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Comparable study of metaheuristic algorithms in path planning

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ABSTRACT

Water is the main and the most important human life requirement. for that, governments work to feed population gatherings. So, it is important to take into care the size of water tanks and pipes to achieve the best reliability for the water distribution systems.

In global, the distribution network consumes 60 percent of the all cost of water distribution system. So for this, we must get the best and the optimum construction of the network as a function of profit to get the best reliability to save a high amount of money.

In recent works, studies depend on the optimization of the network using the reliability of the network by solving the non-linear hydraulic equations which are very difficult and needs a long time to get the best result. So, studies heads into the reliability of the network to have the best profit the minimum cost. This model was developed to a full risk management system to prevent any error in the network and give a good management support program.

This study aims to create a model using MATLAB to give the best solution for the water network distribution system which gives the best solution with a minimum cost.

Key Words: Genetic algorithm, Harmonic algorithm, TABU search.

1. INTRODUCTION

This study gives us a definition for the optimization using the reliability in water distribution system by modeling applications like MATLAB. Targets achieved after this study are:

Achieve the minimum cost design of the water distribution network using a good time-consuming method.
Define the risk parts in the model studied.
Define the border limits of the risky parts in the network under multiple working conditions.
Analyze and evaluate the optimization of the water distribution system.
Create the best solution for the water distribution system the achieves the best cost and reliability at the same time.
Define the network reliability in a specified time stamp.
Build the reliability model using all the previous targets.

Optimization multi objective methods allows us to select between multiple objectives by selecting a collection of Pareto-optimal solutions in the target space. Multi objective analysis is the most real live used model in engineering projects where the cost is not the only target required. All the solutions are gathered in a specific selection lets the designer to choose the best decisions.

Water distribution networks are one of this multi-objective systems where we can say that the foundation cost and the size are the most complicated targets, other targets may take into account, decreasing risks, increase the reliability, increase the different between the performance tasks required, increase the water quality, and decrease the working costs.

In the year 2000 Walski introduces a study about distribution network planning situations showing the decision makers requirements to get the minimum cost network.

We can achieve the pareto-optimal solutions which are non-dominated, that means there is no best solution while taking into account all the other desired targets, we keep moving in this solutions space and selection between each target to get the best solution and eliminate the weak one. Figure (1) showing how we can select between cost and reliability in any system.

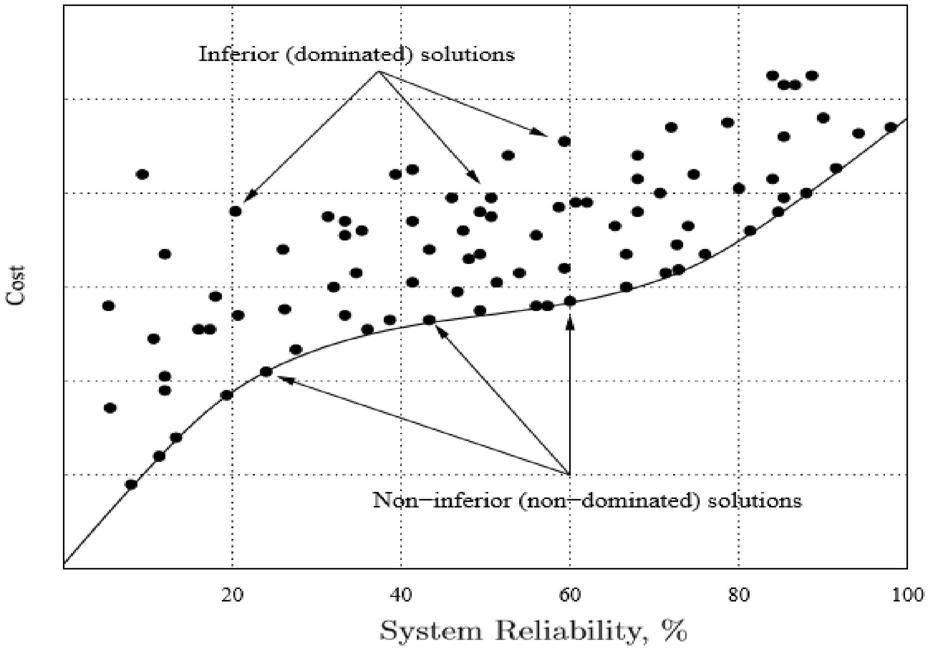

Figure 1. Relation between cost and reliability

The inferior solution is known as a dominated solution because it will be best for one objective at least and it will not get worst for another objectives. The hyper-curve planes over the pareto-optimal space is known as pareto-optimal front.

