Proceedings of the 10th Annual Water Distribution Systems Analysis Conference WDSA2008, Van Zyl, J.E., Ilemobade, A.A., Jacobs, H.E. (eds.), August 17-20, 2008, Kruger National Park, South Africa.

CALIBRATION OF EPANET USING GENETIC ALGORITHM

M. Jamasb[1], M. Tabesh[2] and M. Rahimi[3]

[1]Department of Hydraulic Structures, Parab Fars Consulting Engineering Company
Shiraz, Fars, Iran; email: mehdijamasb@ yahoo.com

[2]Department of Civil Engineering, Tehran University
Tehran, Tehran, Iran; email: mtabesh@ ut.ac.ir

[3]Fars Regional Water Authority
Shiraz, Fars, Iran; email: rahimi_kousar@ yahoo.com

Abstract

Hydraulic models are used widely to simulate the hydraulic performance of water distribution systems in both design and operational stages. These models have a significant role on decision making procedures. It should be noticed that the quality of model outputs are directly related to the quality of input data. However, because of several reasons such as change of pipes friction factors and diameter, nodal demands, etc., the output results are error prone. On the other hand the design's criteria may be changed during operational period. Therefore, to improve the model performance and reduce the uncertainties during different consumptions procedures, it is necessary to calibrate these models. At the moment just a few commercial models such as WaterCAD which requires a considerable money expenditure are capable of calibration calculations (considering pipes friction factors or just nodal consumptions as the variable), besides the hydraulic analysis. In this research considering an optimization procedure using Genetic Algorithm, a computer code is prepared and linked to the hydraulic simulator (herein, EPANET) to calibrate the model. In this method some variables are considered: pipe friction factor (Hazen William Coefficient), nodal consumptions, combinations of both and pipe diameters. Finally to evaluate the advantages of the proposed methodology a test network is considered and the method is applied for different consumption scenarios.

1. INTRODUCTION

Today, with considering limited resources and increased necessities to water, optimized management and programming of available resources are inevitable. On the other hand, together with developing human knowledge, use of model for managing projects in different grounds has basic and determining role. In water distribution systems, models are used for different purposes. However, various factors always cause difference between reality and results of making similarity, including errors and presuppositions of design period, human and tool errors, false simplifying of a design, error in determining border conditions and so on. So, to be sure of model operation for different operating conditions, model calibration is necessary. In simple words, calibration process is the comparison of model results with field observations and as necessity adjusting data and primary information of analysis to obtain coordination between simulated and measured values in different conditions.

About conditions, suitable time and place of collecting required data from considered system known as sampling design; done many investigations and recommended briefly to choose some places that at first decreases uncertainties in system modeling process for different conditions, secondly decreases expenses of getting data and studies as possible, (Kapelan et al., 2003). For adjusting parameters; although all the information that their quantities is together with uncertainty can effect on the results of hydraulic analysis, but in most researches in order to simplify the work, tried to correct the effect of model and decrease errors only by adjusting the pipe friction factors, (Vassiljev et al., 2005). Till now different ways were applied for calibration of hydraulic analysis models that can be divided into three groups. In analytical methods, a try and error procedure in several repetitions is used to correct parameters, (Walski, 1983). In explicit methods, each considered parameter adds one equation to all equations of network, after that, equations are solved simultaneously, (Ormsbee and Wood, 1986). In implicit ones, the process declared as an objective function optimization with some constraints that their solutions cause to get indefinite parameters, (Walski et al., 2003). However, notice to this matter is necessary that most stated points have researching aspects and in a real network do not have required efficiency. Furthermore, for different reasons availability to models contain calibration features have expenditures such as WaterCAD model, (Haestad Methods, 2005).

So, in this research considering an optimization procedure using Genetic Algorithm, a computer code is prepared and linked to the hydraulic simulator (herein, EPANET which is freely available) to calibrate the model. In this method some decision variables are selected: pipe friction factor (Hazen William Coefficient), nodal consumptions, combinations of both and pipe diameters. Finally, to evaluate the advantages of the proposed methodology a test network is studied and the method is applied for different consumption scenarios.

