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# Optimization of Badarawa/Malali Water Distribution Network Using Genetics Algorithm

**A Saminu[*1], IAbubakar[2], U Tsoho[3], I Abdullahi[4]**
[*1,3,4] Department of civil Engineering, Nigerian Defence Academy, Kaduna [2]Professor, Department of [2]Department of civil Engineering, Ahmadu Bello University Zaria
saminuahmed4real@yahoo.com

## Abstract

In this study EPANET, a widely used water distribution package was linked to OptiGa, a Visual Basic ActiveX control for implementation of genetic algorithm, through Visual Basic programming technique, to modify the computer software called OptiNetwork. OptiNetwork was applied to Badarawa / Malali distributionnetwork consistingof 96 pipes of different materials, 75junctions, two tanks, and a source reservoir (i.e treatment plant) from which water is pumped through a pumping main to the overhead reservoir and later distributed to the network by gravity.After several runs the cost obtained from this network using OptiNetwork software under the application of genetics algorithm is $433,520.00which is lower than $435,118.00 obtained from OptiDesigner software. This difference is approximately 3% lower than the result obtained from OptiDesigner(a commercial software) 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.The results obtained shows that the introduction of the modified software( OptiNetwork) is justified. This is because, it has been able to improve the search method in terms of achieving the “least-cost” designed water distribution system that will supply sufficient water quantities at adequate pressure to the consumers.

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

## Introduction

A water distribution network is a system containing pipes, reservoir, pumps and valves of different types,(appurtenances) which are connected to each other to provide water to consumers. 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.

## Literature

### What is Genetic Algorithm?

Genetic algorithms (GAs) are optimization techniques based on the concepts of natural selection and genetics. Genetic algorithms are inspired by Darwin's theory of evolution. In this approach, the variables are represented as genes on a chromosome. Solution to a problem solved by genetic algorithms uses an evolutionary process (it is evolved). GAs features a group of candidate solutions (population) on the response surface. Through natural selection and the genetic operators, mutation and recombination, chromosomes with better fitness are found. Natural selection guarantees that chromosomes with the best fitness will propagate in future populations. Using the recombination operator, the GA combines genes from two parent chromosomes to form two new chromosomes (children) that have a high probability of having better fitness than their parents. Mutation allows new areas of the response surface to be explored. This is repeated until some condition (forexample number of populations or improvement of the best solution) is satisfied.

**Simple Genetic Algorithm**

The mechanics of a simple genetic algorithm are surprisingly simple, involving nothing more complex than copying strings and swapping partial strings (Goldberg, 1989). Basic components of simple genetic algorithm are as follows (Obitko, 1998).

***Encoding a chromosome***

A chromosome should in some way contain information about solution that it represents. The most used way of encoding is a binary string. A chromosome then could look like this

**Table 2.1. Encoding a chromosome**

| | |
|---|---|
| Chromosome 1 | 1101100100110110 |
| Chromosome 2 | 1101111000011110 |

Each chromosome is represented by a binary string. Each bit in the string can represent some characteristics of the solution. Another possibility is that the whole string can represent a number. Of course, there are many other ways of encoding. The encoding depends mainly on the solved problem. For example, one can encode directly integer or real numbers; sometimes it is useful to encode some permutations and so on.

***Reproduction***

During reproduction, **recombination** (or **crossover**) first occurs. Genes from parents combine to form a whole new chromosome. The newly created offspring can then be mutated. **Mutation** means that the elements of DNA are a bit changed. These changes are mainly caused by errors in copying genes from parents. The **fitness** of an organism is measured by success of the organism in its life (survival).

***Selection***

Parents are selected according to their fitness. The better the chromosomes are, the more chances to be selected they have. Imagine a **roulette wheel** where all the chromosomes in the population are placed. The size of the section in the roulette wheel is proportional to the value of the fitness function of every chromosome – the bigger the value is, the larger the section is.

