design of water distribution networks (WDNs). Engineers commonly use nonlinear and complex equations to simulate quantitative and qualitative WDN characteristics. Computer softwares are widely used to overcome the existing complexity of equations. Although the calculations are more precise using those softwares, trial-and-error is used to find optimal/near-optimal solutions. While it is possible to find optimal/near-optimal solutions by trial and error, the probability of success is directly related to the number of times one executes trial-and-error calculations, which can be time-consuming. Thus, use of an optimization method together with a simulation model is recommended to find an optimal solution. Linear and nonlinear programming are two general optimization techniques that can be used to find optimal solutions. However, the corresponding modeling and running time involved can be high when designing WDNs, in which most of the equations are nonlinear and decision variables are discrete. On the other hand, the probability of finding global optima is less than for local optima. Consequently, evolutionary algorithms that can determine optimal/near-optimal solutions by random search have been developed.

Simpson et al. (1994), Dandy et al. (1996), Savic and Walters (1997), Montesinos et al. (1999), Tolson et al. (2004) and Van Zyl et al. (2004) applied genetic algorithm (GA) in WDN optimization problems. Cunha and Sousa (1999), Eusuff and Lansey (2003), Geem (2005), Keedwell and Khu (2006), Bozorg Haddad et al. (2008), Vasan and Simonovic (2010) and Cisty (2010) used simulated annealing (SA), shuffled frog leaping algorithm (SFLA), harmonic search (HS), cellular automata (CA), honey-bee mating optimization (HBMO), differential evolution (DE), and hybrid algorithm of GA and linear programming (GALP) respectively, when solving WDN problems.

In single-objective problems, one optimal/near-optimal solution is presented as the problem solution whereas in multi-objective problems, a set of solutions is identified as the problem solution. Extensive applications of evolutionary algorithms in single-objective WDN problems have prompted the use of these algorithms as optimization tools in multi-objective WDN problems.

Halhal et al. (1997) were the first to use multi-objective GA (MOGA) to solve a WDN problem. They identified minimization of network cost and maximization of benefits as the objectives of the rehabilitation problem. Total benefit was calculated by using weights for hydraulic, physical integrity, and flexibility benefits. They applied structured messy GA (SMGA) to calculate an optimal solution. Prasad and Park (2004) used a MOGA approach to design a WDN. They identified minimization of the network cost and maximization of a reliability measure as objectives and calculated a set of solutions in decision space for two widely-reported example problems. Prasad et al. (2004) applied nondominated sorting GA (NSGA)-II in the booster disinfection of water supply networks. The objectives were minimization of the total disinfection dose and maximization of the volumetric demand within specified residual limits. They utilized the theory of linear superposition in water quality modeling for calculating concentration profiles at network nodes. Jin et al. (2008) used NSGA-II in water supply network rehabilitation considering an artificial inducement mutation (AIM) operation to increase convergence speed in the optimization process. Montalvo et al. (2010) applied an improved multi-objective particle swarm optimization technique to find an appropriate Pareto-front in WDN design by considering minimization of network cost and lack of pressure at nodes.

In all the aforementioned multi-objective applications, the goal has been to find a set of nondominated solutions to be presented as decision alternatives. In fact, those alternatives are input data for the decision process and a final appropriate solution/alternative is then selected by decision-makers for various existing localized conditions. In real problems, different groups or organizations comprise the stakeholders who follow their objectives or utilities. An increase in stakeholder utilities when selecting an appropriate solution can cause conflicts among stakeholders in the project.

Investigations have been conducted in the application of conflict resolution models in the field of water resources management. Kucukmehmetoglu (2009) used linear programming to calculate country and coalition benefits, and game theory concepts (core and Shapley value) to evaluate the impact of reservoir projects throughout a basin, using the case of the Euphrates and Tigris. Mahjouri and Ardestani (2010) developed two cooperative and non-cooperative methodologies in a large-scale water allocation problem. They tried to achieve economic benefits with respect to the physical and environmental constraints of the system. Results showed that the cooperative method is more successful to achieve more revenue in utilizing the surface water resource while the river water quantity and quality issues are addressed. Kerachian et al. (2010) applied Rubinstein's bargaining theory which is a fuzzy game theoretic approach for groundwater resource management. They coupled the aforementioned approach to the NSGA-II to extract an appropriate solution from the trade-off curve. Results showed this approach is capable to overcome existing conflicts between different stakeholders of surface and groundwater resources. Sadegh et al. (2010) developed a crisp and fuzzy Shapley games for the optimal allocation of inter-basin water resources. Their methodology was applied to resolve conflicts between water users in the Rafsanjan plain, Iran. Results showed that water users' benefits from the Shapley games were more than what they gained alone without participating in any coalitions. Sensarma and Okada (2010) used a drama theory approach to bring a new perspective on cooperation analysis in a case study of the Yashino river weir conflict. There were two different stakeholders in this problem: (1) Governmental agency that proposed to remove and replace the old weir by a movable modern dam, and (2) an opposition group whose arguments were that the new weir may not be as effective as compared to the cost of constructing the new renewal project and damage of water quality and ecosystem. To redefine the problem, the objective frame was changed and both stakeholders' preferences gradually appeared to be shifting towards a more integrated flood management issue. Amit and Ramachandran (2010) presented a subgame perfect Nash equilibrium (SPNE) as the solution concept to design an extensive mechanism using fair contract for managing water scarcity. Results showed that to be economically efficient if, in case of deviation by the agent, the gain to the agent and the loss to the principal are small. Getirana and Fátima Malta (2010) applied non-cooperative game theory based on graph theory to evaluate strategies of an irrigation conflict with three groups of irrigators and six different scenarios to use canal water irrigation in Brazil. Salazar et al. (2010) used the nonsymmetric Nash bargaining method to optimize the weighted Nash product to obtain preferred alternatives for supplying water from different resources in the Mexican valley which is one of the most critical areas in term of supplied water in Mexico.

Game theories in general and Young's bargaining method in particular are procedures that consider existing conflicts and utility functions of stakeholders, and can yield an optimal solution from the decision space or an appropriate solution (alternative) from available alternatives.

Shirangi et al. (2008) applied Young's (1993) bargaining method in a simplified reservoir operation problem that considered water quality and quantity issues. They used the MOGA to calculate an appropriate trade-off curve between objectives related to the allocated water quantity and quality. Young's bargaining method was then used for selecting the best solution on the trade-off curve. Niksokhan et al. (2009) identified a stochastic conflict-resolution model for trading pollutant discharge permits in river systems. They applied the NSGA-II to find a trade-off curve. The best solution from this curve was defined by using Young's (1993) model. Utility functions were related to the total treatment cost and a fuzzy risk of violating water quality standards. Bazargan-Lari et al. (2009) proposed a conflict-resolution model for conjunctive use of surface and groundwater resources that considered water quality issues. In their model, stakeholders have conflicting interests related to water supply with acceptable quality, pumping costs, and water-table fluctuations. Thus, quality and quantity simulation models were linked to the NSGA-II as the optimization algorithm to find a trade-off curve. The best solution on the trade-off curve was selected by using Young's (1993) bargaining method.

