Genetically Optimised Design Of Irrigation System Network Using Epanet As A Tool

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ABSTRACT

An irrigation system network design is just like a water distribution system that parcels water from the source reservoir to the respective destination nodes. The aim of this paper is to propose such a system that transmits water by finding the optimal pipe diameters, so that the overall network cost is minimised. For this, we use Genetic Algorithm, coupling it with a network solving tool called Epanet. Also, Rank selection is used to select the best members from the population that will form input to the next generation. Penalty cost is an impacting factor in Cost calculation. The main aim of this study is to reduce the penalty cost of the network as much as possible but at the same time our network cost should not be increased so much. So, in all GA provides an optimum solution after certain number of iterations.

Keywords:
Irrigation network, Genetic Algorithm, Epanet, optimum, Rank Selection, Fitness Function, Network cost, penalty cost.

1. INTRODUCTION

An irrigation system is a water distribution network that transmits water from the source reservoir to the consumers' locations. It consists of elements such as pipes, valves, pumps, tanks and reservoirs. The most important consideration in designing and operating an irrigation system is to satisfy consumer demands under a range of quantity and quality considerations during the entire lifetime for the expected loading conditions.

2. FORMULAE USED

The aim of the irrigation system network design is to find the optimal pipe diameter for each pipe in the network for a given layout, demand loading conditions, and an operation policy. Our model selects the optimal pipe sizes in the final network satisfying all implicit constraints (e.g. conservations of mass and energy), and explicit constraints (e.g. pressure head and design constraints). If the hydraulic head constraint is violated, the penalty cost is added to the network cost. However, diameter constraints enforce the evolutionary algorithms to select the trial solution within a predefined limit. The hydraulic information obtained from network solver is then passed to the GA for the computation of fitness of the design. The fitness of a trial solution representing a pipe network design is based on the hydraulic performance of the network . It consists of two parts: (1) network cost and (2) penalty cost.

The network cost is calculated as the sum of the pipe costs where pipe costs are expressed in terms of cost per unit length. Total network cost is computed as follows:

$$C = \sum_{K=1}^{N} c_k(D_k)\, L_k$$

where $c_k(D_k)$ = cost per unit length of the kth pipe with diameter D_k, L_k = length of the kth pipe, and N = total number of pipes in the system.

The penalty cost is based on the degree of pressure head violation. The penalty functions may be defined, as

$$C1 = P * C_{max} * Max\,(H_{min} - H_i)$$

if the pressure is less than minimum limit and greater than zero; or

$$C1 = 2*P*C_{max} - 2*C$$

if the pressure is less than or equal to zero.

In above two equations , P is the penalty cost coefficient, Cmax is the maximum possible cost that is calculated based on the largest commercial pipe available, (Hmin-Hi) is the maximum pressure deficit, and C is the actual network cost. The maximum pressure deficit is the difference between the required head (Hmin) at each node and the head found after simulation (Hi). If the pressure head is greater than the minimum required limit, no extra cost is charged to the network cost.

The mathematical formulation of water distribution network can thus be stated as follows:

Minimize Cost C = Network cost + Penalty cost

Subjected to:

G(H,D) = 0, a conservation of mass and energy equation

$H_i \geq H_i min$ nodal pressure head bounds

$D_{min} < D(k) < D_{max}$, constraints related to design parameters

where,

H_i = pressure head at node i,

$H_i min$ = minimum head required at the same node,

D(k) = decision variables (pipe sizes).

3. SOLVING THE PROBLEM THROUGH GENETIC ALGORITHM

Here we attempt to solve the problem using genetic algorithms (GAs), an evolutionary optimization technique. GAs is founded as a randomized search and optimization technique based on Darwin's theory of the "survival of the fittest" and a stochastic information exchange procedure .