We may have multiple sub-fronts where we can classify the solution for it as it dominates each other solution. These fronts are arranged from the best to the worst. The first curve is known as non-dominated front. The number of fronts achieved in known as depth or pareto-rank.

2. RELATED WORK

Water distribution networks depends on non-linear equations which are very complex and hard to solve because of the non-linearity of the decision variables like pipes diameters as example. For the water distribution network, we can achieve a large number of solutions chosen by a collection of decision variables to get the solution that increases the level of the problem to the optimum one as Gupta and Kapoor (1994) defines.

Hamdy(1997) shows that some mathematical models may became more complex and can not solve using any of available optimization methods, so it is important to use the heuristic instead of mathematical ones to achieve the best solution which is close to the of the optimum solution. The main property of the heuristic algorithms is the high speed in solving equations.

Dorigo and Thomas(2004) shows that many of the recent studies headed to a new algorithms which are called the metaheuristic algorithms, it is a collection of algorithmic conditions can selected to use the heuristic algorithms in a wide range of problems. These algorithms allow us to reach the ability of finding a large number of solutions hard to reach in a specific acceptable time. Many of these algorithms were used in water distribution networks like: Simulating Annealing (SA), Tabu Search (TS), Guided Local Search (GLS), Greedy Randomized Adaptive Search Procedure (GRASP), Iterated Local Search (ILS), Evolutionary Computation (EC), Scatter Search, and Ant Colony Optimization (ACO).

2.1 Model building

A water distribution network model was build using MATLAB application, we decided to use multi metaheuristic algorithms like harmony, genetic, tabu search and a particular swarm algorithm. First of all, the network was analyzed using EPANET application to build the hydraulic model and then the cost of the network was calculated. This calculation was made on the optimal solution of each algorithm that panned the best solution.

2.2 HARMONY Algorithm

Harmony algorithm is a metaheuristic algorithm that tries to achieve the best harmonic solution in the network to produce the optimum solution, this algorithm used in a wide range of problems recently for many reasons and the most important of them its

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high speed to reach the optimum solution and the ability to give a suitable number of solutions with a good calculations complexity.
This algorithm works fine in many engineering problems including the water distribution systems.

2.3 Genetic Algorithm

It is a revolutionary algorithm depends on reaching the best generations that are powerful to live than the weak generations. The weak generations got less weights which results the distinct across time (which is known as number of loops or generations). So this algorithm is able to reach the optimum solutions.
This algorithm is classified as an inferential mass search system and includes a set of basic criteria such as inheritance, mutation, inference, and hybridization.

2.4 TABU search

A modern heuristic algorithm proposed by Fred Glover, a professor at the University of Colorado in the United States, around 1986. It is a search method used to escape the local optimal solution. You first create an initial outline; Based on this, the algorithm "goes" to an adjacent scheme. After several continuous transfers, the solution quality has been improved.

2.5 Particular Swarm

A computer algorithm discovered by social psychologist James Kennedy and American electrical engineer Russell Eberhartlitz represents a problem by finding its maximum or minimum value based on experimentation and repetition. The idea of the algorithm is based on the presence of a swarm of elements spread in a limited search area and move around it randomly to search for the optimal solution in this area. In general, the greater the number of swarm members and the smaller the search area, the easier and faster it is to find the optimal solution. The fewer the number of elements and the greater the search area, the less chances of finding the optimal solution.

When a swarm of bees swarms a field of flowers, they are often concentrated in the area with the most flowering. The bees reach this region by applying the swarm element optimization algorithm. That is, they spread initially in the field so that each bee records the area with the densest flowers. Then each bee moves randomly, and if it finds a denser area, it updates its information, and so on. And when you're done with a random search. Each bee announces if it is found. And then the swarm of bees' heads to the best location, and while heading, each bee scans the path leading to the optimal area. If you find something better, tell the squadron about it.
After applying these algorithms to calculate the network cost on the main model of the program, we had the results listed in table 1:

Table1. The network cost on the main model of the program

Cost	Algorithm
762801179	Network initial cost
584326445	Harmonic Algorithm
641523941	Genetic Algorithm
751000000	Tabu search
550000000	PSO search