***Crossover***

After we have decided what encoding we will use, we can proceed to crossover operation. Crossover operates on selected genes from parent chromosomes and creates new offspring. The simplest way how to do that is to choose randomly some crossover point and copy everything before this point from the first parent and then copy everything after the crossover point from the other parent. Crossover can be illustrated as follows: ( | is the crossover point):

**Table 2.2. Crossover**

| | |
|---|---|
| Chromosome 1 | 11011 \| 00100110110 |
| Chromosome 2 | 11011 \| 11000011110 |
| Offspring 1 | 11011 \| 11000011110 |
| Offspring 2 | 11011 \| 00100110110 |

There are other ways how to make crossover, for example we can choose more crossover points. Crossover can be quite complicated and depends mainly on the encoding of chromosomes. Specific crossover made for a specific problem can improve performance of the genetic algorithm.

***Mutation***

After a crossover is performed, mutation takes place. Mutation is intended to prevent falling of all solutions in the population into a local optimum of the solved problem. Mutation operation randomly changes the offspring resulted from crossover. In case of binary encoding we can switch a few randomly chosen bits from 1 to 0 or from 0 to 1. Mutation can be then illustrated as follows:

**Table 2.3. Mutation**

| | |
|---|---|
| Original offspring 1 | 1101111000011110 |
| Original offspring 2 | 1101100100110110 |
| Mutated offspring 1 | 1100111000011110 |
| Mutated offspring 2 | 1101101100110110 |

The technique of mutation (as well as crossover) depends mainly on the encoding of chromosomes. For example when we are encoding permutations, mutation could be performed as an exchange of two genes.

***Elitism***

The idea of the elitism has been already introduced. When creating a new population by crossover and mutation, we have a big chance, that we will loose the best chromosome. Elitism is the name of the method that first copies the best chromosome (or few best chromosomes) to the new population. The rest of the population is constructed in ways described above. Elitism can rapidly increase the performance of GA, because it prevents a loss of the best found solution.

**Steps in Using Genetic Algorithms for Network Optimization**

The following steps summarize an implementation of a genetic algorithm for optimizing the design of a water distribution network system (based on Simpson, Murphy and Dandy 1993[1]; Simpson, Dandy and Murphy 1994) [2]

1. Develop a coding scheme to represent the decision variables to be optimized and the corresponding lookup tables for the choices for the design variables.
2. Choose the form of the genetic algorithm operators; e.g. population size (say N=100 or 500); selection scheme - tournament selection or biased Roulette wheel; crossover type - one-point, two-point or uniform; and mutation type - bit-wise or creeping.
3. Choose values for the genetic algorithm parameters (e.g. crossover probability – pc; mutation probability - pm; penalty cost factor *K*).
4. Select a seed for the random number generator.

5. Randomly generate the initial population of WDS network designs.
6. Decode each string in the population by dividing into its sub-strings and then determining the corresponding decision variable choices (using the lookup tables).
7. For the decoded strings, compute the network cost of each of the designs in the population.
8. Analyze each network design with a hydraulic solver for each demand loading case to compute network flows, pressures and pressure deficits (if any).
9. Compute a penalty cost for each network where design constraints are violated.
10. Compute the fitness of each string based on the costs in steps 7 and 9; often taken as the inverse of the total cost (network cost plus penalty cost).
11. Create a mating pool for the next generation using the selection operator that is driven by the "survival of the fittest."
12. Generate a new population of designs from the mating pool using the genetic algorithm operators of crossover and mutation.
13. Record the lowest cost solutions from the new generation.
14. Repeat steps 6 to 13 to produce successive generations of populations of designs stop if all members of the population are the same.
15. Select the lowest cost design and any other similarly low cost designs of different configuration.
16. Check if any of the decision variables have been selected at the upper bound of the possible choices in the lookup table. If so, expand the range of choices and re-run of genetic algorithm.
17. Repeat steps 4 to 16 for say, ten different starting random number seeds.
18. Repeat steps 4 to 17 for successively larger and larger population sizes. Some of the main steps in the genetic algorithm process are now described in more detail.

The literature review shows that the use of optimization is widespread in simple water distribution systems. Few literatures reviewed in the study includes:

(Lee and Lee 2001) [3], used GA to find the optimal pump operation of water distribution system. The paper presents a new management model, H20 NET scheduler, for optimal control and operation of water distribution systems. The proposed model makes use of the latest advances in Genetic Algorithm (GA) optimization to automatically determine the least-cost pump scheduling/operation policy for each pump station in the water distribution system, while satisfying target hydraulic performance requirements. Quasi-dynamic (extended period simulation) hydraulic network simulator (H20NET analyzer 1999) [4], was directly embedded into the optimization model. Starting with an initial feasible set of design parameters and rehabilitation actions, it is passed to the network solver for use in explicitly satisfying the implicit system constraints and in evaluating the implicit bound constraints.