3.1. STEPS FOR THE ALGORITHM

3.1.1. [Start] Generate random population of *n* chromosomes (suitable solutions for the problem).
3.1.2. [Fitness] Evaluate the fitness *f(x)* of each chromosome *x* in the population.
3.1.3. [New population] Create a new population by repeating following steps until the new population is complete.
3.1.4. [Selection] Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected).
3.1.5. [Crossover] With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents.
3.1.6. [Mutation] With a mutation probability mutate new offspring at each locus (position in chromosome).
3.1.7. [Accepting] Place new offspring in a new population.
3.1.8. [Replace] Use new generated population for a further run of algorithm.
3.1.9. [Test] If the end condition is satisfied, **stop**, and return the best solution in current population.
3.1.10. [Loop] Go to step **2**

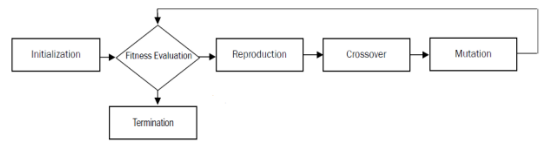

Fig. 1: GA Procedure

4. OVERALL PROCEDURE FOLLOWED

4.1 Generate N population of points randomly in the solution space: These randomly generated chromosomes will serve as a pipe diameter for EPANET network. These pipe diameters are then supply to EPANET to calculate cost and pressure deficit.

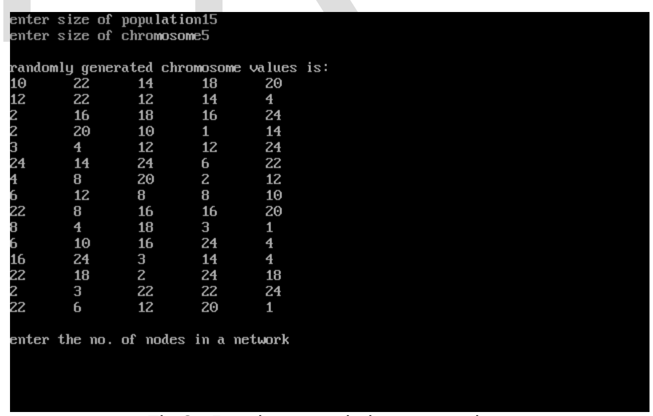

Fig 2: Random population generation

4.2 Compute the network cost for each of the N from the randomly pipe sizes available in the market: In this step program calculate the network cost. Network cost is the function of the length of pipe and the cost per unit diameter. Cost per unit diameter is taken from the commercially available pipe diameters.

The formula for calculating cost is:

$$\text{Network Cost} = \sum_{K=1}^{N} c_k(D_k)L_k$$

where $c_k(D_k)$ = cost per unit length of the kth pipe with diameter D_k, L_k = length of the kth pipe, and N = total number of pipes in the system.

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randomly generated chromosome values is:
10      22      14      18      20
12      22      12      14      4
2       16      18      16      24
2       20      10      1       14
3       4       12      12      24
24      14      24      6       22
4       8       20      2       12
6       12      8       8       10
22      8       16      16      20
8       4       18      3       1
6       10      16      24      4
16      24      3       14      4
22      18      2       24      18
2       3       22      22      24
22      6       12      20      1