In this paper, design of WDNs with two objectives, minimization of cost and maximization of system efficiency (due to hydraulic pressure), are considered in two known problems. Those objectives are identified as the conflicting utilities of stakeholders which include investors and consumers. To determine the best trade-off between those objectives, fast messy GA (FMGA) is used as the optimization tool. To overcome the existing conflict and finding an appropriate decision, Young's (1993) bargaining method is used. Results of the proposed procedure can provide the most utility for both stakeholders at the same time.

2 Multi-Objective Optimization Problems

In the single-objective optimization problems, minimization/maximization of an objective is considered as the goal of problem while there is a vector of minimization/

maximization problems (VMP) in multi-objective optimization that defines objectives as:

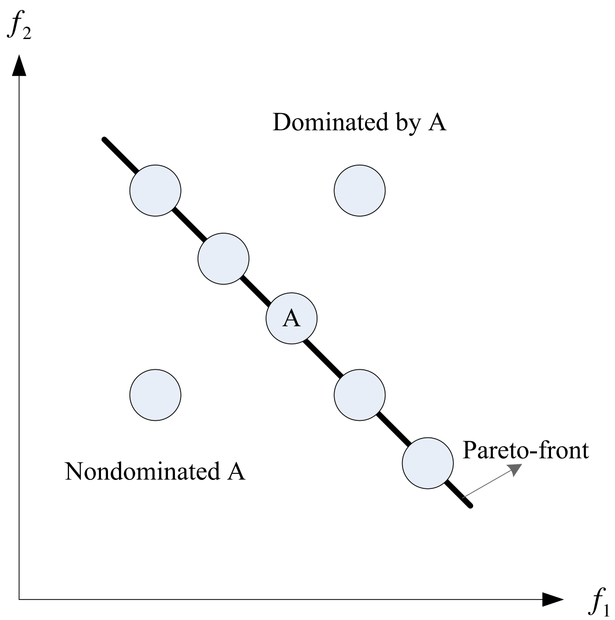
$$Min./Max. \qquad f(x) = (f_1(x), f_2(x), \ldots, f_n(x)) \qquad x \in X \tag{1}$$

$$f : X \to R^n, n \in \mathrm{N} \tag{2}$$

in which: $f(x)$ = VMP; X = decision space; x = decision variable; n = number of objectives; and N = natural value set. If the number of objectives is equal to one, then the problem reduces to a single-objective problem.

Solution of multi-objective problems can be presented as a set of nondominated solutions/Pareto-front, in which none of the solutions is preferred to others. An appropriate Pareto-front starts from the optimum of one objective, and ends up at the optimum of another one. Figure 1 shows a solution in the Pareto-front opposite to another solution in the decision space in a bi-objective minimization problem in which both objectives move toward minimum points. As it is shown, there are several solutions in the Pareto-front which are nondominated by solution A. These solutions have no preference to solution A, because an increase in the first objective causes a decrease of the second objective and vice versa. Thus, these nondominated solutions and solution A comprise a Pareto-front in which all solutions have the same worth in a mathematical analysis. Figure 1 shows a solution of the decision space that has a better (less) value than solution A in both dimensions (f_1 and f_2). Hence, this solution dominates solution A. In contrast, there is a solution which has a worse (high) value in both dimensions and it is dominated by solution A.

Fig. 1 Dominance and nondominance concept in minimization of bi-objective problem



3 Multi-Objective Fast Messy Genetic Algorithm

Results of many applications have shown that GA may not achieve a global solution in some NP (Nondeterministic Polynomial-time) hard problems. Consequently, GA techniques have been developed that can provide a fast convergence to a global solution. Messy GA (MGA), first published by Goldberg et al. (1989), is one of those techniques that attempts to solve optimization problems by messy searching. In the MGA, chromosome length is cut down and these chromosomes are called building-block. To evaluate the solution, building-blocks are then combined with each other and the searching process is continued. Thus, the time of the MGA calculation increases in large-scale problems. To decrease the time of calculation, fast MGA (FMGA) was proposed by Goldberg et al. (1993). Multi-objective FMGA (MOFMGA) is a multi-objective version of the FMGA which has the ability to achieve appropriate nondominated solutions. The MOFMGA filters building-blocks by cutting down the chromosomes and throwing off the genes with less importance.

There are two inner and outer loops in the MOFMGA and the outer loop is called era. Value genes are initialized in the era, then building-blocks are filtered, and the first phase done in the inner loop. Thus, there are two (first and second) phases in the MOFMGA. In the primordial (first) phase, selection alone is run to transfer the population with a high proportion of the best building-blocks. It is also common to adjust the population size to be appropriate for the processing of the second or juxtapositional phase. During the juxtapositional phase, selection is used together with a cut-and-splice operator. Early on when strings are short, the chance of a cut is low, but splicing proceeds at normal rates. Therefore, early in the process, cut-and-splice behaves like splice alone, roughly doubling string lengths at each innovation. Later in a run when string lengths are long, parent strings get cut with near certainty, and the combination of cut-and-splice acts something like the one-point cut crossover operator of simple GA. More information on the MOFMGA is contained in Goldberg et al. (1993).

The capability of the MOFMGA has been verified in several studies. Day et al. (2004) compared the MOFMGA-II, NSGA-II, and multi-objective Bayesian optimization algorithm (MBOA) in five test problems. Results showed that although the string length can affect the efficiency of finding an optimal Pareto-front in the MOFMGA-II, this algorithm is more successful in determining optimal Pareto-front compared to other algorithms. Day and Lamount (1993) compared different versions of the MOFMGA in known test problems by considering metric values such as error ratio (ER), generational distance (GD), hyperarea ratio (HR), spacing (S), and overall nondominated vector generation (ONVG) as the indicators of comparison. Results showed that the MOFMGA-II can find more appropriate solutions compared to other algorithms and especially the MBOA.

4 Young's Bargaining Method

Usually, there is more than one stakeholder in most multi-objective optimization problems in the field of water resources. These stakeholders may have different and even diverse utilities which should be considered in the problem formulation by the solution methods. For instance, weighting and epsilon-constraint methods can present each point of the Pareto-front by transforming the multi-objective problem to a single-objective one by using the weighting vector and constraint level, respectively. Thus, the resulted Pareto-front by such methods is directly dependent on the input data such as a weighting vector or constraint level. Thus, identification of the ideal point among such resulting points (solutions) produced by different weighting vectors or constraint levels can be expressed as a conflicting issue. However, bargaining methods based on game theory have been created, developed, and used to resolve such conflict issues.

