OPTIMIZATION OF WATER DISTRIBUTION NETWORKS USING GENETIC ALGORITHM

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ABSTRACT

OPTIMIZATION OF WATER DISTRIBUTION NETWORKS USING GENETIC ALGORITHM

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This study gives a description about the development of a computer model, RealPipe, which relates genetic algorithm (GA) to the well known problem of least-cost design of water distribution network.

GA methodology is an evolutionary process, basically imitating evolution process of nature. GA is essentially an efficient search method basically for nonlinear optimization cases. The genetic operations take place within the population of chromosomes. By means of various operators, the genetic knowledge in chromosomes change continuously and the success of the population progressively increases as a result of these operations. GA optimization is also well suited for optimization of water distribution systems, especially large and complex systems. The primary objective of this study is optimization of a water distribution network by GA. GA operations are realized on a special program developed by the author called RealPipe. RealPipe optimizes given water network distribution systems by considering capital cost of pipes only.

Five operators are involved in the program algorithm. These operators are generation, selection, elitism, crossover and mutation. Optimum population size is found to be between 30-70 depending on the size of the network (i.e. pipe number) and number of commercially available pipe size. Elitism rate should be around 10 percent. Mutation rate should be selected around 1-5 percent depending again on the size of the network. Multipoint crossover and higher rates are advisable. Also pressure penalty parameters are found to be much important than velocity parameters. Below pressure penalty parameter is the most important one and should be roughly 100 times higher than the other.

Two known networks of the literature are examined using RealPipe and expected results are achieved. N8.3 network which is located in the northern side of Ankara is the case study. Total cost achieved by RealPipe is 16.74 percent lower than the cost of the existing network; it should be noted that the solution provided by RealPipe is hydraulically improved.

Keywords: Water Distribution Systems, Genetic Algorithm, Optimization, Ankara N8 Water Distribution System, Least Cost Design

ÖZ

SU DAĞITIM ŞEBEKELERİNİN
GENETİK ALGORİTMA İLE OPTİMİZASYONU

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Bu çalışmada RealPipe adlı bilgisayar modelinin geliştirilmesi anlatılmaktadır. Su şebekelerinde çokca kullanılan en ucuz maliyet tasarımı yöntemi, Genetik algoritma (GA) yöntemi ile birlikte kullanılarak Ankara N8.3 su şebekesinin ekonomik çözümü elde edilmiştir.

GA yöntemi doğanın genetik evrimini bilgisayar ortamında taklit eden bir optimizasyon tekniğidir. GA esas olarak lineer olmayan optimizasyon durumlarında oldukça etkili bir yöntemdir. Genetik operasyonlar bilgisayar hafızasında oluşturulan kromozomlar vasıtası ile gerçekleştirilir. Çeşitli operatörler yardımıyla kromozomlardaki genetik bilgiler her turda sürekli olarak değiştirerek populasyondaki toplam uygunluğu artırırlar. Bu anlamda GA ile optimizasyon, şehir şebekeleri dağıtım hatları optimizasyonu için, özellikle kompleks sistemlerde, çok uygundur. Bu çalışmanın ana amacı şehir şebeke dağıtım hatlarının genetik algoritma ile optimizasyonudur. Yazar tarafından geliştirilen RealPipe adlı program GA işlemlerini yapmaktadır. RealPipe, verilen bir şebekeyi sadece boru fiyatlarını hesaplayarak optimize eder.

Program algoritması beş operatör içermektedir. Bunlar; üretme, seçme, elitizm, çaprazlama ve mutasyondur. Bu çalışmada genetik algoritma parametreleri de incelenmiştir. Optimum populasyon büyüklüğü, şebeke ve mevcut boru sayısına göre değişmekle beraber 30-70 dir. Elitizm oranı yüzde 10 civarında olmalıdır. Mutasyon oranı şebekeye göre değişmekle beraber, yüzde 1-5 arasında olmalıdır. Çoklu çaprazlama ve yüksek oranlar önerilmektedir. Aynı zamanda basınç ceza parametreleri, hız ceza parametrelerinden çok daha önemlidir. Hedef basınç değeri altı ceza katsayısı en önemli parametredir ve diğerinden 100 kat daha fazla olmalıdır.

RealPipe ile iki bilinen şebeke incelenmiştir ve beklenen sonuçlara ulaşılmıştır. Anakara’nın kuzeyinde bulunan N8.3 şebekesi örnek çalışma olarak incelenmiştir. RealPipe tarafından ulaşılan toplam boru bedeli mevcut şebekeden yüzde 16.74 daha düşük bulunmuştur. Aynı zamanda bu şebeke hidrolik olarak daha verimlidir.

Anahtar Kelimeler: Su Dağıtım Şebekeleri, Genetik Algoritma, Optimizasyon, Ankara N8 Su Dağıtım Şebekesi, En Ucuz Maliyet Tasarımı

TO MY FAMILY

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CHAPTER 1

INTRODUCTION

A water distribution system is an essential infrastructure that conveys water from the source to the consumers. A typical water distribution system consists of pipes, pumps, tanks, reservoirs and valves. System is mainly designed considering a demand pattern, pressure limitations, velocity limitations, quality assurances and maintenance issues at minimum cost, which can be named as optimal design.

Simulation of hydraulic behavior within a pressurized, looped pipe network is quite a complex task, which effectively means solving a number of nonlinear equations. The solution process involves simultaneous consideration of the energy and continuity equations and the head loss function. Even in a small network of fifteen pipes, comprising pumps, valves and tanks, there are millions of combinations for the design depending of commercially available pipe sizes. Traditionally, the design of water distribution networks has been based on the designer's experience. Several trials are run by changing pipe sizes until an economically feasible solution is reached that meets the design criteria in regard to the hydraulic conformity. For this kind of applications; designer's experience, budget and duration of the design period are very important. Success of the modeling is mostly governed by these criteria. Because of time limitations, most of the time, proposed design standards are not fulfilled by a least-cost design. The construction of a large water distribution system costs too much money; that's why designers are looking for various techniques to reach the optimal design for years. That is where optimization comes into the picture.

Main optimisation techniques are used to get optimal design of a water distribution system are linear programming, nonlinear programming, and various enumeration techniques. In this optimization study, problem is defined as minimizing the total pipe cost, subjected to both pressure and velocity constraints in the presence of given nodal demands. Since optimization of a water distribution network is rather complicated due to nonlinear relationship between parameters, former optimization techniques have some disadvantages and difficulties. Some methods such as enumeration and dynamic analysis (Liang (1971), İnözü (1977), Özer (1988), Akdoğan (2005)) take too much time for computations and need more powerful computer. Also a reference book is published by Sevük and Altinbilek (1977) about computer applications of pipe network.

Recently a new approach to the optimization has been introduced, called genetic algorithm. Genetic algorithm is a success which is inspired from Darwin's evolution theory. It uses the same pattern with the genetic evolution. Main advantage of the genetic algorithm is simple nature of its algorithm. Detailed information about optimization techniques will be given in Chapter 2.

The objective of this study is to develop a computer program that optimizes a water network system using genetic algorithm. Several networks will be examined using this program and then they will be compared. As a case study, Ankara water distribution network, pressure zone N8.3 will be examined.

In Chapter 2, a review of optimization techniques of water distribution networks and genetic algorithm are presented. In Chapter 3, the program and the tools that the program uses are presented by two sample networks study. In Chapter 4, the above mentioned case studies are conducted. Finally, conclusions are given in Chapter 5.

CHAPTER 2

GENETIC ALGORITHM

2.1 – What is Genetic Algorithm

A Genetic Algorithm is a member of a class of search algorithms based on artificial evolution (Holland, 1975). Genetic algorithm is the implementation of Darwin's evolution theory in optimization applications. In this method, the variables are presented as numbers on a string called genes and chromosomes respectively. With the help of some mathematical operations, chromosomes are evolved during generations according to their fitness's. The "fitness" evaluation is based on how well the trial solution meets the "objective function" in terms of defined goals (i.e. lowest cost or highest reliability) of the optimization. In each generation, chromosomes with better fitness values survive; on the other hand, weakest chromosomes are eliminated due to their low fitness's. Natural selection ensures that chromosomes with better fitnesses will propagate in the next populations.

2.2 – Mechanism of Genetic Algorithm

Specific parts of the genetic algorithm which have special function are called operators. In its simplest form, a genetic algorithm consists of three basic operators:

- Selection
- Crossover
- Mutation

In addition to these basic operators, **Generation** operator creates the initial population of chromosomes. Also, **Elitism** operator is used in this study which prevents the loss of successful individual chromosomes. These operators are applied to the current generation to form the next generation. Genetic algorithm continues until the design criteria have been reached which is defined by the user at the beginning of the project. Figure 2.1 presents the fundamentals of the genetic algorithm. At first, the population is evaluated and their fitness's are determined. Then, successful individuals are selected and they replaced the unsuccessful ones. Next step is to form the next population using elitism, crossover and mutation operators. These processes continue until predefined population number is reached.

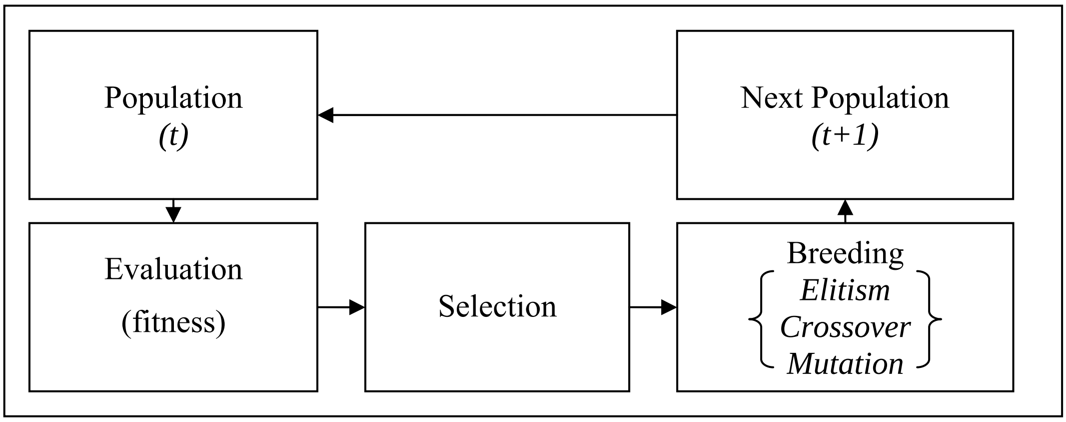


Figure 2.1 – Simple Genetic Algorithm Flowchart

2.1.1 – Chromosome concept

Genetic Algorithm uses chromosome concept to define the variables. Each decision variable (such as pipe sizes, pump settings, etc.) is defined in genes to form chromosomes. The common way of encoding is a binary string. A simple example can be formulated as follows in Table 2.1.

Table 2.1 - Example of Binary Coding

Pipe Size	Binary Code
100 mm	00
200 mm	01
300 mm	10
400 mm	11

2.1.2. – Generation

Based on the data assigned in the beginning of the project, the genetic algorithm will generate an initial population of defined size of population using a random number generator. Each population is composed of chromosomes. Each solution (chromosome) will contain randomly generated decision variables. The random number generator assigns either a 1 or 0 to each bit position in the chromosome where defined number of bits represents specific decision variables. This operator is called "Generation" operator. For example, generation operator generates a population comprising three chromosomes illustrated below in Figure 2.2 with three chromosomes for ten pipes using coding given above.

	Pipe 1	Pipe 2	Pipe 3	Pipe 4	Pipe 5	Pipe 6	Pipe 7	Pipe 8	Pipe 9	Pipe 10
Chrom.1	1 1	0 1	1 1	0 0	0 1	0 1	1 0	0 0	0 1	1 1
	400	*200*	*400*	*100*	*200*	*200*	*300*	*100*	*200*	*400*
Chrom.2	0 1	1 1	0 1	1 1	0 0	0 1	0 0	1 1	0 0	0 0
	200	*400*	*200*	*400*	*100*	*200*	*100*	*400*	*100*	*100*
Chrom.3	1 0	0 0	1 0	1 1	0 1	1 0	1 0	1 0	1 1	0 1
	300	*100*	*300*	*400*	*200*	*300*	*300*	*300*	*400*	*200*

Figure 2.2 - Example of Pipe Coding in Binary

Once the initial population is generated, the Genetic Algorithm will translate each gene into the corresponding variable (i.e. pipe size) and compute the objective function (i.e. total cost). Once the objective function is achieved, an analysis will then be performed for each chromosome of the population and performance deficiencies will be determined. These deficiencies are defined at the set up stage of the problem. For example, obtaining an acceptable pressure at the nodes within defined pressure interval or obtaining an acceptable velocity at the pipes within defined velocity range will not imply any total cost. On the other hand, genetic algorithm assigns a total cost to each solution (i.e. dollars for each headloss) which does not satisfy predefined user criteria. A total cost is computed by adding the pipe cost and related total cost. Genetic algorithm will compute a level of fitness for each solution in the population based on some function of the total solution cost. Each individual's fitness is determined by dividing its penalty value over total penalty values.

2.1.3 – Selection

This operator is used to eliminate the worst chromosomes due to their low fitness's. Once their objective functions are determined at the earlier stage, a certain number of chromosomes with worst fitness's are replaced by the same number of best chromosomes.

2.1.4 – Elitism

Elitism is used to protect the fittest chromosomes from crossover and mutation operations. The objective is to have some of the best fittest chromosomes as they are in the next generation and not to loose them. Elitism can rapidly increase the performance of Genetic Algorithm.

2.1.5 – Crossover

The crossover operator is applied in order to initiate a partial exchange of bits (information) between parent strings to form two offspring strings. Genetic Algorithm will randomly pick two solutions for breeding. Total number of crossover rate is defined by the user at the beginning of the study. Most popular crossover types are single point, two points and multi points crossovers as shown in the figures below. Note that all crossover points are randomly selected.

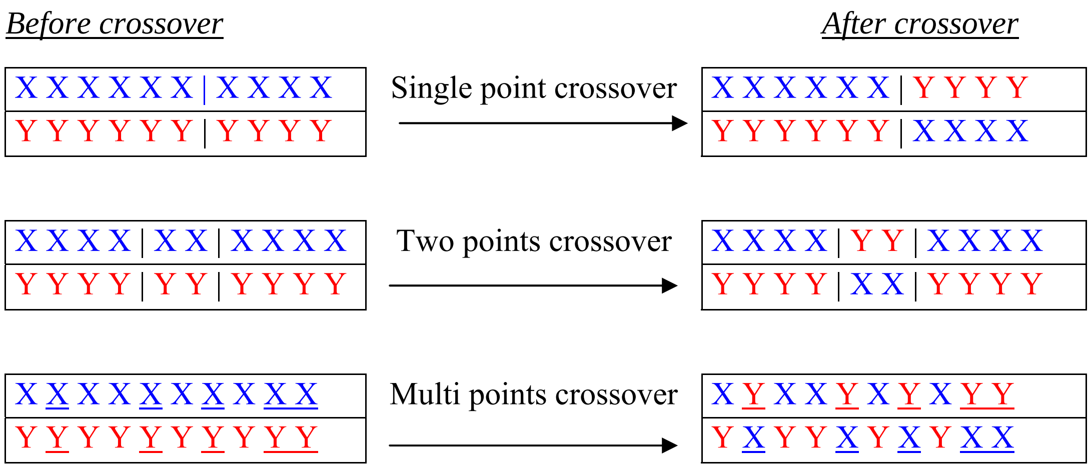


Figure 2.3 – Cross Over Operator

2.1.6 – Mutation

In order to truly imitate the genetic process, a mutation operator needs to be incorporated to the random mistakes committed by nature. By occasionally flipping some of the gene values, the mutation operator allows the introduction of new features into the pool. In the genetic algorithm process, some alternatives in the genetic pool may disappear which may lead to the final solution (i.e. all numbers in a column could be the same). Therefore, introducing the mutation operator creates the chance to catch these alternatives again.

	Pipe 1		Pipe 2		Pipe 3		Pipe 4		Pipe 5		Pipe 6		Pipe 7		Pipe 8		Pipe 9		Pipe 10	
Before mutation	1	1	0	1	1	1	0	0	0	1	0	1	1	**0**	0	0	0	1	1	1
	400		*200*		*400*		*100*		*200*		*200*		*300*		*100*		*200*		*400*	
														mutation						
After mutation	1	1	0	1	1	1	0	0	0	1	0	1	1	**1**	0	0	0	1	1	1
	400		*200*		*400*		*100*		*200*		*200*		*400*		*100*		*200*		*400*	

Figure 2.4 – Mutation Operator

2.3 – Implementation of Genetic Algorithm

A simple example demonstrating first two steps of simple genetic algorithm will help to understand the process. Related figures are taken from Goldberg, (1989). Consider the problem of maximizing the function $f(x) = x^2$, where x is permitted to vary between 0 and 31. With a five bit (binary digit) unsigned integer we can obtain numbers between 0 (00000) and 31 (11111). We now simulate a single generation of a genetic algorithm with reproduction, crossover and mutation. To start with we select an initial population. We select a population of size 4 by tossing a fair coin 20 times.

Table 2.2 – Genetic Algorithm Illustration, Round 1

String Id	**Initial Population**	**x Value**	**f(x)**	**pselect$_i$**	**Expected count**	**Actual count**
	(Randomly generated)	*(Integer)*	x^2	$f_i / \Sigma f$	f_i / f	
1	0 1 1 0 1	13	169	0.14	0.58	1
2	1 1 0 0 0	24	576	0.49	1.97	2
3	0 1 0 0 0	8	64	0.06	0.22	0
4	1 0 0 1 1	19	361	0.31	1.23	1
Sum			1170	1.00	4.00	4
Average			293	0.25	1.00	1
Maximum			576	0.49	1.97	2

We select the mating pool of the next generation by spinning the weighted roulette wheel four times. Actual simulation of this process using coin tosses has resulted in string 1 and string 4 receiving one copy in the mating pool, string 2 receiving two copies, and string 3 receiving no copies as shown in Table 2.2 above. Comparing actual number of copies with the expected number of copies (n.pselect$_i$) it is obtained that it should be expected that the fittest chromosomes gets more copies, the average stays even, and the worst dies off.

Table 2.3 – Genetic Algorithm Illustration, Round 2

Mating Pool After Reproduction *(Cross site shown)*	**Mate** *(Random)*	**Crossover Site** *(Random)*	**New Population**	**x Value**	**f(x)** x^2
0 1 1 0 | 1	2	4	0 1 1 0 0	12	144
1 1 0 0 | 0	1	4	1 1 0 0 1	25	625
1 1 | 0 0 0	4	2	1 1 0 1 1	27	729
1 0 | 0 1 1	3	2	1 0 0 0 0	16	256
Sum					1754
Average					439
Maximum					729

Having a pool of strings, it is observed that simple crossover proceeds in two steps: (1) strings are mated randomly, using coin tosses to pair off the couples, and (2) mated string couples crossover, using coin tosses to select the crossing sites. Single point crossover is applied in this example. Referring again to Table 2.2, random choice of mates has selected the second string in the mating pool to be mated with the first. With a crossing site of 4, the two strings 01101 and 11000 cross and yield two new strings 01100 and 11001. The remaining two strings in the mating pool are crossed at site 2.

The last operator, mutation, is performed on a bit-by-bit basis. We assume that the probability of mutation in this test 0,001. With 20 transferred bit position we should expect 20*0,001 = 0,02 bits to undergo mutation during a given generation. Simulation of this process indicates that no bits undergo mutation for this probability value.

Following reproduction, crossover and mutation, the new population is ready to be tested. To do this, we simply decode the new strings created by the simple genetic algorithm and calculate the fitness function values from the x values thus decoded. The population average fitness has improved from 293 to 439 in one generation. The maximum fitness has increased from 576 to 729 during that same period.

Although random processes help cause these happy circumstances, we start to see that this improvement is not coincidence. The best string of the first generation (11000) receives two copies because of its high, above-average performance. When this combines at random with the next highest string (10011) and is crossed at location 2 (again at random), one of the resulting strings (11011) proves to be a very good choice indeed.

2.4 – Genetic Algorithm in Water Resources

Many branches could use benefits of Genetic algorithm for optimization problems. There are several possible areas in the water resources too. Optimization of pipe diameters (Simpson (1993), Simpson (1994), Simpson (2000), Dandy (1996), Kahraman (2003), Savic and Walters (1997), Morley (2000)), optimal location for control valves on a network, optimization of valve control, calibration of water distribution network, hydraulic management of water distribution system and optimization of pump run periods could be listed as examples.

CHAPTER 3

PROGRAM

3.1 – EpaNet

3.1.1 – Introduction of EpaNet

EpaNet is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks (Reference for Epanet). A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EpaNet tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated.

EpaNet is designed to be a research tool for improving our understanding of the movement and the fate of drinking water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis. Sampling program design, hydraulic model calibration, chlorine residual analysis, and consumer exposure assessment are some examples. EpaNet can help assess alternative management strategies for improving water quality throughout a system. These can include:

- altering source utilization within multiple source systems,
- altering pumping and tank filling/emptying schedules,
- use of satellite treatment, such as re-chlorination at storage tanks,
- targeted pipe cleaning and replacement.

Running under Windows, EpaNet provides an integrated environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. These include color-coded network maps, data tables, time series graphs, and contour plots.

