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THE LEAST COST DESIGN OF EXISTING WATER DISTRIBUTION NETWORK FOR NDA USING GENETICS ALGORITHHM

A Saminu[1], L Rabia[2] U Tsoho[3] I G Haruna [4,] B Faustinus[5]
[*1, 2, 3, 4 5] Department of civil Engineering, Nigerian Defence Academy, Kaduna

ABSTRACT

The research work presents the use of genetic algorithm method coupled with optidesigner software for the optimal design of existing NDA water distribution network consisting of 63 pipes of different materials, 57 junctions, 3 tanks and two source reservoirs. After several runs, the cost obtained from this network using optidesigner software under the application of genetics algorithm was $130,450, with minimum pressure head of 3m and maximum of 100, Pressure penalty of 200,000 and probability of mutation equal to 0.03, also the commercial diameters of 4", 6", 8", 10", 12", 14", 16" 18" 20'', 22''and 24'' d_{min} =4", d_{max} = 24" were used for the distribution network during the optimization process. A feasible solution that can supply water at adequate pressure was obtained.

I. INTRODUCTION

A water distribution system may therefore consist of pipelines of various sizes for carrying the water, valves for controlling the flow in the pipes, hydrants for providing connections with the water mains and for releasing water during fire outbreaks, meters for measuring discharge, pumps for lifting and forcing the water into distribution pipes, service reservoirs for storing the treated water to be fed into the distribution pipes to provide water to consumer Garg.SK, (2005). It is a vital component of the urban infrastructure and requires significant investment.

Optimization, as it applies to water distribution system modeling, is the process of finding the best, or optimal solution to a water distribution system problem, it can also be referred to as mathematical techniques used to automatically adjust the details of the system performance (that is the best value of the objective functions).

The problem of optimal design of water distribution network has various aspects to be considered such as hydraulics, reliability, water quality, and infrastructure and demand pattern. Though, each of these factors has its own part of the planning, design and management of the system despite the inherent dependence. An adequate approach to the design and maintenance optimization of pipe networks for the water supply distribution should consider the nonlinear relations between head-losses in each pipe, its diameter, length, and hydraulic property Fanni.A et al.,(2001).

Keywords: Water distribution systems, Least cost, optimization, genetic algorithms

II. LITERATURE

Genetic Algorithm

Basically, GA is a search procedure for the minimum or maximum of an unconstrained function using random selection processes which simulate the following living creature reproduction operators: selection, crossover, and mutation. The initial population (set of networks) is randomly generated, and from this population new sets of solutions are created by selecting and modifying the lowest cost networks. Any selected solution can undergo two kinds of transformations: crossover and mutation. Crossover creates new solutions by combining parts from other solutions, while mutation alters a small part of one solution. With efficient procedures of selection and crossover, the best partial solutions easily pass from one iteration to the next. Just as in natural populations, the fittest individuals produce more offspring, spreading their genes over the next generation. Although mutation is necessary to create new solutions that cannot be produced by other means and to maintain diversity of the gene pool, it involves the risk of destroying good existing solutions. GA has already been applied to obtain optimal water distribution networks and have demonstrated their capacity to obtain better solutions than classical methods Simpson et al., 1994; Dandy et al., (1996)

A genetic algorithm (GA) can also be termed search algorithm like other evolution algorithm based upon the mechanics of natural selection, derived from the theory of natural evolution. GAs simulates mechanisms of population genetics and natural rules of survival in pursuit of the ideas of adaptation. Indeed this has led to a vocabulary borrowed from natural genetics.

A brief description of the steps in using GA for pipe network optimization is as Follows, Simpson et al. (1999):

1. *Generation of initial population.* The GA randomly generates an initial population of coded strings representing pipe network solutions of population size *NG*. Each of the *NG* strings represents a possible combination of pipe sizes.

2. *Computation of network cost.* For each string in the population, the GA decodes each substring into the corresponding pipe size and computes the total material cost. The GA determines the costs of each trial pipe network design in the current population.

3. *Hydraulic analysis of each network.* A steady state hydraulic network solver computes the heads and discharges under the specified demand patterns for each of the network designs in the population. The actual nodal pressures are compared with the minimum allowable pressure heads, and any pressure deficits are noted. In this study, the Newton technique is used.