The results obtained indicate that the developed model can effectively reduce the cost of energy consumed for pumping in a complex water distribution system while maintaining satisfactory level of services.

(Tospornsampon et al.2007) [5]Applied a combination of Tabusearch (TS) and Genetic Algorithm (GA) to solve a problem of split-pipe design of water distribution network.

The first, is the two-loop network which was first introduced by (Alperovits and Shamir 1997) [6]. 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 $\alpha = 10.5088$ and $\alpha = 10.6792$, 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) [7], and (Dandy et.al 1999) [8]. 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) [5], 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.

## Methodology

**MATERIALS.**The materials used includes: topographical map, EPANET, OPTIDESIGNER, andModified OPITNETWORK optimization software.

**METHOD OF DATA COLLECTION:** The topographical map of Badarawa / Malali study area, was produced using GIS software at Integrated Engineering Consultancy Kaduna, after obtaining the map, the existing water network for the study area was drawn on the map, together with the junctions and their elevations. This was done with the help of experienced water board personnel, after proper editing, the full water supply network of the area was produced on the recent topographical map, and later transferred t into the Epanet software work space using a process called map transport.

The demand was obtain after surveying the network in the area, average of 25 to 30 houses were connected to each individual model/Junction also the study area falls under the category of urban settlement, as a result of this development, the standard from the Federal Ministry of Water Resources manual on water demand was used, for this research 180 L/C/D was considered with an average of nine (9) persons in each house.We obtain a demand at particular junction by multiplying (number of houses at junction by number of people in the house by 180L/C/D).

A computer software called optiNetwork was modified by linking EPANET to Optiga, a visual basic ActiveX control for implementation of genetics algorithm, through visual basic programming techniques.

**Steps for Optinetwork Software**

The following steps are to be taken for the use of OptiNetwork software:

1. Draw the system using EPANET and set system properties.
2. Export the network from EPANET as an INP file to OptiNetwork 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.

***Modified Program (OptiNetwork Software)***

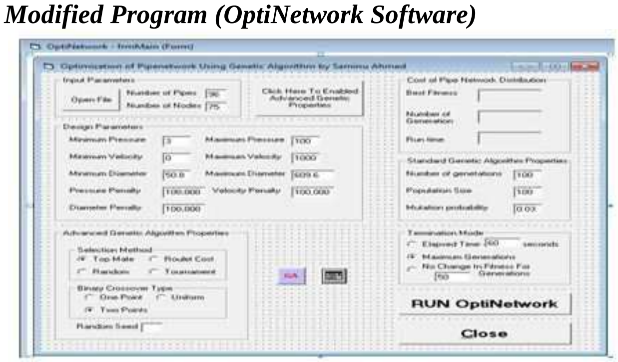


**Figure 3.1: The modified software OptiNetwork**

## Results

**The Case Study Area**

The existing distribution network of Badarawa/ Malali was studied and analyzed. It consists of 96 pipes of different materials,75junctions, twotanks, a source reservoir (i.e treatment plant) from which water is pumped through a pumping main to the overhead reservoir and later distributed to the network by gravity, as shown in ( figure 4.1).

OptiNetwork software was applied to Badarawa / Malali networks distribution designs. The optimum result of $433,520.00 was obtained, which is lower than $435,118.00 obtained from OptiDesigner (a commercial software).The commercial available diameters used for the network are given in table 4.1.Other hydraulic results that satisfies the constraints requirements are given in table 4.2 .