Young's (1993) model is a bargaining game (method) that includes two stakeholders who try to maximize their payoffs as much as possible at the same time. In this model, the role of each stakeholder is represented by a utility function which is identified as weakly concave and strictly increasing. The goal of Young's model is maximization of $R(Z)$ as follows (Shirangi et al. 2008):

$$Max.\ R(Z) = Min.\left\{ \underset{p\in I_1}{Min.} \frac{\frac{\partial U_p(Z_1)}{\partial Z_1}}{U_p(Z_1)}, \underset{q\in I_2}{Min.} \frac{\frac{\partial U_q(Z_2)}{\partial Z_2}}{U_q(Z_2)} \right\} \tag{3}$$

in which: $R(Z)$ = Young's function; U_p = utility function of pth stakeholder; U_q = utility function of qth stakeholder; I_1, I_2 = first and second stakeholders, respectively; and Z_1, Z_2 = first and second objective values (Young's values) with the same unit, respectively. The relation between Z_1 and Z_2 is:

$$Z_1 + Z_2 = 1 \tag{4}$$

Shirangi et al. (2008) proposed the following relations to standardize the value of objectives with different values:

$$Z_1 = \frac{l_1}{l_1 + l_2} \tag{5}$$

$$Z_2 = \frac{l_2}{l_1 + l_2} \tag{6}$$

where l_1, l_2 = first and second objective values with different units, respectively.

Young's bargaining method uses weakly concave and strictly increasing functions for both utility functions. So, in multi-objective problems, which consist of the utility functions of minimization objectives with decreasing function, the minimization objective should be changed to the maximization one that can be used by the Young bargaining method. On the other hand, although Eqs. 4–6 have been used in the calculation process of Eq. 3, the range of l_1 or l_2 values affects the final values of Z_1 and Z_2. Thus, the higher the value of l_1 or l_2, the greater the effect on Z_1 and Z_2. In this paper, to apply weakly concave and strictly increasing utility functions and produce a similar effect on the objectives, values of l_1 and l_2 have been chosen between 0 and 1, as follows:

$$l_1 = \frac{f_1^{Max} - f_1}{f_1^{Max} - f_1^{Min}} \tag{7}$$

$$l_2 = \frac{f_2 - f_2^{Min}}{f_2^{Max} - f_2^{Min}} \tag{8}$$

in which: f_1 = value of the first objective function with maximization goal; f_1^{Max} = maximum value of the first objective function; f_1^{Min} = minimum value of the first objective function; f_2 = value of the second objective function with minimization goal; f_2^{Max} = maximum value of the second objective function; and f_2^{Min} = minimum value of the second objective function. Equations 7 and 8 transfer numbers for the maximization and minimization objectives, respectively.

The Young bargaining method is an evolutionary framework that imposes perturbations on individual behaviors in the population. Young considers two finite the populations as the player/stakeholder which all individuals in population have the same condition (utility) during the calculations. One of the main limitations of the Young bargaining method relates to the number of players which should be equal to two players. Thus, the Young bargaining method is used in a problem with more than two players by breaking down the main problem into correlative problems that consider two players in each problem.

5 Water Distribution Network Design

WDN design is one of the important problems in urban water systems that involve different stakeholders. In this paper, minimization of cost for investors and maximization of the system efficiency (hydraulic pressure) for consumers are considered as the objectives of WDN design, as follows:

$$Min. \quad f_1 = \sum_{i=1}^{NP} Cost_i\left(D_i, L_i, T_i\right) \tag{9}$$

$$Max. \quad f_2 = \sum_{j=1}^{ND} \left[\frac{De_j}{De_{Total}}\right] \left(\frac{P_j - P_j^{Min}}{P_j^{Min}}\right)^a \tag{10}$$

in which: f_1 = total cost; NP = number of pipes in the system; $Cost_i$ = cost of ith pipe; D_i = diameter of ith pipe; L_i = length of ith pipe; T_i = type of ith pipe; f_2 = total efficiency of the system from resulting hydraulic pressures; ND = number of nodes in the system; De_j = demand of jth node; De_{Total} = total demand of the system; P_j = supplied pressure of jth node; P_j^{Min} = minimum allowable pressure for jth node; and a = weighting coefficient of pressure in the system.

When coefficient a is 1.0, each unit of pressure improvement is worth as much as the same benefit score. However, usually as pressure increases, each additional unit of pressure benefit is worth less. Therefore, a should usually be less than 1.0 (Watergems user's manual 2005).

According to Eq. 9, the cost of each pipe is directly related to its diameter, length, and type of pipe. Thus, the first objective is minimization of the system total cost. Equation 10 shows that the system efficiency is the excess pressure in each node. Thus, the second objective is maximization of total efficiency of the system extracted from hydraulic pressure. The other relations of the model are:

$$D_i^{Min} \le D_i \le D_i^{Max} \tag{11}$$

$$P_j^{Min} \le P_j \le P_j^{Max} \tag{12}$$

where: D_i^{Min} = minimum diameter of ith pipe; D_i^{Max} = maximum diameter of ith pipe; and P_j^{Max} = maximum allowable pressure for jth node. It should be noted that the pipe diameters are decision variables and they should be selected from a discrete set of diameters.

6 Case Study

To illustrate the capability of Young's bargaining method in determining an appropriate solution, two benchmark problems (Two-loop and Hanoi) in WDN design are considered.

6.1 Two-loop Network

The two-loop network is a benchmark WDN problem for simulation and optimization first considered by Alperovits and Shamir (1977). There are seven nodes and eight pipes, each having a length of 1,000 m. The schematic of this network is presented in Fig. 2. The Hazen-Williams coefficient for all pipes is equal to 130. The minimum and maximum allowable pressures for each node are equal to 30 and 60 m of water, respectively.

In this paper, pipe diameters are considered as decision variables. Thus, there are 15 different states for each pipe and the total number of state solutions is 8^{15}. Table 1 shows pipe cost data for various diameters in the Two-loop problem.

