

Gas transportation pipelines network cost reduction using genetic algorithm

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Abstract

In recent years, researchers interested in using the evolutionary computations such as dynamic programming, gradient methods, ant colony optimization, particle swarm optimization, and genetic algorithm, in order to optimization the presented models in related process with gas pipelines. Among this, utilizing the genetic algorithm (GA) for total network cost reduction and pipelines optimization problem is actually appropriate. In this paper, by modifying the penalty function in genetic algorithm, we designed a non-cyclic network with specified topology and reduced the total network cost up to 27% in compared with heuristic approach that network design engineers applied. Also, in our method, the computation time is absolutely small. On the other hand, we can apply this work for another pipelines networks, find optimal solution in the large and complicated networks.

Keywords: Genetic algorithm, Optimization, Pipeline, Pipe diameter, Natural gas network, Evolutionary computation, Artificial intelligence.

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1. Introduction

In the entire processes of extracting, refining, transport, and distribution, the natural gas is transferred through a network of pipelines to the other areas. Therefore, optimization and modification of the pipe diameter with respect to the standard operational conditions, will lead to economic saving in the natural gas industry. Industrial factories produce pipes with discrete diameters and based on their components. In view of the same components, the manufacturing cost per meter of pipe increases with increasing diameter. Here, the purpose of the pipe diameter is the inner diameter. If we assume that the flow in the pipe is constant, then, by reducing the pipe diameter, the pressure drop occurs. Thus, by choosing thicker pipes, we create a much safer network, but equally, the cost of the network will also increase. In this paper, we consider a network consisting of 24 pipes, that each pipe diameter can be determined in the 6 different sizes of 1, 1.25, 1.5, 2, 2.5 and 3 inch. Thus, the total number of the space of solutions is obtained from equation (1) (number of all options in choosing different diameters of pipes):

$$6^{24} \cong 3 \times 10^{19} \quad (1)$$

Now, we introduce the supply and demand nodes. Pipes are connected to the 25 nodes. Through this, 22 and 2 pipes are related to the demand nodes and supply nodes respectively (supply nodes have specific pressures and flows that feed the demand nodes). In figure 1, this non-cyclic network topology has been depicted.

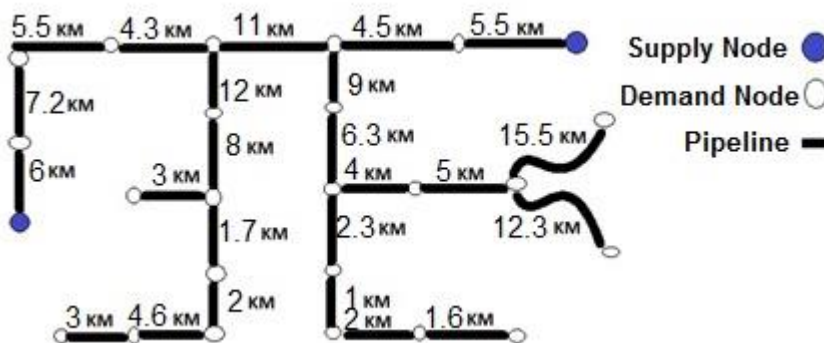


Fig 1. Hypothetical topology of pipelines network

As you seen, to find the best pipelines composition for this large scale network, the high computations impose to the designer and will be required to spend a lot of time. Therefore, in order to design the desired pipelines composition, we will use from the experiences of two engineers involved in this field, based on heuristic approach. Then, we compare the obtained results from genetic algorithm with their results. In the flowchart of figure 2, the working procedure of this paper has been shown. The rest of this paper is classified in following sections. After a brief introduction of the scheme in section 2, we describe the key concepts and requirements of the genetic algorithm and will briefly overview the works that have been done in this field in section 3. Then, in section 4, by using the genetic algorithm, the problem is solved and the optimal solution will be find (optimal solution = best combination of pipelines

for the network). Finally, in section 5, we will point out to the success of this work, the challenges and future works.