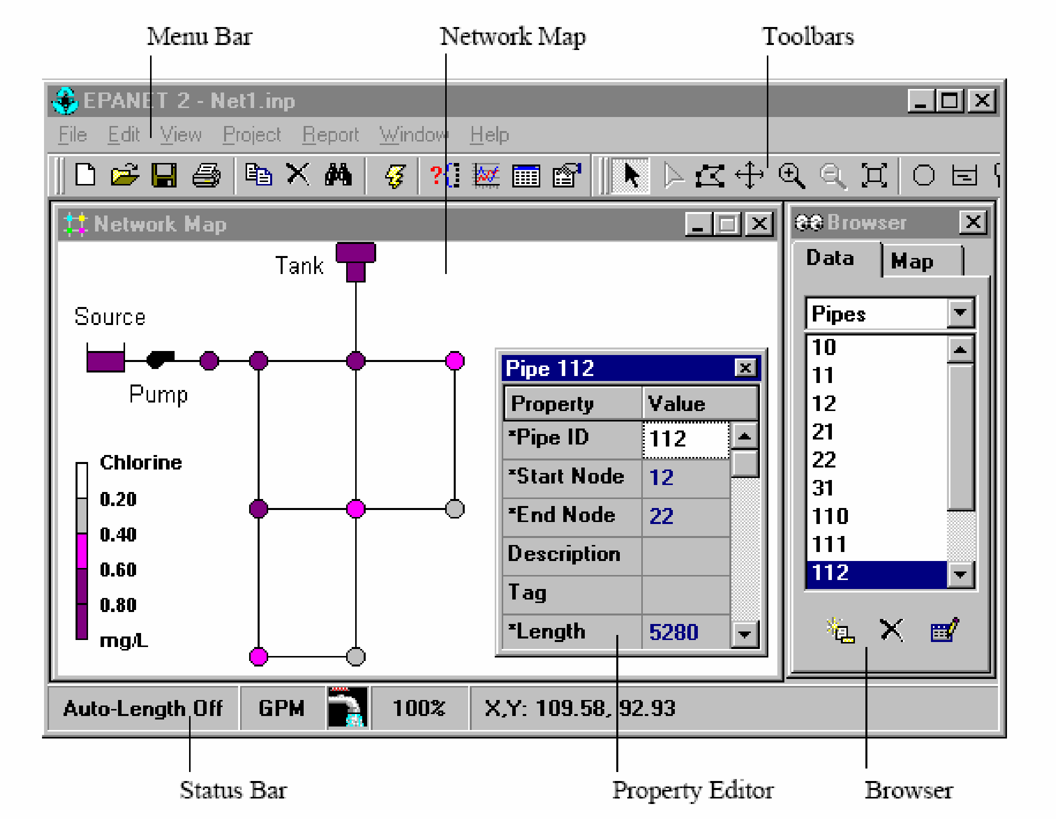


Figure 3.1 - EpaNet Working Space

3.1.2 – Hydraulic Modeling Capabilities

Full-featured and accurate hydraulic modeling is a prerequisite for doing effective water quality modeling. EpaNet contains a state-of-the-art hydraulic analysis engine that includes the following capabilities:

- places no limit on the size of the network that can be analyzed
- computes friction headloss using the Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas

- includes minor head losses for bends, fittings, etc.
- models constant or variable speed pumps
- computes pumping energy and cost
- models various types of valves including shutoff, check, pressure regulating, and flow control valves
- allows storage tanks to have any shape (i.e., diameter can vary with height)
- considers multiple demand categories at nodes, each with its own pattern of time variation
- models pressure-dependent flow issuing from emitters (sprinkler heads)
- can base system operation on both simple tank level or timer controls and on complex rule-based controls.

3.1.3 – Water Quality Modeling Capabilities

In addition to hydraulic modeling, EpaNet provides the following water quality modeling capabilities:

- models the movement of a non-reactive tracer material through the network over time
- models the movement and fate of a reactive material as it grows (e.g., a disinfection by-product) or decays (e.g., chlorine residual) with time
- models the age of water throughout a network
- tracks the percent of flow from a given node reaching all other nodes over time
- models reactions both in the bulk flow and at the pipe wall

- uses n-th order kinetics to model reactions in the bulk flow
- uses zero or first order kinetics to model reactions at the pipe wall
- accounts for mass transfer limitations when modeling pipe wall reactions
- allows growth or decay reactions to proceed up to a limiting concentration
- employs global reaction rate coefficients that can be modified on a pipe-by-pipe basis
- allows wall reaction rate coefficients to be correlated to pipe roughness
- allows for time-varying concentration or mass inputs at any location in the network
- models storage tanks as being either complete mix, plug flow, or two-compartment reactors.

By employing these features, EpaNet can study such water quality phenomena as:

- blending water from different sources
- age of water throughout a system
- loss of chlorine residuals
- growth of disinfection by-products
- tracking contaminant propagation events.

3.1.4 – Steps in Using EpaNet

One typically carries out the following steps when using EpaNet to model a water distribution system:

1. Draw a network representation of your distribution system or import a basic description of the network placed in a text file.

2. Edit the properties of the objects that make up the system

3. Describe how the system is operated

4. Select a set of analysis options

5. Run a hydraulic/water quality analysis

6. View the results of the analysis

3.1.5 – Hydraulic Simulation Model

EpaNet's hydraulic simulation model computes junction heads and link flows for a fixed set of reservoir levels, tank levels, and water demands over a succession of points in time. From one time step to the next reservoir levels and junction demands are updated according to their prescribed time patterns while tank levels are updated using the current flow solution. The solution for heads and flows at a particular point in time involves solving simultaneously the conservation of flow equation for each junction and the headloss relationship across each link in the network. This process, known as "hydraulically balancing" the network, requires using an iterative technique to solve the nonlinear equations involved. EpaNet employs the "Gradient Algorithm" for this purpose. Consult Appendix D for details. The hydraulic time step used for extended period simulation (EPS) can be set by the user. A typical value is 1 hour. Shorter time steps than normal will occur automatically whenever one of the following events occurs:

- the next output reporting time period occurs
- the next time pattern period occurs
- a tank becomes empty or full

- a simple control or rule-based control is activated.

3.1.6 – Hydraulic Analysis Algorithms

The method used in EpaNet to solve the flow continuity and head loss equations that characterize the hydraulic state of the pipe network at a given point in time can be termed a hybrid node-loop approach. Detailed information on EpaNet implementation of the hydraulic solution and other information can be found on the EpaNet manual.

3.2 – RealPipe

3.2.1 – Introduction

RealPipe is a water distribution network optimization program. It is written in Microsoft Visual Basic using genetic optimization algorithm by the author. RealPipe uses EpaNet, open source module, discussed in the previous chapter for hydraulic analysis step. Flowchart of running an optimization project is shown below in Figure 3.2.

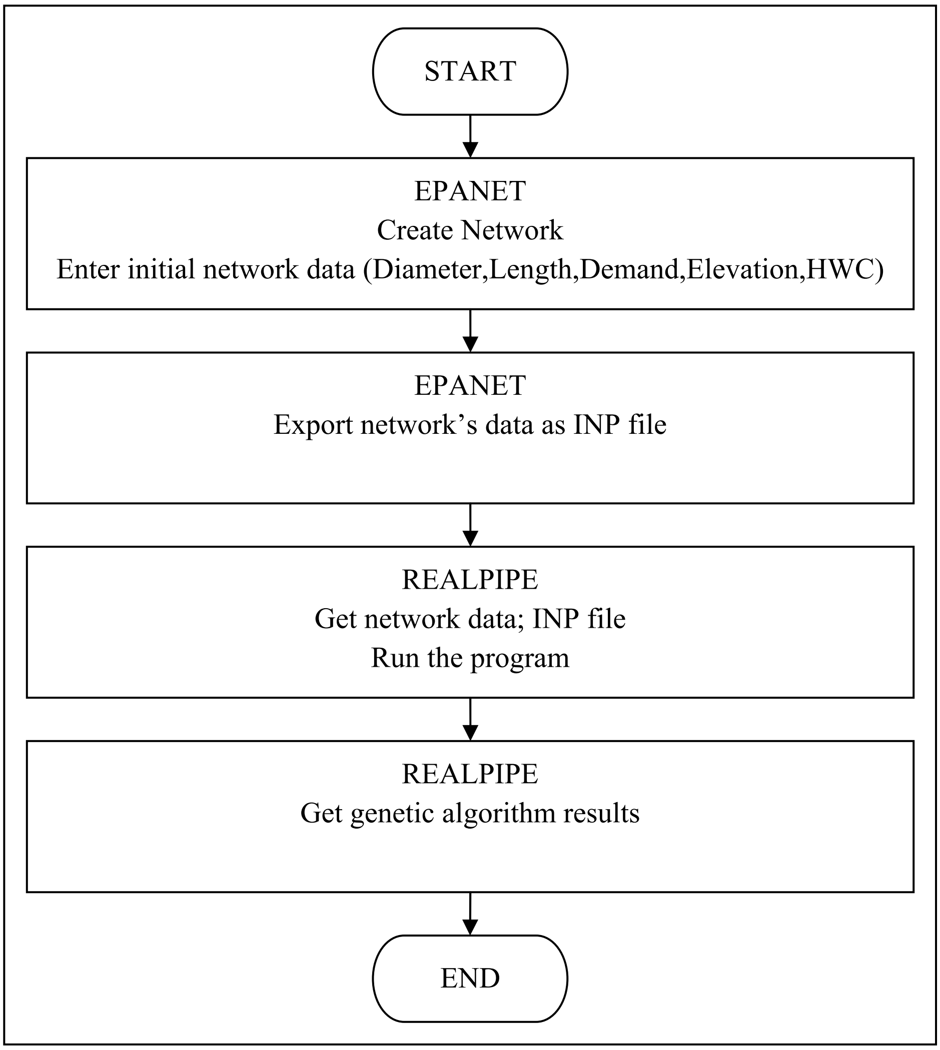


Figure 3.2 – Overall Optimization Flowchart with RealPipe

RealPipe's run algorithm is shown as a flowchart on Figure 3.3 below.

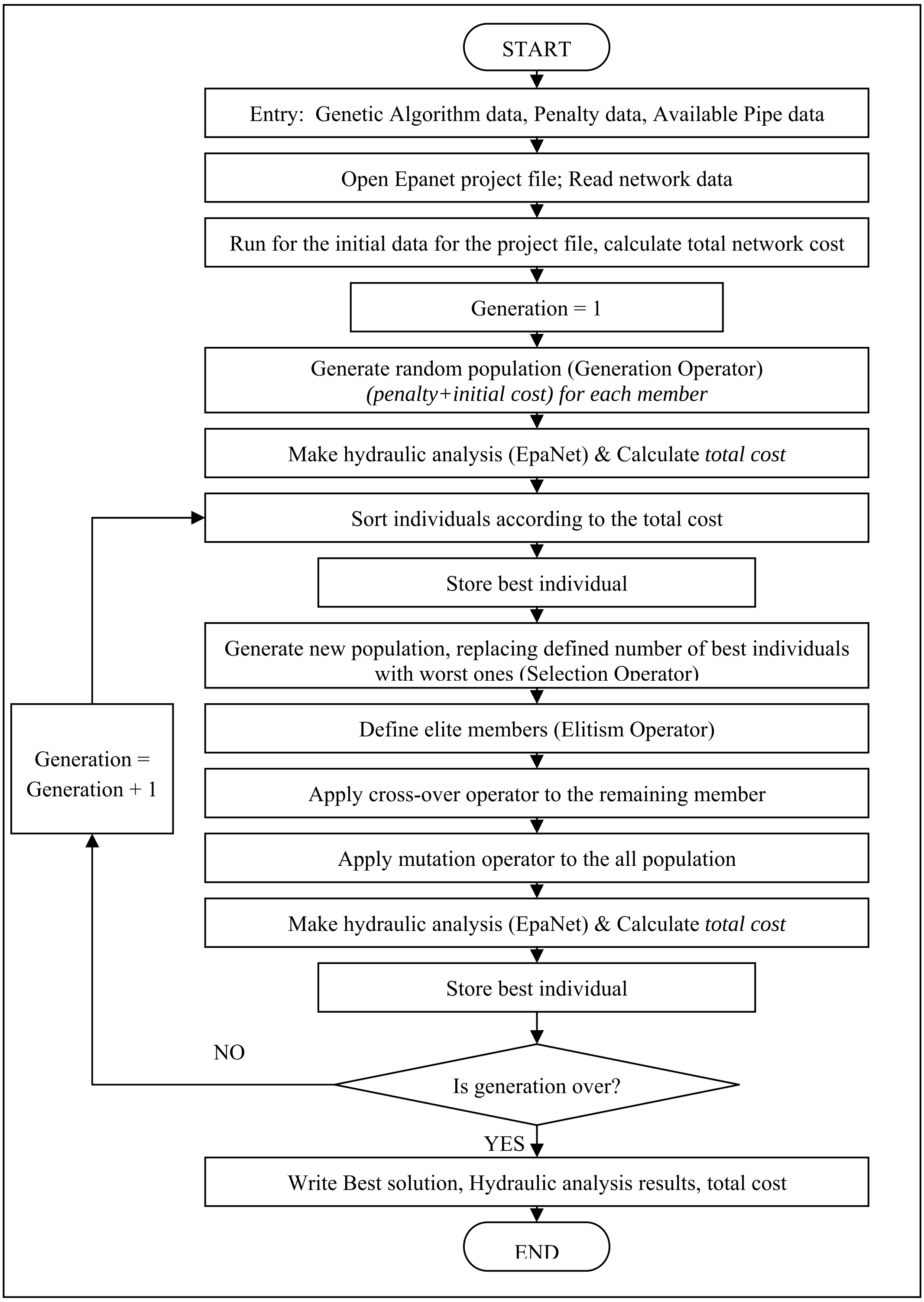


Figure 3.3 – RealPipe Genetic Algorithm Flowchart

RealPipe requires network data prepared by EpaNet to run. At first, any hydraulically successful network should be defined in EpaNet platform. Then, objective network's information data should be exported in the EpaNet's export format called INP file with inp extension.

RealPipe has a simple user interface shown in Figure 3.4.

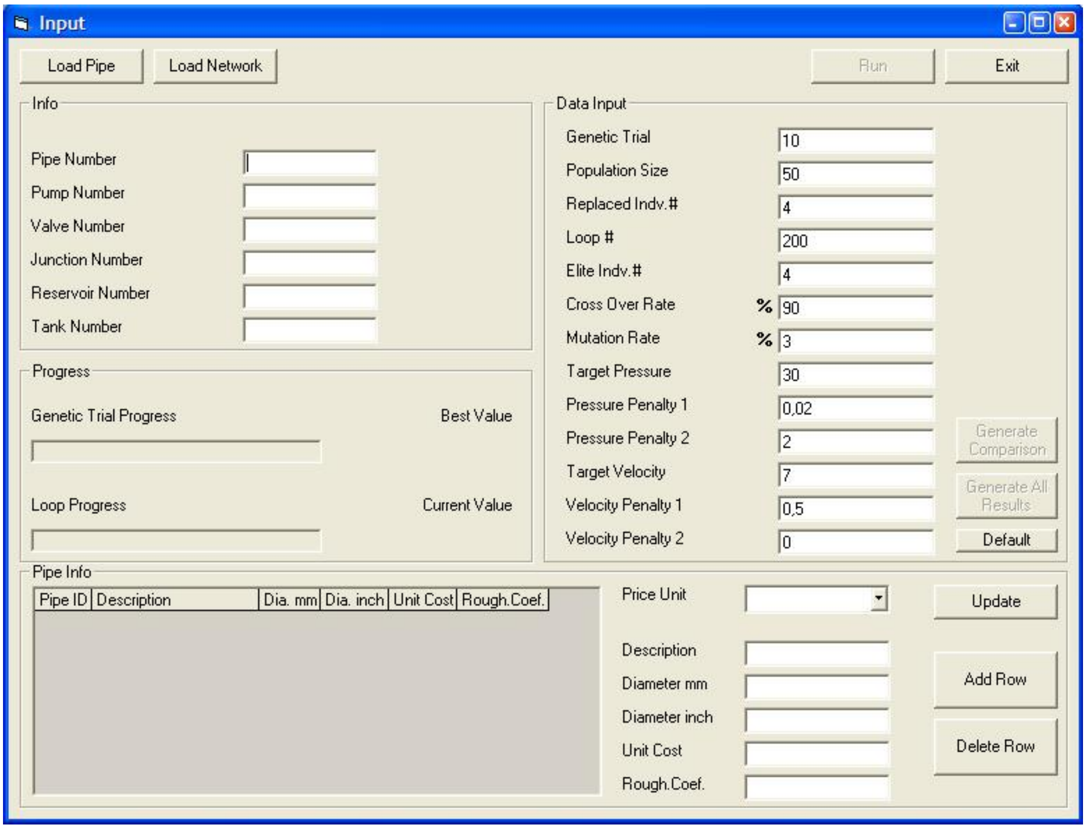
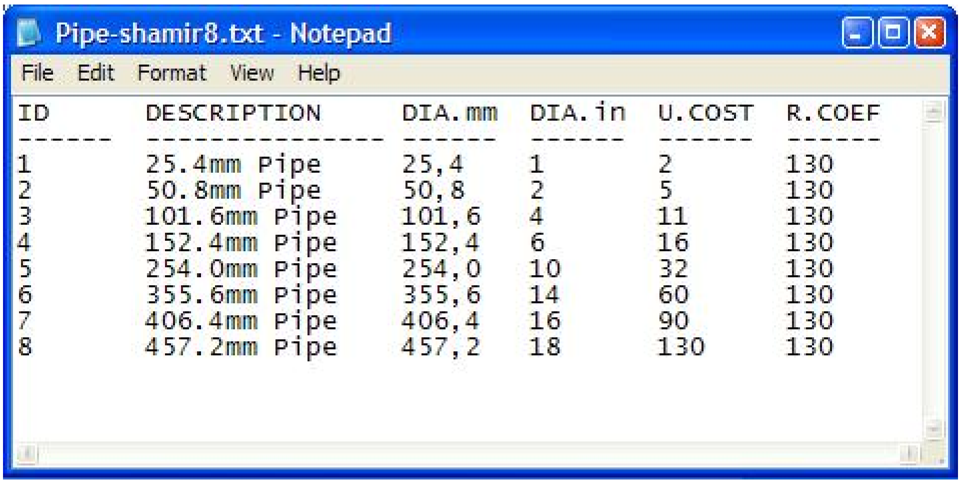


Figure 3.4 – RealPipe User Interface

All network data and data input information are kept on the separate editable text files. Different network data can be stored separately and user can re-open related networks data without re-entering each time. Also user can edit, copy, and duplicate existing data at the windows environment easily. User only uses open icon in the program to call the related text file in to the program. Loaded information can be editable also. A sample "available pipe information" data is on the Figure 3.5.



Pipe-shamir8.txt - Notepad

File Edit Format View Help

ID	DESCRIPTION	DIA.mm	DIA.in	U.COST	R.COEF
1	25.4mm Pipe	25,4	1	2	130
2	50.8mm Pipe	50,8	2	5	130
3	101.6mm Pipe	101,6	4	11	130
4	152.4mm Pipe	152,4	6	16	130
5	254.0mm Pipe	254,0	10	32	130
6	355.6mm Pipe	355,6	14	60	130
7	406.4mm Pipe	406,4	16	90	130
8	457.2mm Pipe	457,2	18	130	130

Figure 3.5 – RealPipe, Available Pipe Information Text

3.2.2 – Penalty Calculations

Total cost includes pipe costs, velocity penalty costs and pressure penalty costs. Total cost formula that is used in the program algorithm is presented below;

Total Cost = Length * UPC * PPC * VPC * LC

$PPC = 1 + \Sigma (P_i - TP) * PP1 + \Sigma (TP - P_i) * PP2$

$VPC = 1 + \Sigma (V_i - TV) * VP1 + \Sigma (TV - V_i) * VP2$

Where;

UPC : Unit pipe cost in meters

PPC : Pressure penalty constant

VPC : Velocity penalty constant

LC : Loop constant which is loop number over total number of loops

P_i : Pressure of member i

V_i : Velocity of member i

TP : Target pressure

TV : Target velocity

PP1 : Penalty pressure coefficient above target pressure

PP2 : Penalty pressure coefficient below target pressure

VP1 : Velocity pressure coefficient above target velocity

VP2 : Velocity pressure coefficient below target velocity

In this study, only one target value is used instead of a range composed of two limitations that are lower and upper boundaries (Savic and Walters (1997)). Reason for using one target value and two different constraints is to have solutions as possible as close to the target value. Since there is no upper critical pressure value in three case studies examined in this thesis, the program doesn't contain any upper target value.

3.2.3 – Hardware Requirements

It is recommended that program should be used on an updated computer. Program doesn't have any specific hardware constraints. Recommended system is; Pentium 4 2000 mhz or AMD XP+ 2000 mhz, 256mb ram, 100mb empty space on Hard disk. Similar or higher systems show better performance.

3.2.4 – Software Requirements

Program is designed to use under Windows XP or higher. This doesn't mean that program could not run under other operating systems. Compatibility should be checked by making trial runs.

In order to prepare a network and to see the results of RealPipe, EpaNet software is needed as it is mentioned previously. EpaNet is a small freeware program and can be downloaded from the following internet address: www.epa.gov

3.2.5 – Installation

RealPipe has an installation file *RealPipe.exe*. To install the program execute installation file under operating system and follow the instructions.