4. *Computation of penalty cost.* The GA assigns a penalty cost for each demand pattern if a pipe network design does not satisfy the minimum pressure constraints. The pressure violation at the node, at which the pressure deficit is maximum, is used as the basis for computation of the penalty cost. The maximum pressure deficit is multiplied by a penalty factor, which is a measure of the cost of a deficit of one unit of pressure head.

5. *Computation of total network cost.* The total cost of each network in the current population is taken as the sum of the network cost (Step 2) plus the penalty cost (Step 4).

6. *Generation of a new population using the selection operator.* The GA generates new members of the next generation by a selection scheme.

7. Repeat steps 2 to 6 to produce successive generations.

A number of investigators have dealt with the problem of optimization of water distribution network by applying deterministic optimization techniques (where the decision variable are continous). Several researchers employed linear programming to optimize a water distribution network. Principal approaches include those of Alperrovits and Shamir (1977), Kessler and Shamir (1989). The technique given by Alperovits and Shamir (1977) requires that a set of variables (pipe flows) be set to particular values before the linear programming can be formulated.

The literature review shows that the use of optimization techniques is widespread as far as water distribution systems are concerned. Few literatures reviewed in the study includes:

The first, are the two-loop network which was first introduced by Alperovits and Shamir (1997). The system is to supply water to meet the required demand and to satisfy minimum pressure head at each node. Three different values of α are adopted in the study which consist of the maximum and minimum values. The unit of the "Q" (flow rate) and "D" (diameters) maintained in the study are m3/h and centimeter "C". The results obtained using α = 10.5088 and α = 10.6792, produced a cost of $400, 337.97 and $403, 751.22, lower than that of simulated Annealing (SA) with a cost of $408,035.00.

The second network is the New York City water supply network. The data of the New York City water supply tunnels are taken from Fujirawa and Khang (1990), and Dandy et.al (1999). The challenge in the third network is to construct additional gravity flow tunnels parallel to the existing system to satisfy the increased demands at the required pressures. The results obtained from the TS-GA are $36.87 and $38.05 when compared to the work of Tospornsampan et.al (2007), with a cost of $40.04, after satisfying the demand pressure requirements at all nodes, the result shows that a combination algorithm is better than the SA for the design problem of water distribution network. A number of good solutions are obtained by the TS-GA more than the SA.

Solomon .E (2001) described the use of GA with OptiDesigner, a commercial software package using four water distribution networks namely: Hanoi Water distribution network, Hypothetical Water Distribution Network, proposed Abuja Aviation Village Water Distribution Network and proposed Bwari Water Distribution Network. The study established an optimum result of $125, 410.00 and $ 126,160.00 in proposed Bwari network.

Tospornsampon et al. (2007) applied a combination of Tabusearch (TS) and Genetic Algorithm (GA) to solve a problem of split-pipe design of water distribution network.

III. METHODOLOGY

3.1 MATERIALS:

The materials used includes: topographical map, EPANET and OPTIDESIGNER optimization software.

3.2 OPTIDESIGNER SOFTWARE

Optidesigner is a Windows software for the optimal design of water distribution systems using "Genetic Algorithms" (GA). The program uses EPANET (a hydraulic simulator distributed by the US EPA). Optidesigner will design the system pipes and

find their minimal cost under a set of constraints like:
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- Minimal and maximal pressures at networks nodes.
- Minimal and maximal velocities at networks pipes.
- Maximal sources flow. With optidesigner you can find the most cost effective design, rehabilitation and expansion of your water distribution system.