2. Literature review and basic concepts

The Importance of pipelines network optimization is Due to its many applications in various industries such as oil transmission and distribution networks, water storage and distribution networks, irrigation networks and liquefied gas networks (LPG). Application of genetic algorithm to optimize the real-world problems, such as water and natural gas transmission networks emphasizes on a key feature. This feature is the ability of genetic algorithm in dealing directly with the discrete nature, and standard dimensions of decision variables (pipe with different diameters). In determining of the standard size of the pipe, the process of rounding a solution obtained by techniques based on continuous variables is very difficult [1]. This process, itself requires an optimization problem. In fact, if we want that the proposed value for the pipe diameter after rounding process be correct, we should estimate the standard diameters higher than the rounded values [2]. Dandy performed some researches to compare the pipeline network optimization techniques [3]. He used four optimization techniques namely Partial enumeration, linear and non-linear programming and genetic algorithm. Dandy claimed that in using Partial enumeration technique, there is risk of loss of the optimal solution. Also, in both of the linear and non-linear programming methods, continuous values rounding process of the pipe sizes was a difficult process; moreover, he showed that the genetic algorithm (GA) has the most ability in producing the solution with minimum cost. Furthermore, GA was able to identify the optimal solution on 80% of the time. Wolf [4] is another researcher who has done a lot of work using this idea.

3. Key concepts of genetic algorithm (GA)

The first step in the optimization problem using Genetic Algorithm, is creating an initial population of individuals. We do this by selecting a group of solutions (individuals-chromosomes) randomly in the form of binary codes. In this problem, an individual or a solution of initial population is the proposed composition of the pipe for the desired topology. Initially, the minimum pressure and the maximum flow rate in each pipe section are determined as problem constraints. We apply on each solution a function namely evaluation or cost function. This assessment is done to determine the number of solutions close to the optimal solution. Creating the new population is applicable by using roulette wheel technique. The new generated population, essentially have characteristics that inherit from the previous population. It is expected that the cost of the new population in comparison with the cost of their parents be improved. To ensure that improvement of a new population to other population has occurred, genetic operators such as crossover operator and mutation operator are used. These operators, are applied new solutions to the population. Also, the best chromosomes are kept away from the deformation and directly transmitted to the next step without any change; this procedure is known namely 'elitism'.