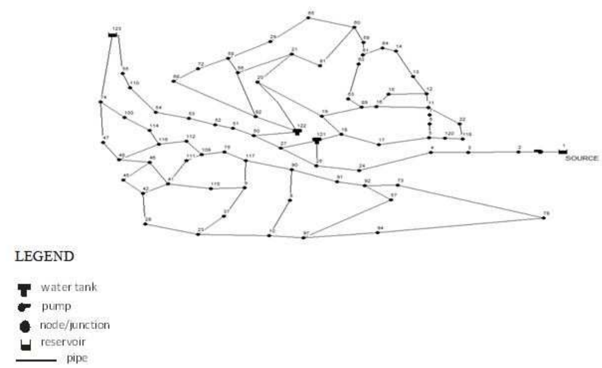


**Figure 4.1 Badarawa/ Malali water distribution network**

**Table 4.1: Cost of Commercial Available pipe Diameter for Badarawa/ Malali water distribution**

| Diameter (mm) | Cost per Linear meter ($) |
|---|---|
| 152.40 | 16 |
| 203.20 | 23 |
| 254.00 | 32 |
| 304.80 | 50 |
| 355.60 | 60 |
| 406.40 | 90 |
| 457.20 | 130 |
| 508.00 | 170 |
| 558.80 | 300 |
| 609.60 | 550 |

**Table 4.3: Network Data for Badarawa/Malali Water Distribution Network with two Reservoirs. After Optimization.(Using OptiNetwork)**

| Link ID | Length m | Diameter mm | Roughness mm | Flow LPS | Velocity m/s | Unit Headloss m/km | Friction Factor |
|---|---|---|---|---|---|---|---|
| Pipe 3 | 218.88 | 609.6 | 0.005 | -38.32 | 0.13 | 0.03 | 0.019 |
| Pipe 11 | 323.23 | 254 | 0.005 | -6.64 | 0.13 | 0.08 | 0.023 |
| Pipe 12 | 120.65 | 508 | 0.005 | -1.41 | 0.01 | 0 | 0 |
| Pipe 13 | 250.34 | 101.6 | 0.005 | -6.09 | 0.75 | 5.44 | 0.019 |
| Pipe 14 | 350.21 | 406.4 | 0.005 | 2.13 | 0.02 | 0 | 0.038 |
| Pipe 15 | 230.23 | 101.6 | 0.005 | -0.67 | 0.08 | 0.11 | 0.033 |
| Pipe 19 | 388.48 | 101.6 | 0.005 | -12.55 | 1.55 | 20.1 | 0.017 |
| Pipe 20 | 145.68 | 101.6 | 0.005 | -16.43 | 2.03 | 32.84 | 0.016 |
| Pipe 22 | 151.33 | 355.6 | 0.005 | 30.9 | 0.31 | 0.24 | 0.018 |
| Pipe 23 | 540.56 | 101.6 | 0.005 | -40.97 | 5.05 | 176.89 | 0.014 |
| Pipe 24 | 230.56 | 508 | 0.005 | -43.32 | 0.21 | 0.08 | 0.018 |
| Pipe 26 | 202.41 | 101.6 | 0.005 | -13.38 | 1.65 | 22.6 | 0.017 |
| Pipe 43 | 170.88 | 355.6 | 0.005 | -17.25 | 0.17 | 0.09 | 0.02 |
| Pipe 8 | 123.54 | 101.6 | 0.005 | -5.24 | 0.65 | 4.16 | 0.02 |
| Pipe 46 | 535.74 | 152.4 | 0.005 | -37.16 | 2.04 | 20.42 | 0.015 |
| Pipe 47 | 118.59 | 406.4 | 0.005 | -29.27 | 0.23 | 0.12 | 0.018 |
| Pipe 48 | 175.18 | 101.6 | 0.005 | -20.18 | 2.49 | 47.84 | 0.015 |
| Pipe 57 | 240.12 | 101.6 | 0.005 | 10.11 | 1.25 | 13.59 | 0.017 |
| Pipe 58 | 134.77 | 101.6 | 0.005 | 12.27 | 1.51 | 19.29 | 0.017 |
| Pipe 62 | 125.76 | 457.2 | 0.005 | -20.96 | 0.13 | 0.04 | 0.02 |
| Pipe 63 | 75.43 | 101.6 | 0.005 | -18.71 | 2.31 | 41.67 | 0.016 |
| Pipe 64 | 240.25 | 355.6 | 0.005 | -2.47 | 0.02 | 0 | 0.035 |
| Pipe 66 | 101.45 | 101.6 | 0.005 | 0.18 | 0.02 | 0.01 | 0.031 |
| Pipe 67 | 278.9 | 508 | 0.005 | 13.69 | 0.07 | 0.01 | 0.023 |
| Pipe 68 | 102.33 | 457.2 | 0.005 | -7.42 | 0.05 | 0.01 | 0.026 |
| Pipe 74 | 230.79 | 609.6 | 0.005 | -3.16 | 0.01 | 0 | 0.033 |
| Pipe 75 | 160.23 | 508 | 0.005 | -5.51 | 0.03 | 0 | 0.031 |
| Pipe 76 | 1350.68 | 203.2 | 0.005 | 75.45 | 2.33 | 18.51 | 0.014 |
| Pipe 84 | 90.22 | 101.6 | 0.005 | -14.91 | 1.84 | 27.52 | 0.016 |
| Pipe 87 | 42.84 | 152.4 | 0.005 | -26.92 | 1.48 | 11.33 | 0.016 |
| Pipe 94 | 200.12 | 508 | 0.005 | 2.83 | 0.01 | 0 | 0.038 |
| Pipe 16 | 1400 | 101.6 | 0.005 | -51.71 | 6.38 | 273.03 | 0.013 |
| Pipe 1 | 220.23 | 203.2 | 0.005 | -233.18 | 7.19 | 150.89 | 0.012 |
| Pipe 60 | 450.43 | 558.8 | 0.005 | 50.37 | 0.21 | 0.07 | 0.017 |
| Pipe 77 | 250.12 | 609.6 | 0.005 | 48.02 | 0.16 | 0.04 | 0.018 |
| Pipe 95 | 280.12 | 152.4 | 0.005 | 45.67 | 2.5 | 29.82 | 0.014 |
| Pipe 96 | 1000 | 254 | 0.005 | 23.79 | 0.47 | 0.77 | 0.017 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pipe 97 | 200.65 | 101.6 | 0.005 | 21.44 | 2.64 | 53.47 | 0.015 |
| Pipe 98 | 240.65 | 406.4 | 0.005 | 25.12 | 0.19 | 0.09 | 0.019 |
| Pipe 99 | 230.65 | 304.8 | 0.005 | 22.67 | 0.31 | 0.29 | 0.018 |