3.2.6 – Program Options; Data Input Window

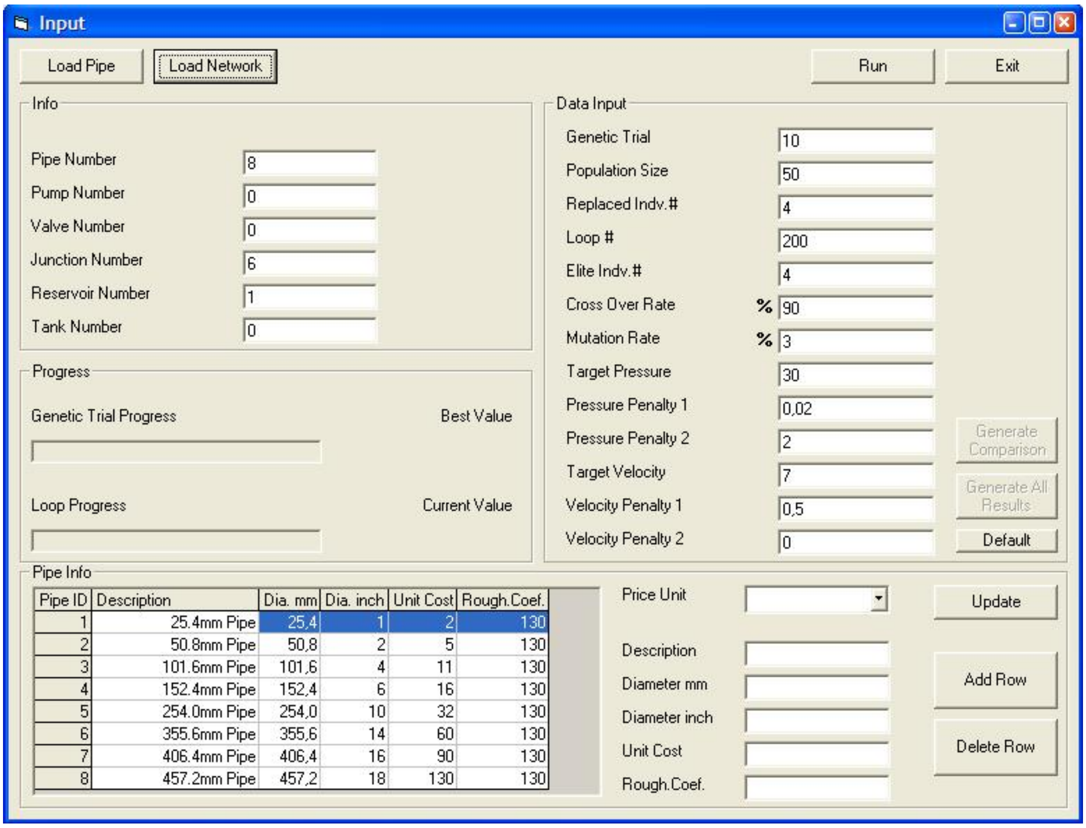


Figure 3.6 – Data Input Window

Load Pipe	: Loads “available pipe” information from the existing, pre-defined text file
Load Network	: Opens the exported INP file of the network and reads the network data from that file that is necessary for the program to run
Run button	: Runs the program with the data exist in the Input window
Exit button	: Exits the program

Info Section

Shows general network data after loading network (for information purposes only)

Data Input Section

Genetic trial	: Number of genetic run
Population size	: Number of population size for each genetic run
Replaced individual number	: Number of individuals to be replaced in *selection operation*
Loop number	: Number of loop for each trial
Elite individual number	: Defines the number of elite individuals for *elitism operation*
Cross over rate	: Defines the rate for *cross over operation*
Mutation rate	: Defines the rate for *mutation operation*
Target Pressure	: Desired target value for pressure in meter
Pressure penalty 1	: Penalty coefficient above target pressure
Pressure penalty 2	: Penalty coefficient below target pressure
Target velocity	: Desired target value for velocity in m/sec
Velocity penalty 1	: Penalty coefficient above target velocity
Velocity penalty 2	: Penalty coefficient below target velocity
Generate comparison button	: Generate initial and final values in excel
Generate all results button	: Generate above report including genetic algorithm steps

Default button	: Returns the default values defined in the default text

Pipe Info Section

Price unit	: Selects the price unit (reporting purposes)
Description	: Description of the pipe (information purposes)
Diameter mm	: Diameter of the pipe in mm (used for calculation)
Diameter inch	: Diameter of the pipe in inch (information purposes)
Unit cost	: Unit cost of the pipe per length
Roughness coefficient	: Roughness coefficient of the pipe
Update button	: Updates changes in the values of selected pipe
Add row button	: Ads new pipe information, sorts automatically
Delete row button	: Deletes selected pipe information

3.2.7 – Running Program

Using load pipe button, select available pipe information text and click open. Then using load network button, select inp file that contains network information.

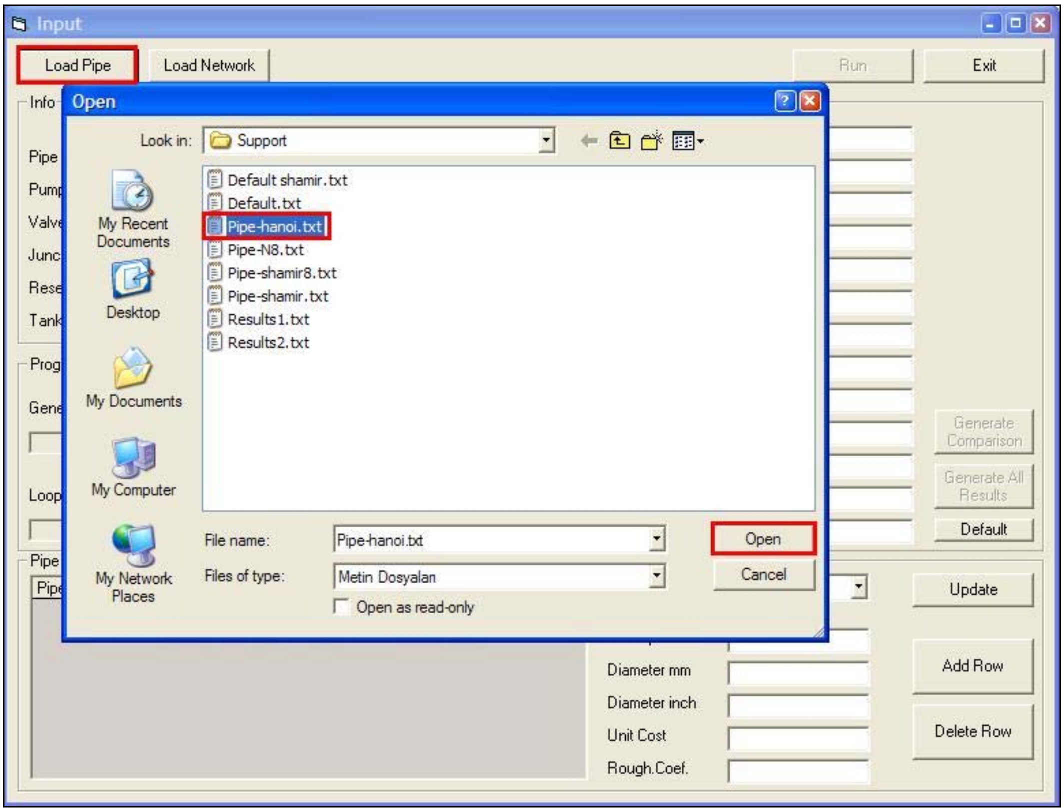


Figure 3.7 – Loading Network Information

After having fulfilled these two steps, the program shows network elements in the info section as shown on Figure 3.8 below.

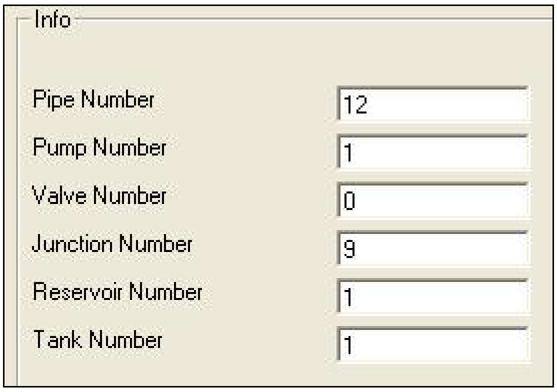
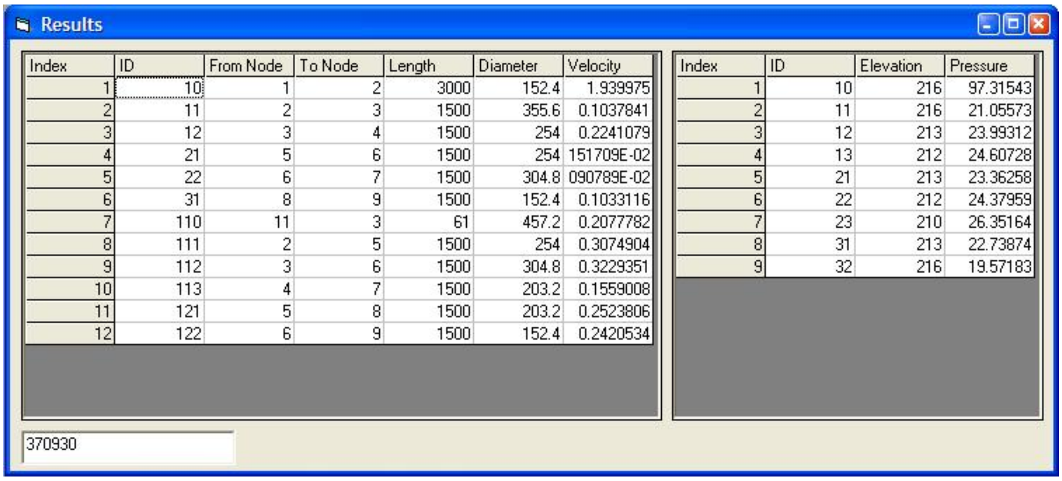


Figure 3.8 – Information Window

At the same time a window, *initial results*, shows the initial networks hydraulic solution results with the total cost.



Index	ID	From Node	To Node	Length	Diameter	Velocity
1	10	1	2	3000	152.4	1.939975
2	11	2	3	1500	355.6	0.1037841
3	12	3	4	1500	254	0.2241079
4	21	5	6	1500	254	151709E-02
5	22	6	7	1500	304.8	090789E-02
6	31	8	9	1500	152.4	0.1033116
7	110	11	3	61	457.2	0.2077782
8	111	2	5	1500	254	0.3074904
9	112	3	6	1500	304.8	0.3229351
10	113	4	7	1500	203.2	0.1559008
11	121	5	8	1500	203.2	0.2523806
12	122	6	9	1500	152.4	0.2420534

Index	ID	Elevation	Pressure
1	10	216	97.31543
2	11	216	21.05573
3	12	213	23.99312
4	13	212	24.60728
5	21	213	23.36258
6	22	212	24.37959
7	23	210	26.35164
8	31	213	22.73874
9	32	216	19.57183

Figure 3.9 – Initial Results Window

At the beginning program reads general information for the data input section from default.txt file. After making necessary arrangements click on the run button to start the genetic algorithm operations. Run button can only be active after loading of pipe and network information. After clicking run button, program starts genetic algorithm. This operation may take time depending on the network, loop number, genetic trial number, population size and computer configuration. Progress can be followed during genetic algorithm operation in the progress window.

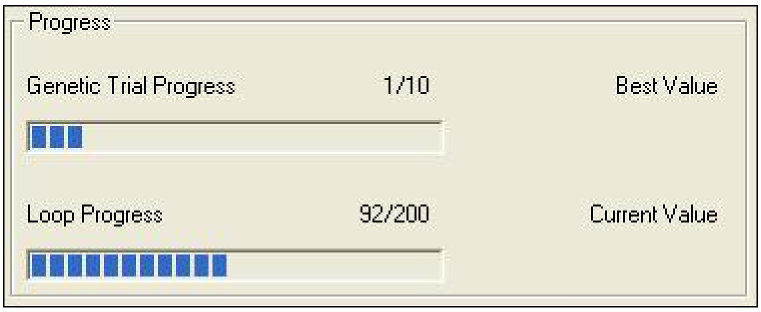
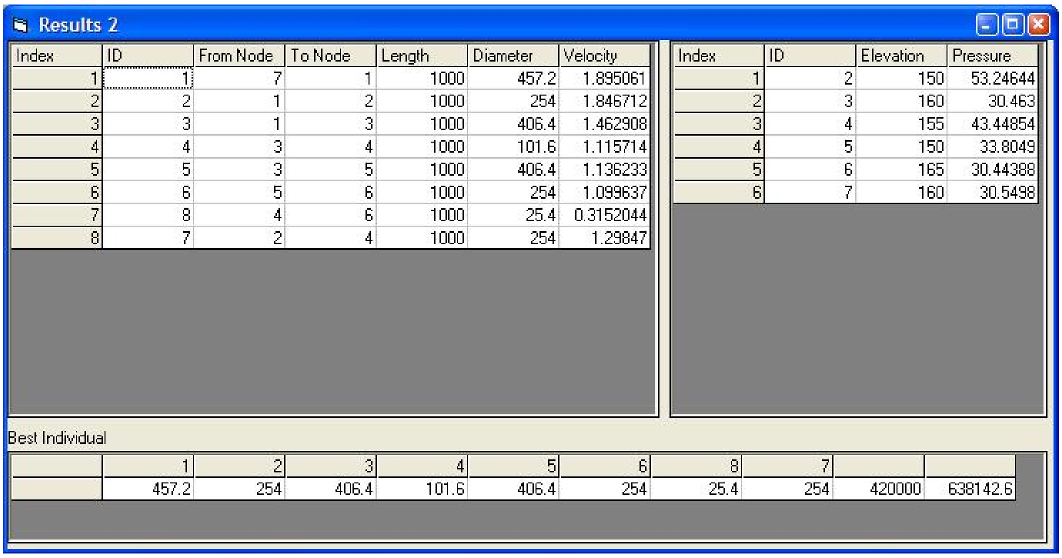


Figure 3.10 – Progress Window

When the calculations are finished, program opens a new window, *final results*, showing the best solution achieved, final networks hydraulic solution results and the total cost.



Index	ID	From Node	To Node	Length	Diameter	Velocity
1	1	7	1	1000	457.2	1.895061
2	2	1	2	1000	254	1.846712
3	3	1	3	1000	406.4	1.462908
4	4	3	4	1000	101.6	1.115714
5	5	3	5	1000	406.4	1.136233
6	6	5	6	1000	254	1.099637
7	8	4	6	1000	25.4	0.3152044
8	7	2	4	1000	254	1.29847

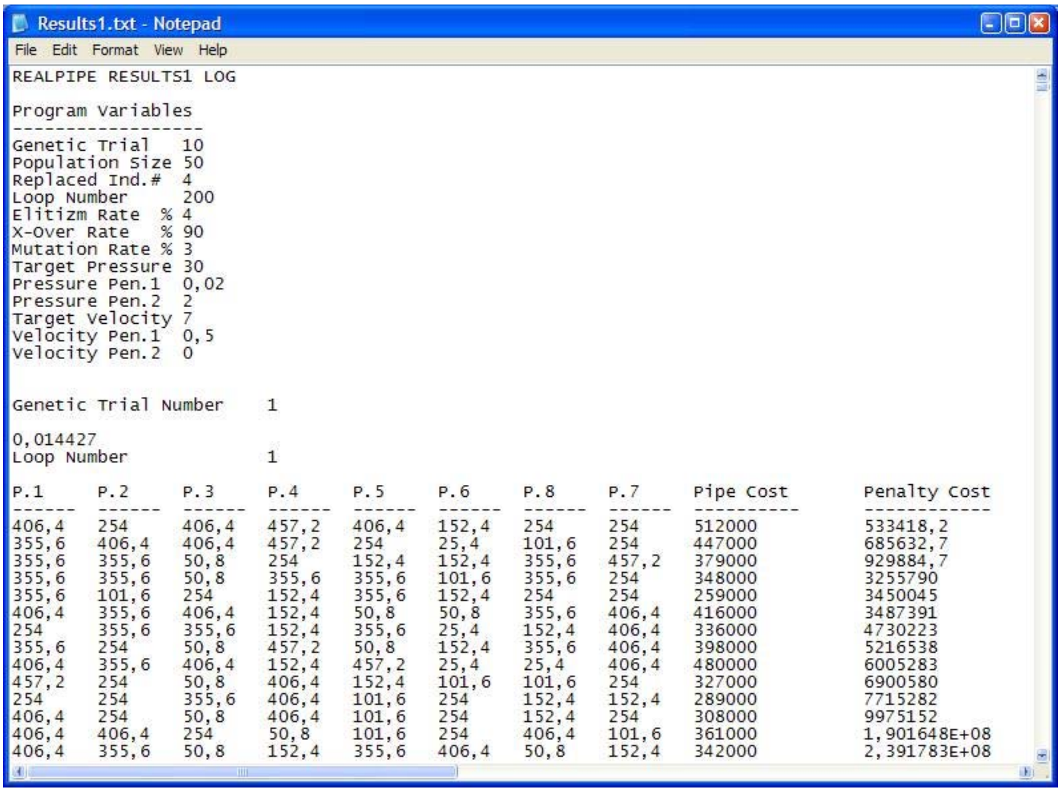
Index	ID	Elevation	Pressure
1	2	150	53.24644
2	3	160	30.463
3	4	155	43.44854
4	5	150	33.8049
5	6	165	30.44388
6	7	160	30.5498

	1	2	3	4	5	6	8	7		
	457.2	254	406.4	101.6	406.4	254	25.4	254	420000	638142.6

Figure 3.11 – Final Results Window

3.2.8. – Reports

Program generates four special reports to examine the genetic algorithm steps and to make the comparisons. Two text files are automatically generated. First one includes all generated pipe sizes for all loops called Results1.txt. Second one is summarized version of the first one. It includes best result of each loop. These reports can be used to observe the genetic algorithm steps and to determine the genetic algorithm parameters. Results1.txt report is shown in Figure 3.12 below.



Results1.txt - Notepad

File Edit Format View Help

REALPIPE RESULTS1 LOG

Program Variables

Genetic Trial 10
Population Size 50
Replaced Ind.# 4
Loop Number 200
Elitizm Rate % 4
X-Over Rate % 90
Mutation Rate % 3
Target Pressure 30
Pressure Pen.1 0,02
Pressure Pen.2 2
Target Velocity 7
Velocity Pen.1 0,5
Velocity Pen.2 0

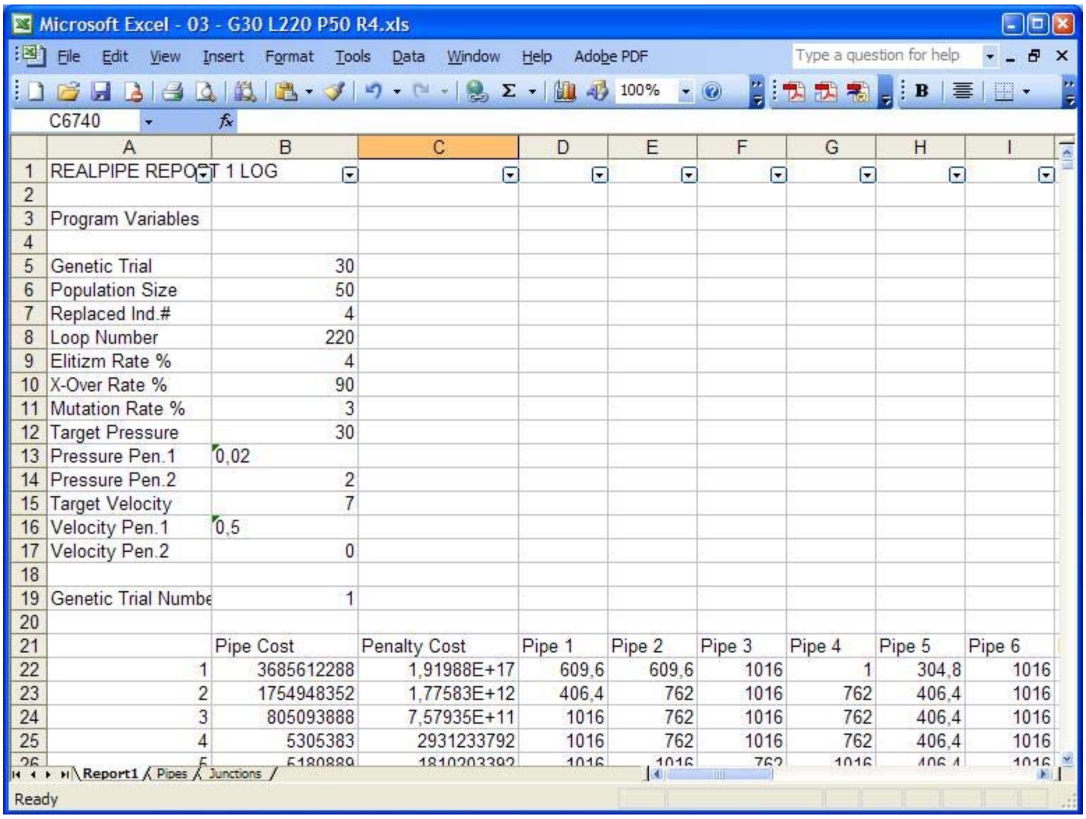
Genetic Trial Number 1

0,014427
Loop Number 1

P.1	P.2	P.3	P.4	P.5	P.6	P.8	P.7	Pipe Cost	Penalty Cost
406,4	254	406,4	457,2	406,4	152,4	254	254	512000	533418,2
355,6	406,4	406,4	457,2	254	25,4	101,6	254	447000	685632,7
355,6	355,6	50,8	254	152,4	152,4	355,6	457,2	379000	929884,7
355,6	355,6	50,8	355,6	355,6	101,6	355,6	254	348000	3255790
355,6	101,6	254	152,4	355,6	152,4	254	254	259000	3450045
406,4	355,6	406,4	152,4	50,8	50,8	355,6	406,4	416000	3487391
254	355,6	355,6	152,4	355,6	25,4	152,4	406,4	336000	4730223
355,6	254	50,8	457,2	50,8	152,4	355,6	406,4	398000	5216538
406,4	355,6	406,4	152,4	457,2	25,4	25,4	406,4	480000	6005283
457,2	254	50,8	406,4	152,4	101,6	101,6	254	327000	6900580
254	254	355,6	406,4	101,6	254	152,4	152,4	289000	7715282
406,4	254	50,8	406,4	101,6	254	152,4	254	308000	9975152
406,4	406,4	254	50,8	101,6	254	406,4	101,6	361000	1,901648E+08
406,4	355,6	50,8	152,4	355,6	406,4	50,8	152,4	342000	2,391783E+08

Figure 3.12 – Report1 Text

Other two reports are generated manually by using buttons on the input window. These reports are generated in Excel media. First one contains general and hydraulic network information both predefined and final result. Second one generates the first one including Results2 report in excel shown in Figure 3.13. These reports can be more useful since results can be manipulated according to the user's needs and desires depending on his/her requirements and limitations.