2. PROBLEM DEFINITION

The design of hydraulic model calibration as an optimization matter; has better development and speed in addition of accuracy than others, (Walski et al., 2003). In this relation, different researchers have given various functions and methods, (Vassiljev et al., 2005) and (Greco and Del Giudice, 1999). To compare kinds of functions, because of better efficiency, chosen a structure for optimization process given in equation (1):

$$Min \qquad f(x)=\sum_{i=1}^{N} W_n \left(\frac{H_{calc}-H_{meas}}{H_{meas}}\right)^2 + \sum_{i=1}^{S} W_s \left(\frac{Q_{calc}-Q_{meas}}{Q_{meas}}\right)^2 \tag{1}$$

In this equation N is the number of points which have a barometer and S is the number of pipes which have a flowmeter. H_{calc} and Q_{calc} are nodal calculated heads and flow rates. W_n and W_s are weighted coefficients that can consider them as a function of headlosses and flow rates according to equation (2) and also WaterCAD model:

$$W_n = f\left[\frac{(Hloss)_n}{\sum (Hloss)_n}\right] \qquad \& \qquad W_s = f\left[\frac{(Q_{obs})_s}{\sum (Q_{obs})_s}\right] \tag{2}$$

Where $(Hloss)_n$ is headlosses in a route to the place of barometer *(n)* and $(Q_{obs})_s$ is the flow rate in the pipe *(s)* divided into all measured headlosses and flow rates. The constraints of problem include: 1- Hydraulic limitations of system which the programming of hydraulic models principally bases on equations dominant on networks. 2- Implicit limitations: under each demand condition, pressure of junctions and flow in pipes place between minimum and maximum quantities (according to field studies and conditions on networks). 3- Explicit border limitations: determine the range of decision variables.

3. CALIBRATION TECHNIQUE

In different researches, various approaches have been proposed for optimization process. But, because of considerable numbers of unknowns, existent uncertainty and difficulties in real water distribution systems, these methods have not appropriate efficiency. So, in following classic methods and together with increasing computer roles in solving complicated problems which have many decision variables, new techniques have been suggested and formulated. A statistical approach for optimization and search is Genetic Algorithm (GA) which is an applicable solution with high power to handle non-linear functions or constraints, (Haestad Methods, 2005). On this basis, GA is used to optimize above-mentioned function.

Linking Process of Optimization Model and EPANET

EPANET hydraulic simulator has been developed in C programming language and in some parts by the United States Environmental Protection Agency, (Rossman, 2000). But, account of complexities resulted in coordinating of different parts, model is planned as a source of orders and functions by using MATLAB7 programming language, then systems can be analyzed whenever required functions called. An input file (contains network features) and an output file was prepared in a special format and introduced to codes, after that it is possible to get results of analysis such as pressures at the location of nodes, flow rates in pipes and so on, (Jamasb, 2006). In optimization through genetic algorithm technique, value of decision variables will be adjusted in each generation and network analysis is done for all answers of populations and the objective function is calculated respectively. In this research, the optimization of problem is prepared by using genetic algorithm tool box in MATLAB7. After this, the program will be able to determine final value of variables automatically.

4. APPLICATION

To demonstrate the capability and feasibility of proposed procedure in calibration of EPANET model, one sample water distribution network has been investigated, applied trend on it and studied results. As information of networks is needed in different condition of consumptions for a complete comparison and study, considering these matters, many articles and researches were reviewed. The chosen pipe network shown in Figure 1 consists of 4 loops, 16 pipes, 12 nodes and a reservoir, (Lansey et al., 2001).

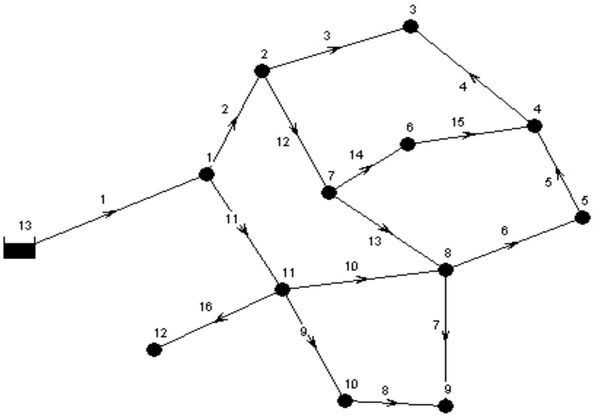

Figure 1. Sample network schematic, (Lansey et al., 2001)

Input data and features related to nodes and pipes given in tables 1 and 2. Pressure head measurement at four nodes (2, 5, 9, 11) from four operating conditions, often occur in water distribution systems, were used for EPANET calibration. The maximum (or peak) and minimum (or slack) demand conditions are set by increasing and decreasing normal demand by 40 and 60 percent. The fire fighting condition is produced at node 3 and 8 at 127 lit/s with consumer withdrawal at all other nodes reduced 80% of normal.