enter the no. of nodes in a network4

enter the values of length of pipe1000 1000 1000 1000 1000

value of cmax is2750000

Network cost is:692000
enter the value of pressure for nodes
```

Fig 3: Calculation of Network Cost

4.3 Perform hydraulic analysis of each network:

The randomly generated population is serving as pipe diameter that is used in the network. Run EPANET and measure nodal pressure for each set of diameter. This pressure deficit is then use to calculate the penalty cost.

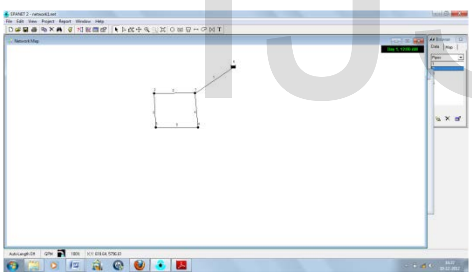

Fig. 4 : EPANET network

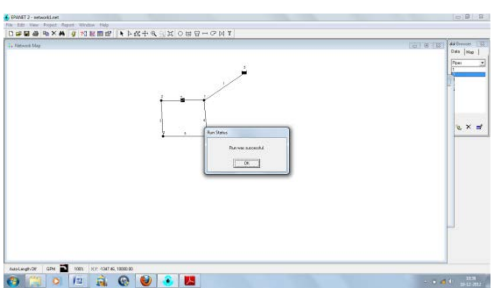

Fig. 5 : Execution of EPANET

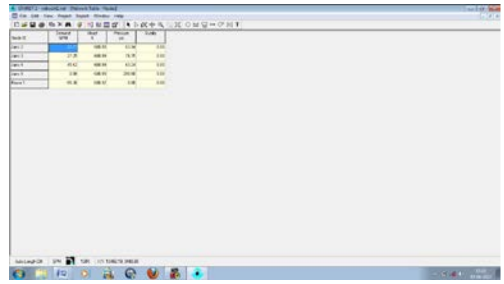

Fig.6: Result table of Pressure at every node

4.4 Compute penalty cost, if the nodal head at any node is less than the required minimum:

In this step program calculate the penalty cost. Penalty cost depends upon the nodal pressure deficit. Penalty cost equation is:

If the pressure is less than minimum limit and greater than zero

$$C1 = P*C_{max}*Max\,(H_{min} - H_i)$$

if the pressure is less than or equal to zero.

$$C1 = 2*P*C_{max} - 2*C$$

Where P is the penalty cost coefficient, Cmax is the maximum possible cost that is calculated based on the largest commercial pipe available, (Hmin- Hi) is the maximum pressure deficit, and C is the actual network cost. The maximum pressure deficit is the difference between the required head (Hmin) at each node and the head found after simulation (Hi). If the pressure head is greater than the minimum required limit, no extra cost is charged to the network cost.

```
24      14      24      6       22
4       8       20      2       12
6       12      8       8       10
22      8       16      16      20
8       4       18      3       1
6       10      16      24      4
16      24      3       14      4
22      18      2       24      18
2       3       22      22      24
22      6       12      20      1

enter the no. of nodes in a network4

enter the values of length of pipe1000 1000 1000 1000 1000

value of cmax is2750000

Network cost is:692000
enter the value of pressure for nodes63.94 78.15 63.24 298.50

penalty cost is:0
total cost & fitness is:692000

Network cost is:471000
enter the value of pressure for nodes
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Fig. 7: Penalty cost calculation

4.5 Calculate the total cost of the network:

The total cost of the network is the sum of the network cost and the penalty cost found in steps 2 and 4 respectively.

Total Cost C = Network cost + Penalty cost

4.6 The total cost found in step 4.5 is used as the fitness value for each of the trial network: this fitness function will further help in selection procedure, where two chromosomes are selected from the randomly generated population.

4.7 Two Chromosomes are selected from the population based on their fitness value and apply GA: In this step Rank selection is used in order to select the two chromosomes from the randomly generated population. The two selected chromosome will serve as our parent chromosome and further take part in crossover and mutation in order to generate child chromosome.

Rank selection first ranks the population and then every chromosome receives fitness from this ranking. The worst will have fitness ***1***, second worst ***2*** etc. and the best will have fitness ***N.***

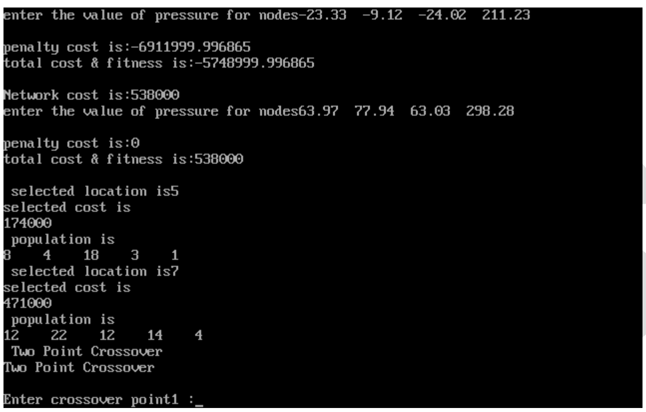

Fig.8: Rank Selection

4.8 Corresponding Crossover and Mutation is performed on the chromosomes: In this step crossover and mutation is performed on the parent chromosome found in step 7. Crossover operator is to generate child chromosomes from two 'parent' chromosomes by combining the information extracted from the parents. Mutation is responsible for the genetic diversity of the new chromosome.