3. STUDY OF RELIABILITY

Reliability is an essential measure of user satisfaction with the performance of the water distribution network and greatly affects the performance of the water distribution network, as studies currently focus on system settings as a whole, valve distribution, pressure and demand requirements, in addition to system performance in general in cases of failure of any element of Elements.
Reliability does not depend on a fixed standard, as it varies according to different studies, which we explain as follows:
• Kaufmann et al. [1] It is the probability that the system will be able to perform the tasks required of it under specific conditions within a specified period of time.
• Cullinane et al. [2] Reliability is defined as the system's ability to provide services within an acceptable level of interruption to which it may be exposed due to emergencies.
• Goulter et al. [3] shows that Reliability is the ability of a system to meet the requirements imposed on it that are met by the amounts of flow that must be met within a specified pressure range and which achieve those flow rates.

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• Arf Al-Zahrani et al. [4] Reliability is defined as the ability of the network to provide water to users with the required limits and the appropriate quality within the permissible head pressure.
This study aims to verify the reliability of the distribution network in the city of Jableh within the minimum pressure limits and standard flow rates, which were reached using the EPANET hydraulic analysis program, within the failure rates that the pipeline network was exposed to within the city during a time period of about two years.
The reliability value is calculated as a standard value ranging from 0 to 100 percent depending on the hydraulic analysis rates of the network. 100% means that the system performs its tasks completely even if the pipes are damaged.
The following criteria were used in the study:

3.1 Hydraulic Reliability

It describes system performance to achieve desired flow requirements.
• Reliability of the elements: which determines the probability that the element will not be exposed to malfunctions during its lifetime.
• Mechanical reliability: It is a criterion that we use to measure the impact of component failure on system performance. Mechanical reliability depends on hydraulic reliability and component reliability.
• Network/System Reliability: It is the least mechanical reliability present in all elements of the system.
For example, a single transmission pipe will have zero hydraulic reliability but 98 percent mechanical reliability if it has a 2 percent chance of failure.

3.2 Reliability Analysis Techniques

During recent decades, many techniques have been developed to measure the reliability of water distribution networks. Some of these methods were successful and effective while others were less effective. Ostfeld [5] classified these techniques into three main categories: analytical (connection), simulation (hydraulic), and heuristic (entropy).

The analytical method:

This method relies on addressing the design of the water distribution network, as this design is associated with the probability that the network will remain physically connected, and the reliability of its elements is given. This method is related to access and contact rates and is not related to the hydraulic simulation of the system. One of the algorithms adopted in this method is the Minimum Cut Set algorithm, where the cut-off point is defined as a group of elements that have been subjected to failure and caused the isolation of points from the system as a whole.

Simulation:

mainly related to hydraulic reliability and availability. Therefore, this method analyzes the hydraulic performance of the network such as the required flow quantities, and the flows that are achieved under specific pressure values to specific locations within the network during a hypothetical period of time. Therefore, this method is largely based on hydraulic models and requires extensive knowledge of network design and performance including failure records.
This method is considered one of the most widely adopted methods at the present time for reliability analysis, and it adopts two main methods, which are Demand Driven Analysis (DDA) and Pressure Dependent Demand (PDD).
Goulter et al [7] presented a method to determine reliability based on the relationship between flow and pressure, if the request is fulfilled but with less flow then the network reliability decreases. Also, if the pressure achieves the minimum value required by the valve but the flow is not achieved then the reliability also decreases. If the two previous problems occur together, the reliability of the network collapses dramatically.

The indicative method:

This method does not directly measure the reliability of the network, but relies on other criteria such as capacity and energy, which are considered to have a high relationship with reliability. Many of the techniques included under this method have been relied upon such as Entropy-Based Method by K. Awamah et al [8], Network Resilience by Prasad et al [9], Performance Index by Dziedzic et al. [10].

4. PIPES FAILURE MODELLING

Element reliability is defined as the probability that an element will not fail within a time period starting at moment 0 and ending at time T[11]. This method explicitly describes the unreliable components that must be replaced upon failure. However, components in water systems are considered to have high reliability and thus reliability is considered as component availability.
We define Availability A as the percentage of time that an element is in working condition while U is considered unavailable when it is broken or in repair condition. Pipe failure models are statistical models that rely on historical data of pipe failure to derive its own failure model and then predict the future probability of pipe failure. Statistical models are classified into two groups according to Kleiner et al. [13], Liu et al. [14] and Scheidegger et al. [15th]