**Table 4.3: Network Data for Badarawa/Malali Water Distribution Network with two Reservoirs. After Optimization.(Using OptiNetwork)( continued).**

| Link ID | Length m | Diameter mm | Roughness mm | Flow LPS | Velocity m/s | Unit Headloss m/km | Friction Factor |
|---|---|---|---|---|---|---|---|
| Pipe100 | 150.77 | 152.4 | 0.005 | 21.94 | 1.2 | 7.81 | 0.016 |
| Pipe101 | 200.99 | 406.4 | 0.005 | 12.65 | 0.1 | 0.03 | 0.022 |
| Pipe102 | 200.12 | 254 | 0.005 | 10.3 | 0.2 | 0.17 | 0.021 |
| Pipe103 | 230.43 | 254 | 0.005 | 4.55 | 0.09 | 0.04 | 0.025 |
| Pipe123 | 100.54 | 101.6 | 0.005 | -10.02 | 1.24 | 13.35 | 0.017 |
| Pipe126 | 350.12 | 101.6 | 0.005 | -46.76 | 5.77 | 226.25 | 0.014 |
| Pipe127 | 400.12 | 101.6 | 0.005 | -49.01 | 6.04 | 246.99 | 0.013 |
| Pipe128 | 200 | 304.8 | 0.005 | -6.23 | 0.09 | 0.03 | 0.024 |
| Pipe129 | 280.79 | 254 | 0.005 | -8.93 | 0.18 | 0.13 | 0.021 |
| Pipe137 | 135.35 | 152.4 | 0.005 | 4.13 | 0.23 | 0.39 | 0.023 |
| Pipe138 | 200.43 | 609.6 | 0.005 | 1.48 | 0.01 | 0 | 0.174 |
| Pipe139 | 250.35 | 558.8 | 0.005 | -1.22 | 0 | 0 | 0.131 |
| Pipe140 | 120.32 | 254 | 0.005 | 3.62 | 0.07 | 0.03 | 0.027 |
| Pipe141 | 110.11 | 101.6 | 0.005 | 1.07 | 0.13 | 0.25 | 0.029 |
| Pipe142 | 100.32 | 101.6 | 0.005 | -1.58 | 0.19 | 0.5 | 0.026 |
| Pipe143 | 2600.54 | 203.2 | 0.005 | -0.35 | 0.01 | 0 | 0.032 |
| Pipe144 | 300.12 | 254 | 0.005 | -3.05 | 0.06 | 0.02 | 0.028 |
| Pipe 5 | 70.21 | 101.6 | 0.005 | -25.03 | 3.09 | 71.09 | 0.015 |
| Pipe 10 | 80.12 | 101.6 | 0.005 | -36.16 | 4.46 | 140.23 | 0.014 |
| Pipe 18 | 70.32 | 101.6 | 0.005 | -38.86 | 4.79 | 160.3 | 0.014 |
| Pipe 29 | 100.22 | 101.6 | 0.005 | -41.66 | 5.14 | 182.44 | 0.014 |
| Pipe 49 | 210.99 | 101.6 | 0.005 | 18.24 | 2.25 | 39.76 | 0.016 |
| Pipe 51 | 100.43 | 558.8 | 0.005 | 15.99 | 0.07 | 0.01 | 0.021 |
| Pipe 4 | 420 | 203.2 | 0.005 | 10.1 | 0.31 | 0.48 | 0.02 |
| Pipe 6 | 400 | 406.4 | 0.005 | 3.2 | 0.02 | 0 | 0.029 |
| Pipe 9 | 600 | 101.6 | 0.005 | -44.11 | 5.44 | 202.93 | 0.014 |
| Pipe 17 | 220 | 609.6 | 0.005 | 19.43 | 0.07 | 0.01 | 0.022 |
| Pipe 50 | 220 | 101.6 | 0.005 | 8.47 | 1.05 | 9.86 | 0.018 |
| Pipe 53 | 110 | 609.6 | 0.005 | 67.57 | 0.23 | 0.08 | 0.017 |
| Pipe 55 | 110 | 254 | 0.005 | 34.42 | 0.68 | 1.5 | 0.016 |