With optidesigner you can find the most effective cost design, rehabilitation and expansion of your water distribution system. The figures below shows the optidesigner map:

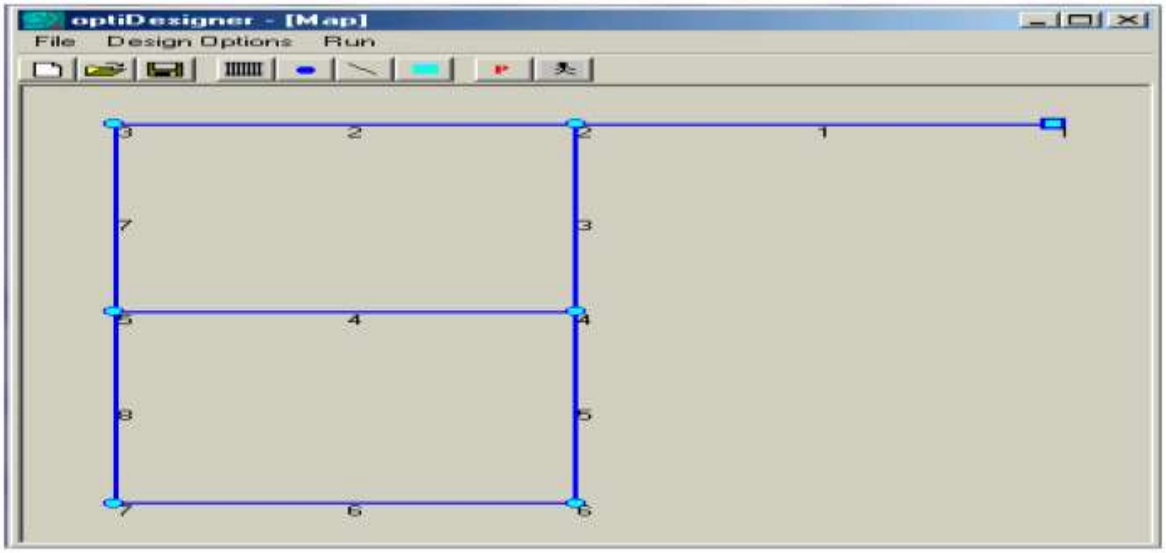

Figure 2 Optidesigner Map

3.5 STEPS IN USING OPTIDESIGNER

1. Draw the system using EPANET and set system properties.
2. Export the network from EPANET as an INP file to Optidesigner software directory.
3. Edit the text file called cost. Text with appropriate commercial diameters pipes with corresponding cost.
4. Start the program by clicking OPEN, to select the imported file you want to work with and key in the correct number of pipes and nodes in the network.
5. Set constraint that is the design parameters i.e. pressures, velocities and diameters.
6. Set optimization parameters (standard genetic properties), you can change the defaults setting of advanced genetic properties by enabling it.
7. Set the termination mode.
8. Run the simulation.

View results using EPANET software

IV. RESULTS

4.1 THE CASE STUDY AREA

The NDA water distribution system consists of 63 pipes all made of different mataerials,57 junctions 3 tanks and 2 source reservoirs from which water is pumped to the surface reservoir and later distributed to other parts of the network. The diagram below shows the distribution network.