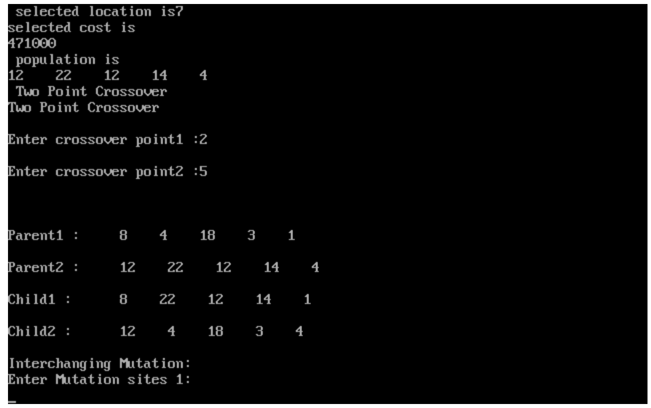

Fig. 9 : Crossover

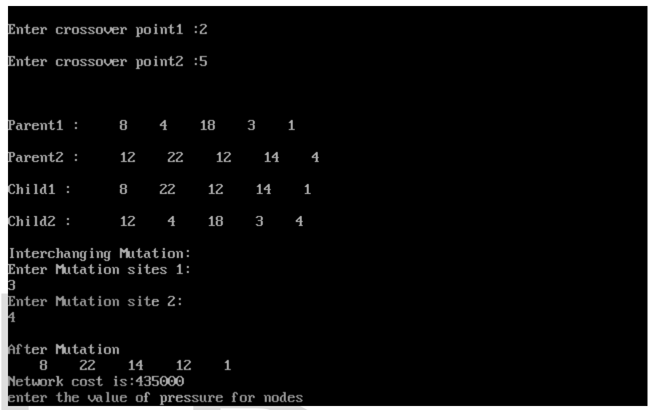

Fig 10: Mutation

4.9.Cost calculation for newly generated children: In this step program calculate total cost (network cost + penalty cost) using two newly generated child chromosomes as pipe diameters of network. If this cost is optimal then we stop else we evolve new population.

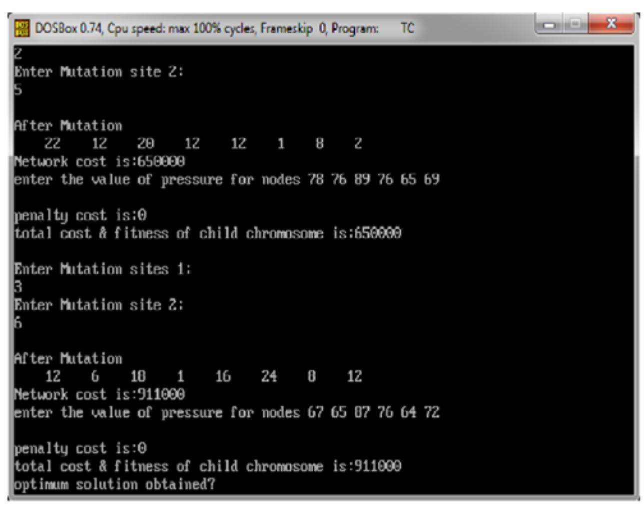

Fig 11: Total cost Calculation

4.10 If the cost is optimized then STOPS: If calculated cost is optimum then stop and the respective child chromosome is our solution else go to step 11, else generate new population and go to step 5.7.