**Table 4.3: Network Data for Badarawa/Malali Water Distribution Network with two Reservoirs. After Optimization.(Using OptiNetwork) (continued).**

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| Link ID | Length m | Diameter mm | Roughness mm | Flow LPS | Velocity m/s | Unit Headloss m/km | Friction Factor |
|---|---|---|---|---|---|---|---|
| Pipe 56 | 380 | 101.6 | 0.005 | 15.64 | 1.93 | 30.03 | 0.016 |
| Pipe 59 | 89 | 101.6 | 0.005 | 1.53 | 0.19 | 0.47 | 0.026 |
| Pipe 70 | 150 | 152.4 | 0.005 | 32.49 | 1.78 | 15.96 | 0.015 |
| Pipe 73 | 260 | 101.6 | 0.005 | 4.5 | 0.56 | 3.18 | 0.021 |
| Pipe 79 | 200 | 406.4 | 0.005 | 22.43 | 0.17 | 0.07 | 0.019 |
| Pipe 80 | 380 | 254 | 0.005 | 2 | 0.04 | 0.01 | 0.031 |
| Pipe 81 | 300 | 152.4 | 0.005 | 0.55 | 0.03 | 0.01 | 0.041 |
| Pipe 82 | 60 | 558.8 | 0.005 | 10.99 | 0.04 | 0 | 0.027 |
| Pipe 83 | 270 | 457.2 | 0.005 | 8.54 | 0.05 | 0.01 | 0.025 |
| Pipe 86 | 200 | 152.4 | 0.005 | -3.92 | 0.22 | 0.36 | 0.023 |
| Pipe 90 | 380 | 101.6 | 0.005 | 8.06 | 0.99 | 9.01 | 0.018 |
| Pipe 91 | 250 | 101.6 | 0.005 | -1.62 | 0.2 | 0.52 | 0.026 |
| Pipe 92 | 300 | 101.6 | 0.005 | 4.03 | 0.5 | 2.61 | 0.021 |
| Pipe 93 | 260 | 304.8 | 0.005 | 6.94 | 0.1 | 0.04 | 0.023 |
| Pipe104 | 200 | 101.6 | 0.005 | 6.87 | 0.85 | 6.77 | 0.019 |
| Pipe105 | 300 | 355.6 | 0.005 | 4.17 | 0.04 | 0.01 | 0.027 |
| Pipe106 | 390 | 254 | 0.005 | 3.31 | 0.07 | 0.02 | 0.027 |
| Pipe107 | 200 | 304.8 | 0.005 | 4.85 | 0.07 | 0.02 | 0.026 |
| Pipe108 | 300 | 203.2 | 0.005 | 4.24 | 0.13 | 0.1 | 0.024 |
| Pipe109 | 1000 | 101.6 | 0.005 | 1.68 | 0.21 | 0.56 | 0.026 |
| Pipe110 | 280 | 508 | 0.005 | 10.86 | 0.05 | 0.01 | 0.024 |
| Pipe111 | 200 | 558.8 | 0.005 | 8.21 | 0.03 | 0 | 0.029 |
| Pipe 2 | 350 | 152.4 | 0.005 | 35.97 | 1.97 | 19.23 | 0.015 |
| Pipe 7 | 120 | 101.6 | 0.005 | 12.87 | 1.59 | 21.06 | 0.017 |
| Pipe 21 | 110 | 609.6 | 0.005 | -10.22 | 0.04 | 0 | 0.026 |
| Pipe 25 | 200 | 101.6 | 0.005 | 8.95 | 1.1 | 10.9 | 0.018 |
| Pump52 | #N/A | #N/A | #N/A | 197.21 | 0 | -33.23 | 0 |