Diameter (mm)	Cost per Linear meter ($)
15	3
50	7
80	10
100	12
150	16
200	23

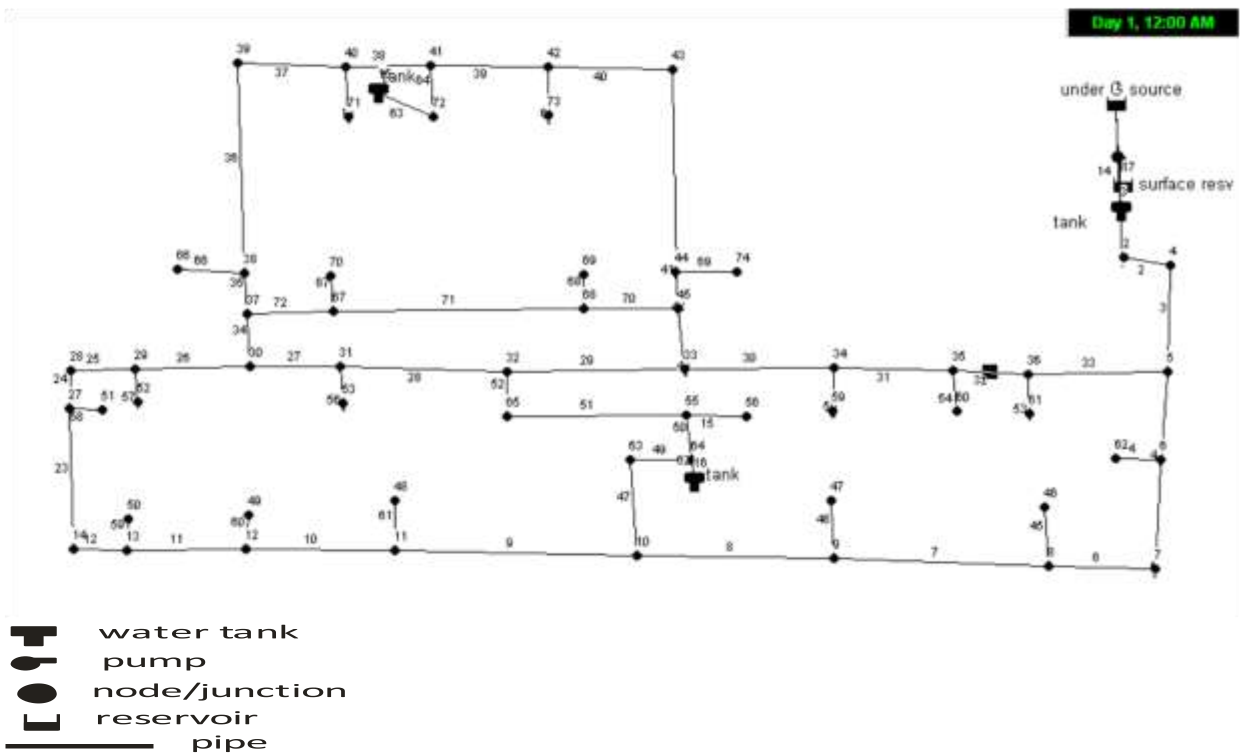

Figure 4: Existing NDA Pipeline Water Distribution System

OptiDesigner (a commercial software) was applied to NDA networks distribution designs to obtain the Cost in ($) of NDA Water Distribution Network using 3 bits representative, commercial diameters=15mm, 50mm, 80mm, 100mm, 100mm, 150mm,150mm, 200mm . dmin = 15mm, dmax = 200mm. Probability of mutation 0.03 as shown in figure 4.1 and 4.2. Other hydraulic results that satisfies the constraints requirements are given in table 4.3 and 4.4 respectively.

Table 4.2: Cost in ($) of NDA Water Distribution Network

No. of Runs	Cost ($)
1	153,373
2	156,264
3	130,450
4	153,374
5	154,974

Table 4.3: Network Pipes Data for NDA Water Distribution Network.(After Optimization)

	Length (m)	Diameter (mm)	Roughness (mm)	Flow (LPS)	Velocity (m/s)	Unit Head loss (m/km)
Pipe 1	50	200	0.005	17.78	0.90	0.023
Pipe 2	50	200	0.005	17.47	0.99	0.021
Pipe 3	100	200	0.005	16.19	0.88	0.022
Pipe 4	50	150	0.005	9.30	0.71	0.023
Pipe 5	130	150	0.005	6.83	0.59	0.032
Pipe 6	150	150	0.005	9.50	0.67	0.023
Pipe 7	250	150	0.005	6.80	0.53	0.024
Pipe 8	250	150	0.005	7.20	0.60	0.021
Pipe 9	150	300	0.005	6.09	0.56	0.031
Pipe 10	150	150	0.005	5.50	0.30	0.024
Pipe 11	150	150	0.005	4.10	0.38	0.021
Pipe 12	50	150	0.005	2.55	0.24	0.025
Pipe 23	350	150	0.005	2.31	0.23	0.023
Pipe 24	50	150	0.005	6.80	0.50	0.032
Pipe 25	100	150	0.005	5.50	0.39	0.033
Pipe 26	200	150	0.005	5.03	0.36	0.024
Pipe 27	130	150	0.005	3.07	0.36	0.031
Pipe 28	250	150	0.005	3.60	0.69	0.031
Pipe 29	250	150	0.005	6.10	0.52	0.025
Pipe 30	200	150	0.005	6.90	0.34	0.033
Pipe 31	120	150	0.005	6.59	0.37	0.025
Pipe 32	120	150	0.005	7.09	0.40	0.025
Pipe 33	270	150	0.005	8.50	0.43	0.027
Pipe 34	120	100	0.005	3.80	0.24	0.026
Pipe 35	80	100	0.005	3.60	0.31	0.021
Pipe 36	330	100	0.005	2.90	0.32	0.027
Pipe 37	200	100	0.005	1.52	0.21	0.021
Pipe 38	150	100	0.005	2.09	0.21	0.023
Pipe 39	220	100	0.005	1.03	0.12	0.026
Pipe 40	220	100	0.005	1.90	0.15	0.024
Pipe 41	50	100	0.005	1.98	0.20	0.022
Pipe 42	120	100	0.005	2.90	0.25	0.027
Pipe 43	150	150	0.005	3.99	0.28	0.022
Pipe 44	70	150	0.005	1.20	0.21	0.023
Pipe 45	120	80	0.005	0.99	0.06	0.026
Pipe 46	110	80	0.005	1.06	0.15	0.022
Pipe 47	250	100	0.005	1.09	0.13	0.021
Pipe 49	110	100	0.005	2.09	0.22	0.029
Pipe 50	100	80	0.005	0.92	0.18	0.022