	A	B	C	D	E	F	G	H	I
1	REALPIPE REPORT 1 LOG								
2									
3	Program Variables								
4									
5	Genetic Trial	30							
6	Population Size	50							
7	Replaced Ind.#	4							
8	Loop Number	220							
9	Elitizm Rate %	4							
10	X-Over Rate %	90							
11	Mutation Rate %	3							
12	Target Pressure	30							
13	Pressure Pen.1	0,02							
14	Pressure Pen.2	2							
15	Target Velocity	7							
16	Velocity Pen.1	0,5							
17	Velocity Pen.2	0							
18									
19	Genetic Trial Numbe	1							
20									
21		Pipe Cost	Penalty Cost	Pipe 1	Pipe 2	Pipe 3	Pipe 4	Pipe 5	Pipe 6
22	1	3685612288	1,91988E+17	609,6	609,6	1016	1	304,8	1016
23	2	1754948352	1,77583E+12	406,4	762	1016	762	406,4	1016
24	3	805093888	7,57935E+11	1016	762	1016	762	406,4	1016
25	4	5305383	2931233792	1016	762	1016	762	406,4	1016

Figure 3.13 – Report Exported in to Excel

3.3 – Example 1: Shamir Network

Using the program "RealPipe", two well known networks of the literature have been examined. First one is the simplest one with 8 pipes and 2 loops. This network is imaginary and created by Alperovits and Shamir (1977). This network is widely used earlier for optimization studies. Second one is also widely used, a famous network called Hanoi Network which is bigger than Shamir Network with 34 pipes. It is a highly skeletonized projection of the water distribution network of Hanoi city, Vietnam.

3.3.1 – Introduction of the Alperovits and Shamir Network

This network is an imaginary network created by Alperovits and Shamir (1977). The system has 1 reservoir, 8 pipes and 6 nodes. Each pipe has 1000 m long and

Hazen-Williams constant is assumed to be 130. Available pipes and unit prices are given below in Table 3.1.

Table 3.1 – Shamir Network, Available Pipe Information

Diameter (inch)	Diameter (mm)	HW Roughness Coefficient	Unit Price (USD/m)
1	25.4	130	2
2	50.8	130	5
4	101.6	130	11
6	152.4	130	16
10	254.0	130	32
14	355.6	130	60
16	406.4	130	90
18	457.2	130	130

Network layout, network data and optimum pipe diameters are sketched below in Figure 3.14.

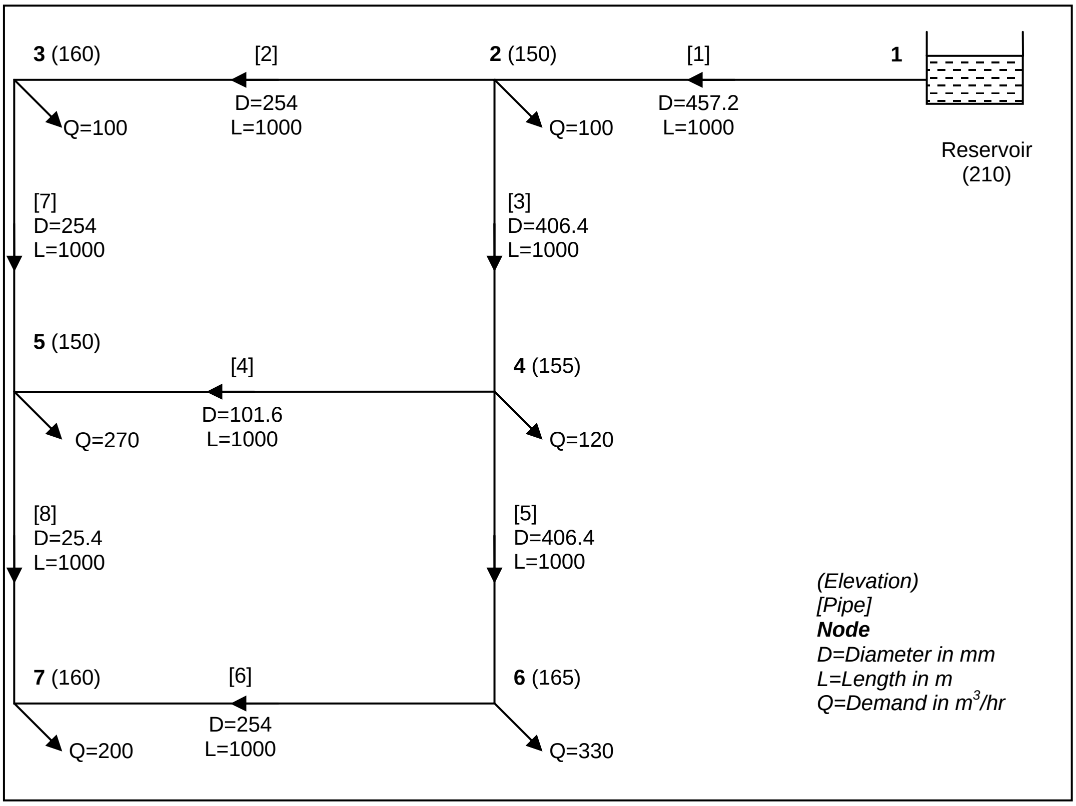


Figure 3.14 – Shamir Network, Layout

3.3.2 – EpaNet file derivation

At first, system is defined in EpaNet. System layout and system elements are defined in the program. General information like system units, layout properties, roughness coefficients are assigned. Then length, elevation and demand information are defined.

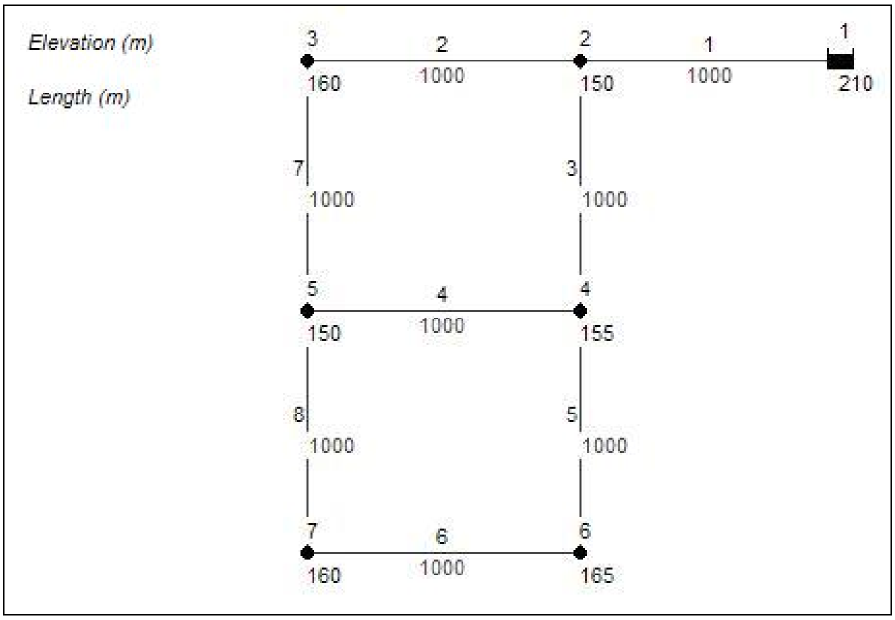


Figure 3.15 – Shamir Network, Elevations and Pipe Lengths

As initial diameters, best diameters are assigned having encountered in the literature. With this best diameter information, best results to achieve are obtained as shown in Figure 3.16.

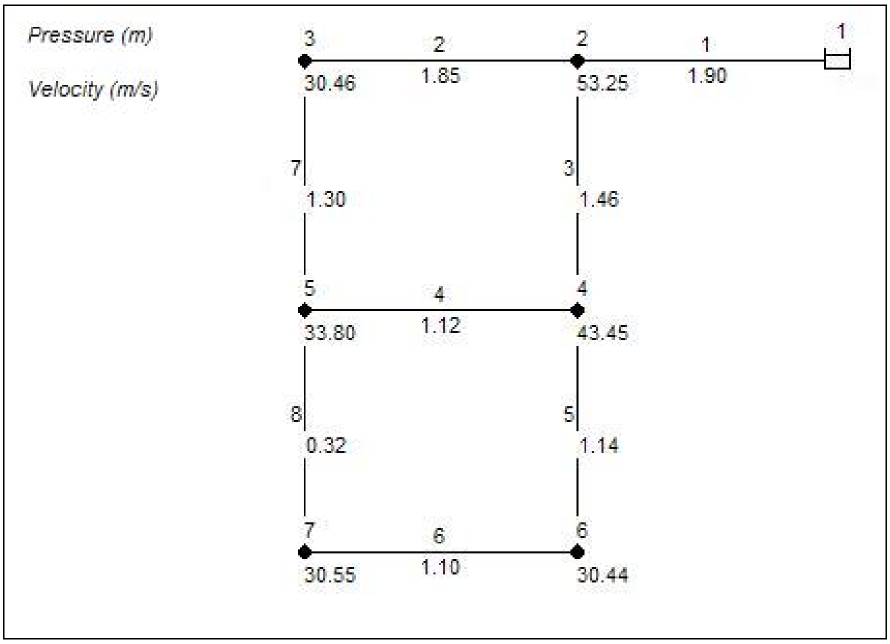


Figure 3.16 – Shamir Network, Velocities and Pressures

3.3.3 – Determination of Genetic Algorithm Parameters

RealPipe needs basically three elements to run. Available network information which is inp file, pipe information and genetic algorithm parameters. First two elements are discussed above. Third element is the key element. It determines the success and duration of genetic algorithm. It is user dependant. There isn't known solution for determining them. It can be determined by trial and error and with the experience of the user. Different combinations parameters can lead to the solution, however some can provide quicker response.

3.3.4 – Solution using RealPipe

Several trials have been made using several parameters. Most of the trials, the best solution is achieved. But one set of parameter is selected as base parameter set which leads to the result in shortest time period and the most effective way. Base optimization parameters for this network are given below.

Genetic trial number	: 50
Population size	: 50
Replaced individual number	: 4
Loop number	: 40
Elite individual number	: 4
Cross over rate	: 90%
Mutation rate	: 3%
Target pressure	: 30
Pressure penalty above target	: 0.02
Pressure penalty below target	: 2
Target velocity	: 1
Velocity penalty above target	: 0.1
Velocity penalty below target	: 0.5

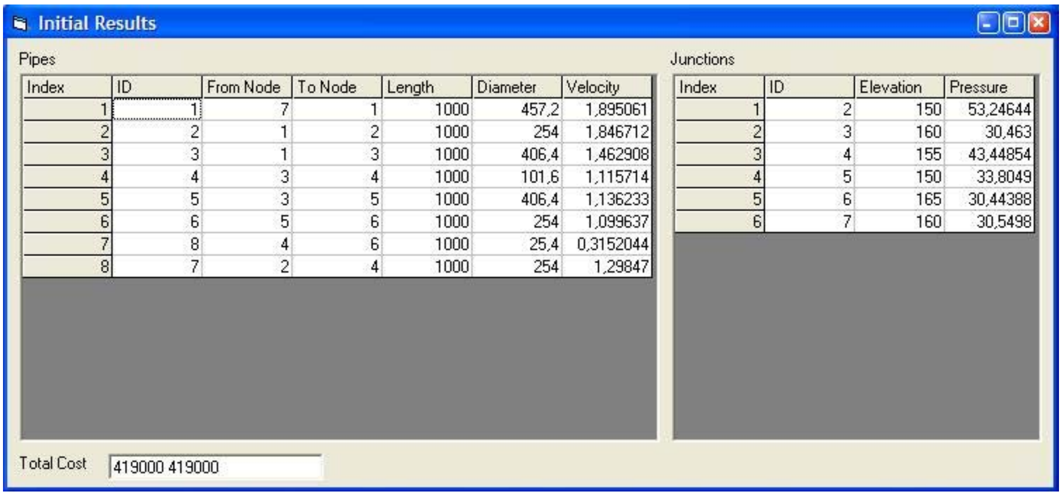


Figure 3.17 – Shamir Network, Initial Results

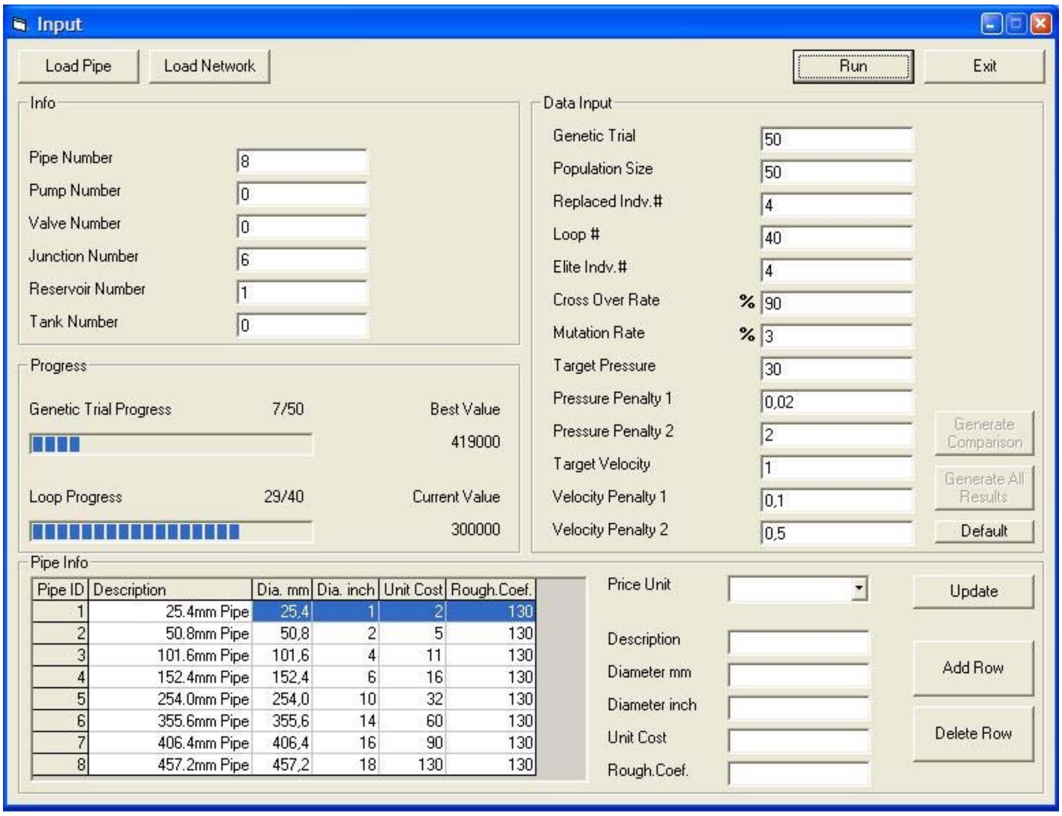
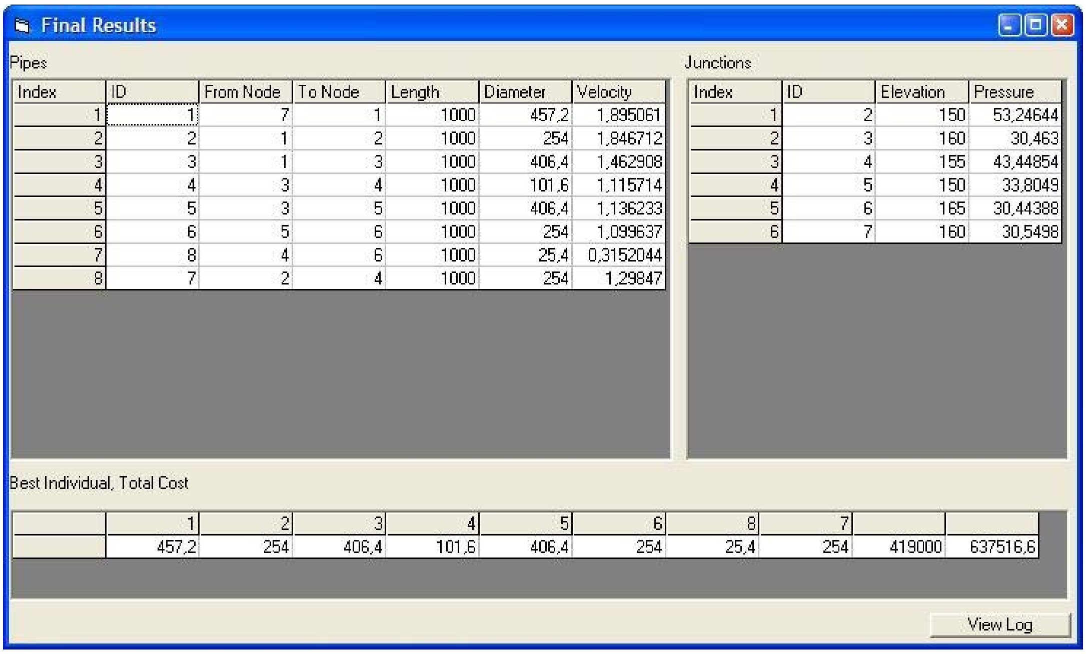


Figure 3.18 – Shamir Network, Run Progress



Final Results

Pipes

Index	ID	From Node	To Node	Length	Diameter	Velocity
1	1	7	1	1000	457,2	1,895061
2	2	1	2	1000	254	1,846712
3	3	1	3	1000	406,4	1,462908
4	4	3	4	1000	101,6	1,115714
5	5	3	5	1000	406,4	1,136233
6	6	5	6	1000	254	1,099637
7	8	4	6	1000	25,4	0,3152044
8	7	2	4	1000	254	1,29847

Junctions

Index	ID	Elevation	Pressure
1	2	150	53,24644
2	3	160	30,463
3	4	155	43,44854
4	5	150	33,8049
5	6	165	30,44388
6	7	160	30,5498

Best Individual, Total Cost

	1	2	3	4	5	6	8	7		
	457,2	254	406,4	101,6	406,4	254	25,4	254	419000	637516,6

View Log

Figure 3.19 – Shamir Network, Final Results

In Table 3.2 optimum results achieved by RealPipe compared to the best solution are presented below.

Table 3.2 – Optimum Pipe Results

Pipe ID	From Node	To Node	Length (m)	Diameter, Initial (mm)	Velocity, Initial (m/s)	Diameter, Final (mm)	Velocity, Final (m/s)
1	7	1	1000	457.2	1.90	457.2	1,90
2	1	2	1000	254.0	1.85	254.0	1,85
3	1	3	1000	406.4	1.46	406.4	1,46
4	3	4	1000	101.6	1.12	101.6	1,12
5	3	5	1000	406.4	1.14	406.4	1,14
6	5	6	1000	254.0	1.10	254.0	1,10
8	4	6	1000	25.4	0.32	25.4	0,32
7	2	4	1000	254.0	1.30	254.0	1,30
Total Cost		(USD)		419.000		419.000	

When Table 3.2 is examined, the diameters found by RealPipe are the same as the best result. Also, the computation time to achieve this result is very short which about 3 minutes is. As it is clearly being seen that RealPipe can achieve the best result, almost every genetic run in very short time. Savic and Walters (1997), Abebe and Solomatine (1998), Cunha and Sousa (1999), Kahraman (2003) and Liong and Atiquazzam (2004) are achieved the same result as well.

Table 3.3 – Optimum Junction Results

Junction ID	Elevation (m)	Pressure Head, Initial (m)	Pressure Head, Final (m)
2	150	53.246	53.246
3	160	30.463	30.463
4	155	43.449	43.449
5	150	33.805	33.805
6	165	30.444	30.444
7	160	30.550	30.550

In Table 3.3, it can be seen that there is no pressure less than 30 meters which is the most important criterion of the program.

3.3.5 –Effects of Parameters of Genetic Algorithm

In this section, alterations in the parameter values and their effects on the genetic algorithm will be discussed. In order to have a reliable conclusion, 50 trials are made for each parameter set. Parameters for each set are given below. Alterations from the base set are marked. 2a is the base set.