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Deterministic models:
These models are developed from historical data of pipeline failure in order to predict future failure rates (number of failures per year, failure rate, or time to next failure). Shamir et al. [16] Using regression analysis to derive a predictive model of fracture, which correlates with the rate of fracture in the pipes proportionally with the age of the pipe. Walski et al. [17] The previous exponential model by adding two parameters to the model, the first parameter for previous historical failures and fractures based on the idea that the pipe that was previously fractured will be exposed to a higher probability of fracture in the future, the second parameter is the effect of different diameter models on fracture rates.
Clark et al. [18] developed two regression models. The first is to predict the life time between the installation and the first fracture condition, and the second model aims to predict the number of subsequent fractures after the first fracture.
Kleiner et al. [19] an exponential multivariate model which can be used with pipes with dissimilar properties which can affect their performance later on.
Parvizsedghy et al. [20] developed a pipeline fault monitoring model which can be divided into physical, ambient, and operational faults. The model showed that the age of the pipe is a reference for predicting its failure rates.

2- Probabilistic models:
They are models that rely on previous statistical models to predict the possibility of future failures in the pipes. There are many studies that have been carried out in this field, which we list as follows:
Cox [21] provided a general formulation of the prediction model that can predict the time until the next failure, while Goulter et al. [22] and Su et al. [23] Poisson probability distribution to determine the failure probability of pipes as independent components.
Developed by Andreou et al. [24] Variable probabilistic ray function During the analysis of the available failure data, it was observed that the time lag between the first three consecutive failures takes an upward curve. After the third failure, these time intervals become fixed and therefore it is considered that the model operates in two phases, the first in which fewer failures occur, which are represented using a proportional probabilistic function, and the second phase, which includes more frequent pipe breaks, which is based on the Poisson distribution model.
Constantine et al. [25] developed a time-based Poisson distribution model with average fracture rate dependent on the pipe age, the algorithm used is called Weibull process because the cumulative result of the distribution in this process is equivalent to the cumulative distribution function inferred by Weibull.
Kleiner et al. [26] developed the I-WARP (Individual Water mAin Renewal Planner) application, which is a tool for analyzing failure records for fracture models for independent pipelines. This software is based on the proposition that fractures in separate pipes occur in a condition that does not depend on the Wassonian function.
Scheidegger et al. [27] a model based on the suggestion that the time for the first failure case is modeled according to the Whipple distribution model, while the rest of the failure cases are modeled based on the exponential distribution, but this method gives an unstable failure model that cannot display the wear cases during time.

5. STUDY MYTHOLOGY

This study aims to carry out an analytical study to calculate the reliability of the water distribution network in the city of Jableh. The method depends initially on deducing the hydraulic model of the network after designing it using the EPANET software and determining the criteria for the work of this network in terms of flow and pressure required to achieve the ideal limits for the network's work.
Reliability modeling was based on breakage rates for various reasons over three years. The network was divided into segments, each of which is processed independently, as each segment consists of eight tubes and a number of connections.
Table.2 shows the failure rates of pipes in the water distribution network in the city of Jableh:

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Table2. The failure rates of pipes in the water distribution network in the city of Jableh.