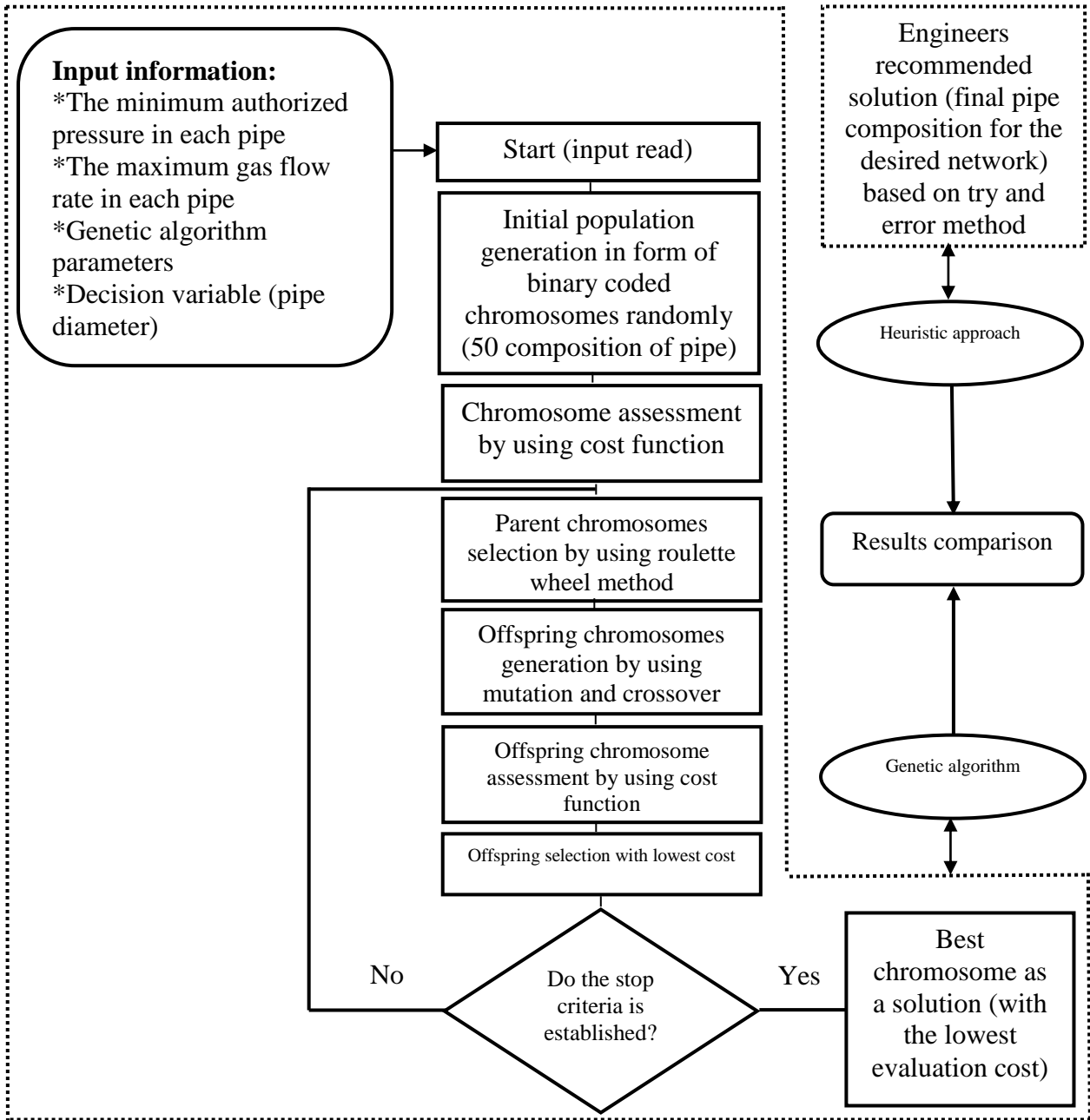


Fig 2. Recommended algorithm flowchart

3.1. Chromosome arrangement (an individual or a possible Solution in the population)

Chromosome is a string of coded bits that provides a solution of the network. By selecting chromosome, rather than we code the actual diameter of the pipes, we are dealing with the pipes indexes. By this method, formulation of the discrete nature of pipe diameters is easily done. According to the table 1, the index associated with each standard pipe diameter is coded by 3-bit binary code. For example, in Figure 3, by using this coding system that presented in Table 1, a chromosome as a proposed solution (the composition of the proposed pipeline) for a network with 6 pipes has been considered. The chromosome in this example, in order from left to right is consists of pipes with diameters of 3, 1, 2.5, 2, 1.25, and 3 inches. Each chromosome composed of a number of genes that each gene shows a coded single pipe diameter in the network. Total of genes for all of the pipe diameters create a chromosome that this chromosome is a proposed pipelines for the network. In this paper, each chromosome includes 25 genes.

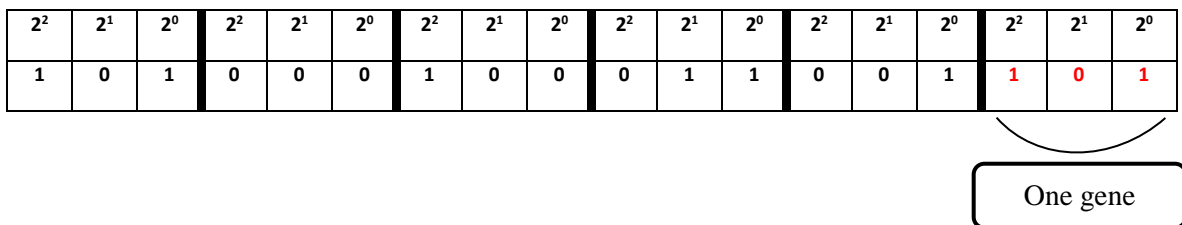


Fig 3. Example of binary chromosome for a network with 6 pipes

Table 1. Binary codes for pipes with different sizes, available in markets

Pipe index	Binary code	Pipe diameter (inch)	Imaginary price (per meter)
1	000	1	1000
2	001	1.25	1500
3	010	1.5	2000
4	011	2	3000
5	100	2.5	3800
6	101	3	4300

3.2. Formulation of optimization problem

Cost function or evaluation function is a function that allocates score to each chromosome based on its ability in observing the identified constraints. In this problem, the cost function is to minimize of the network creation cost and is known based on equations (2), (3):

$$\text{Minimize } F(x) = \text{Cost}(d) \quad (2)$$

$$\text{Cost}(d) = \sum_{j=1}^n L_j c(d_j) \quad (3)$$

In above equation, n, number of pipes, L, length of pipe, and c (d) is the price of pipe with a diameter of d. In the following, we will describe the constraints of the problem. In order to calculate the pressure drop and gas velocity in the pipeline, we use the following formulas [6] (Assuming an initial pressure and reference temperature, T):

$$P_1^2 - P_2^2 = \frac{L}{1076 D^{4.82}} Q^{1.8} \quad (4)$$

In this equation, P_1 , absolute pressure in the first of the pipe, P_2 , absolute pressure at the end of the pipe, L, length of pipe in terms of meter, D, pipe inner diameter in terms of millimeters and Q, is the gas flow rate in terms of $\frac{m^3}{h}$. Mean Pressure and mean velocity will get from the following equations:

$$P_M = \frac{2}{3} [(P_1 + P_2) - \frac{P_1 P_2}{P_1 + P_2}] \quad (5)$$

$$V_M = 0.0155 \frac{QT}{P_M D^2} \quad (6)$$

The minimum acceptable pressure and the minimum acceptable gas flow rate in the demand nodes should be more than mean pressure and mean gas velocity (constraints) that were defined in equations (5), (6). If these constraints are violated by a demand node, a cost namely 'penalty cost' will be applied to the total cost of the network. Thus, the total cost of the network in order to compute the evaluation function for each chromosome will be according to the equation (7):

$$\text{Cost}(d) = \sum_{j=1}^n L_j c(d_j) + w \left(\frac{\sum_{j=1}^n c(d_j)}{n} \right) \sum_{k=1}^p L(k) \quad (7)$$

In the above equation, 'C(d_j)' is the price of each pipe in terms of $\left(\frac{\text{Monetary Unit}}{\text{meter}} \right)$ and 'w' is all of nodes that have violated the problem constraints. Innovation of this paper is to apply the new penalty function. Here, L, is the number of pipes that are adjacent with the node that has violated the constraints (instead of considering all of the network pipes [7]). Thus, chance of solutions that have violated the constraints somewhat increase and therefore the possibility to reach the best solution will be provided. It is always advised that by using the genetic algorithm in optimization of problems, it is an algorithm that maximizes the profit [8]. If the goal is to minimize the cost, then the evaluation function is reversed, and its name refers to the 'cost function'. In the most of review articles, the evaluation function is expressed inversely. In this paper, the cost function is in its simplest form and is used according to the equation (8):

$$f(X_k) = \frac{1}{F(X_k)} \quad (8)$$

In this equation, X_k is a chromosome, and $F(X_k)$ is the assessment of this chromosome based on equation (2) that was previously expressed.

3.3. Method of parent chromosome selection (roulette wheel method)

Selection operator is responsible for determining the parental chromosomes in order to make a better evaluation function values, which are allowed to mate and produce new solutions. Therefore, we choose the roulette wheel selection method. In this method, for each chromosome X_k , the cost $f(X_k)$ will be considered. The probability of $P(X_k)$ for each chromosome is obtained according to the equation (9):

$$P(X_k) = \frac{f(X_k)}{\sum_{k=1}^N f(X_k)} \quad (9)$$

In this equation, N is the total number of population. The entire population according to the probability are sorted in ascending order. Then, for each chromosome in the new population, we calculate the cumulative probability. Now, in the N iterations (population size), a random number α , that has a value in the range $[0, 1]$ is generated. In each iteration, chromosome with higher cumulative probability is selected to go to the next generation. Consider the value of $P_c(X_k)$, the cumulative probability, assigned to the chromosome X_k , such that: $P_c(X_k) < \alpha < P_c(X_{k+1})$. The chromosome X_{k+1} is considered as a parent chromosome in the current population that is basis for the formation of the next generation.

3.4. Mutation and crossover operators

In this paper, the operators, Single point crossover and Uniform mutation has been used. Simpson and his colleagues have used these operators in optimization of the water pipes network problem. Crossover probability rate is recommended between 0.6 and 1. Crossover probability of 0.7 for use in this paper is very useful. Uniform mutation technique is a powerful method for generating diversity in population. Each bit in each status, depending on the length of the chromosome by using probabilistic method changes from zero to one or vice versa. Always a small mutation rate between 0.001 and 0.01 is selected. Haupt did a study about the use of the high mutation rate on the applied magnetic field problem [9]. By using a high mutation rate, probability of having same chromosomes in offspring and their parent rises. Also, high mutation rate eliminates the possibility of trapping in local minimum. So, tendency to use of the high mutation rate of 0.3 was used in this paper. In Figure 4, how the performance of crossover and mutation operators have been shown.