Table 3.4 – Trial Sets

ID of the set	1a	1b	1c	2a	2b	3	4	5a	5b	6	7a	7b
Population size	50	30	70	50	50	50	50	50	50	50	50	50
Replaced indv. number	4	2	6	4	4	4	4	4	4	4	4	4
Loop number	65	65	65	40	20	40	40	40	40	40	40	40
Elite indv. number	4	4	4	4	4	0	4	4	4	4	4	4
Cross over rate	90%	90%	90%	90%	90%	90%	5%	90%	90%	90%	90%	90%
Mutation rate	3%	3%	3%	3%	3%	3%	3%	0%	30%	3%	3%	3%
Target pressure	30	30	30	30	30	30	30	30	30	30	30	30
Press.pen. above target	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.2	0.02	0.02
Press.pen. below target	2	2	2	2	2	2	2	2	2	1	2	2
Target velocity	1	1	1	1	1	1	1	1	1	1	1	1
Vel.pen. above target	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	0
Vel.pen. below target	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5	0

Table 3.5 – Run Results for Parameter Sets 1

Trial Number	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost
	01a	*Pop=50 Rep=4*	*01b*	*Pop=30 Rep=2*	*01c*	*Pop=70 Rep=6*	*02a (Base)*	*Loop=40*
1	450,000	731,059	462,000	781,650	419,000	637,517	447,000	679,267
2	450,000	747,001	419,000	637,517	420,000	663,240	475,000	761,506
3	478,000	817,721	420,000	663,240	419,000	637,517	420,000	663,240
4	457,000	772,250	428,000	700,886	419,000	637,517	471,000	783,780
5	419,000	637,517	450,000	747,001	419,000	637,517	452,000	737,643
6	419,000	637,517	436,000	712,839	466,000	773,037	419,000	637,517
7	420,000	663,240	475,000	759,920	445,000	703,418	459,000	748,197
8	448,000	739,956	436,000	712,839	419,000	637,517	457,000	772,250
9	419,000	637,517	457,000	772,250	420,000	663,240	436,000	712,839
10	475,000	761,506	419,000	637,517	420,000	663,240	477,000	774,540
11	420,000	663,240	482,000	767,260	419,000	637,517	419,000	637,517
12	420,000	663,240	554,000	843,560	436,000	712,839	466,000	787,761
13	450,000	731,059	434,000	698,086	420,000	663,240	450,000	747,001
14	478,000	817,721	450,000	731,059	419,000	637,517	457,000	772,250

Table 3.5 (continued)

Trial Number	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost
15	457,000	772,250	436,000	712,839	419,000	637,517	419,000	637,517
16	420,000	663,240	436,000	712,839	450,000	747,001	462,000	770,896
17	419,000	637,517	477,000	774,540	419,000	637,517	423,000	669,535
18	420,000	663,240	466,000	787,761	462,000	770,896	419,000	637,517
19	434,000	698,086	420,000	663,240	462,000	770,896	450,000	715,407
20	450,000	731,059	466,000	787,761	450,000	731,059	419,000	637,517
21	452,000	737,643	501,000	839,678	419,000	637,517	450,000	731,059
22	420,000	663,240	419,000	637,517	420,000	663,240	466,000	767,601
23	457,000	772,250	450,000	747,001	420,000	663,240	419,000	637,517
24	450,000	731,059	450,000	731,059	450,000	743,040	420,000	663,240
25	460,000	777,698	419,000	637,517	420,000	663,240	482,000	794,217
26	459,000	701,992	436,000	712,839	450,000	743,040	436,000	712,839
27	450,000	731,059	419,000	637,517	445,000	703,418	445,000	703,418
28	450,000	743,040	419,000	637,517	450,000	731,059	457,000	772,250
29	450,000	731,059	419,000	637,517	450,000	747,001	478,000	789,764
30	471,000	783,780	477,000	774,540	462,000	770,896	457,000	772,250
31	462,000	770,896	478,000	817,721	420,000	663,240	420,000	663,240
32	419,000	637,517	436,000	712,839	420,000	663,240	448,000	715,931
33	508,000	769,376	469,000	787,635	445,000	703,418	422,000	641,708
34	450,000	731,059	521,000	812,609	436,000	712,839	419,000	637,517
35	452,000	737,643	447,000	679,267	419,000	637,517	420,000	663,240
36	419,000	637,517	462,000	770,896	419,000	637,517	450,000	715,407
37	419,000	637,517	447,000	679,267	420,000	663,240	461,000	719,246
38	419,000	637,517	419,000	637,517	420,000	663,240	459,000	741,489
39	419,000	637,517	450,000	731,059	436,000	712,839	480,000	786,315
40	445,000	703,418	436,000	712,839	457,000	772,250	445,000	703,418
41	436,000	712,839	466,000	769,866	419,000	637,517	436,000	712,839
42	443,000	717,255	457,000	772,250	445,000	703,418	466,000	773,037
43	420,000	663,240	457,000	772,250	457,000	772,250	450,000	715,407
44	447,000	679,267	419,000	637,517	482,000	767,260	450,000	747,001
45	419,000	637,517	419,000	637,517	450,000	743,040	445,000	703,418
46	455,000	747,827	419,000	637,517	434,000	698,086	419,000	637,517
47	420,000	663,240	419,000	637,517	420,000	663,240	450,000	715,407
48	480,000	801,193	450,000	715,407	419,000	637,517	447,000	679,267
49	445,000	703,418	419,000	637,517	420,000	663,240	441,000	704,506
50	450,000	743,040	466,000	741,572	450,000	743,040	445,000	703,418
Average	442,980	710,551	447,760	717,958	433,920	690,468	445,600	714,143
Minimum	419,000	637,517	419,000	637,517	419,000	637,517	419,000	637,517
Maximum	508,000	817,721	554,000	843,560	482,000	773,037	482,000	794,217
Std.Dev.	21,339.33		28,693.00		17,484.50		19,442.22	
Best sol.#	10		13		14		8	

Table 3.6 – Run Results for Parameter Sets 2

Trial Number	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost
	02b	*Loop=20*	*03*	*Elitism=0*	*04*	*Xover=5*	*05a*	*Mutation=0*
1	507,000	857,895	484,000	775,808	471,000	770,394	576,000	965,519
2	523,000	839,473	450,000	747,001	547,000	840,153	469,000	774,255
3	475,000	769,016	459,000	701,992	469,000	787,635	462,000	733,121
4	573,000	960,410	497,000	887,259	420,000	663,240	510,000	1,453,381
5	467,000	771,485	496,000	840,280	469,000	786,511	526,000	855,379
6	534,000	932,454	496,000	800,831	450,000	715,407	569,000	935,996
7	455,000	709,972	452,000	806,025	420,000	663,240	461,000	739,559
8	508,000	842,142	445,000	799,558	454,000	745,059	666,000	2,150,498
9	522,000	788,333	563,000	895,203	450,000	731,059	487,000	873,315
10	451,000	734,637	524,000	891,484	419,000	637,517	608,000	39,746,712
11	566,000	933,188	518,000	861,182	467,000	764,042	435,000	587,269,696
12	536,000	908,535	536,000	920,465	563,000	883,936	731,000	1,267,144
13	436,000	760,071	473,000	751,788	482,000	785,229	580,000	2,100,439
14	543,000	910,793	448,000	710,336	419,000	637,517	597,000	1,013,615
15	506,000	880,650	457,000	776,219	450,000	743,040	706,000	40,819,864
16	556,000	956,144	494,000	807,460	420,000	663,240	439,000	9,312,287
17	494,000	814,719	510,000	814,240	419,000	637,517	504,000	847,007
18	460,000	777,887	487,000	826,170	419,000	637,517	622,000	10,183,394
19	555,000	915,481	478,000	873,138	450,000	743,040	566,000	2,031,393
20	483,000	759,908	529,000	903,427	471,000	770,394	480,000	822,627
21	529,000	914,633	482,000	785,229	480,000	849,944	617,000	1,314,475
22	487,000	741,584	459,000	751,138	478,000	789,764	565,000	1,954,980
23	518,000	808,660	494,000	818,049	428,000	700,886	469,000	769,385
24	487,000	780,772	508,000	807,876	471,000	770,394	621,000	1,067,530
25	507,000	862,077	503,000	826,654	419,000	637,517	509,000	855,815
26	553,000	939,157	423,000	669,535	477,000	774,540	522,000	844,944
27	436,000	760,071	443,000	803,592	420,000	663,240	422,000	7,329,734
28	499,000	875,614	442,000	723,020	438,000	698,802	529,000	858,680
29	542,000	901,829	485,000	836,182	457,000	772,250	524,000	877,529
30	482,000	814,363	422,000	641,708	419,000	637,517	445,000	703,418
31	546,000	954,588	469,000	786,102	422,000	691,977	487,000	1,599,199
32	492,000	753,770	466,000	741,572	450,000	731,059	470,000	1,756,708
33	554,000	961,928	450,000	715,407	419,000	637,517	576,000	1,031,856
34	511,000	817,358	545,000	928,246	419,000	637,517	533,000	3,975,929
35	530,000	892,227	469,000	788,261	434,000	698,086	548,000	939,199
36	464,000	774,527	487,000	772,972	420,000	663,240	472,000	776,715
37	557,000	936,532	448,000	729,166	436,000	712,839	500,000	821,686
38	493,000	795,301	518,000	832,871	445,000	703,418	496,000	842,859
39	501,000	786,002	469,000	778,018	420,000	663,240	597,000	1,018,064
40	543,000	926,470	429,000	681,439	434,000	698,086	541,000	1,608,843
41	596,000	1,003,262	557,000	875,674	450,000	715,407	520,000	1,176,252
42	541,000	889,817	479,000	780,457	436,000	712,839	540,000	1,115,573

Table 3.6 (continued)

Trial Number	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost
43	473,000	772,425	484,000	775,808	450,000	747,001	402,000	539,584,768
44	465,000	903,767	456,000	753,037	419,000	637,517	457,000	772,250
45	452,000	731,294	564,000	956,570	423,000	669,535	550,000	939,133
46	561,000	957,265	502,000	804,056	450,000	743,040	575,000	1,484,741
47	510,000	809,267	464,000	712,881	419,000	637,517	529,000	873,590
48	535,000	855,678	452,000	705,079	482,000	767,260	466,000	773,037
49	513,000	858,427	478,000	782,256	445,000	703,418	544,000	1,484,986
50	469,000	752,261	523,000	853,014	450,000	747,001	543,000	980,075
Average	509,920	847,082	483,320	796,115	446,780	716,361	531,260	25,700,543
Minimum	436,000	709,972	422,000	641,708	419,000	637,517	402,000	703,418
Maximum	596,000	1,003,262	564,000	956,570	563,000	883,936	731,000	587,269,696
Std.Dev.	38,594.62		35,379.83		30,846.75		69,849.93	
Best sol.#	0		0		10		0	

Table 3.7 – Run Results for Parameter Sets 3

Trial Number	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost
	05b	*Mutation =30*	*06*	*P.Pen: 0,2 - 1*	*07a*	*V.Pen: 1 - 5*	*07b*	*V.Pen: 0 - 0*
1	481,000	787,504	422,000	3,501,189	420,000	978,144	450,000	693,404
2	464,000	743,765	417,000	3,780,232	419,000	931,342	420,000	628,250
3	469,000	773,329	368,000	3,549,562	436,000	998,601	419,000	604,869
4	506,000	866,442	424,000	3,402,793	439,000	1,018,993	419,000	604,869
5	506,000	839,071	564,000	4,018,248	420,000	978,144	420,000	628,250
6	487,000	741,584	417,000	3,780,232	419,000	931,342	459,000	662,182
7	481,000	769,802	496,000	3,579,738	419,000	931,342	422,000	654,225
8	452,000	806,726	424,000	3,402,793	475,000	1,032,069	466,000	723,388
9	452,000	724,846	448,000	4,280,426	439,000	1,018,993	434,000	647,899
10	497,000	816,903	457,000	3,851,784	439,000	1,018,993	448,000	711,575
11	480,000	777,087	396,000	3,599,262	419,000	931,342	475,000	693,714
12	481,000	800,711	454,000	3,774,194	436,000	998,601	490,000	703,616
13	501,000	848,012	422,000	3,501,189	420,000	978,144	455,000	703,996
14	485,000	788,005	484,000	3,610,573	448,000	995,387	473,000	683,925
15	427,000	698,292	366,000	3,429,138	471,000	1,141,722	457,000	722,161
16	469,000	765,713	366,000	3,429,138	419,000	931,342	448,000	711,575
17	523,000	842,408	352,000	3,521,809	436,000	998,601	445,000	670,742
18	464,000	758,292	478,000	4,385,010	419,000	931,342	436,000	681,088
19	530,000	844,833	424,000	3,688,957	452,000	1,059,765	450,000	705,331
20	471,000	791,538	422,000	3,501,189	420,000	978,144	466,000	723,078
21	473,000	766,125	424,000	3,402,793	445,000	999,470	448,000	711,575
22	562,000	852,768	434,000	4,487,746	445,000	999,470	462,000	661,924

Table 3.7 (continued)

Trial Number	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost	Pipe Cost	Total Cost
23	450,000	783,502	422,000	3,501,189	477,000	1,295,353	434,000	647,899
24	479,000	801,120	424,000	3,402,793	419,000	931,342	447,000	634,324
25	522,000	856,765	422,000	3,501,189	450,000	1,018,241	438,000	668,427
26	467,000	773,099	366,000	3,429,138	445,000	997,505	436,000	681,088
27	482,000	784,906	426,000	3,842,238	471,000	1,197,871	419,000	604,869
28	499,000	845,065	368,000	3,549,562	438,000	972,177	436,000	681,088
29	499,000	829,497	450,000	4,474,808	439,000	1,018,993	434,000	647,899
30	470,000	785,850	368,000	3,549,562	464,000	1,086,812	445,000	681,795
31	503,000	839,018	424,000	3,402,793	436,000	998,601	450,000	670,434
32	515,000	859,588	426,000	3,588,295	436,000	998,601	438,000	668,427
33	521,000	862,666	424,000	3,402,793	419,000	931,342	419,000	604,869
34	478,000	766,784	392,000	4,085,721	469,000	1,065,018	475,000	693,714
35	518,000	833,577	466,000	3,609,071	438,000	972,177	447,000	634,324
36	477,000	726,253	366,000	3,429,138	450,000	1,122,035	445,000	670,742
37	495,000	843,302	399,000	3,637,201	451,000	1,012,719	434,000	647,899
38	482,000	781,352	366,000	3,429,138	436,000	998,601	462,000	713,069
39	453,000	724,734	352,000	3,521,809	450,000	1,122,035	445,000	670,742
40	501,000	853,699	396,000	4,297,234	420,000	978,144	476,000	733,233
41	501,000	807,811	457,000	3,851,784	475,000	1,026,720	438,000	668,427
42	455,000	733,898	424,000	3,402,793	464,000	1,086,812	450,000	638,857
43	450,000	717,805	424,000	3,402,793	448,000	995,387	450,000	693,404
44	522,000	844,944	396,000	3,599,262	445,000	997,505	457,000	722,161
45	422,000	641,708	424,000	3,402,793	438,000	972,177	447,000	634,324
46	487,000	772,972	424,000	3,402,793	439,000	1,005,015	448,000	675,911
47	548,000	851,058	426,000	3,588,295	424,000	978,773	466,000	705,872
48	557,000	849,160	494,000	3,509,579	436,000	998,601	475,000	693,714
49	523,000	863,465	424,000	3,688,957	436,000	998,601	480,000	702,707
50	454,000	742,047	454,000	3,590,127	420,000	978,144	419,000	604,869
Average	487,820	795,588	421,260	3,651,417	439,760	1,010,732	447,440	672,534
Minim.	422,000	641,708	352,000	3,402,793	419,000	931,342	419,000	604,869
Maxim.	562,000	866,442	564,000	4,487,746	477,000	1,295,353	490,000	733,233
Std.Dev.	30,508.41		41,316.50		17,410.48		18,119.96	
Best sl.#	0		0		8		5	

<u>*3.3.5.1 – Population Size*</u>

Population size is an important part of genetic algorithm process. It is important to find an optimum number for population size for a specific network which is related to the number of pipes. It is obvious that large number of population is better but beyond some point, increasing population does not have the same positive effect on convergence rate. Therefore, it should be large enough to have various numbers of random individual gene and small enough to make program faster.

In this study Population size 30-replaced individual number 2 (1a), Population size 50-replaced individual number 4 (1b) and Population size 70-replaced individual number 6 (1c) and are run. Results are as follows.

Table 3.8 – Results Comparison Table for Population Size

	Population=30 (01b)		***Population=50 (01a)***		***Population=70 (01c)***	
	Pipe Cost	**Total Cost**	**Pipe Cost**	**Total Cost**	**Pipe Cost**	**Total Cost**
Average	447,760	717,957,57	442,980	710,551,29	433,920	690,467,78
Minimum	419,000	637,516,63	419,000	637,516,63	419,000	637,516,63
Maximum	554,000	843,559,75	508,000	817,721,25	482,000	773,037,06
Std.deviation	28,693.00		21,339.33		17,484.50	
Best Solution #	13		10		14	

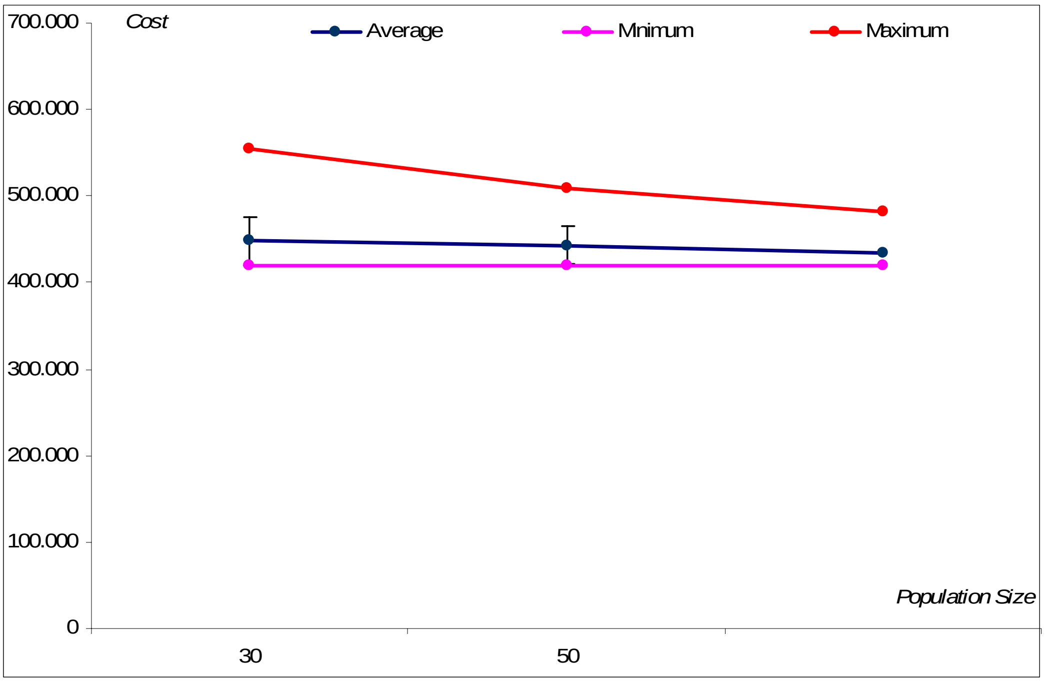


Figure 3.20 – Results Comparison Chart for Population Size

Results show that 50 for population are good enough for this network.

3.3.5.2 – Loop Number

Loop number is very similar to the previous parameter. Larger number improves the result but beyond a point it will be useless and extends the run time.

For this case 20, 40 and 65 loop numbers are tested. Results are as follows.

Table 3.9 – Results Comparison Table for Loop numbers

	Loop=20 (02b)		***Loop=40 (02a-base)***		***Loop=65 (01a)***	
	Pipe Cost	**Total Cost**	**Pipe Cost**	**Total Cost**	**Pipe Cost**	**Total Cost**
Average	509,920	847,082,28	445,600	714,143,47	442,980	710,551,29
Minimum	436,000	709,971,88	419,000	637,516,63	419,000	637,516,63
Maximum	596,000	1,003,261,63	482,000	794,216,69	508,000	817,721,25
Std.deviation	38,594.62		19,442.22		21,339.33	
Best Solution #	0		8		10	

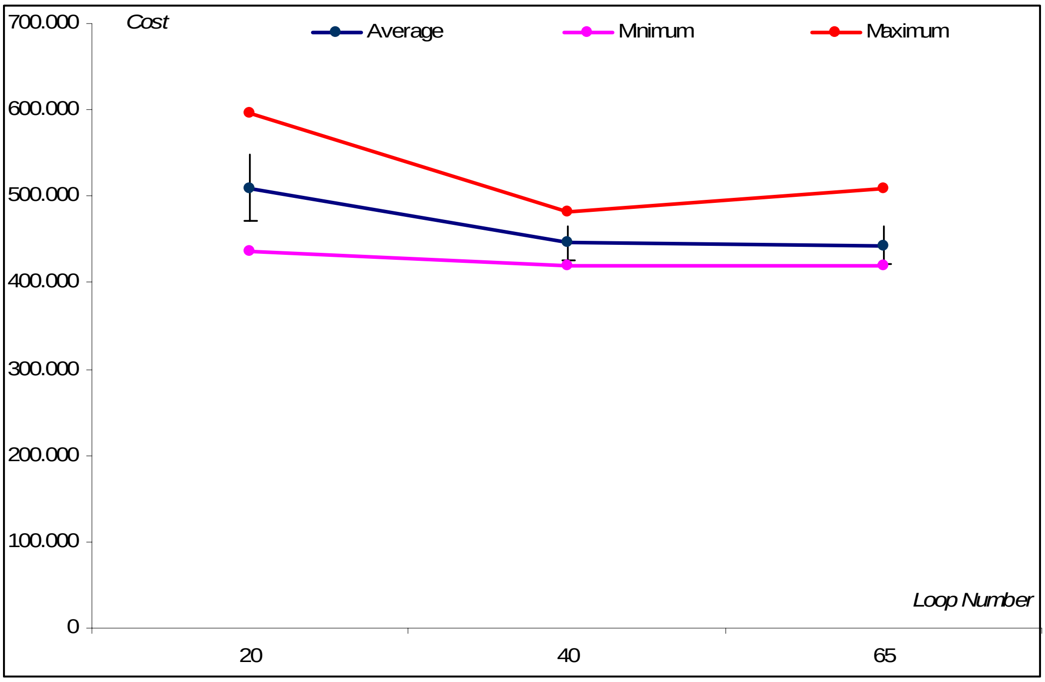


Figure 3.21 – Results Comparison Chart for Loop numbers

As it can be read from the Figure 25, 20 is insufficient for this network and results stand immature. 40 and 65 reflects almost same results means 65 is unnecessarily long and lengthen the run time. 40 is good enough to catch the convergence for this network.