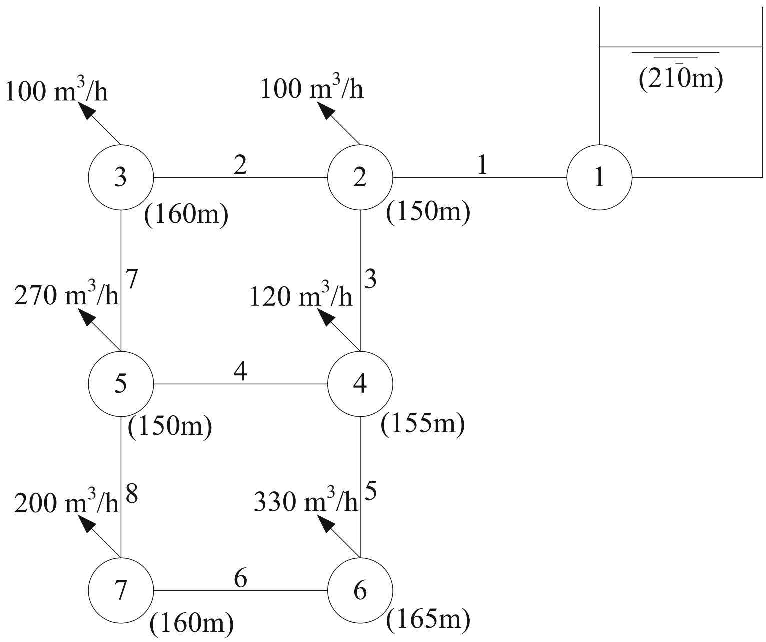


Fig. 2 Schematic of the Two-loop network

Table 1 Pipe cost for the Two-loop network

Diameter (m)	0.000	0.025	0.051	0.076	0.102	0.152	0.203	0.254
Cost ($/m)	0	2	5	8	11	16	23	32
Diameter (m)	0.305	0.356	0.406	0.457	0.508	0.559	0.610	
Cost ($/m)	50	60	90	130	170	300	550	

6.2 Hanoi Network

A schematic of the Hanoi network, which was first considered by Fujiwara and Khang (1987), is shown in Fig. 3. It consists of three loops with 32 nodes, 34 pipes with a Hazen–Williams coefficient equal to 132 for all pipes and a reservoir with a head of 100 m. In this network, as in the Two-loop network, pipe diameters are decision variables and the total number of state solutions is 34^6, considering seven different states for each pipe. Table 2 shows pipe cost data for various diameters in the Hanoi problem.

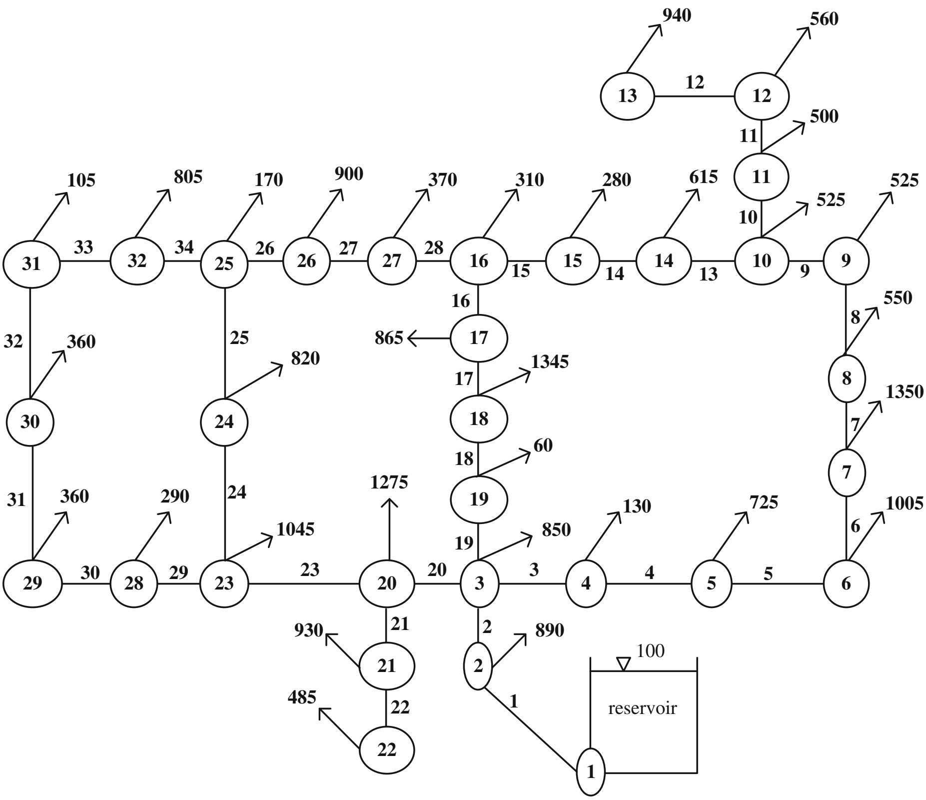


Fig. 3 Schematic of the Hanoi network

Table 2 Pipe cost for the Hanoi network

Diameter (m)	0.305	0.406	0.508	0.610	0.762	1.016
Cost ($/m)	45.726	70.4	98.378	129.333	180.748	278.28

7 Results and Discussion

In this paper, minimization of cost and maximization of system efficiency have been considered as the objective functions and the MOFMGA, whose capability has been verified compared to other algorithms, has been used as the optimization tool.

Watergems (Watergems user's manual 2005) is a software package that simulates quality and quantity specification of WDNs determining the water source and age, or track the growth or decay of a chemical constituent throughout the network and it is capable to apply the MOFMGA in WDN design and finding the Pareto-front as the set of nondominated solutions. This software performs steady-state analyses of WDNs with pumps, tanks, and control valves. Analysis of fire flow is the other capability of Watergems which simulate system behavior under extreme conditions. Also, Watergems software is capable to find the appropriate diameter for both WDNs based either on the gravity potential energy or a pumped system. Therefore, it has been used for designing the Two-loop and Hanoi networks. Both of the considered benchmark networks (Two-loop and Hanoi) are based on the gravity potential.

The MOFMGA is a stochastic algorithm that searches the decision space by randomly seed numbers, so different runs can result in different Pareto-fronts. Hence, results of ten different runs have been merged together and nondominated solutions have been extracted as the best Pareto-front. Figures 4a, b show the resulting final Pareto-front found by merging results of ten different runs for the Two-loop and Hanoi networks, respectively. It should be noted that the *a* parameter in Eq. 10 has been considered to be 0.001 for both networks. Tables 3 and 4 show statistical measures for resulting pipe diameters from 161 and 215 nondominated solutions for the Two-loop and Hanoi networks, respectively. Table 3 shows that the coefficient of variation for the 1st, 2nd, 3rd, 5th, 6th, 7th, and 8th pipes is less than one, which is a small value and variation of these pipes per unit is 0.1. The 4th pipe, which is a connecting pipe between the 4th and 5th nodes in the Two-loop network, has the maximum value of variation.