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**Table 4.3 Network Data for Badarawa/Malali Water Distribution Network with two Reservoirs. After Optimization.(continued)**

| Node ID | Elevation m | Demand LPS | Head m | Pressure m |
|---|---|---|---|---|
| Junc 2 | 600 | 0 | 615.23 | 15.23 |
| Junc 3 | 610 | 2.35 | 621.96 | 11.96 |
| Junc 4 | 611 | 2.65 | 621.97 | 10.97 |
| Junc 5 | 655 | 2.35 | 712.03 | 57.03 |
| Junc 6 | 660 | 2.55 | 712.03 | 52.03 |
| Junc 7 | 665 | 2.65 | 712 | 47 |
| Junc 11 | 667 | 2.55 | 712.05 | 45.05 |
| Junc 12 | 650 | 2.55 | 712.05 | 62.05 |
| Junc 13 | 703 | 2.45 | 713.41 | 10.41 |
| Junc 14 | 704 | 2.45 | 713.41 | 9.41 |
| Junc 15 | 700 | 2.8 | 712.05 | 12.05 |
| Junc 16 | 675 | 2.7 | 712.07 | 37.07 |
| Junc 17 | 685 | 2.45 | 712.23 | 27.23 |
| Junc 18 | 710 | 2.35 | 720.04 | 10.04 |
| Junc 19 | 715 | 2.35 | 724.83 | 9.83 |
| Junc 20 | 720 | 2.25 | 724.99 | 4.99 |
| Junc 21 | 700 | 2.55 | 724.95 | 24.95 |
| Junc 22 | 660 | 2.7 | 711.98 | 51.98 |
| Junc 24 | 650 | 2.35 | 717.59 | 67.59 |
| Junc 25 | 700 | 2.55 | 717.61 | 17.61 |
| Junc 27 | 718 | 2.7 | 722.18 | 4.18 |
| Junc 37 | 1351 | 2.35 | 1404.36 | 53.36 |
| Junc 41 | 1351 | 2.7 | 1405.14 | 54.14 |
| Junc 42 | 1352 | 2.8 | 1405.16 | 53.16 |
| Junc 45 | 1353 | 2.35 | 1405.64 | 52.64 |
| Junc 46 | 1355 | 2.65 | 1405.66 | 50.66 |
| Junc 47 | 1360 | 2.25 | 1424.98 | 64.98 |
| Junc 48 | 1353 | 2.45 | 1416.6 | 63.6 |
| Junc 50 | 700 | 2.65 | 727.17 | 27.17 |
| Junc 51 | 720 | 2.7 | 738.41 | 18.41 |
| Junc 52 | 730 | 2.8 | 749.68 | 19.68 |
| Junc 53 | 755 | 2.45 | 767.96 | 12.96 |
| Junc 54 | 800 | 2.65 | 889.72 | 89.72 |
| Junc 55 | 1000 | 2.7 | 1067.76 | 67.76 |
| Junc 56 | 700 | 2.35 | 721.69 | 21.69 |
| Junc 58 | 700 | 2.55 | 719.09 | 19.09 |