NAME	**Id pipe**	DIAMETER	DATE_DAMAG	DATE_REHAB
Jableh City	P1	450mm	6/20/2017	6/20/2017
Jableh City	P1	450mm	11/14/2017	11/14/2017
Jableh City	P1	450mm	11/29/2017	11/29/2017
Jableh City	P1	450mm	4/30/2018	4/30/2018
Jableh City	P1	450mm	11/6/2018	11/6/2018
Jableh City	P1	450mm	11/24/2018	11/24/2018
Jableh City	P13	110mm	8/6/2018	8/7/2018
Jableh City	P15	110mm	1/29/2017	1/30/2017
Jableh City	P15	150mm	12/4/2018	12/4/2018
Jableh City	P2	250mm	6/5/2016	6/5/2016
Jableh City	P2	250mm	8/8/2017	8/8/2017
Jableh City	P2	250mm	4/29/2018	4/29/2018
Jableh City	P2	250mm	8/28/2018	8/29/2018
Jableh City	P20	110mm	4/23/2018	4/23/2018
Jableh City	P26	110mm	3/15/2017	3/15/2017
Jableh City	P27	110mm	5/9/2017	5/10/2017
Jableh City	P28	110mm	5/7/2017	5/7/2017
Jableh City	P28	110mm	10/29/2017	10/29/2017
Jableh City	P29	110mm	8/28/2017	8/28/2017
Jableh City	P3	110mm	7/17/2018	7/17/2018
Jableh City	P32	110mm	8/20/2017	8/20/2017
Jableh City	P33	110mm	4/23/2018	4/23/2018
Jableh City	P33	110mm	5/7/2017	5/7/2017
Jableh City	P34	150mm	1/4/2016	1/4/2016
Jableh City	P34	150mm	3/8/2016	3/8/2016
Jableh City	P34	150mm	4/14/2016	4/14/2015
Jableh City	P34	250mm	6/9/2016	6/9/2016
Jableh City	P34	150mm	10/24/2016	10/24/2016
Jableh City	P34	150mm	3/28/2017	3/28/2017
Jableh City	P34	150mm	6/14/2017	6/14/2017
Jableh City	P34	150mm	7/9/2018	7/9/2018
Jableh City	P34	150mm	8/4/2017	8/5/2017
Jableh City	P35	110mm	5/15/2017	5/15/2017
Jableh City	P36	110mm	2/15/2016	2/15/2016
Jableh City	P38	110mm	8/6/2017	8/6/2017
Jableh City	P39	110mm	4/13/2018	4/13/2018
Jableh City	P40	110mm	4/14/2018	4/14/2018
Jableh City	P45	110mm	4/30/2018	4/30/2018
Jableh City	P5	110mm	1/4/2017	1/5/2017
Jableh City	P5	110mm	6/21/2017	6/21/2017
Jableh City	P6	110mm	1/19/2016	1/19/2016
Jableh City	P7	110mm	10/29/2017	10/29/2017
Jableh City	P8	200mm	11/13/2016	11/13/2016
Jableh City	P8	200mm	11/28/2016	11/28/2016
Jableh City	P8	200mm	8/8/2017	8/9/2017
Jableh City	P9	110mm	2/8/2017	2/8/2017
Jableh City	P9	110mm	9/26/2017	9/26/2017

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The algorithm begins with the process of downloading the fault record and then entering the data of the sections, flow and pressure requirements, and pipe lengths in each of the sections. Figure (1) shows the distribution of sections within the study in the city of Jableh.
After the process of arranging the sections, a group of pipes (8 pipes) will be inserted with the characteristics of the flow and the compressor for them and the calculation of reliability in relation to the cost. The average flow within the pipe network is calculated according to the following relationship:

$$Q_{ave} = Q_{req}\left(\frac{P_i}{P_{min}}\right)^{1/nn}$$

Where Q_ave is the average flow required, Q_req is the flow in the pipe, P_i is the pressure in the specified pipe, P_min is the minimum permissible pressure, nn is the number of pipes. Then the network performance is calculated by calculating the average flow for the required flow according to the relationship:

$$NR = Q_{ave}/Q_{req}$$

This ratio determines the hydraulic effectiveness of the flow within the network, and to calculate the maximum value of the flow within the network, we must take into account the value of the total average flow in the network relative to the total flow required to determine the pressure losses and losses within the network according to the following relationship:

$$vr = sum(Q_{ave})/sum(Q_{req})$$

$$nf = nr^{\frac{1}{nn}}$$

$$sr = vr * nr$$

The maximum value that will be produced in the final matrix for each of the sections, sr, will determine the hydraulic reliability of the network. To calculate the general (effective) reliability of the studied section, the following relationship is used:

$$R = 1 - sr$$

In order to reach high reliability rates within the network, we need to add additional costs related to the cost of replacement and the structure of the pipes, which are calculated based on the following relationship:
CST(i,j)=LP(j)*CS(D(:,j))
Where CST is the cost of the section, LP is the length of the pipe, CS is the previous maintenance cost of the specified section. This value must be added in order to achieve complete network reliability.
After applying the previous algorithm to the group of segments within the network, we obtain the results are shown in table 3:

Table3. The Failures of records, addition cost, reliability and Pipes of the network

Failures of records	addition cost	reliability	Pipes of the network
4.2%	11149	98.0222	Pipe PI68
			Pipe PI69
			Pipe P37
			Pipe P38
			Pipe PI75
			Pipe PI74
			Pipe PI73
			Pipe PI72
			Pipe PI71
			Pipe P16
			Pipe P17
			Pipe P36
			Pipe PI66
			Pipe PI67
34.04%	4867	97.78	Pipe P15
			Pipe PI70
			Pipe P40
			Pipe P39
			Pipe P34
			Pipe P35
			Pipe P26
			Pipe P25
			Pipe P24