Table 1. Pipe data and measured pressures for application network

Node No.	Node El. (m)	Normal Demand (lit/s)	Node No.	Measured pressure (m) in different operating conditions of system			
				Normal	Maximum	Minimum	Fire Flow
1	45.7	0	2	58.3	50.7	63.7	45.5
2	48.7	44					
3	50.3	41					
4	48.7	37	5	59.4	47	66	39.8
5	45.7	31					
6	47.2	24					
7	44.2	24	9	65.5	56.2	72	49.5
8	42.7	0					
9	39.6	27					
10	41.1	22	11	63.4	56.2	68.4	51
11	44.2	0					
12	39.6	17					
A source reservoir (node number 13) with fixed grade at elevation 115.8 m.							

Table 2. Pipe distribution system characteristics

Pipe No.	1	2	3	4	5	6	7	8
Length (m)	3048	1524	1524	1676	1066	1676	1371	762
Diameter (mm)	610	457	406	356	305	356	305	152
C_{HW}	110	110	100	100	120	120	90	90
Pipe No.	9	10	11	12	13	14	15	16
Length (m)	1066	670	1981	1524	1676	914	1219	1219
Diameter (mm)	305	381	457	356	305	356	305	406
C_{HW}	90	90	110	100	120	100	100	90

In order to estimate the considered variables include Hazen-Williams roughness coefficient (C_{HW}), nodal consumptions, combinations of both and pipe diameters; EPANET was calibrated by using measured pressures (in adjusting process) for four loading conditions. In applying the general calibration algorithm it is assumed that all the necessary field data are reliable. It is clear that the results being able to simulate other conditions in a system with lower error can be used effectively. Therefore, In order to evaluate the results, a factor named Mean Absolute Percentage Error (MAPE) will be used and described as equation (3). If mentioned factor closed to zero, it means that the results are more precise.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{\left|Actual_i - Forecast_i\right|}{Actual_i}\times 100 \tag{3}$$

Where, n is the number of data, $Actual_i$ and $Forecast_i$ are the measured and simulated value of considered parameters (like pressure, flow rate and so on) at point i. After that, the results of EPANET calibration process for each four basic conditions is evaluated by putting them in the model to analyze (or forecast) other loading conditions (MAPE is calculated for nodes 2, 5, 9, 11 which have measured pressure). A summary of calculations is illustrated by using calibration process results in different basic condition of consumptions. Pipe friction factors (in Table 3), nodal consumptions (in Table4), combinations of pipe friction factors and nodal consumptions (in Table5) and pipe diameters (in Table 6) were assumed as uncertain variables. Detailed results are available in (Jamasb, 2006). It is concluded that applying the fire fighting condition and related observations while both of pipe friction factors and nodal consumptions considered as decision variables in the EPANET calibration conduce to more precise forecasts of different loading conditions on the system (minimum average errors in the calculated results, 1.113 percent in Table 5). Figure 2 and Figure 3 represent the results graphically.

Moreover, estimation of calibrated model in the minimum demand condition as the base of adjusting process, have considerable error percentage, so it means that there is not a proper condition for calibration.

In fact, by applying the fire flow condition that demands are altogether more than the other conditions in this sample, the pipe roughness and nodal consumptions which are two basic variables in determination of pipe network headlosses, play a special role and calibration results are much closer to reality. Indeed, water distribution networks should be designed to satisfy these requirements and in other conditions, the amount of headlosses and as a result roughness and consumption effects will lessen.