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| Node ID | Elevation m | Demand LPS | Head m | Pressure m |
|---|---|---|---|---|
| Junc 59 | 690 | 2.25 | 716.56 | 26.56 |
| Junc 60 | 712 | 2.45 | 716.56 | 4.56 |
| Junc 61 | 693 | 2.55 | 713.42 | 20.42 |
| Junc 62 | 685 | 2.65 | 713.42 | 28.42 |
| Junc 63 | 692 | 2.65 | 713.42 | 21.42 |
| Junc 64 | 696 | 2.7 | 713.41 | 17.41 |
| Junc 65 | 713 | 2.8 | 716.57 | 3.57 |
| Junc 68 | 701 | 2.55 | 719.09 | 18.09 |
| Junc 72 | 701 | 2.35 | 719.09 | 18.09 |
| Junc 73 | 1353 | 2.55 | 1403.79 | 50.79 |
| Junc 74 | 1400 | 2.65 | 1424.99 | 24.99 |
| Junc 75 | 1354 | 2.45 | 1405.08 | 51.08 |
| Junc 78 | 1351 | 2.35 | 1403.78 | 52.78 |
| Junc 81 | 709 | 2.25 | 716.57 | 7.57 |
| Junc 82 | 700 | 2.35 | 722.52 | 22.52 |
| Junc 89 | 673 | 2.8 | 713.42 | 40.42 |
| Junc100 | 1380 | 2.35 | 1424.96 | 44.96 |
| Junc109 | 1349 | 2.55 | 1405.1 | 56.1 |
| Junc110 | 880 | 2.25 | 968.93 | 88.93 |
| Junc111 | 1355 | 2.7 | 1405.11 | 50.11 |
| Junc112 | 1355 | 2.35 | 1415.83 | 60.83 |
| Junc114 | 1360 | 2.35 | 1424.95 | 64.95 |
| Junc115 | 1351 | 2.65 | 1405.14 | 54.14 |
| Junc116 | 1353 | 2.45 | 1416.6 | 63.6 |
| Junc117 | 1353 | 2.35 | 1405.01 | 52.01 |
| Junc118 | 654 | 2.7 | 711.98 | 57.98 |
| Junc120 | 655 | 2.65 | 711.98 | 56.98 |
| Junc 90 | 1352 | 2.35 | 1403.83 | 51.83 |
| Junc 91 | 1351 | 2.35 | 1403.83 | 52.83 |
| Junc 92 | 1351 | 2.55 | 1403.79 | 52.79 |
| Junc 94 | 1350 | 2.7 | 1403.78 | 53.78 |
| Junc 97 | 1349 | 2.35 | 1403.79 | 54.79 |
| Junc 57 | 1350 | 2.65 | 1403.79 | 53.79 |
| Junc 8 | 1350 | 2.7 | 1403.83 | 53.83 |
| Junc 9 | 1352 | 2.55 | 1405.14 | 53.14 |
| Junc 10 | 1350 | 2.7 | 1403.79 | 53.79 |
| Junc 23 | 1349 | 2.55 | 1403.8 | 54.8 |
| Junc 28 | 1350 | 2.7 | 1403.81 | 53.81 |
| Junc 29 | 703 | 2.65 | 716.57 | 13.57 |

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| | | | | |
|---|---|---|---|---|
| Resvr123 | 1450 | -127.16 | 1450 | 0 |
| **Resvr 1** | 582 | 35.97 | 582 | 0 |
| Tank 122 | 715 | -74.01 | 725 | 10 |

## Discussion of Results

After several runs the cost obtained from this network using OptiNetwork software under the application of genetics algorithm is $433,520.00 which is lower than $435,118.00 obtained from OptiDesigner software. This difference is approximately 3% lower than the result obtained from OptiDesigner (a commercial software) with minimum pressure head of 3m and maximumof 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 commercial diameters used for the distribution network during the optimization process.

## Conclusions

The performance of the OptiNetwork software was compared with OptiDesigner a commercial software package. The results obtained prove the introduction of the OptiNetwork is justified, as it has been able to improve the search in terms of achieving least cost of the distribution network.

## Recommendations

The use of OptiNetwork software should be encouraged in the design of water distribution network, as it has proved effective in obtaining optimal results satisfying the constraints requirements. Also the use of OptiNetwork software is recommended for solving similar problems in water distribution network,

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