It is no doubt that higher loop numbers may improve some genetic trials. On the other hand it takes longer times and it is an open end. A stop point should be selected carefully. Therefore, more trial numbers should be preferred instead of longer loop numbers.

3.3.5.3 – Elitism

Elitism is introduced in earlier chapters and its importance was already mentioned. Elitism reserves the best individual for each tour and carries on to the next tour in order to prevent the probability of losing it. Same network is run without elitism. Results are presented below in Table 3.10.

Table 3.10 – Results Comparison Table for Elitism Rate

	Elite ind.num=4/50 (02a)		***Elite ind.num=0/50 (03)***	
	Pipe Cost	**Total Cost**	**Pipe Cost**	**Total Cost**
Average	445,600	714,143,47	483,320	796,114,65
Minimum	419,000	637,516,63	422,000	641,707,94
Maximum	482,000	794,216,69	564,000	956,569,50
Std.deviation	19,442.22		35,379.83	
Best Solution #	8		0	

It can clearly be seen that without elitism, program could not achieve the best result. Each loop best result is subjected to the cross over and mutation. Therefore it would be impossible to guarantee them to carry for the next round. This trial shows us the importance of this operator.

3.3.5.4 – Crossover

RealPipe uses multipoint crossover as it is mentioned earlier. Larger number of crossover leads higher ratio of mixing of two individuals which fastens the convergence. Fourth trial is based on this subject.

Table 3.11 – Results Comparison Table for Crossover Rate

	Crossover=90% (02a)		***Crossover=5% (04)***	
	Pipe Cost	**Total Cost**	**Pipe Cost**	**Total Cost**
Average	445,600	714,143,47	446,780	716,360,98
Minimum	419,000	637,516,63	419,000	637,516,63
Maximum	482,000	794,216,69	563,000	883,935,81
Std.deviation	19,442.22		30,846.75	
Best Solution #	8		10	

Since the network is small, very small percent of crossover can achieve the result with the help of Elitism and Mutation of course. On the other hand, much greater standard deviation indicates that genetic algorithm mechanism is not strong enough with smaller ratio of crossover. On the greater networks, smaller crossover ratios give results away from the global optimum value.

3.3.5.5 – Mutation

Mutation is another important operator of the Genetic Algorithm. Earlier researches say that smaller value should be used, i.e. 1-5%. 3% is used in the base optimization parameter set. Also the sample network is run with 0% and 30%. Results are shown in Table 3.12.

Table 3.12 – Results Comparison Table for Mutation

	Mutation=0% (05a)		*Mutation=3% (02a)*		*Mutation=30% (05b)*	
	Pipe Cost	**Total Cost**	**Pipe Cost**	**Total Cost**	**Pipe Cost**	**Total Cost**
Average	531,260	25,700,543.07	445,600	714,143.47	487,820	795,588.02
Minimum	402,000	703,417.94	419,000	637,516.63	422,000	641,707.94
Maximum	731,000	587,269,696	482,000	794,216.69	562,000	866,442.13
Std.deviation	69,849.93		19,442.22		30,508.41	
Best Solution #	0		8		0	

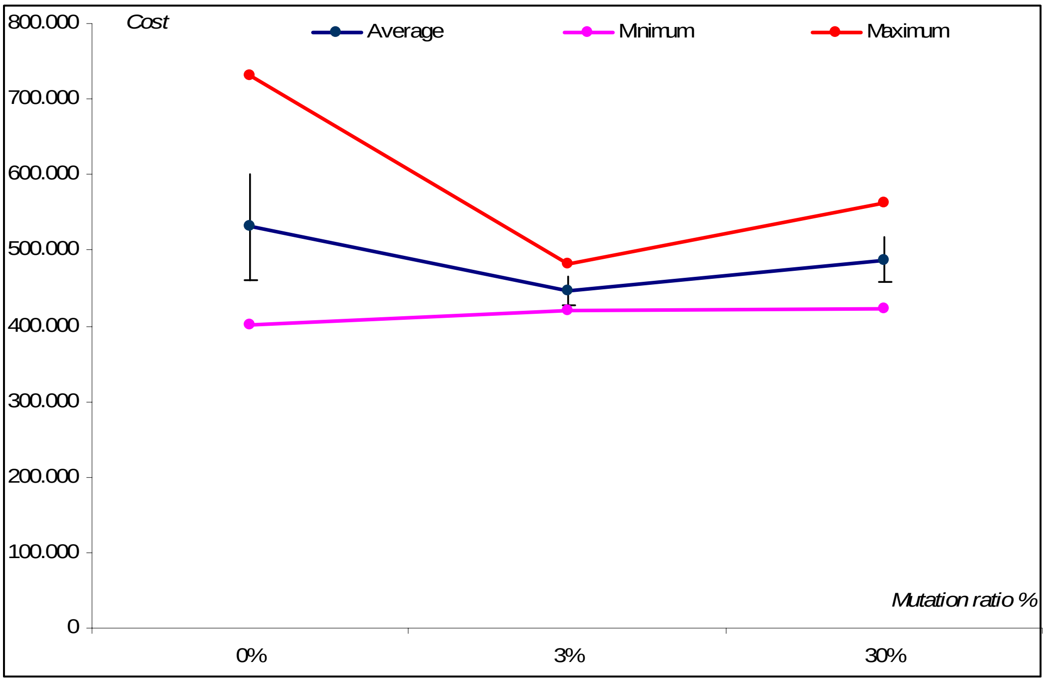


Figure 3.22 – Results Comparison Chart for Mutation

Without mutation, no goal is achieved. Report created by the program tells that a better network was found but its total cost is greater than (703,417) the best one (637,516) which means that its hydraulic properties are away from the desired limits. Also bigger mutation value could not achieve the result since individuals are distorted too much during evolution. Another important point is that both extreme trials have greater variances.

3.3.5.6 – Pressure Penalty

Pressure penalty is the most important penalty tool at this study. This penalty drives the algorithm to converge to the global optimum. Therefore, related two penalty values must be chosen carefully.

Balance between the above target pressure constant and below target pressure constant and balance between velocity constants is very critical. Trial runs show that below target pressure constant should be approximately 100 times bigger than above one, since it is not desired to have pressure under target pressure. Table 3.13 shows the effects of change in the constants on the results.

Table 3.13 – Results Comparison Table for Pressure Penalty

	above=0,02 below=2 (Base,02a)		***above=0,2 below=1 (06)***	
	Pipe Cost	**Total Cost**	**Pipe Cost**	**Total Cost**
Average	445,600	714,143.47	421,260	3,651,416.60
Minimum	419,000	637,516.63	352,000	3,402,792.50
Maximum	482,000	794,216.69	564,000	4,487,745.50
Std.deviation	19,442.22		41,316.50	
Best Solution #	8		0	

Trial 06 clearly shows that there is no balance between the penalty constants and program can not be able to understand where the target is. Results for this run are just numbers.

3.3.5.7 – Velocity Penalty

Velocity penalty can be the named as supporting mechanism. Two different run are made with different velocity constant as it is shown in Table 3.14.

Table 3.14 – Results Comparison Table for Velocity Penalty

	above=0,1 below=0,5 (Base,02a)		***above=1 below=5 (07a)***		***No penalty i.e.above=0 below=0 (07b)***	
	Pipe Cost	**Pipe Cost**	**Pipe Cost**	**Total Cost**	**Pipe Cost**	**Total Cost**
Average	445,600	714,143.47	439,760	1,010,731.6	447,440	672,534.48
Minimum	419,000	637,516.63	419,000	931,342.1	419,000	604,869.38
Maximum	482,000	794,216.9	477,000	1,295,353.8	490,000	733,232.63
Std.deviation	19,442.22		17,410.48		18,119.96	
Best Solution #	8		8		5	

As it is seen in Table 3.14 above, change in the velocity constants without disturbing the balance between pressure constants has very small effect on the result. No velocity penalty even leads the result. On the other hand, velocity penalty has a secondary convergence effect on the network. The validity of this fact can be observed more clearly on the greater networks.

3.4 – Example 2: Hanoi Network

3.4.1 – Introduction of Network

This network is a real network constructed in Hanoi city in Vietnam. Fujiwara and Khang (1990) at first studied on this network to explore the optimum solution. Later, many researchers (Savic and Walters (1997); Abebe and Solomatine (1998); Cunha and Sousa (1999); Kahraman (2003); Liong and Atiquazzam (2004)) worked on the same network. This network is considered as a moderate sized example network.

The network consists of 32 nodes, 34 links, 1 reservoir and 3 loops shown in Figure 25. Elevations are zero meters for nodes and Hazen-Williams constant is 130 for pipes. Other data and layout of the network are given in Figure 25.

Available pipes and unit prices are given below in Table 3.15 below.

Table 3.15 – Hanoi Network, Available Pipe Information

Diameter (inch)	Diameter (mm)	HW Roughness Coefficient	Unit Price (USD/m)
12	304.8	130	45.73
16	406.4	130	70.40
20	508	130	98.38
24	609.6	130	129.33
30	762	130	180.75
40	1016	130	278.28

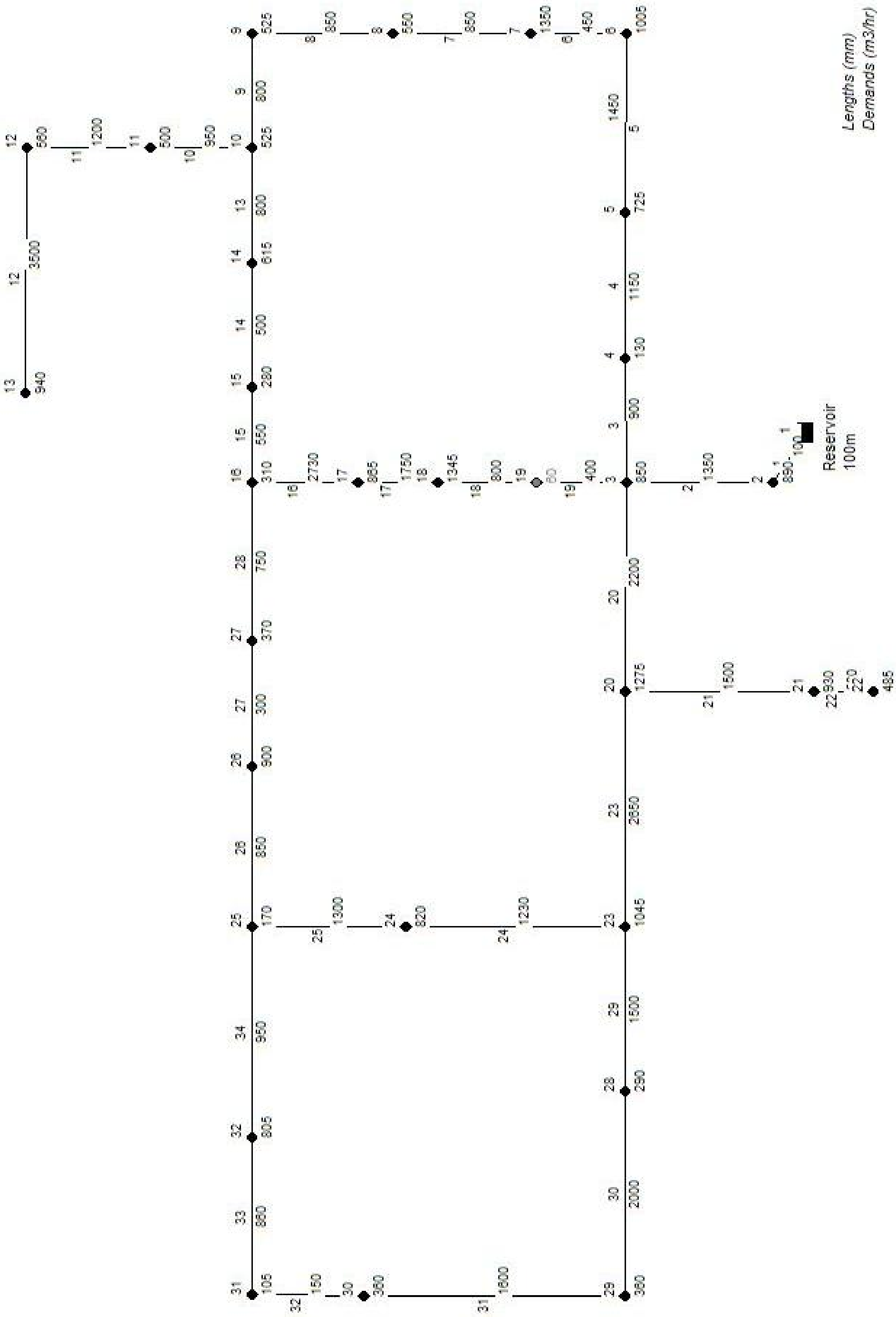
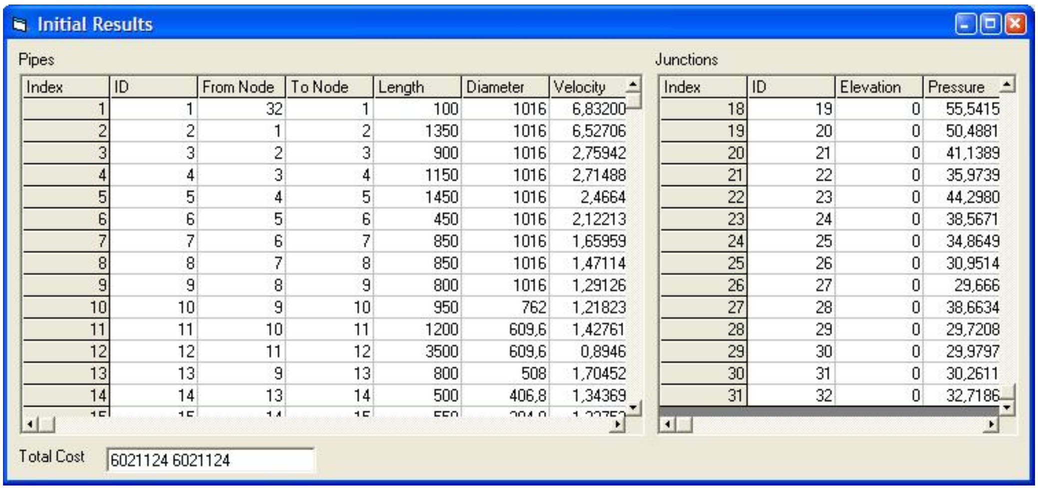


Figure 3.23 – Hanoi Network, Layout

3.4.2 – Solution using RealPipe

Below parameters are used for the optimization of Hanoi network.

Genetic trial number	: 10
Population size	: 50
Replaced individual number	: 4
Loop number	: 200
Elite individual number	: 4
Cross over rate	: 90%
Mutation rate	: 3%
Target pressure	: 30
Pressure penalty above target	: 0.02
Pressure penalty below target	: 2
Target velocity	: 7
Velocity penalty above target	: 0.5
Velocity penalty below target	: 0



Index	ID	From Node	To Node	Length	Diameter	Velocity
1	1	32	1	100	1016	6,83200
2	2	1	2	1350	1016	6,52706
3	3	2	3	900	1016	2,75942
4	4	3	4	1150	1016	2,71488
5	5	4	5	1450	1016	2,4664
6	6	5	6	450	1016	2,12213
7	7	6	7	850	1016	1,65959
8	8	7	8	850	1016	1,47114
9	9	8	9	800	1016	1,29126
10	10	9	10	950	762	1,21823
11	11	10	11	1200	609,6	1,42761
12	12	11	12	3500	609,6	0,8946
13	13	9	13	800	508	1,70452
14	14	13	14	500	406,8	1,34369

Index	ID	Elevation	Pressure
18	19	0	55,5415
19	20	0	50,4881
20	21	0	41,1389
21	22	0	35,9739
22	23	0	44,2980
23	24	0	38,5671
24	25	0	34,8649
25	26	0	30,9514
26	27	0	29,666
27	28	0	38,6634
28	29	0	29,7208
29	30	0	29,9797
30	31	0	30,2611
31	32	0	32,7186

Figure 3.24 – Hanoi Network, Initial Results

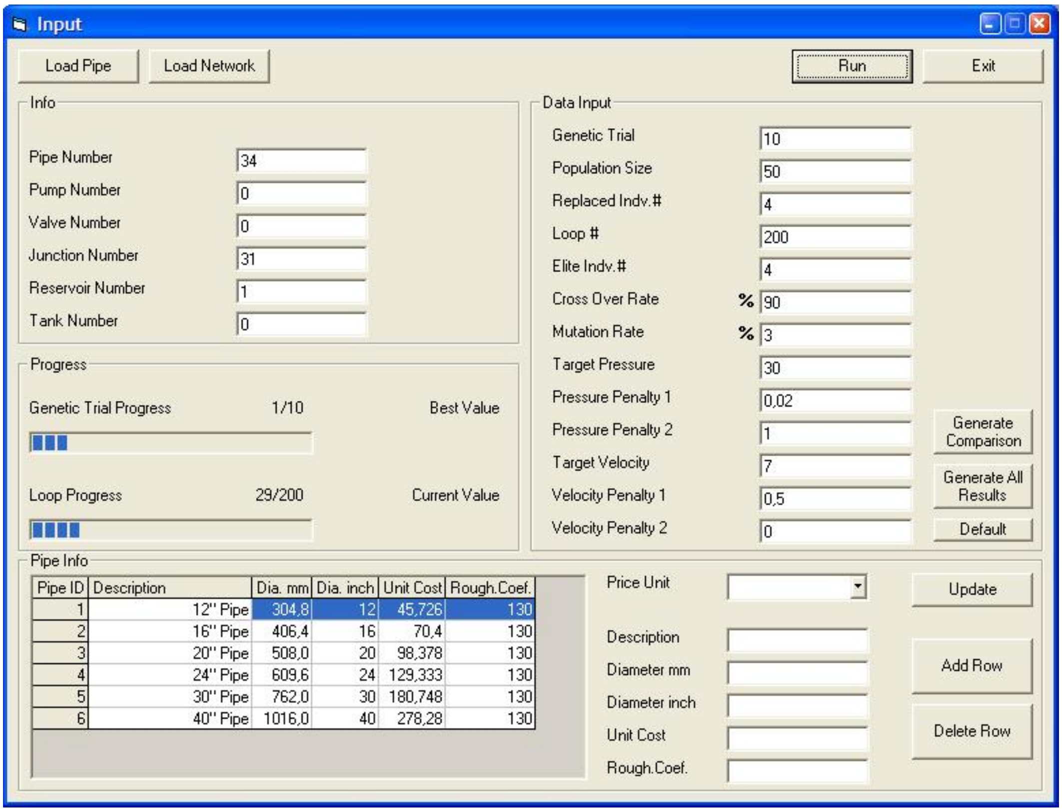


Figure 3.25 – Hanoi Network, Run Progress

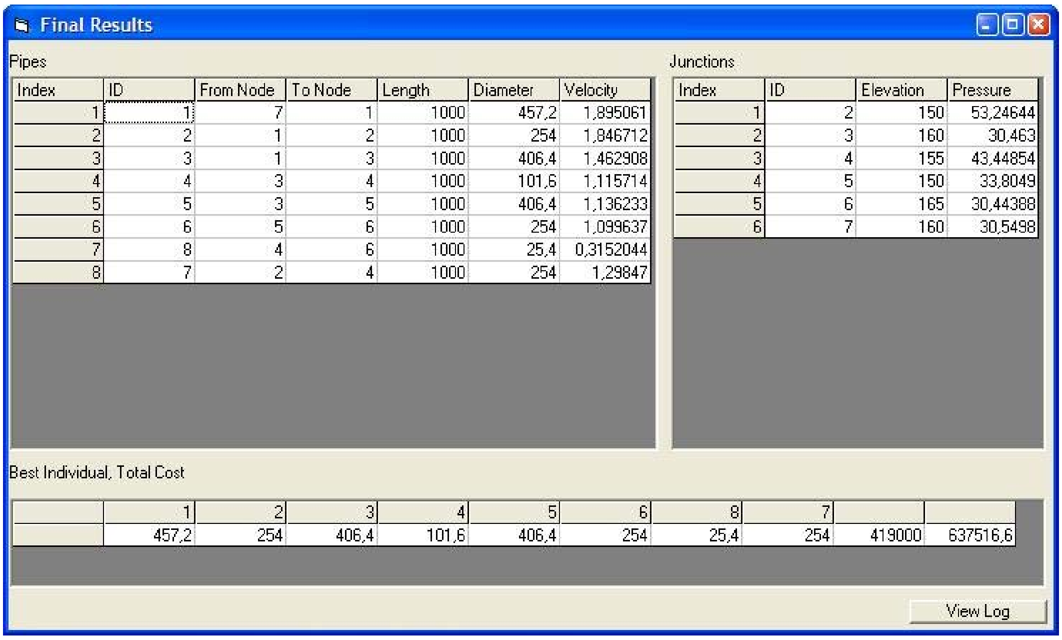


Figure 3.26 – Hanoi Network, Final Results

Optimum results achieved by RealPipe and comparison to the past studies are given below in Table 3.16.