Table 3. MAPE calculations whereas pipe friction factors are assumed as uncertain parameters

Condition of Modeling	Basic operating condition in calibration process			
	Normal	Maximum	Minimum	Fire Flow
	MAPE (%)	MAPE (%)	MAPE (%)	MAPE (%)
Normal	0	0.750	17.416	1.272
Maximum	1.751	0	36.637	1.128
Minimum	2.912	2.787	0	2.842
Fire Flow	2.169	2.639	58.294	0
Average MAPE	1.708	1.544	28.087	1.310

Table 4. MAPE calculations whereas nodal consumptions are decision variables

Condition of Modeling	Basic operating condition in calibration process			
	Normal	Maximum	Minimum	Fire Flow
	MAPE (%)	MAPE (%)	MAPE (%)	MAPE (%)
Normal	0	0.746	17.412	1.603
Maximum	1.751	0.004	36.629	1.360
Minimum	2.912	2.787	0	2.643
Fire Flow	2.791	1.997	13.024	0.636
Average MAPE	1.863	1.383	16.766	1.561

Table 5. MAPE calculations whereas pipe friction factors and nodal consumptions are decision variables

Condition of Modeling	Node No.	Basic operating condition in calibration process							
		Normal		Maximum		Minimum		Fire Flow	
		Pressure (m)	MAPE	Pressure (m)	MAPE	Pressure (m)	MAPE	Pressure (m)	MAPE
Normal	2	58.3	0	58.31	0.750	48.55	17.408	57.96	1.025
	5	59.4		57.71		47.73		57.67	
	9	65.5		65.47		53.28		65.71	
	11	63.4		63.34		54.14		63.22	
Maximum	2	50.69	1.751	50.7	0	32.5	36.632	50.06	0.66
	5	50.15		47		28.38		46.92	
	9	56.25		56.2		33.46		56.64	
	11	56.31		56.2		39.03		55.96	
Minimum	2	65.49	2.912	65.49	2.787	63.7	0	65.43	2.766
	5	68.14		67.83		66		67.82	
	9	74.24		74.23		72		74.28	
	11	70.1		70.09		68.40		70.06	
Fire Flow	2	45.45	2.846	46.84	2.108	32.81	26.907	45.5	0
	5	43.28		40.49		28.43		39.8	
	9	50.18		48.68		34.37		49.5	
	11	51.59		52.07		40.49		51	
Average MAPE		1.877		1.411		20.237		1.113	

Table 6. MAPE calculations whereas pipe diameters are assumed as decision variables

Condition of Modeling	Basic operating condition in calibration process			
	Normal	Maximum	Minimum	Fire Flow
	MAPE (%)	MAPE (%)	MAPE (%)	MAPE (%)
Normal	0	0.745	17.420	1.056
Maximum	1.751	0	36.641	1.254
Minimum	2.912	2.787	0	2.820
Fire Flow	2.409	1.797	53.151	0
Average MAPE	<u>1.768</u>	<u>1.333</u>	<u>26.803</u>	<u>1.283</u>