The other parameters which are shown in Tables 3 and 4 are median and mode. The median is the number in the middle of a set of pipe diameter; that is, half the diameters have values that are greater than the median, and half have values that are less. The mode is the number that most frequently occurs in the range of diameters for a pipe. Thus, these measures are important to find an appropriate diameter for a pipe. Results of the median and mode for the Two-loop network show that the 1st, 2nd, 3rd, 7th, and 8th pipes have the same value for the median and mode. Thus, these diameters can meet essential pressure considering the cost of the project. However, choosing an appropriate diameter for the 4th and 6th pipes with a high level of standard deviation and difference between median and mode is difficult.

The aforementioned results are more important in a more complex network whose selection of a diameter affects the other system parts. In the schematic of the Hanoi

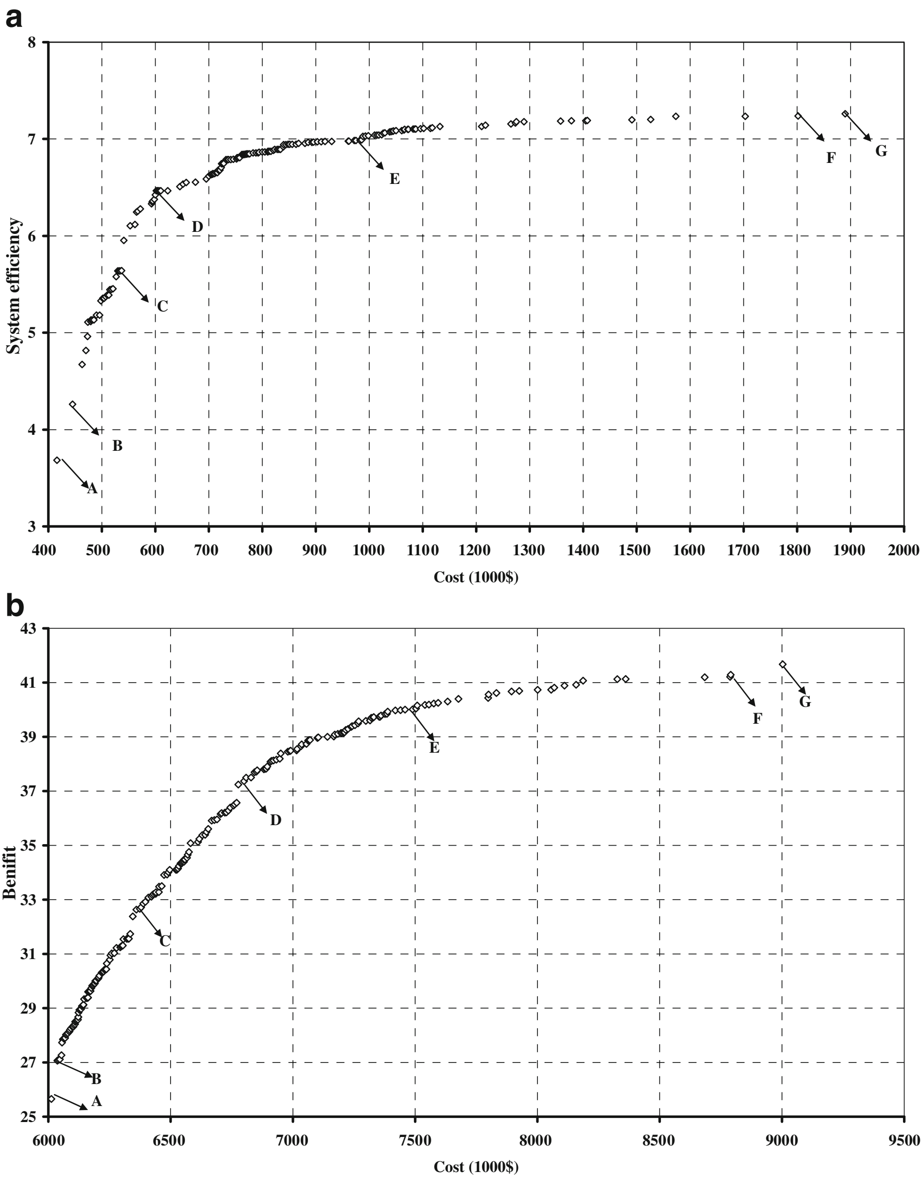


Fig. 4 Resulted Pareto-front for **a** the Two-loop and **b** the Hanoi networks

network, the 1st and 2nd pipes which are closer to the reservoir and have a main role to transfer water to the other nodes have the same diameter in all solutions of the Pareto-front. Although the aforementioned pipes have the same diameter, other pipes, especially 16th, 25th, 27th, and 28th pipes, have a considerable range of variations. According to Table 4, the pipes with the smaller values of coefficient of variation are better alternatives for the decision-maker to select the appropriate

Table 3 Statistical measures for pipe diameters of final nondominated solutions in the Two-loop network

Pipe number	Minimum (m)	Average (m)	Maximum (m)	Standard deviation (m)	Coefficient of variation	Median (m)	Mode (m)
1	0.457	0.536	0.559	0.038	0.071	0.559	0.559
2	0.254	0.472	0.559	0.048	0.102	0.457	0.457
3	0.356	0.432	0.559	0.064	0.147	0.406	0.406
4	0.000	0.081	0.559	0.132	1.631	0.051	0.000
5	0.305	0.409	0.559	0.058	0.143	0.406	0.356
6	0.000	0.097	0.559	0.094	0.969	0.051	0.203
7	0.254	0.406	0.559	0.051	0.125	0.406	0.406
8	0.000	0.348	0.559	0.066	0.190	0.356	0.356

Table 4 Statistical measures for pipe diameters of final nondominated solutions in the Hanoi network