Table 3.16 – Hanoi Network, Compared Achieved Optimum Pipe Diameters

Pipe ID	Lengths (m)	Pipe Diameters (inch)					
		Savic and Walters (1997)	Abebe and Solomatine (1998)	Cunha and Sousa (1999)	Kahraman (2003)	Liong and Atiquazzam (2004)	Güç (2006)
1	100	40	40	40	40	40	40
2	1350	40	40	40	40	40	40
3	900	40	40	40	40	40	40
4	1150	40	40	40	40	40	40
5	1450	40	30	40	40	40	40
6	450	40	40	40	40	40	40
7	850	40	40	40	40	40	40
8	850	40	30	40	40	30	40
9	800	40	30	40	30	30	40
10	950	30	30	30	30	30	24
11	1200	24	30	24	24	30	24
12	3500	24	30	24	24	24	24
13	800	20	16	20	16	16	12
14	500	16	24	16	12	12	12
15	550	12	30	12	12	12	16
16	2730	12	30	12	16	24	12
17	1750	16	30	16	20	30	20
18	800	20	40	20	24	30	30
19	400	20	40	20	24	30	20
20	2200	40	40	40	40	40	40
21	1500	20	20	20	20	20	20
22	500	12	20	12	12	12	12
23	2650	40	30	40	40	30	40
24	1230	30	16	30	24	30	30
25	1300	30	20	30	24	24	30
26	850	20	12	20	20	12	30
27	300	12	24	12	12	20	20
28	750	12	20	12	16	24	16
29	1500	16	24	16	20	16	16
30	2000	16	30	12	16	16	20
31	1600	12	30	12	16	12	16
32	150	12	30	16	12	16	20
33	860	16	30	16	12	20	16
34	950	20	12	24	20	24	24
Total Cost (Million USD)		6073	7006	6056	6062	6224	6334

Shamir network solution was relatively easy to accomplish since it is a small network. However, in this case, sample space is much larger than the previous one. Therefore, only one best solution is not expected. Instead, similar results close to each other are achieved. It is important that observing RealPipe strictly obeys the minimum pressure rule and all pressure values at the nodes are above 30m. On the other hand, there are only some nodal pressures under 30m in the other studies that is highlighted at Table 3.17 below.

Table 3.17 – Hanoi Network, Compared Nodal Pressure Heads

Node ID	Nodal Pressure Heads (m)					
	Savic and Walters (1997)	Abebe and Solomatine (1998)	Cunha and Sousa (1999)	Kahraman (2003)	Liong and Atiquazzam (2004)	Güç (2006)
1	100	100	100	100	100	100
2	97.14	97.14	97.14	97.14	97.14	97.14
3	61.67	61.67	61.67	61.67	61.67	61.67
4	56.88	58.60	56.87	57.18	57.54	57.54
5	50.94	54.84	50.92	51.61	52.43	52.44
6	44.68	39.51	44.64	45.77	47.13	47.14
7	43.21	38.71	43.16	44.42	45.92	45.93
8	41.45	37.93	41.39	42.84	44.55	44.57
9	40.04	35.72	39.98	41.59	40.27	43.51
10	39.00	34.37	38.93	37.91	37.24	42.77
11	37.44	32.81	37.37	36.35	35.68	38.15
12	34.01	31.65	33.94	32.93	34.52	34.72
13	29.80	30.23	29.74	28.72	30.32	30.51
14	35.13	36.43	35.01	30.68	34.08	30.08
15	33.14	37.24	32.95	27.90	34.08	30.08
16	30.23	37.70	29.87	27.75	36.13	30.59
17	30.32	48.14	30.03	38.57	48.64	44.05
18	43.97	58.63	43.87	50.44	54.00	51.97
19	55.57	60.64	55.54	57.83	59.07	54.00
20	50.44	53.89	50.49	51.28	53.62	49.58
21	41.09	44.54	41.14	41.93	44.27	40.23
22	35.93	44.11	35.97	36.76	39.11	35.07
23	44.21	39.89	44.30	45.75	38.79	42.62
24	38.90	30.62	38.57	34.85	36.37	36.53
25	35.55	30.61	34.86	28.85	33.16	32.52
26	31.53	32.23	30.95	26.58	33.44	31.66
27	30.11	32.71	29.66	26.58	34.38	31.23
28	35.50	33.61	38.66	40.43	32.64	32.62
29	30.75	31.56	29.72	28.93	30.05	30.62

Table 3.17 (continued)

Node ID	Nodal Pressure Heads (m)					
	Savic and Walters (1997)	Abebe and Solomatine (1998)	Cunha and Sousa (1999)	Kahraman (2003)	Liong and Atiquazzam (2004)	Güç (2006)
30	29.73	30.55	29.98	26.17	30.10	30.06
31	30.19	30.50	30.26	26.16	30.35	30.09
32	31.44	30.28	32.72	26.41	31.09	30.98

In the light of Table 3.17 above, it is observed that solution with lowest cost is achieved by Cunha and Sousa (1999), however this solution could not meet the pressure constraint at five nodes. The solution with the highest cost is achieved by Abebe and Solomatine (1998). This solution meets all the constraints.

Also, it can be concluded that RealPipe can find solutions that is between the past studies. Moreover RealPipe's solution has no constraint defect. It should be pointed that only 10 trials had performed. More trials should have performed to obtain a better solution.

CHAPTER 4

CASE STUDY

Genetic algorithm program developed for this study called RealPipe has already been introduced and two sample networks have then been studied using this program. In this chapter, as a case study, a skeletonized model of an existing network (N8.3) of Ankara water distribution system is examined (Merzi et al. 1998a, 1998b). N8.3 is located at the end of the North main pressure zone of the city. The pressure zone N8.3 comprises the districts Çiğdemtepe, Sancaktepe, Şehit Kubilay and Yayla (Yenimahalle and Keçiören counties). There are about 25000 people living there with lower incomes. This is the largest network examined in this study with 83 pipes and 60 nodes.

4.1 – Optimization of N8.3 Network

4.1.1 – Introduction of Network

This network is a skeletonized model of the pressure zone N8.3 of northern Ankara. It has 83 pipes, 60 nodes and 2 reservoirs. Pump is not introduced in this model in order to simplify the network; a reservoir has been placed instead of existing pump (P23). Network link information of the existing system is given in Table 4.1 below.

Table 4.1 – N8.3 Network Existing Pipe Information

Pipe Id	Length (m)	Diameter (mm)	Pipe Id	Length (m)	Diameter (mm)
82015	46	150	85008	273,6	150
82009	56	150	85014	122,4	100
82014	268	150	85015	181	125
82024	27	100	85016	136	200
82023	65	250	85017	272	125
82021	115	200	85019	292	150
82026	356	150	84001	479,4	100
83001	258	100	84002	178	200
83002	180	100	84003	161	100

Table 4.1 (continued)

Pipe Id	Length (m)	Diameter (mm)	Pipe Id	Length (m)	Diameter (mm)
83021	213,5	250	84005	140	150
83018	52	125	84006	191	125
83013	70	100	84009	349	150
83015	109	125	84010	294	200
83017	28	125	83003	159,5	150
83008	136	100	83005	282	250
83006	76	100	83009	181	150
85024	59	150	83010	453	150
84007	116	100	83012	561	250
84008	268	150	83016	136	125
85018	183	200	83019	440,5	125
85013	55	125	83020	528,5	150
85021	58	200	82002	449	250
85012	108	200	82003	184	250
85011	114	200	82004	401	150
85022	23	100	82005	270	100
M24	175	500	82006	252	150
83011	402	125	82007	104	200
83007	5	125	82008	181	150
83014	5,1	100	82010	267	150
84012	29,3	150	82011	304	125
84011	13,5	150	82013	323	100
85020	7,6	150	82012	203,5	200
83004	41	250	82018	170	200
85023	18	100	82019	284	200
82001	15	250	82020	652	125
84004	23	150	82022	69	200
85001	100	100	82025	101	100
85002	161	100	80027	386	200
85003	196	100	M23	999,99	500
85004	103	200	M9	306,6	500
85005	135	200	M1	424,1	500
85007	521	150			

Nodal demand data were obtained after having examined the daily demand curve of August 16, 2001, at which one of the highest water usages of the year occurs. Nodal demands of the related peak hour values of that day are presented on Table 4.2. Network layout is given on Figure 31 as well.

Table 4.2 – N8.3 Network, Existing Node Information

Node Id	Elevation	Demand (lt/s)	Node Id	Elevation	Demand (lt/s)
100	1130.65	0.681448	783	1102.07	0.787211
103	1121.22	1.760420	784	1103.6	2.016490
109	1093.83	0.452250	785	1107.49	1.134420
113	1128.25	1.558580	790	1081.46	3.931400
122	1113.44	2.102530	794	1118.86	1.060320
133	1096.15	1.021000	799	1078.28	0.924975
138	1083.85	1.509020	801	1116.19	0.699398
160	1121.51	0.825735	802	1115.64	1.013580
411	1117.74	2.150740	813	1103.82	0.632420
416	1120.65	0.191525	817	1097.32	1.827250
419	1127.29	1.895270	819	1108.57	1.090780
420	1099.27	1.194620	820	1107.13	0.841508
575	1099.91	0.680308	822	1096.42	0.190796
578	1120.68	0.620925	823	1095.11	0.329633
580	1124.97	0.815858	1910	1082.93	2.816240
587	1118.99	0.838415	3078	1098.98	1.809030
588	1133.48	0.565602	3144	1112.1	1.148520
589	1079.97	1.244130	3147	1121.36	0.581499
591	1071.41	1.503890	3209	1096.29	4.684320
595	1083.36	1.286100	3212	1097.05	0.082779
607	1093.23	1.646500	3213	1071.26	0.888419
612	1076.44	0.947418	3221	1105.05	0.548160
618	1101.7	0.659789	3222	1104.91	0.095903
624	1114.46	0.299486	3286	1115.21	0.543169
628	1089.6	0.284781	3299	1096.87	0.101758
629	1089.8	0.790042	3300	1095.67	0.041481
631	1114.77	0.692856	AN23	1151.66	0.000000
771	1103.82	0.947974	AN24	1051.32	0.000000
774	1117.1	0.875683	511	1096.42	4.283320
780	1108.65	1.833420	3285	1103.32	0.723867
782	1098.99	0.706399	3830	1079.02	0.710366

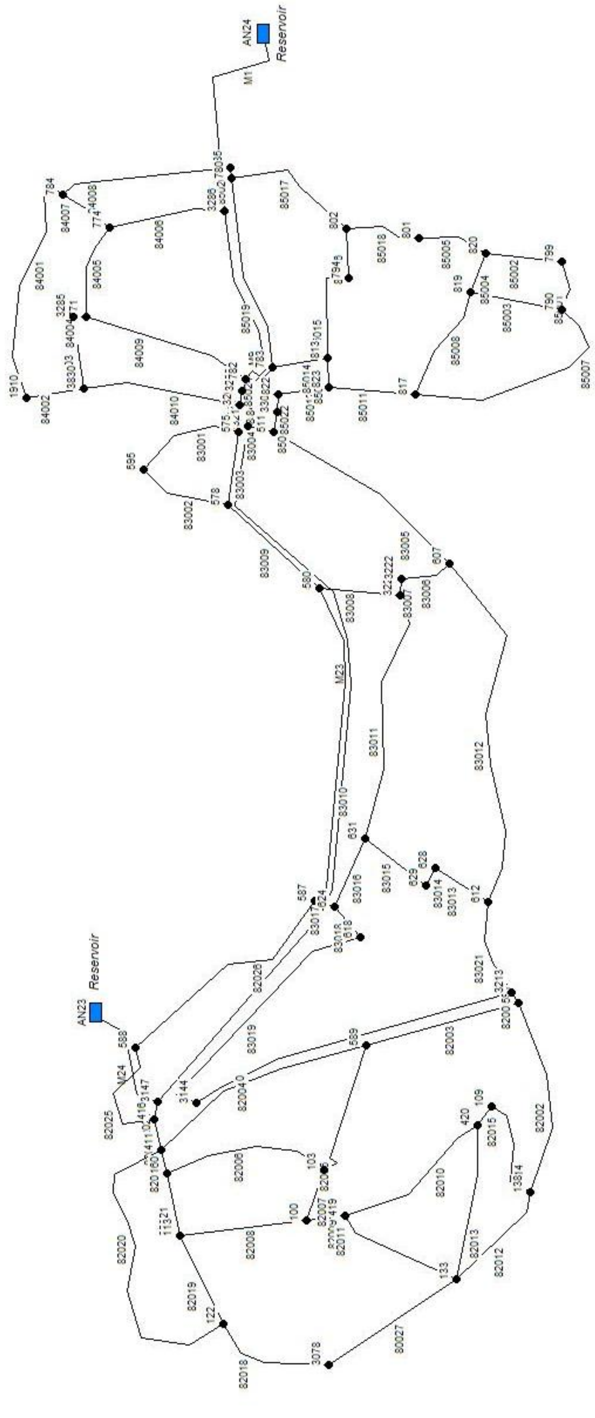


Figure 4.1 – N8.3 Network, Layout

Hazen-Williams coefficient is taken 130 for each pipe. Eleven commercially available ductile iron pipes are used for the solution whose unit prices are taken from Keleş (2006). Pipe diameters and unit prices are given below in Table 4.3.

Table 4.3 – N8.3 Network, Available Pipe Information

Diameter (mm)	Roughness Coefficient	Unit Price (USD/m)
100	130	16.19
125	130	17.51
150	130	19.04
200	130	24.98
250	130	31.43
300	130	37.86
350	130	45.96
400	130	51.78
450	130	65.88
500	130	71.27
600	130	93.57

4.1.2 – Solution using RealPipe

Below parameters are used for the optimization of N8.3 network.

Genetic trial number : 20
Population size : 50
Replaced individual number : 4
Loop number : 300
Elite individual number : 4
Cross over rate : 90%
Mutation rate : 3%
Target pressure : 30
Pressure penalty above target : 0.02
Pressure penalty below target : 2
Target velocity : 7
Velocity penalty above target : 0.5
Velocity penalty below target : 0

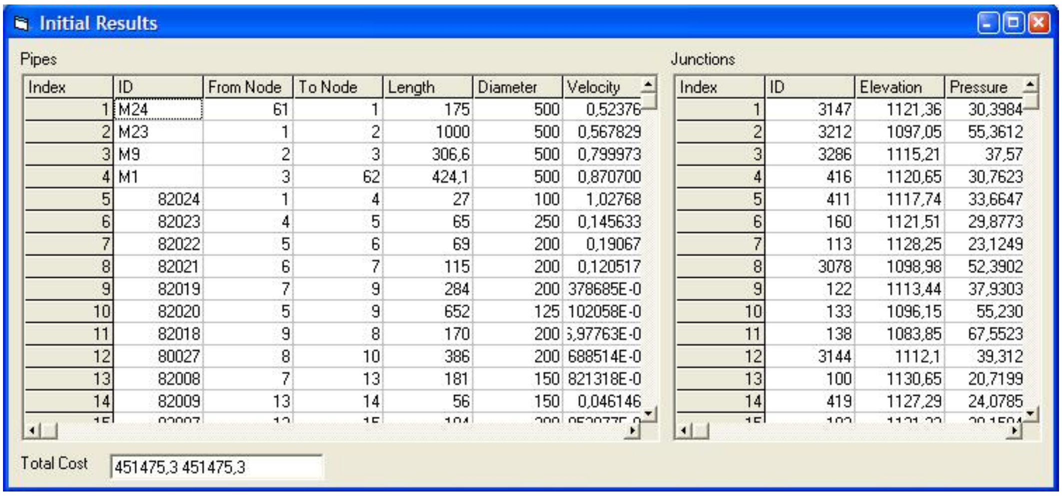


Figure 4.2 – N8.3 Network, Initial Results

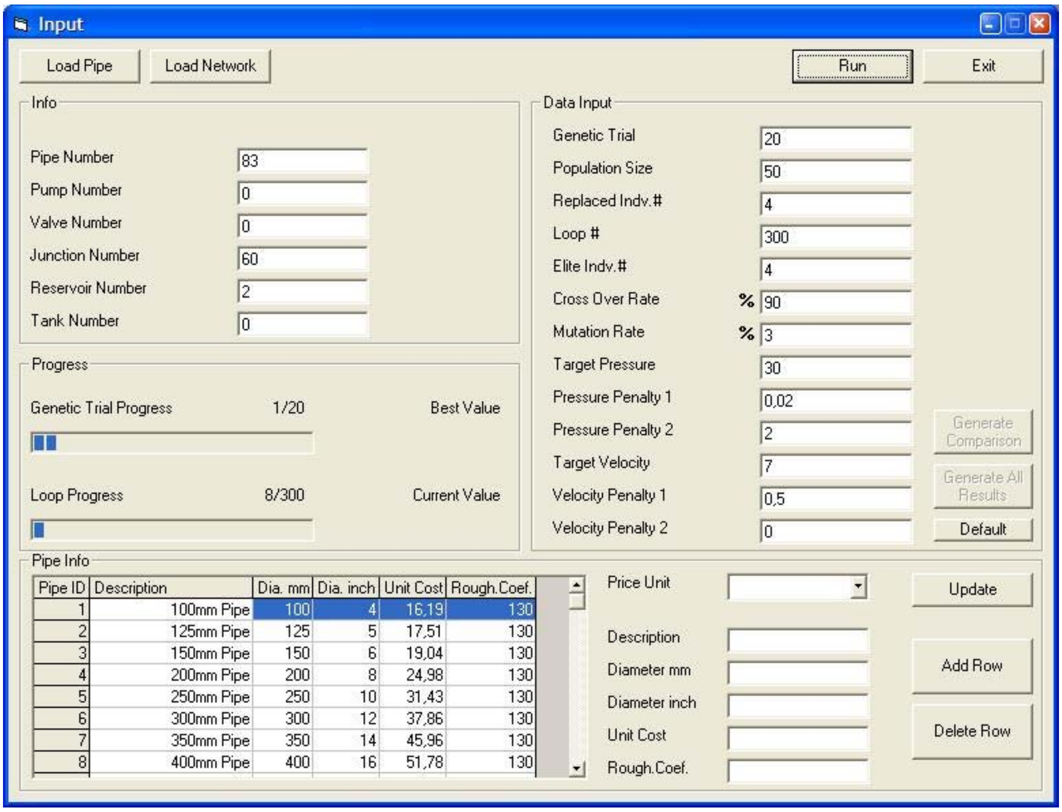


Figure 4.3 – N8.3 Network, Run Progress

20 trials have been accomplished; obtained total pipe costs and total total costs are tabulated below in Table 4.4.

Table 4.4 – Results Comparison Table for Population Size

Trial No	Pipe Cost (YTL)	Total Cost (YTL)
17	375,884	2,325,425
8	383,316	2,376,106
13	386,255	2,347,722
14	389,274	2,367,675
2	389,662	2,391,751
10	396,542	2,371,988
4	408,313	2,385,053
5	418,978	2,377,690
20	453,371	2,131,344
11	457,592	2,180,971
9	460,108	2,157,317
3	463,271	2,012,622
1	464,899	2,133,176
18	467,879	2,135,391
16	468,391	2,052,304
12	474,716	2,002,782
6	477,225	2,050,423
7	485,942	2,095,401
15	491,359	2,146,285
19	496,573	2,127,289

In the light of results tabulated above, it was founded that total pipe costs of some solutions are cheaper than the cost of the existing system that is 451,475 YTL. On the other hand, there are solutions with lower total costs than the cheapest solution. Since all velocities are within the defined range, there is no velocity penalty in the total costs.

Total pipe cost over total cost graph is presented below in order to compare results with a linear trendline showing the relation on Figure 4.4.

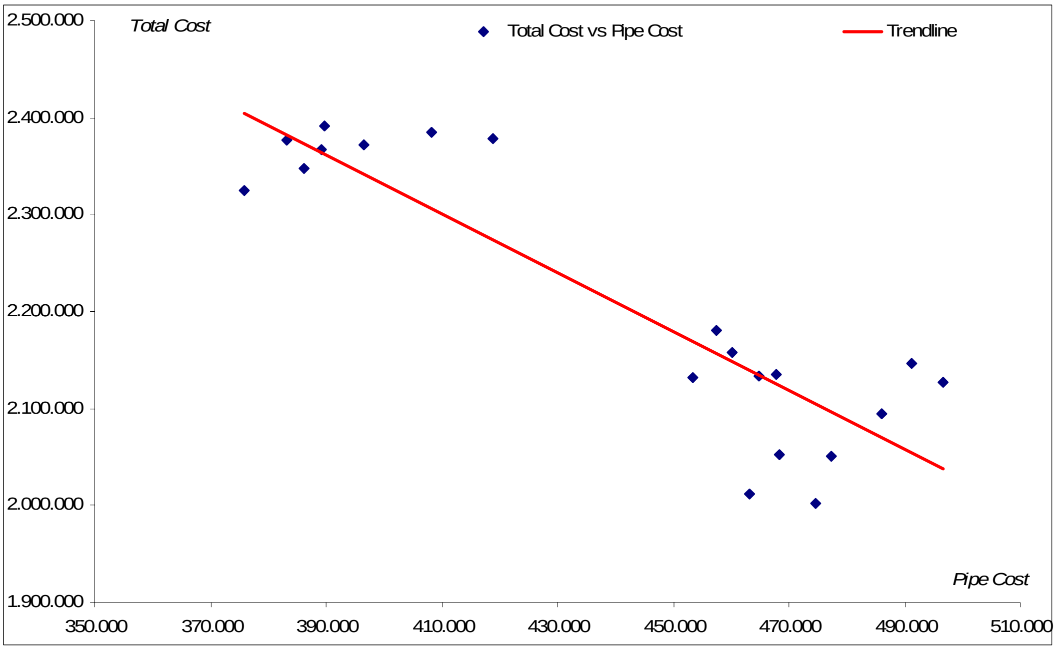


Figure 4.4 – N8.3 Network, Total Cost over Pipe Cost

In order to decide which solution is best for the network, pressures should be examined. Four solutions are selected to compare with the existing system, two with lower pipe costs and two with lower total costs that are trial number; 3, 8, 17, 20 in Table 26. Optimum results achieved by RealPipe for five selected networks are on Table 4.5.