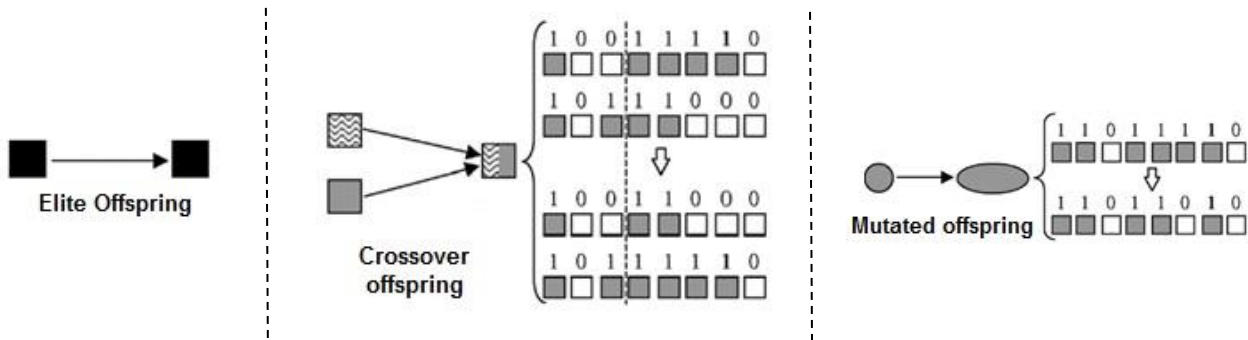


Fig 4. Genetic algorithm operators (Elitism, Crossover, Mutation)

4. Experimental results

In this research, standards of National Iranian Gas Company (NIGC) have been considered in conjunction with pipeline [6], such that the minimum pressure in the pipeline with a diameter of 90 mm or more is 59.7 kPa; in the other pipelines, the minimum pressure is equal to 44.7 kPa. The maximum gas velocity is equal to $21.34 \frac{m}{s}$. To simulate this process, MATLAB software has been used. The results of genetic algorithm will be compared with heuristic approach based on human experiences. In the heuristic approach, two design engineers offered the primary combinations of pipes. Required time to compute a solution (compound of 25 pipes in the network, shown in Figure 1) by a design engineers was about 5 to 6 hours, while by using genetic algorithm, a lot more solutions obtained at a slight time (less than 1 hour). In figure 5, running of genetic algorithm have been shown for 100 times. At the end, as can be seen in figure 5, the genetic algorithm in the worst case (iteration 100) has suggested the combination of proposed pipeline that in terms of cost and in comparison with heuristic approach has a considerable difference. On average, in this design, the genetic algorithm in comparison with the heuristic approach has improved the optimization by 27% that will has a significant impact on the overall cost of network.

5. Conclusion and future works

In this paper, we considered the standards of National Iranian Gas Company (NIGC), associated with the pressure and velocity of the gas flow in pipelines and by using genetic algorithm and changes in its penalty function designed a non-cyclic pipeline network with specific topology. In compared with the heuristic approach based on the engineer's experiences, we achieved to 27% better solution that economically it would be very useful in reducing costs. Also, the computational time in comparison with the heuristic approach is much lower (less than 1 hours). The results of this study confirm the effectiveness of the genetic algorithm in the optimization of the gas transmission network and it can also be used in similar projects. In future works, we decide to optimize the design of a cyclic pipeline system (based on its strict standards) with genetic algorithm that its penalty function has improved.

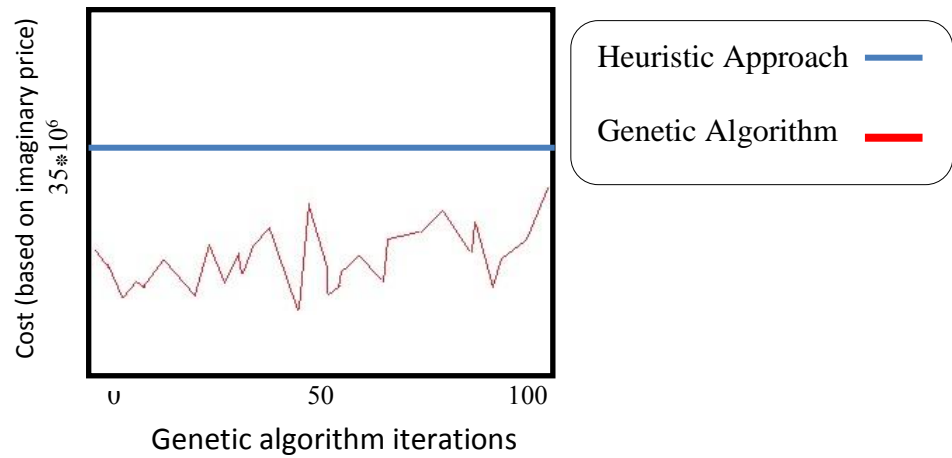


Fig 5. Results of 100 iterations of GA versus heuristic approach (engineer designs)

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