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COST OPTIMIZATION OF PIPELINE SYSTEMS USING GENETIC ALGORITHM

Palak Sharma, Shelza, Gurjit Singh Randhawa, Rajinder Singh Virk

Department of Computer Science & Engineering,
Guru Nanak Dev University, Amritsar, India.

ABSTRACT

The aim of this paper is optimization of cost of irrigation networks using genetic algorithms. The genetic algorithm presented in this paper tries to find layout of irrigation network that incurs minimum cost by optimizing diameters of pipes. Along with that, algorithm is implemented. The method starts with a predefined network layout, which include all links and then tries to optimize pipe diameter. In this paper GA has been used to solve pipe network problem in steady state, considering all constraints like head requirements.

Keywords: Genetic Algorithm, Irrigation Network, Optimization, Pipeline System

1. INTRODUCTION

Pipe networks are essential almost everywhere, like for gas, sewer, irrigation, etc. The cost of construction of these networks is very high. So, a decrease in cost can lead to a huge saving. Optimization of pipe network cost involves analysis of hydraulic, quality requirements. Optimization techniques used can be deterministic or stochastic. Deterministic techniques include linear, non-linear techniques and dynamic programming, and the stochastic techniques include simulated annealing and genetic algorithms. Deterministic techniques always guarantee an optimal solution but need the system to satisfy a number of constraints, which is difficult to achieve in an irrigation system. So, genetic algorithms are used, which always try to optimize the objective function and can produce acceptable near optimal or near optimal solution in comparatively lesser time.

2. PROBLEM DEFINITION

When designing or rehabilitating a water distribution system using trial-and-error methods or with formal optimization tools, a broad range of concerns can be considered. Cost is likely to be the primary emphasis and includes the costs for construction, operation, and maintenance. The initial capital investment is for system components: pipes, pumps, tanks, and valves. Energy consumption occurs over time to operate the system. The main constraints are that the desired demands are supplied with adequate pressure head being maintained at withdrawal locations. Also, the flow of water in a distribution network and the nodal pressure heads must satisfy the governing laws of conservation of energy and mass. In summary, the problem can be verbally stated as: Minimize capital investment plus energy costs, subject to:

- Meeting hydraulic constraints,
- Fulfilling water demands and
- Satisfying pressure requirements

3. COST AND CONSTRAINTS IN A PIPELINE NETWORK

Pipeline system design problem taken in this paper is solved by optimizing the pipe diameter. The cost of system is subject to minimization by optimizing pipe diameter. The main objective of minimizing cost is achieved by optimizing pipe diameter under steady state flow constraints.

The total network cost [4] is given by:

$$TC = \sum_{i=1}^{n} L_i \, C_i(d_A) \dots\dots\dots\dots\dots (1)$$

Subject to

$$H_{A_j} \geq H_{R_j} \qquad \dots\dots\dots\dots\dots\dots\dots . (2)$$

$$d_A = d_i \qquad \dots\dots\dots\dots\dots\dots (3)$$

Where, TC= total cost of network

L_i= Length of i^{th} pipe in meter
$C_i(d_i)$= Cost per unit length for that diameter of i^{th} pipe in Rs.
n = total no. of pipes in network
α = penalty parameter in Rs.
H_{Aj} = Head available at j^{th} node in meter
k = total no. of outlets in network
H_{Rj} = Head required at j^{th} node in meter = $(1.1*f*L_i*Q_i^2)/(3*d^5_A)$
f = Friction constant
Q_i = Discharge required in i^{th} outlet in lps
d_i = diameter of i^{th} pipe in meter
d_A= commercially available diameter in meter

Head Loss:

Head loss is the measure of the reduction in the total head of the liquid as it moves through a system. The total head is the sum of the elevation head, velocity head and pressure head, where *Pressure head* is a term used in fluid mechanics to represent the internal energy of a fluid due to the pressure exerted on its container. It is usually expressed as:

$$\varphi = \frac{p}{\rho g} \dots\dots\dots (4)$$

Where, p is fluid pressure, ρ is density of fluid and g is acceleration due to gravity

The *elevation head* is energy possessed by a liquid due its height above some reference level and *velocity head* is because of bulk motion of fluid. Head losses in a pipe system are unavoidable and are present because of friction between fluid and walls of pipes and are present between fluid particles as they move along the pipe. Head loss in a pipe is directly proportional to length of pipe.