Pipe number	Minimum (m)	Average (m)	Maximum (m)	Standard deviation (m)	Coefficient (m)	Median of variation	Mode (m)
1	1.016	1.016	1.016	0.000	0.000	1.016	1.016
2	1.016	1.016	1.016	0.000	0.000	1.016	1.016
3	1.016	1.016	1.016	0.000	0.000	1.016	1.016
4	1.016	1.016	1.016	0.000	0.000	1.016	1.016
5	1.016	1.016	1.016	0.000	0.000	1.016	1.016
6	1.016	1.016	1.016	0.000	0.000	1.016	1.016
7	0.762	1.003	1.016	0.055	0.055	1.016	1.016
8	0.762	0.947	1.016	0.110	0.116	1.016	1.016
9	0.610	0.805	1.016	0.098	0.121	0.762	0.762
10	0.762	0.777	1.016	0.058	0.074	0.762	0.762
11	0.610	0.686	1.016	0.080	0.117	0.610	0.610
12	0.508	0.566	0.610	0.050	0.088	0.610	0.610
13	0.305	0.389	0.508	0.090	0.231	0.406	0.305
14	0.305	0.439	1.016	0.138	0.313	0.508	0.305
15	0.305	0.437	1.016	0.125	0.286	0.508	0.508
16	0.305	0.699	1.016	0.293	0.418	0.762	1.016
17	0.508	0.782	1.016	0.218	0.278	0.762	1.016
18	0.610	0.859	1.016	0.170	0.198	1.016	1.016
19	0.508	0.843	1.016	0.183	0.216	1.016	1.016
20	1.016	1.016	1.016	0.000	0.000	1.016	1.016
21	0.508	0.579	1.016	0.115	0.199	0.508	0.508
22	0.305	0.373	0.762	0.090	0.241	0.305	0.305
23	0.762	0.975	1.016	0.093	0.095	1.016	1.016
24	0.508	0.711	1.016	0.145	0.204	0.762	0.762
25	0.305	0.594	1.016	0.208	0.349	0.762	0.762
26	0.305	0.549	1.016	0.155	0.282	0.508	0.508
27	0.305	0.549	1.016	0.220	0.401	0.406	0.406
28	0.305	0.551	1.016	0.235	0.426	0.508	0.305
29	0.406	0.478	1.016	0.090	0.188	0.508	0.508
30	0.305	0.381	1.016	0.093	0.243	0.406	0.406
31	0.305	0.315	1.016	0.075	0.238	0.305	0.305
32	0.305	0.401	1.016	0.095	0.237	0.406	0.406
33	0.305	0.424	1.016	0.073	0.171	0.406	0.406
34	0.508	0.632	1.016	0.108	0.170	0.610	0.610

diameters. Thus, it is difficult or even impossible to select appropriate pipe diameter for the 16th, 25th, 27th and 28th pipes.

In this paper, design of WDNs has been considered subject to different optimization objectives, including installation costs and hydraulic performance improvement of the network. If minimization of cost had been considered as the objective, the pipe with a smaller diameter can be used in the network. However, the maximization of system efficiency is the other objective which is directly related to nodal pressure. Thus, large diameters are more proper to meet increasing system efficiency, which is conflicting to minimization of cost.

According to obtained results, investors and consumers are willing to use pipes with smaller and larger diameters to supply their utilities. WDN design can involve stakeholders that have different utilities. There are both investor and consumer stakeholders that are conflicting together. Investors' utility is increased by cost minimization resulting from pipe selection with smaller diameters. In contrast, consumers' utility is increased by system efficiency maximization due to pipe selection with larger diameters.

In this paper, to overcome existing conflicts and making an appropriate decision, Young's bargaining method is applied. Two objective functions with different units are used. Moreover, one of them is maximization and the other is minimization. Thus, Eqs. 7 and 8 have been used to transfer objective function values to standard values.

Values of l_1 and l_2 have been transferred to Z_1 and Z_2 using Eqs. 5 and 6. Young's model needs to identify utility functions of stakeholders. The utility function must be increasing concave. In the problem under consideration, three different types of utility functions have been considered:

$$U_{1m} = Z_m \quad for \quad m = 1, 2 \tag{13}$$

$$U_{2m} = \sqrt[2]{1 - (Z_m - 1)^2} \quad for \quad m = 1, 2 \tag{14}$$

$$U_{3m} = \sqrt[10]{1 - (Z_m - 1)^{10}} \quad for \quad m = 1, 2 \tag{15}$$

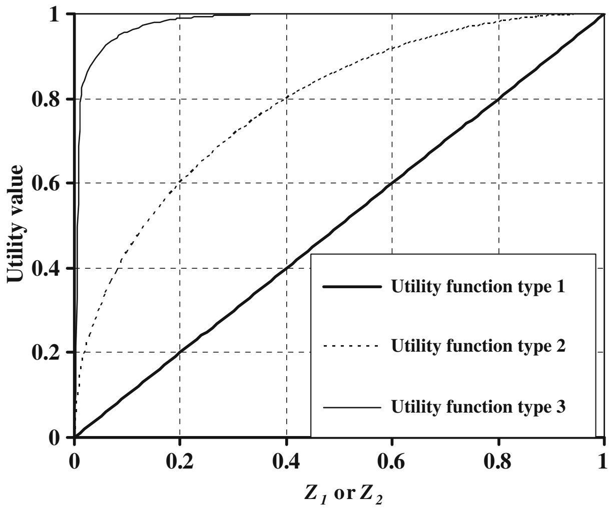


Fig. 5 The utility values for the different stakeholders

Table 5 Result of decision-making using the Young bargaining method

Two-loop network											
A	f_1	416000	Pipe number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Diameter (m)	0.508	.0.254	0.406	0.000	0.356	0.254	0.254	0.000
			Cost ($)	170	32	90	0	60	32	32	0
	f_2	3.68	Node number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	–
			Pressure (meter water)	–	56.0	30.7	46.6	32.3	30.8	31.0	–
B	f_1	445000	Pipe number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Diameter (m)	0.457	0.305	0.406	0.000	0.356	0.203	0.356	0.254
			Cost ($)	130	50	90	0	60	23	60	32
	f_2	4.26	Node number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	–
			Pressure (meter water)	–	53.2	34.1	44.9	41.4	30.7	30.4	–
C	f_1	537000	Pipe number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Diameter (m)	0.457	0.051	0.406	0.051	0.356	0.025	0.356	0.356
			Cost ($)	130	130	90	5	60	2	60	60
	f_2	5.64	Node number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	–
			Pressure (meter water)	–	53.2	41.3	46.0	46.8	33.6	35.8	–
D	f_1	695000	Pipe number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Diameter (m)	0.508	0.457	0.406	0.000	0.457	0.051	0.406	0.356
			Cost ($)	170	130	90	0	130	5	90	60
	f_2	6.59	Node number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	–
			Pressure (meter water)	–	56.0	44.0	48.7	51.7	38.0	40.7	–
E	f_1	972000	Pipe number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Diameter (m)	0.559	0.559	0.406	0.000	0.457	0.025	0.406	0.356
			Cost ($)	300	300	90	0	130	2	90	60
	f_2	6.99	Node number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	–
			Pressure (meter water)	–	57.5	46.7	50.2	54.3	39.5	43.4	–

Table 5 (continued)

Two-loop network											
F	f_1	1802000	Pipe number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Diameter (m)	0.559	0.508	0.559	0.559	0.559	0.457	0.559	0.025
			Cost ($)	300	170	300	300	300	130	300	2
	f_2	7.24	Node number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	–
			Pressure (meter water)	–	57.5	46.8	51.6	56.6	41.0	45.7	–
G	f_1	1890000	Pipe number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Diameter (m)	0.559	0.508	0.559	0.559	0.559	0.508	0.559	0.305
			Cost ($)	300	170	300	300	300	170	300	50
	f_2	7.26	Node number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	–
			Pressure (meter water)	–	57.5	46.8	51.6	56.6	41.2	46.1	–