Pipe 51	270	80	0.005	0.93	0.14	0.029
Pipe 52	100	80	0.005	1.02	0.14	0.027
Pipe 53	80	50	0.005	1.23	0.16	0.027
Pipe 54	80	50	0.005	1.22	0.16	0.022
Pipe 55	100	50	0.005	0.26	0.16	0.024
Pipe 56	80	50	0.005	1.30	0.15	0.023
Pipe 57	80	50	0.005	0.87	0.12	0.025
Pipe 58	60	50	0.005	0.65	0.14	0.022
Pipe 59	70	50	0.005	0.24	0.15	0.020
Pipe 60	80	50	0.005	0.93	0.19	0.029
Pipe 61	110	80	0.005	1.26	0.13	0.023
Pipe 62	488	15	0.005	1.03	0.17	0.020
Pipe 63	100	15	0.005	1.06	0.13	0.022
Pipe 64	100	50	0.005	1.21	0.11	0.027
Pipe 65	120	50	0.005	1.32	0216	0.024
Pipe 66	110	50	0.005	0.93	0.17	0.029
Pipe 67	80	50	0.005	1.27	0.24	0.023
Pipe 68	70	50	0.005	1.28	0.24	0.020
Pipe 69	100	50	0.005	1.25	0.23	0.021
Pipe 70	170	100	0.005	1.24	0.16	0.021
Pipe 71	320	100	0.005	1.70	0.19	0.023
Pipe 72	150	100	0.005	1.11	0.21	0.020
Pipe 13	120	50	0.005	1.32	0.16	0.026
Pipe 15	160	80	0.005	1.23	0.25	0.027
Pump 14	N/A	N/A	N/A	133.28	2.03	0.027

Table 4.4: Network Nodes Data for NDA Water Distribution Network.(After Optimization)

Node ID	Elevation (m)	Demand (Lps)	Head (m)	Pressure (m)
Junc 2	350	0.31	398.94	58.9
Junc 4	340	0.28	397.91	66.01
Junc 5	390	0.27	395.94	45.14
Junc 6	368	0.25	394.62	56.62
Junc 7	367	0.31	391.63	66.62
Junc 8	345	0.35	388.50	55.59
Junc 9	340	0.31	384.28	55.43
Junc 10	335	0.22	380.83	60.87
Junc 11	348	0.24	380.81	55.71
Junc 12	349	0.25	379.86	60.36
Junc 13	350	0.31	379.15	69.15
Junc 14	362	0.24	378.99	46.90
Junc 27	340	0.25	378.07	45.07
Junc 28	345	0.23	377.99	40.99
Junc 29	348	0.33	377.86	55.80
Junc 30	350	0.26	377.76	35.16
Junc 31	350	0.27	377.84	38.80
Junc 32	349	0.25	378.18	37.10
Junc 33	351	0.27	379.40	56.09
Junc 34	350	0.32	382.22	43.20
Junc 35	379	0.28	385.37	16.37
Junc 36	388	0.33	388.29	5.29