The minimization of objective function [1] ***is most of times subject to*:**

(a) *Mass balance constraint*:

$$\sum_{j=1}^{M} Q_j = 0 \dots\dots\dots (5)$$

Where, Q_j represents the discharges into or out of the node j.

(b) *Energy balance constraint*:

$$\sum h_f = E_p \dots\dots\dots (6)$$

The conservation of energy states that the total head loss around any loop must equal to zero or is equal to the energy delivered by a pump *p, E*, if there is any. The head loss due to friction in a pipe h_f is expressed by the Hazen-William formula:

$$h_{f_i} = \frac{4.727\ L_i Q_i^{1.852}}{C_i^{1.852} D_i^{4.8704}} \dots (7)$$

Where, Q_i is the pipe flow (ft^3/s), D_i is pipe diameter (ft), L_i is pipe length (ft) and C_i is the Hazen-Williams coefficient.

(c) *Decision variables constraint*:

The design constraints (the pipe diameter bounds (maximum and minimum)) and the hydraulic constraints are given respectively as:

$$D_{min} \leq D_i \leq D_{max} \qquad i = 1 \dots\dots\dots n \quad \dots (8)$$

Where, D_i is the discrete pipe diameter selected from the set of commercially available pipe sizes.

4. DESIGN CONSIDEARTION

The Data required for pipe network is total number of links, irrigable area at each outlet, discharge required at each outlet diameters of pipes, length of pipes, available head losses. The network layout considered is shown in Fig. 1.

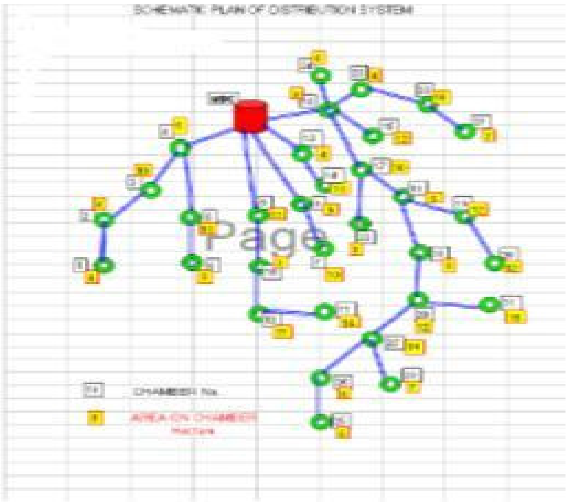


Fig 1: Network Layout

5. VARIOUS OPTIMIZATION METHODS

i. *Branched network*:

In branched networks, pipe systems are optimized using linear programming. Pipes are broken into parts of different diameter and then pipe length of each diameter is optimized [3].

ii. *Looped system via Linearization*:

Iterative methods are applied by fixing pipes flow rate, after that optimizing the pipe size for that flow and then updating the flow rate and then re- optimizing [3].

iii. *Non linear Programming*

Non linear programming (**NLP**) is the process of solving an optimization problem defined by a system of equalities and inequalities, constraints, along with an objective function to be maximized or minimized, where some of the constraints or the objective function are nonlinear. According to this method, the minimal value of the pipe network is obtained from the minimal value of the objective function by determining the optimal friction losses meeting the specific functional and non negativity constraints [2,6].

iv. *Stochastic Techniques*

In case of stochastic optimization techniques, objective value is evaluated for a set of solutions. New decision vectors are generated, based upon the objective values of previous solutions. Genetic algorithms come under this category [3].

6. PROPOSED GENETIC ALGORITHM APPROACH FOR COST OPTIMIZATION OF IRRIGATION NETWORK

A genetic algorithm (GA) [5] is a search heuristic that mimics the process of natural evolution. GA's are based on Darwin's principle of "survival of fittest". GA's use operators like crossover for evolving solutions [7]. The brief idea of GA is to select population of initial solution points scattered randomly in the optimized space, then converge to better solutions by applying in iterative manner the following three processes (reproduction / selection, crossover and mutation) until a desired termination criteria is achieved [8].