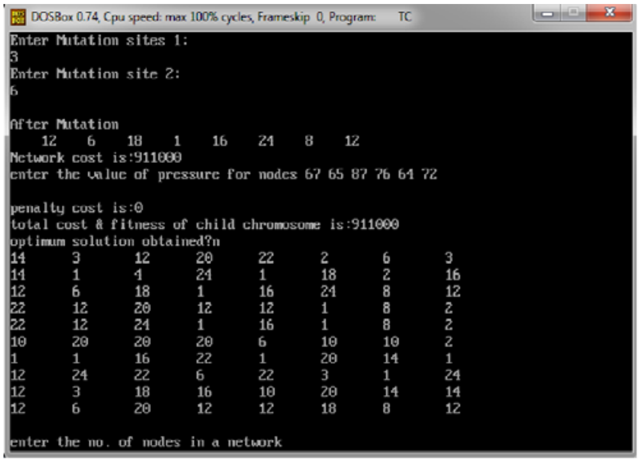

Fig. 12: Evolution of new population

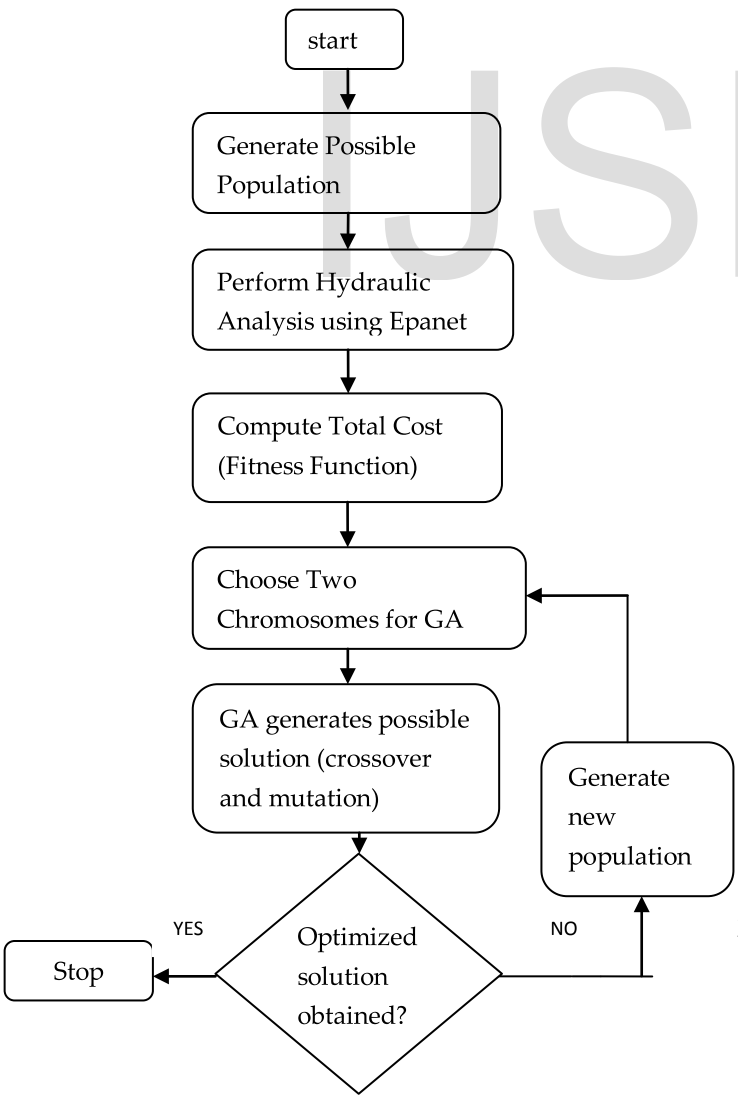

Fig 13: Optimization Flowchart of Irrigation Network

5. RESULT AND ANALYSIS

Genetic Algorithm is applied in conjunction with EPANET to find optimum results.
For cost per unit diameter it uses commercially available pipe sizes.

TABLE 1- COST DATA FOR PIPES

Diameter (In)	Diameter(Mm)	Cost
1	25.4	2
2	50.8	5
3	76.2	8
4	101.6	11
6	152.4	16
8	203.2	23
10	254.0	32
12	304.8	50
14	355.6	60
16	406.4	90
18	457.2	130
20	508.0	170
22	558.8	300
24	609.6	550

In this case a simple network optimization is performed. The network has 4 node, one reservoir (water supply mean) and 5 pipes.

The following GA parameters were established for the problem.