Hanoi network

Decision point	A	B	C	D	E	F	G
f_1	6012407	6037159	6379542	6800132	7503466	8787868	9002918
f_2	25.65	27.06	32.72	37.37	40.04	41.21	41.67

A the best solution from Pareto-front for the first stakeholder, *B* result of the Young model using U_{2m} or U_{3m} for the first and U_{1m} for the second stakeholders, *C* result of the Young model using U_{3m} for the first and U_{2m} for the second stakeholders, *D* result of the Young model using U_{2m} or U_{3m} for both stakeholders, *E* result of the Young model using U_{2m} for the first and U_{3m} for the second stakeholders, *F* result of the Young model using U_{1m} for the first and U_{2m} or U_{3m} for the second stakeholders, *G* Best solution from Pareto-front for the second stakeholder where: U_{1m} = first type of utility function for mth stakeholder; $Z_m = m$th Young's value; U_{2m} = second type of utility function for mth stakeholder; and U_{3m} = third type of utility function for mth stakeholder.

Figure 5 shows the first, second, and third types of utility values for stakeholders (Z_1 or Z_2). The first utility function shows a linear relation between Z_1 or Z_2 and the utility value. This function can be identified as both concave and non-concave functions. The second and third types of utility are concave. The more concave the utility function, the more emphasis on meeting the best (maximum) possible utility by

Table 6 Pipes and nodes specifications for the Hanoi network in different optimum alternatives

Alternative A				Alternative B			
f_1		f_2		f_1		f_2	
6012407		25.65		6037159		27.06	
Pipe number	Diameter (m)	Node number	Pressure (water meter)	Pipe number	Diameter (m)	Node number	Pressure (water meter)
1	1.016	1	–	1	1.016	1	–
2	1.016	2	97.20	2	1.016	2	97.20
3	1.016	3	62.50	3	1.016	3	62.50
4	1.016	4	58.20	4	1.016	4	58.20
5	1.016	5	52.90	5	1.016	5	52.90
6	1.016	6	47.20	6	1.016	6	47.20
7	1.016	7	46.00	7	1.016	7	46.00
8	1.016	8	44.40	8	1.016	8	44.40
9	0.762	9	43.30	9	0.762	9	43.30
10	0.762	10	39.80	10	0.762	10	39.80
11	0.610	11	38.30	11	0.610	11	38.30
12	0.610	12	34.90	12	0.610	12	34.90
13	0.406	13	30.80	13	0.406	13	30.80
14	0.305	14	33.50	14	0.305	14	33.50
15	0.305	15	31.60	15	0.305	15	31.60
16	0.305	16	31.60	16	0.305	16	31.60
17	0.508	17	45.60	17	0.508	17	45.60
18	0.610	18	53.50	18	0.610	18	53.50
19	0.610	19	59.40	19	0.610	19	59.40
20	1.016	20	51.50	20	1.016	20	51.50
21	0.508	21	42.40	21	0.508	21	42.40
22	0.305	22	37.30	22	0.305	22	37.30
23	1.016	23	45.40	23	1.016	23	45.40
24	0.762	24	39.70	24	0.762	24	39.70
25	0.762	25	36.00	25	0.762	25	36.00
26	0.508	26	32.00	26	0.508	26	32.00
27	0.406	27	31.60	27	0.406	27	31.60
28	0.305	28	39.90	28	0.305	28	39.90
29	0.406	29	31.00	29	0.406	29	31.00
30	0.305	30	31.20	30	0.305	30	31.20
31	0.305	31	31.50	31	0.305	31	31.50
32	0.406	32	33.90	32	0.406	32	33.90
33	0.406	–	–	33	0.406	–	–
34	0.610	–	–	34	0.610	–	–

Table 6 (continued)

Alternative C				Alternative D			
f_1		f_2		f_1		f_2	
6379542		32.72		6800132		37.37	
Pipe number	Diameter (m)	Node number	Pressure (water meter)	Pipe number	Diameter (m)	Node number	Pressure (water meter)
1	1.016	1	–	1	1.016	1	–
2	1.016	2	62.50	2	1.016	2	62.50
3	1.016	3	58.80	3	1.016	3	59.30
4	1.016	4	54.20	4	1.016	4	55.30
5	1.016	5	49.40	5	1.016	5	51.20
6	1.016	6	48.30	6	1.016	6	50.30
7	1.016	7	47.10	7	1.016	7	49.40
8	0.762	8	43.50	8	1.016	8	48.80
9	0.762	9	41.00	9	0.762	9	47.10
10	0.762	10	39.50	10	0.762	10	45.60
11	0.610	11	36.20	11	0.762	11	44.40
12	0.610	12	32.10	12	0.508	12	34.40
13	0.406	13	40.10	13	0.305	13	48.60
14	0.305	14	41.90	14	0.508	14	49.70
15	0.406	15	43.70	15	0.508	15	51.80
16	0.610	16	52.10	16	1.016	16	55.40
17	0.762	17	56.20	17	1.016	17	58.80
18	0.762	18	60.40	18	1.016	18	61.30
19	0.762	19	53.20	19	1.016	19	57.00
20	1.016	20	44.10	20	1.016	20	47.80
21	0.508	21	42.80	21	0.508	21	42.80
22	0.406	22	48.50	22	0.305	22	49.20
23	1.016	23	44.60	23	0.762	23	45.70
24	0.762	24	42.40	24	0.508	24	44.70
25	0.762	25	39.60	25	0.305	25	48.50
26	0.406	26	40.00	26	0.508	26	50.00
27	0.406	27	43.00	27	0.610	27	46.20
28	0.406	28	34.30	28	0.762	28	41.10
29	0.406	29	34.60	29	0.508	29	39.70
30	0.305	30	34.90	30	0.406	30	39.80
31	0.305	31	37.30	31	0.305	31	40.80
32	0.406	32	97.20	32	0.406	32	97.20
33	0.406	–	–	33	0.406	–	–
34	0.508	–	–	34	0.508	–	–

stakeholders. However, the third one is more concave and it shows that the decision maker is forced to supply the better utility by considering this type of function.