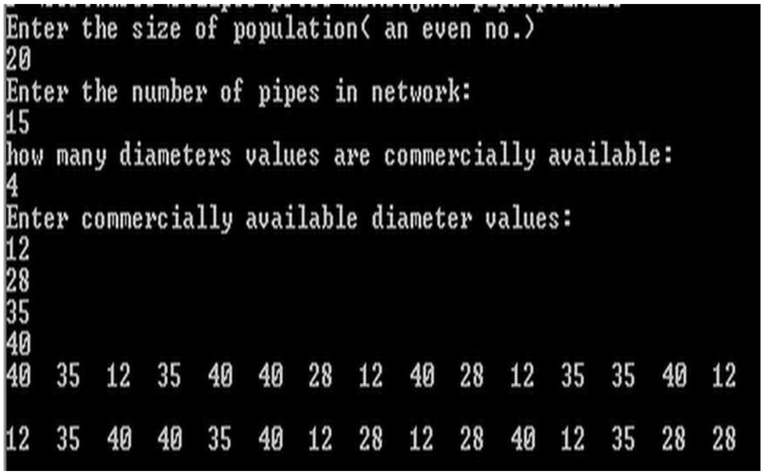
The following sequences of steps are taken to apply GA for cost optimization of pipeline systems:

- ***Initial population generation*:**

For generating initial populations, first of all chromosomes are produced. The structure of chromosome used for this problem is:

D1	D2	.	.	.	Dn-1

Where, D_1, D_2, …, D_{n-1} are diameters of pipes and n is number of pipes in system. So, length of chromosome is taken as number of pipes in the network. By picking up random values from commercially available diameter values, chromosomes are generated. The commercially available diameter values are called allele values.

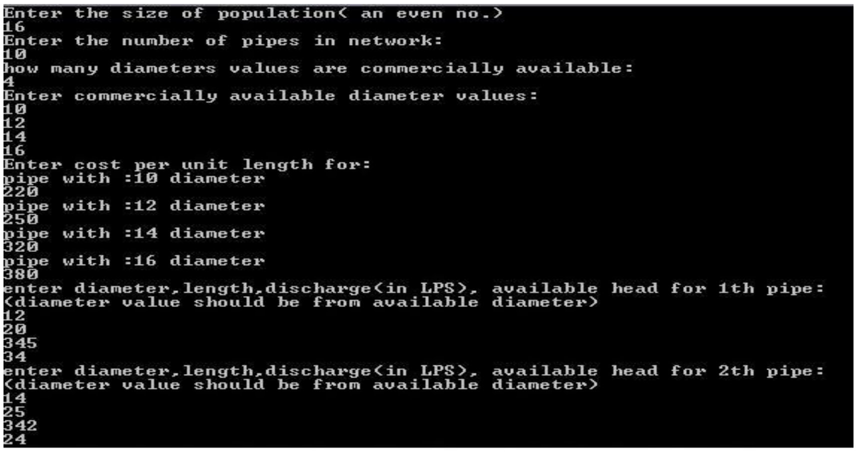


```
Enter the size of population( an even no.)
20
Enter the number of pipes in network:
15
how many diameters values are commercially available:
4
Enter commercially available diameter values:
12
28
35
40
40  35  12  35  40  40  28  12  40  28  12  35  35  40  12

12  35  40  40  35  40  12  28  12  28  40  12  35  28  28
```

Fig 2: Chromosome representation

Chromosomes for a particular number of pipes and commercially available diameter values are randomly generated as shown in Fig. 2. Input parameters are given as shown in Fig 3. Proposed algorithm is implemented and tested with different population sizes and at the end population size is taken as 6.



```
Enter the size of population( an even no.)
16
Enter the number of pipes in network:
10
how many diameters values are commercially available:
4
Enter commercially available diameter values:
10
12
14
16
Enter cost per unit length for:
pipe with :10 diameter
220
pipe with :12 diameter
250
pipe with :14 diameter
320
pipe with :16 diameter
380
enter diameter,length,discharge(in LPS), available head for 1th pipe:
(diameter value should be from available diameter)
12
20
345
34
enter diameter,length,discharge(in LPS), available head for 2th pipe:
(diameter value should be from available diameter)
14
25
342
24
```

Fig 3: Different Parameters Input

- ***Calculate initial cost*:**

After initial population generation, initial cost of network is calculated using the formula:

$$Initial\ Cost = \sum_{i=1}^{n} L_i\, C_i(d_A) \quad \ldots..\ (9)$$

The initial cost is calculated on the basis of initial parameter values and using the same formula system cost is calculated for all chromosomes.