Population= 30

Generation= 50

Rank Selection

Two point crossover

Interchanging mutation

Following are the EPANET parameters :
Minimum pressure requirements= 60.00 psi
Cmax=2750000
Penalty coefficient=0.004

TABLE 2- PIPE PROPERTY OF EACH PIPE IN SAMPLE NETWORK

Pipe Id	Length(M)	Roughness
1	1000	130
2	1000	130
3	1000	130
4	1000	130
5	1000	130

TABLE 3- DEMAND AND ELEVATION AT EACH NODE

Node	*Demand(GPM)*	*Elevation(Feet)*
Node 1	22.71	541.33
Node 2	27.25	508.53
Node 3	45.42	542.93
Node 4	74.95	492.12
Reservoir	N/A	688.97

Data Input: data is to be inputted to the EPANET. It contains the possible set of diameters generated by GA. Then calculate result that is the pressure at each node.

TABLE 4- RANDOMLY TAKEN PIPE DIAMETERS

NO.	Pipe1 Diameter(in)	Pipe2 Diameter(in)	Pipe3 Diameter(in)	Pipe4 Diameter(in)	Pipe5 Diameter(in)
1	10	22	14	18	20
2	12	22	12	14	4
3	2	16	18	16	24
4	2	20	10	1	14
5	3	4	12	12	24
6	24	14	24	6	22
7	4	8	20	2	12
8	6	12	8	8	10
9	22	8	16	16	20
10	8	4	18	3	1
11	6	10	16	24	4
12	16	24	3	14	4
13	22	18	2	24	18
14	2	13	22	22	24
15	22	6	12	20	1

Calculate pressure at each node for all possible set of diameters, this pressure helps in calculating penalty cost:

TABLE 5- PRESSURE AT EACH NODE FOR EACH TRAIL IN SAMPLE N/W

No.	Node 1 Pressure(psi)	Node2 Pressure(psi)	Node3 Pressure(psi)	Node4 Pressure(psi)	Total Cost(Rs) (N/W cost+Penalty cost)
1	63.94	78.15	63.24	298.50	692000
2	63.96	78.17	63.26	298.51	471000
3	-23.33	-9.12	-24.02	211.23	865000+(-5123999)=-4258999
4	-23.33	-9.12	-24.03	211.23	269000+(-1547999)=-1278999
5	51.86	66.06	51.16	286.42	669000+(186780)=855780
6	63.97	78.18	63.28	298.53	1476000

7	60.99	75.14	60.24	295.55	259000
8	63.56	77.77	62.85	298.11	144000
9	63.97	78.18	63.28	298.53	673000
10	63.87	76.36	61.46	296.72	174000
11	63.56	77.75	62.85	298.10	699000
12	63.97	78.18	62.90	298.16	719000
13	63.97	78.18	63.28	298.53	1115000
14	-23.33	-9.12	-24.02	211.23	1163000+(-6911999)=-5748999
15	63.97	77.94	63.03	298.28	538000

The result is obtained after applying selection, crossover and mutation on the randomly generated diameters. The optimum result is obtained after applying 5 iterations. Our optimum result is minimum cost of the network.

Table 6 Result after applying GA

Diameters	Pipe 1	Pipe 2	Pipe 3	Pipe 4	Pipe 5	Total Cost
Child 1	8	22	14	12	1	435000(not optimum)
Child 2	12	18	4	3	4	210000(optimum)

Optimum result will serve as the final diameter that is to be applied in the EPANET. This has been noticed that GA give result after 5 iteration. Minimum cost is obtained with Zero penalty cost.

7. CONCLUSION

Optimal water distribution network design is a complex task. Various search algorithms have been proposed and attempted. Main concerns are to achieve the optimal solution with the minimum design cost and, at the same time, satisfies required minimum pressure head at certain demand nodes and can use only commercially available pipe sizes.

In this study Genetic Algorithm, has been coupled with the widely used irrigation network software, EPANET, and applied to irrigation network designs. It has been observed that the program reaches to the optimum result after some iteration.

Rank selection is used to select the best members from the population that will form input to the next generation.

Penalty cost is very impacting factor in Cost calculation. The main aim of this study is to reduce the penalty cost of the network as much as possible but at the same time our network cost should not be increased so much.

The study shows that GA yields categorically better performance in term of optimal network design cost and/or computational speed. It has been seen that, traditional methods are not capable to design the network required by the time. Traditional heuristics have the limitations with the possible constraints. The proposed genetic algorithm approach can provide the good results with the required constraints.

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