Junc 37	361	0.34	375.13	43.13
Junc 38	360	0.35	373.78	33.78
Junc 39	365	0.36	371.89	26.80
Junc 40	361	0.33	371.46	30.40
Junc 41	361	0.34	371.46	40.41
Junc 42	360	0.26	372.01	16.02
Junc 43	361	0.28	374.05	18.01
Junc 44	360	0.27	374.75	24.73
Junc 45	377	0.25	377.84	12.80
Junc 46	343	0.31	388.17	55.10
Junc 47	340	0.26	384.06	54.00
Junc 48	345	0.26	380.60	45.60
Junc 49	340	0.23	375.89	39.85
Junc 50	347	0.24	375.37	48.30
Junc 51	370	0.25	374.55	7.55
Junc 52	367	0.24	373.54	17.50
Junc 53	367	0.30	371.10	34.10
Junc 55	350	0.26	378.09	34.15
Junc 56	360	0.23	377.88	28.80
Junc 58	361	0.25	379.80	38.89
Junc 59	365	0.26	386.09	66.34
Junc 60	356	0.22	381.73	27.73
Junc 61	340	0.23	348.31	48.30
Junc 62	345	0.25	394.62	59.60
Junc 63	346	0.23	379.27	36.20
Junc 64	343	0.27	378.86	39.85
Junc 65	350	0.24	378.09	28.09
Junc 66	350	0.33	362.57	43.50
Junc 67	351	0.32	375.13	30.19
Junc 68	352	0.26	376.15	29.10
Junc 69	355	0.28	371.01	26.09
Junc 70	355	0.27	369.66	24.60
Junc 71	359	0.32	359.96	10.90
Junc 72	359	0.27	367.22	18.20
Junc 73	360	0.32	360.51	10.59
Junc 74	360	0.25	368.89	18.80
Resvr 1	400	110.23	405.00	0.00
Resvr 17	470	109.23	405.00	0.00
Tank 3	425	40.78	420.00	15.00
Tank 15	430	28.98	435.00	15.00
Tank 16	435	40.01	498.00	10.00

V. DISCUSSION

A total number of 5 runs was made and the least cost for the design was obtained as **$130,450** at the 3rd run as indicated in table 4.2, which is lower than the other values in the table. Also a reasonable pressures and velocities were obtained at all the nodes and links after the optimization.

VI. CONCULUSIONS

The results obtained prove that the performance of the OptiDesigner a commercial software package is justified, as it has been able to improve the search in terms of achieving least cost of $130,450 that satisfies the constraint requirements which succeeded in obtaining a feasible solution that will supply water at adequate pressure to the consumers.

VII. REFRENCES

(1) Alperovists, E. and Shamir, U. [1997]. Design of Optimal water distribution systems. Water Resources Research, 1977, 13 (6), 885 – 900.

(2) Dandy G.C, Simpson A. R, and L.J. Murphy L.J [1999]. An Improved Genetic Algorithm for Pipe Network Optimization. Water Resources Research, vol. 157, pp. 221

(3) Dandy G.C, Simpson, A.R and Murphy, L.J (1996). An improved genetic algorithm for pipe network optimization "Water resources research"

(4) Fanni, A. Liberate, S. Sechi, G.M Saro, M and Zuddas, P. Optimization ofwater distribution systems by a tabu search metaheuristic, University of Caglian, Italy 2001.

(5) Fujirawa, O. and Khang, D. B [1990]., A two phase decomposition method for optimal design of looped water distribution networks. Water Resources Research, 1990, 26 (4) 539 – 549.

(6) Garg.S.K (2005). Water supply engineering." Khanna publishers Delhi. Pg681-700 page 690

(7) Kesseler, A. and Shamir, U [1989]., Analysis of the linear programming gradient method for optimal design of water supply networks. Water Resource Research, 25 (7), 1469 – 1480

(8) Solomons E. (2001). OptiDesigner Version 1, User Manual http://www.optiwater.com/opti

(9) Simpson, AR., Dandy, G.O and Murph, L.J. "Genetic algorithms compared to other techniques for pipe optimization. Water resource planning and management 1994.

(10) Tospornsampan J, Kita J. Ishii M. and Kitamura. Y [2007]. Split-pipe Design of Water Distribution Networks using a Combination of Tobu Search and genetic Algorithm. International Journal of Computer, Information and Systems Science, and Engineering.

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