According to Eqs. 13–15, six different combinations of utility functions are used in Young's model. Results of Young's model and two nondominated solutions from the Pareto-front with the best value of each objective are reported in Table 5 for the Two-loop and Hanoi networks. Results show that the decision solution is the same when using the same utility functions in both Two-loop and Hanoi networks. Thus, the same power of stakeholders moves toward a same decision and there is no dependency between the utility function types and the decision point; concavity of

Table 6 (continued)

Alternative E				Alternative F				Alternative G			
f_1		f_2		f_1		f_2		f_1		f_2	
7503466		40.04		8787868		41.21		9002918		41.67	
Pipe number	Diameter (m)	Node number	Pressure (water meter)	Pipe number	Diameter (m)	Node number	Pressure (water meter)	Pipe number	Diameter (m)	Node number	Pressure (water meter)
1	1.016	1	–	1	1.016	1	–	1	1.016	1	–
2	1.016	2	62.50	2	1.016	2	62.50	2	1.016	2	62.50
3	1.016	3	59.30	3	1.016	3	59.40	3	1.016	3	59.60
4	1.016	4	55.40	4	1.016	4	55.40	4	1.016	4	56.00
5	1.016	5	51.30	5	1.016	5	51.50	5	1.016	5	52.40
6	1.016	6	50.50	6	1.016	6	50.60	6	1.016	6	51.60
7	1.016	7	49.60	7	1.016	7	49.80	7	1.016	7	50.80
8	1.016	8	49.00	8	1.016	8	49.20	8	1.016	8	50.30
9	0.762	9	47.30	9	1.016	9	48.80	9	1.016	9	50.00
10	0.762	10	45.80	10	1.016	10	48.40	10	1.016	10	49.70
11	0.762	11	44.70	11	0.762	11	47.30	11	0.762	11	48.50
12	0.610	12	40.60	12	0.610	12	43.20	12	0.610	12	44.40
13	0.305	13	49.40	13	0.406	13	49.50	13	0.406	13	52.50
14	0.610	14	49.90	14	0.610	14	50.00	14	1.016	14	52.50
15	0.508	15	52.10	15	0.508	15	52.40	15	0.762	15	53.00
16	1.016	16	55.60	16	1.016	16	55.80	16	1.016	16	56.20
17	1.016	17	58.90	17	1.016	17	59.00	17	1.016	17	59.20
18	1.016	18	61.30	18	1.016	18	61.30	18	1.016	18	61.40
19	1.016	19	56.70	19	1.016	19	56.50	19	1.016	19	55.70
20	1.016	20	53.00	20	1.016	20	56.20	20	1.016	20	55.40
21	0.610	21	47.90	21	1.016	21	51.20	21	1.016	21	54.90
22	0.305	22	54.70	22	0.305	22	54.30	22	0.508	22	52.90
23	1.016	23	50.70	23	1.016	23	52.60	23	1.016	23	52.60
24	0.508	24	48.70	24	0.610	24	51.90	24	1.016	24	51.70
25	0.305	25	49.10	25	0.406	25	52.00	25	0.508	25	52.50
26	0.762	26	50.50	26	1.016	26	52.10	26	0.508	26	52.80
27	0.610	27	53.20	27	1.016	27	54.10	27	0.762	27	52.10
28	0.762	28	51.00	28	1.016	28	51.30	28	1.016	28	51.90
29	0.610	29	48.00	29	1.016	29	51.30	29	0.762	29	50.80
30	0.508	30	48.00	30	0.508	30	51.30	30	1.016	30	50.80
31	0.305	31	48.20	31	1.016	31	51.50	31	0.508	31	50.80
32	0.406	32	97.20	32	0.508	32	97.20	32	0.508	32	97.20
33	0.508	–	–	33	0.508	–	–	33	1.016	–	–
34	0.762	–	–	34	0.762	–	–	34	0.610	–	–

utility function is an ineffective parameter in the decision process. Figure 5 shows results of using Young's model for these combinations of utilities, presented by point D for both Two-loop and Hanoi networks. In this state, the first (consumers) and second (investors) stakeholders have achieved 6.59 and 37.37 m of water with an investment of $695,000 and $6,800,132 for the Two-loop and Hanoi networks, respectively.

Results showed that using the first type of utility function for each stakeholder is ineffective and the decision point is presented as the nearest nondomminated solution to the best solution. In Table 5, F and B are two decision points using the first type of utility function for the first and second stakeholders, respectively. It means that using a linear utility function for a stakeholder is ineffective in the process of decision-making. Figure 5 shows that F and B points have the minimum distance from G and A as the best solutions for the second and first stakeholders, respectively.

To compare the concavity effect of the utility function in decision-making, two different combinations of utility functions for the first and second stakeholders are considered. Results of these combinations are shown by C and E points in Table 5. According to these results, the decision point is nearer the best solution of each stakeholder when using the more concave utility function. The first stakeholders can design the water network with \$537,000 and \$6,379,542 and the consumers can achieve 5.64 and 32.72 m of water pressure using the third type of utility function for the first stakeholder in the Two-loop and Hanoi networks, respectively. However, the objective value for the first stakeholder is increased 81.01% and 24.80% and the value of the second stakeholder is decreased 23.94% and 3.92% by the third type of utility function for the second stakeholder in the Two-loop and Hanoi networks, respectively. Table 6 shows pipe diameters and nodal pressure of various decision points of the Hanoi network. Results showed that using a more concave utility function for the investor and consumer leads to a pipe with a small diameter and high nodal pressure, respectively.

8 Concluding Remarks

This paper introduced an application of Young's bargaining method in multi-objective WDN design. Consumers who try to increase pressure by using a high level of pipe diameters and investors who try to decrease cost by using a low level of pipe diameters are two groups of stakeholders in which their utilities are conflicting in a WDN project. Young's bargaining method was capable to overcome existing conflicts among different stakeholders. Thus, two nonlinear concave functions and a linear function were identified as utility functions, and nondominated solutions using the MOFMGA were extracted and considered as input data to Young's bargaining method. Six different combinations of utility functions were used and decisions were identified. Results showed that more concavity of utility functions lead the decision toward the best (maximum) utility value of each stakeholder. In addition, the utility function type is ineffective on the final decision and decisions that considered the same utilities are equal for stakeholders. In the other words, the concavity of an utility function forces the stakeholders emphasizing on meeting their most utility. Results showed that the objective of the first stakeholder improved (decreased) 6.19% and 22.73% for the Two-loop and Hanoi networks respectively and the second stakeholder's objective improved (increased) 7.14% and 6.07% for the Two-loop and Hanoi networks respectively with an increase in the concavity of the utility function.

In this paper, total cost and system efficiency as reflected by hydraulic pressures were considered as the two parameters in WDN design. Velocity is another parameter whose variation directly affects the operator's utilities, maintaining velocity within an acceptable range is an additional stakeholder in the design of WDNs. Opposite impacts of the small and high velocity values causes more conflicts between stakeholders by increasing or decreasing cost and system efficiency. On the other hand, the Young bargaining method was only applied in the two-player game. By using other bargaining methods which are capable to overcome existing conflicts between investor, consumer, and operator groups in the design and operation of WDNs will be considered in future investigations.

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