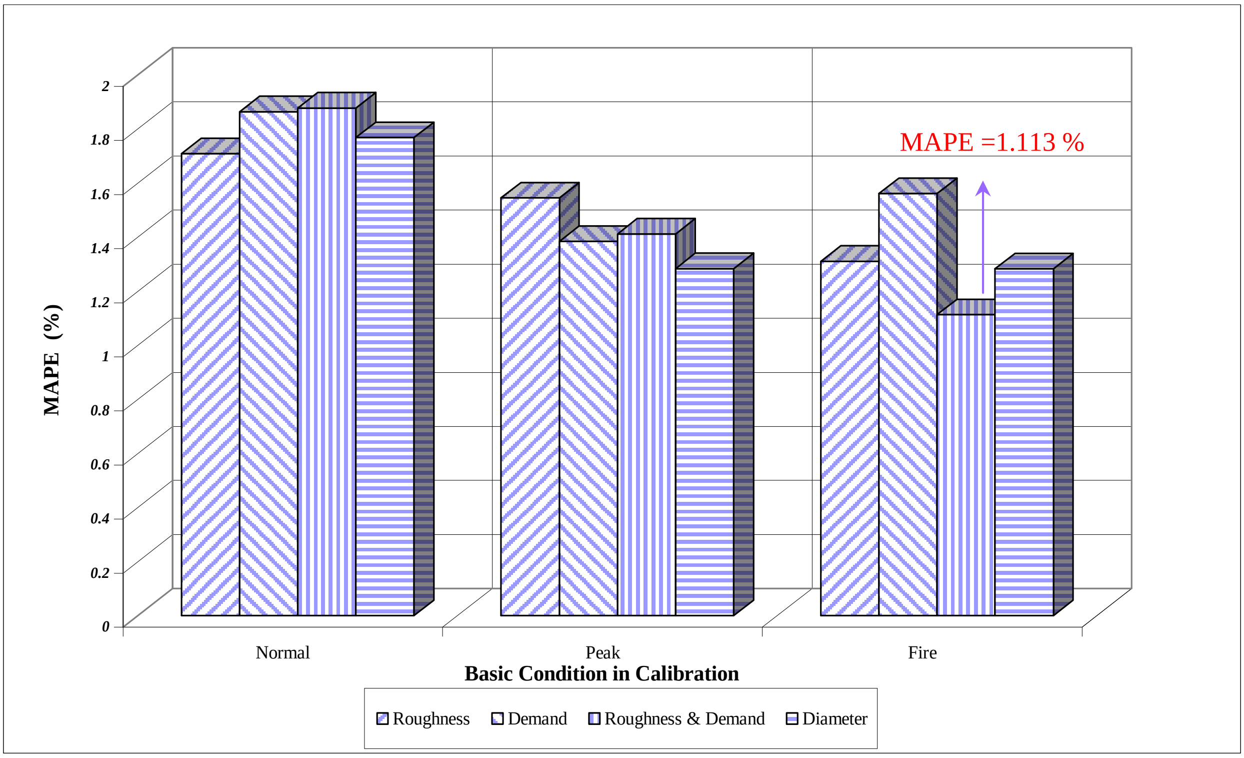

Figure 2. Assessment of EPANET calibration process through different conditions and decision variables