- ***Check for constraints***:

Penalty cost is added to system's initial cost if system doesn't meet all constraints.

- ***Calculate Fitness*:**

Fitness value of a chromosome is calculated as:

$$fitness\_value_i = {}^{1}\!/_{cost_i} \quad \ldots\ldots\ldots\ (10)$$

Where, $fitness\_value_i$ represents fitness value of i^{th} chromosome and $cost_i$, shows system cost for i^{th} chromosome.

- ***Selection*:**

Selection of chromosomes for mating pool is done by using roulette wheel selection method. A chromosome is selected with probability:

$$selection_i = \frac{fitness\_value_i}{\sum_{j=1}^{r} fitness\_value_j} \quad \ldots\ (11)$$

Where, $selection_i$ stands for probability of selection of i^{th} chromosome.

- ***Crossover:***

One point crossover f is used to generate new population from chromosomes selected as parent in mating pool. Crossover point is generated randomly which lies between 0 and length of chromosome. Crossover probability for this problem is taken as 0.7.

- ***Mutation***:

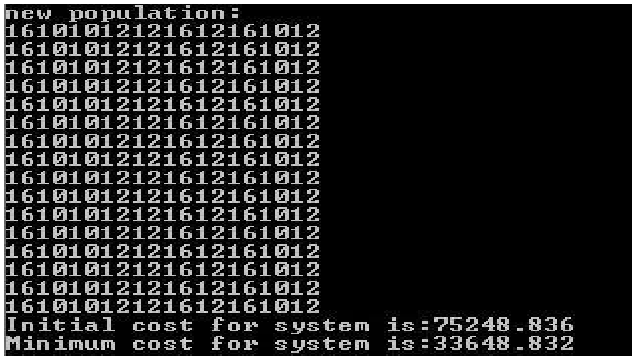
Mutation generally takes place because of some environmental changes. One or more bits of chromosomes get changed with a very small probability. Mutation probability for this problem is taken as 0.6.

- ***New population***:

After crossover new population is generated and whole procedure is repeated for specific number of generations.

- ***Termination and Results***:

After a termination criterion (specific number of generations) is met, the algorithm is terminated to obtain final fitness function value as cost of pipeline network. Fig. 4 shows cost reduction improvement in final solution as compared to the initial solution.



```
new population:
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
16101012121612161012
Initial cost for system is:75248.836
Minimum cost for system is:33648.832
```

Fig 4: Final Result obtained Show improvement in Cost Reduction

7. GENERAL OUTLINE OF PROPOSED APPROACH

The performance of the proposed system with time i.e. the effect of deviation in probability of crossover and mutation on the number of generations required to generate final solution, as well as the comparison of proposed genetic algorithm approach with available deterministic algorithms for this problem has been studied. The results of these comparisons have been represented in form of comparison charts.

The effect of deviation in crossover probability is analyzed, by keeping the population size, number of generations and the mutation probability fixed at a certain value. The Fig. 5 shows that the probability of crossover, pc, gives better results at a value pc= 0.6 to pc= 0.8. Hence, a crossover probability of 0.7 has been chosen.

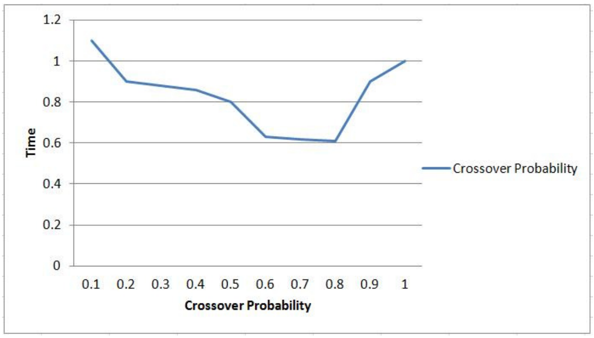


Fig 5: Crossover Probability Deviation Graph

The effect of deviation in probability of mutation has been analyzed by keeping the size of the population, the number of generations and the crossover probability fixed at a certain value. The analysis graph in Fig. 6 shows that, the probability of mutation pm, gives optimal results at a value pm= 0.4 to pm= 0.6. Thus for this problem, the mutation probability is chosen to be 0.6