Table 4.5 – N8.3 Network, Pipe Diameters of Selected Optimum Results

Pipe Id	Diameter (m)				
	Existing	Trial 3	Trial 8	Trial 17	Trial 20
M24	500	100	500	400	100
M23	500	500	250	100	400
M9	500	500	100	350	400
M1	500	500	200	300	400
82024	100	450	400	300	250
82023	250	600	500	300	250
82022	200	400	250	200	350
82021	200	200	150	125	150
82019	200	125	125	100	100
82020	125	100	150	150	250
82018	200	100	150	125	100
80027	200	100	100	100	150

Table 4.5 (continued)

Pipe Id	Diameter (m)				
	Existing	Trial 3	Trial 8	Trial 17	Trial 20
82008	150	100	100	100	100
82009	150	125	125	100	100
82007	200	125	125	200	100
82006	150	350	125	250	125
82005	100	200	250	100	150
82003	250	200	450	125	125
82012	200	100	125	100	200
82002	250	125	100	100	150
82014	150	125	125	125	125
82015	150	150	450	600	500
82010	150	100	100	100	100
82013	100	125	125	125	200
82001	250	450	400	250	125
83020	150	100	100	150	150
82004	150	250	250	150	200
82011	125	100	125	125	125
83019	125	125	200	100	250
83018	125	125	125	200	250
83016	125	400	300	200	350
83015	125	100	250	200	500
83014	100	600	150	300	450
83013	100	100	125	125	400
83021	250	100	100	250	125
83011	125	125	125	125	150
83007	125	500	250	150	150
83008	100	250	125	150	150
83006	100	250	150	125	450
83012	250	150	150	200	125
83017	125	200	350	450	400
83010	150	100	100	100	125
83009	150	150	100	100	125
82025	100	150	100	100	100
82026	150	125	100	100	100
83002	100	100	125	125	200
83001	100	100	125	125	100
83003	150	250	150	125	125
83005	250	500	150	250	400
83004	250	400	350	500	250
85023	100	100	100	125	600
85022	100	100	100	150	125
85021	200	100	100	100	200
84011	150	600	500	100	300
84012	150	100	100	300	125

Table 4.5 (continued)

Pipe Id	Diameter (m)				
	Existing	Trial 3	Trial 8	Trial 17	Trial 20
84010	200	125	125	150	150
84002	200	125	100	150	200
84003	100	100	125	250	150
84004	150	150	450	125	200
84009	150	100	100	300	125
84001	100	125	100	100	125
84007	100	150	125	150	200
84006	125	100	250	125	450
84005	150	250	300	350	250
84008	150	200	200	150	125
85020	150	125	300	500	300
85019	150	125	150	150	150
85024	150	125	250	125	500
85012	200	100	250	125	250
85011	200	500	200	100	150
85013	125	100	500	400	100
85014	100	125	125	100	150
85015	125	350	200	300	250
85016	200	400	250	100	250
85017	125	150	100	125	200
85018	200	100	350	200	250
85005	200	200	100	100	250
85002	100	125	125	250	150
85001	100	100	125	100	200
85003	100	125	125	150	100
85004	200	150	150	125	400
85008	150	150	100	250	100
85007	150	100	125	150	100
Pipe Cost (YTL)	451,475	463,271	383,316	375,884	453,371
Total Cost (YTL)		2,012,622	2,376,106	2,325,425	2,131,344

Related pressures at the nodes are shown in Table 4.6. Unsatisfied nodes are highlighted.

Table 4.6 – N8.3 Network, Pressure Heads of Selected Optimum Results

Junction ID	Pressure Heads at the nodes (m)				
	Existing	Trial 3	Trial 8	Trial 17	Trial 20
3147	30.40	31.78	30.28	30.29	31.39
3212	55.36	56.15	54.20	55.25	55.82
3286	37.58	38.06	36.62	37.29	37.81
416	30.76	32.49	30.99	31.00	32.08
411	33.66	35.40	33.89	33.90	34.95
160	29.88	31.63	30.11	30.09	31.17
113	23.12	24.86	23.29	23.30	24.40
3078	52.39	53.89	52.44	52.39	53.45
122	37.93	39.53	38.02	38.00	39.21
133	55.23	56.73	55.18	55.20	56.27
138	67.55	69.04	67.47	67.50	68.58
3144	39.31	40.96	38.97	39.60	40.48
100	20.72	22.39	20.78	20.91	21.87
419	24.08	25.68	24.08	24.09	25.14
103	30.15	31.91	30.29	30.36	31.38
420	52.10	53.61	52.05	52.07	53.15
109	57.54	59.05	57.49	57.51	58.59
589	71.48	73.15	71.54	71.67	72.65
591	80.04	81.68	80.10	80.30	81.13
3213	80.20	81.83	80.25	80.45	81.29
588	17.92	19.65	17.98	18.17	19.19
587	32.41	34.10	32.08	32.72	33.60
624	36.94	38.63	36.61	37.25	38.13
618	49.70	51.38	49.37	50.01	50.89
612	75.12	76.66	74.64	75.30	76.15
629	61.67	63.29	61.27	61.92	62.79
628	61.88	63.49	61.47	62.12	62.99
631	36.69	38.32	36.30	36.95	37.82
578	30.66	32.45	30.03	30.82	31.91
575	51.42	53.22	50.79	51.58	52.68
595	67.95	69.75	67.33	68.13	69.23
580	26.41	28.20	26.02	26.81	27.72
3221	46.51	48.13	46.01	46.80	47.74
3222	46.66	48.27	46.15	46.95	47.89
607	58.70	59.96	57.85	58.87	59.57
3209	53.95	52.99	54.49	54.66	56.37
3299	53.39	52.41	53.91	54.13	55.79
782	51.27	50.19	51.81	52.01	53.65
511	55.84	56.77	54.83	55.88	56.39
3300	55.72	56.35	55.36	56.26	57.14
822	53.86	54.12	54.34	55.31	56.25
3830	71.22	70.16	72.09	71.93	73.79

Table 4.6 (continued)

Junction ID	Pressure Heads at the nodes (m)				
	Existing	Trial 3	Trial 8	Trial 17	Trial 20
1910	67.30	66.17	67.97	67.99	69.88
774	33.59	32.14	34.54	33.90	35.91
771	46.62	45.41	47.81	47.18	49.15
3285	47.12	45.91	48.30	47.64	49.65
784	46.63	45.51	47.35	47.32	49.36
783	48.16	47.04	48.73	48.88	50.57
823	55.10	53.95	55.64	55.86	57.55
813	46.37	45.23	46.93	47.15	48.78
817	52.85	51.74	53.40	53.02	55.30
790	68.59	67.38	69.02	68.86	71.05
819	41.53	40.33	41.94	41.77	43.99
799	71.77	70.58	72.20	72.06	74.24
820	42.97	41.77	43.38	43.21	45.43
801	33.91	32.71	34.53	34.52	36.38
794	31.25	30.19	31.87	32.11	33.73
802	34.47	33.41	35.08	35.10	36.95
785	42.69	41.59	43.38	43.38	45.12
780	41.53	40.43	42.22	42.22	43.96
Pipe Cost (YTL)	451,475	463,271	383,316	375,884	453,371
Total Cost (YTL)		2,012,622	2,376,106	2,325,425	2,131,344

Pressure constraint could not be satisfied at some points on the existing networks that are highlighted. Real pipe results also could not succeed to solve the pressure problem except one node, 160. It can be easily concluded that, these areas are problematic areas and could not be solved only by changing pipe diameters. Some other precautions should be taken such as introducing pumps and/or tanks.

By definition, an optimization problem requires the satisfaction of the objective function and constraints. However, genetic algorithm, due to its nature, produces solutions where some of the constrains are not fulfilled. (Savic and Walters (1997), Cunha and Sousa (1999))

If these unsatisfied nodes are compared with the RealPipe results, almost all results have higher pressures that the nodes of existing one. Solutions with lower total costs make more improvements than higher total costs. However these differences are very small. Tendency to select the network from the solution set should be the smallest total pipe cost.

Since there are too many pipes and the network is complicated, solution space is much larger than the previous examples. Solution is user dependent at this case. Author’s solution is trial 17 which is the solution with lowest total pipe cost. The total cost achieved by RealPipe is 16.74 percent lower than the existing system and also this solution hydraulically improved.

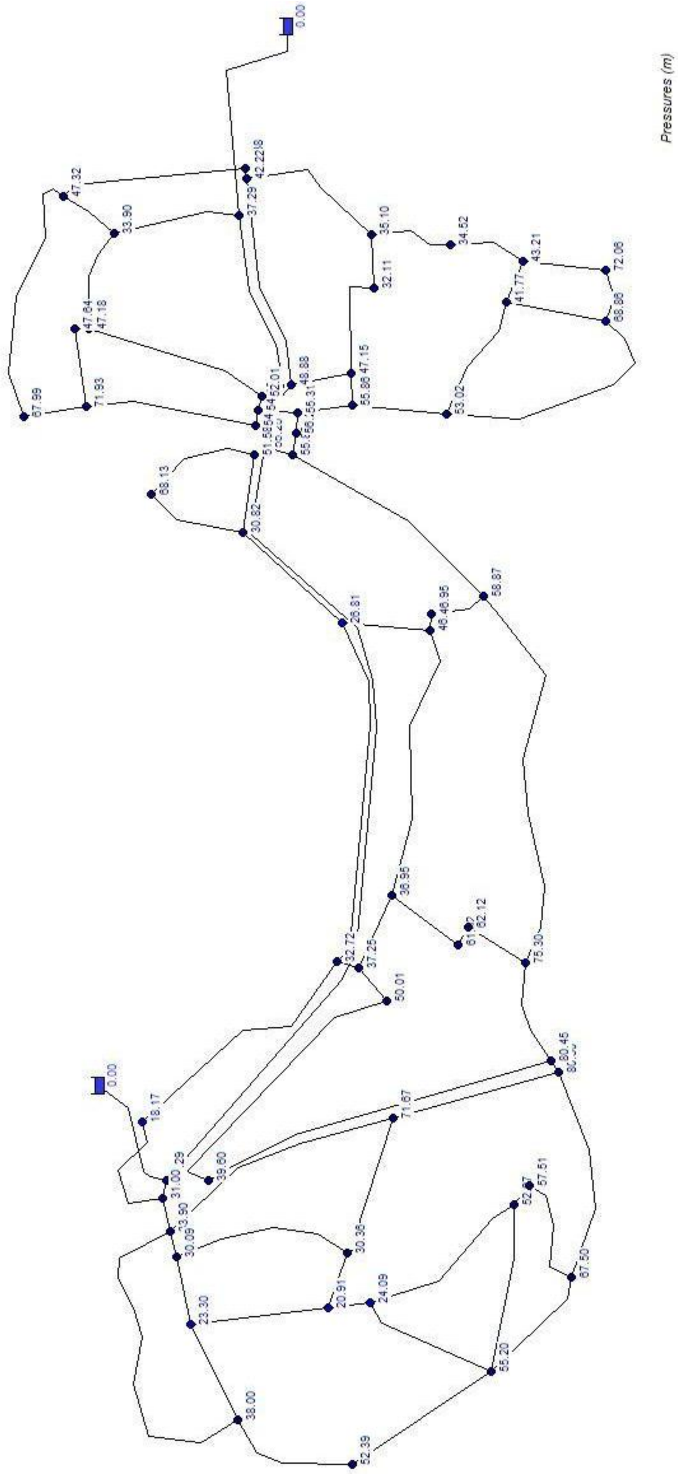


Figure 4.5 – N8.3 Network, Pressures of Selected Network

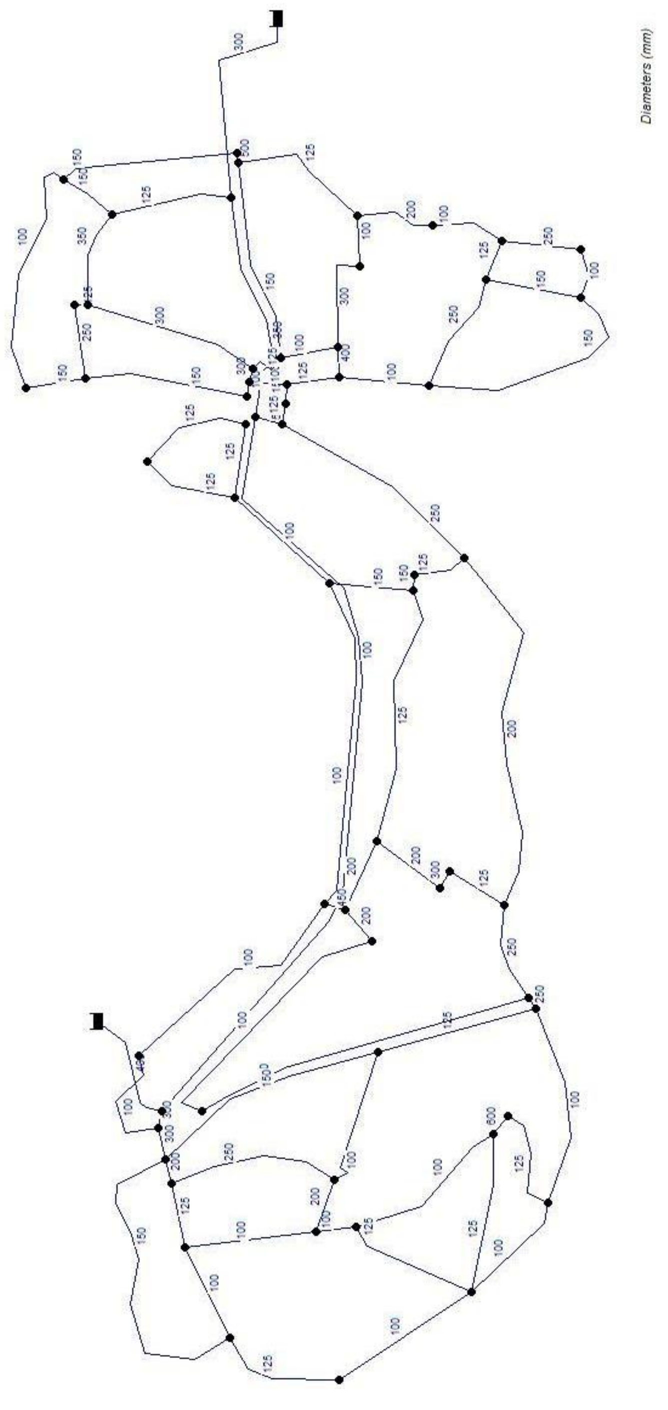


Figure 4.6 – N8.3 Network, Pipe Diameters of Selected Network

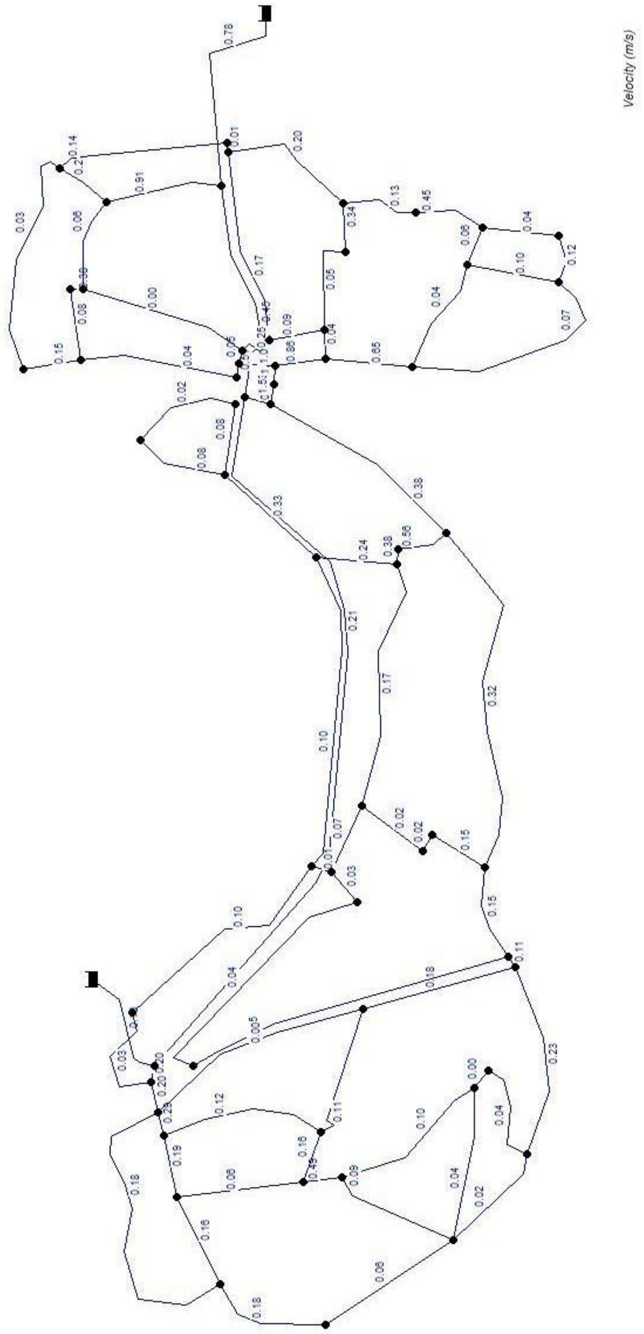


Figure 4.7 – N8.3 Network, Velocities of Selected Optimum Network

CHAPTER 5

CONCLUSION

5.1 – Summary of the Study

The capital cost of a water distribution network including its initial cost, cost of repair, maintenance, and operation is huge; that's why researchers are searching for new methods to obtain more economical designs. However, the determination of the optimal design of a water distribution network is very complex. In addition to the capital cost and different elements of the operational costs, an integral design of a water distribution network should consider not only pipe cost, but also, tank cost, pump cost, valve cost and fitting cost. Nevertheless, for the sake of simplicity, this study deals only with the optimization of pipes of water distribution networks using a genetic algorithm program, called RealPipe; RealPipe works in combination with EpaNet.

5.2 – Conclusion

In the light of the results of Shamir and Hanoi networks, it can be concluded that RealPipe works fairly well. The program can reach the best result almost every time with Shamir network in couple of minutes with necessary reports. Also for Hanoi network, the program finds a solution, its total pipe costs between the best results. Hydraulically, it was the best solution together with Liong and Atiquazzam (2004) solution.

Selection of parameters in genetic algorithm is a difficult and important task to accomplish. Therefore, while using Shamir network, genetic algorithm parameters are studied very carefully.

Effects of the parameters on the solution are examined. Large numbers of population size (i.e. chromosomes) lead to quicker results but it increases the program run time. Optimum population size is between 30-70 depending on the network size (i.e. pipe number) and number of available pipe size. These two network variables also limit the loop number. For smaller networks, less number of loops can be enough but for bigger networks need more loops are needed to converge to the solution.

Elitism is one of the most important operators mentioned in the earlier chapters. Smaller elitism rates can cause the loss of probable optimal solution. On the other hand larger rates hinder the progress of the population. Mutation operator effect is very much like the Elitism effect. It acts as if it were fixing a mistake in the nature. Mutation should be selected around 1-5 percent depending on the network. Larger ratios of mutation results in adverse effect. It increases randomness and harms the evolution progress. Crossover rate accelerates information exchange between chromosomes. Multipoint crossover and higher rates are advisable. Ratio over ninety percent crossover showed good results in this study.

Previous parameters are dealing with the genetic algorithm itself. Hydraulic conformity of the network is checked and approved by the penalty functions. Pressure penalty is the driving factor in the optimization of water distribution networks. RealPipe uses four different penalty constants, two for pressure, and two for velocity. Each constraint has above and below target constants separately. Velocity is the secondary driving penalty. Therefore, balance between these constants should be maintained carefully. Studies show that pressure penalty should be around 100 times bigger than velocity penalty. Velocity penalty could be ignored in some networks. For the pressure penalty, since below values of target pressure is the most unwanted case, this constant should be higher than the other one. In this study, it is taken as 100 times bigger than the other.

Relation between total cost and total pipe cost should also be examined carefully. It is very hard to call one of the solutions with minimum total cost as best solution in larger networks. Similar solutions should be examined carefully in regard to their nodal pressures. Tendency to select the network from the solution set should be the smallest pipe cost.

Case study results show that, a total cost with lower value and hydraulically improved solution is found using RealPipe with respect to the existing Network N8.3.

5.3 – Future Studies

The future study for this subject should mainly be dealing with the determination of genetic algorithm parameters. Concentration on this kind of study should be on the penalty constants.

Also program could be updated even though it is very user friendly and flexible. Further studies on the genetic algorithm coding of the program may result in more powerful genetic algorithm structure which improves the program's convergence.

RealPipe is designed for single loading scenario. Multi loading adaptation of the program may result in better networks.

Finally, this study assumes constant diameter between two nodes. Variable diameter study results in improved solution sets.

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