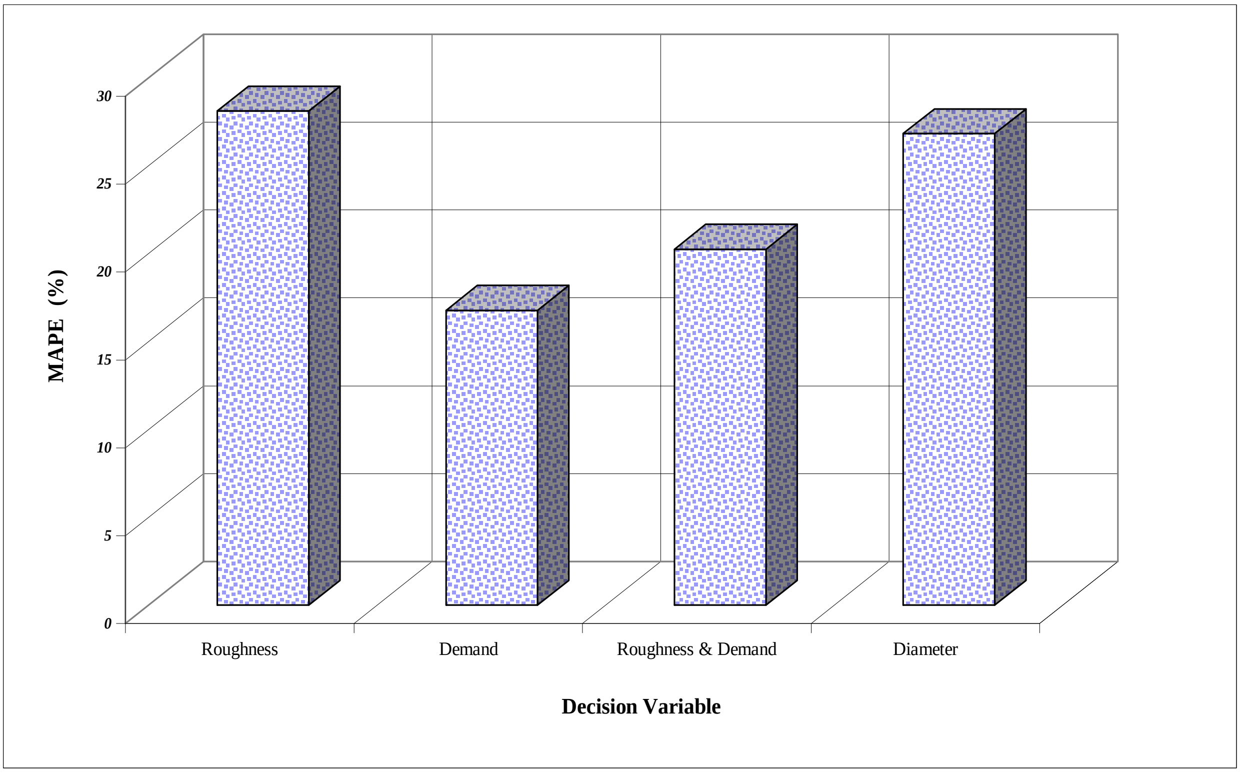

Figure 3. EPANET calibration in minimum demand condition (base of process)

Finally, as shown in Table 7, the network is simulated by true input values (presented in Tables 1 and 2) and the results are compared to calculations of analysis obtained from the parameter estimations when both of roughness and demand assumed as decision variables and applied fire fighting observations (require maximum demands and least errors).

Table 7. The power and accuracy of developed program in EPANET calibration

Condition of Modeling	MAPE (%)	
	True values	Calibration process
Normal	0.049	1.025
Maximum	1.753	0.660
Minimum	2.912	2.766
Fire Flow	2.242	0
Average MAPE	1.73	1.113

5. CONCLUSIONS

As a water distribution system executing requires considerable expenditures and the great importance of supplying water in an acceptable level for different purposes, it is necessary to simulate (and analyze) networks accurately. So, the computerized program developed herein (in MATLAB7 programming language and genetic algorithm technique) for determining pipe roughness coefficients, nodal demands or pipe diameters (through EPANET calibration process) offers a powerful approach to decrease the effects of uncertainties. Furthermore, by studying the common operating conditions in an example system demonstrated that, synchronized adjusting demands and roughness as decision variables and using the observations related to the fire fighting condition (with maximum demand) lead to more precise results in calibration of model and system simulations.

6. REFERENCES

Greco, M., and Del Giudice, G. (1999) "New Approach to Water Distribution Network Calibration", *Journal of Hydraulic Engineering*, ASCE, Vol. 125, No. 8, pp. 849-854.

Haestad Methods, (2005) *WaterGEMS User'S Guide*, Bentley Systems Incorporated, Haestad Methods Solution Center, Watertown, USA.

Jamasb, M. (2006) "Calibration of Hydraulic Simulation Models Using Genetic Algorithms", *M.Sc. Thesis*, Department of Civil Engineering, University of Tehhran, Iran.

Kapelan, Z., Savic, D. A., and Walters, G. A. (2003) "Multiobjective Sampling Design for Water Distribution Model Calibration", *Journal of Water Resources Planning and Management*, ASCE, Vol. 129, No. 6, pp. 466-479.

Lansey, K. E., El-Shorbagy, W., Ahmed, I., Araujo, J., and Haan, C. T. (2001) "Calibration Assessment and Data Collection for Water Distribution Networks", *Journal of Hydraulic Engineering*, Vol. 127, No. 4, pp. 270-279.

Ormsbee, L. E., and Wood, D. J. (1986) "Explicit Pipe Network Calibration", *Journal of Water Resources Planning and Management*, ASCE, Vol. 112, No. 2, pp. 166-182.

Rossman, L. (2000) *EPANET2 User 'S Manual*, Risk Reduction Engineering Laboratory, U. S. Environmental Protection Agency, Cincinnati, Ohio.

Vassiljev, A., Koppel, T., and Puust, R. (2005) "Calibration of the Model of an Operational Water Distribution system", *Proceedings of the Eighth International Conference on Computing and Control for the Water Industry*, University of Exeter, UK., pp. 155-159.

Walski, T. M. (1983) "Technique for Calibrating Network Models", *Journal of Water Resources Planning and Management*, ASCE, Vol. 109, No. 4, pp. 360-372.

Walski, T. M, Chase, D., Savic, D. A., Grayman, W., Bechwith, S., and Koelle, E. (2003) *Advanced Water Distribution Modeling and Management*, Haested Press, Waterbury, Connecticut.