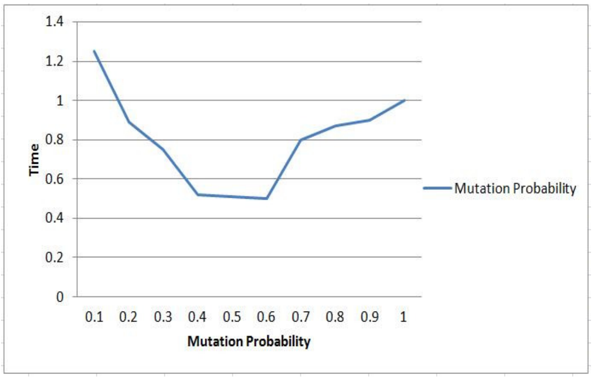


Fig 6: Mutation Probability Deviation Graph

The effect on the number of generations has been analyzed with respect to the probability of crossover and mutation, by keeping the population size fixed and varying the probability of crossover and mutation from 0.1 to 1. The Fig. 7 shows that the near optimal results are achieved at crossover probability, pc= 0.7 and mutation probability, pm= 0.6.

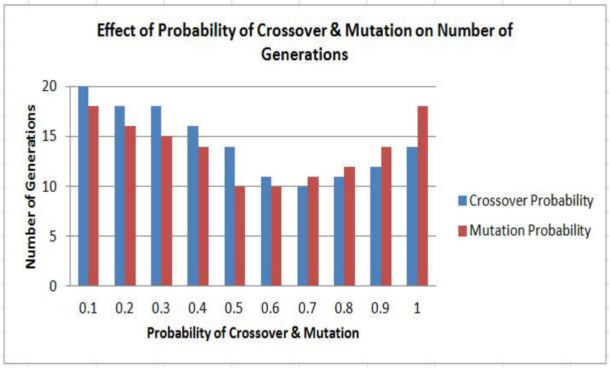


Fig 7: Effect on number of generations

A comparative analysis of using proposed genetic algorithm approach and the other available deterministic algorithms has been shown in Fig. 8. The graphical analysis shows that, the performance of genetic algorithms up to the number of pipes in the network ≈ 4 increases slowly and steadily. The deterministic search algorithms give better results up to the number of pipes in the network < 4, as they take less time to obtain final optimal solution whereas, the genetic algorithms take comparatively more time to reach at solution.

However, at the number of pipes in the network = 4, the performance of genetic algorithms improves exponentially, as they show better results, taking less time to obtain the final result. Whereas, the performance of deterministic algorithms deteriorates after this point as they take much time to obtain final solution as the number of pipes increases in the network.

Hence, for this problem, where the numbers of pipes in the network are greater than or equal to 4, the genetic algorithms have been chosen to provide near optimal results.

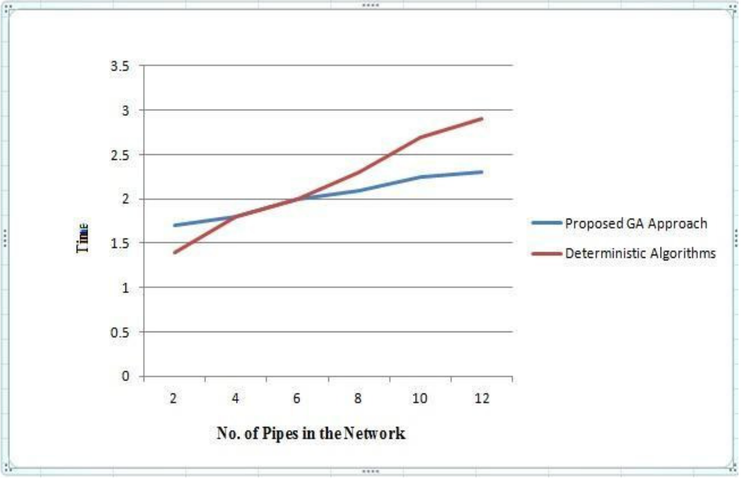


Fig 8: Comparison of Proposed GA Approach with Deterministic Algorithms

8. CONCLUSIONS

In this paper, cost of a pipeline network is achieved by using genetic algorithms. Pipe diameter is used for encoding of parameters, as various types of losses like frictional losses etc. depends on diameters. By randomly generating different layouts, cost of network can be calculated. Cost of network gets reduced by a large factor after a specific number of generations. Comparative analysis of proposed Genetic Algorithm approach with available deterministic algorithms shows that, GA takes comparatively less time than deterministic approaches as number of pipes in the network increases.

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