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			Pipe P23
			Pipe P22
			Pipe P21
			Pipe P20
			Pipe P19
			Pipe P18
23.4%	23448	98.27	Pipe PI51
			Pipe PI52
			Pipe PI54
			Pipe PI55
			Pipe PI56
			Pipe PI57
			Pipe PI58
			Pipe PI59
			Pipe PI60
			Pipe P3
			Pipe P4
			Pipe P5
			Pipe PI62
			Pipe PI61
			Pipe P7
			Pipe P6
			Pipe PI53
			Pipe PI46
			Pipe PI47
			Pipe PI48
			Pipe PI49
			Pipe PI50
			Pipe P1
14.89%	25646	98.8	Pipe PI65
			Pipe PI64
			Pipe PI63
			Pipe P27
			Pipe P28
			Pipe P30
			Pipe P31
			Pipe P32
			Pipe P33
			Pipe P41
			Pipe P42
			Pipe P43
			Pipe P44
			Pipe P45
			Pipe 151
			Pipe 153
			Pipe 155
			Pipe P29
21.27%	9684	99.93	Pipe P2
			Pipe P9
			Pipe P8
			Pipe P10
			Pipe P11

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			Pipe P12
			Pipe P13
			Pipe P14

We note from the previous results the relationship between reliability and the percentage of breakage rates within the sections, where the lowest reliability percentage was adopted in the event that there is more than one section within the same sector, and we note the low reliability of the section with high rates of breakage and faults, while these faults cause additional costs.

We also notice from the previous results that the cost values differ between the different reliability cases, and this depends on the length of the pipes within the studied section in addition to the diameters of the pipes.

Returning to the fault records and their relationship with faults, we noticed the relationship of the fault percentage with respect to the studied pipe diameter are shown in table 4

Table4. The relationship of the fault percentage with respect to the studied pipe diameter

Failure range	Pipe diameter
12.76%	450 Mm
10.63%	250 Mm
6.38%	200mm
19.14%	150mm
51%	110mm

That is, most of the faults occurred in the pipes with a diameter of 110 mm, which raised the cost of maintenance in the sections that contain a greater number of these pipes.

The following figure (2) shows the relationship between reliability and cost with an upward value. We note from the chart that the change in cost with reliability is a non-linear process due to the variation between sections and the number of pipes, and some sections contain a number of pipes that are smaller and more prone to breakdowns than in other sections, which affects the cost. generally.

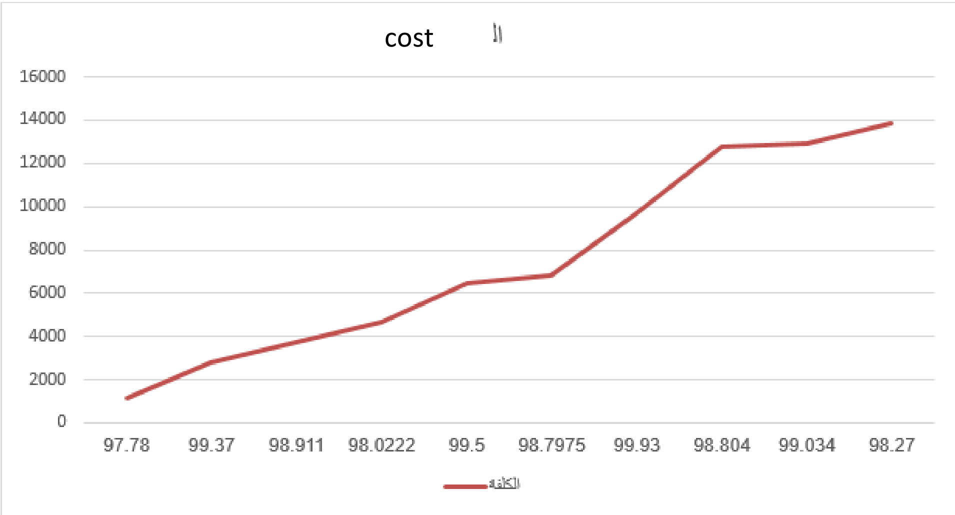

Figure (2) The relationship between reliability and cost

Figure (3) shows the values of the maximum cost to achieve the reliability of the sections, which was mentioned previously that some sections include pipes with a diameter of 110 mm, which do not meet the conditions, which causes them to be exposed to permanent malfunctions, and thus the high operating cost for them.

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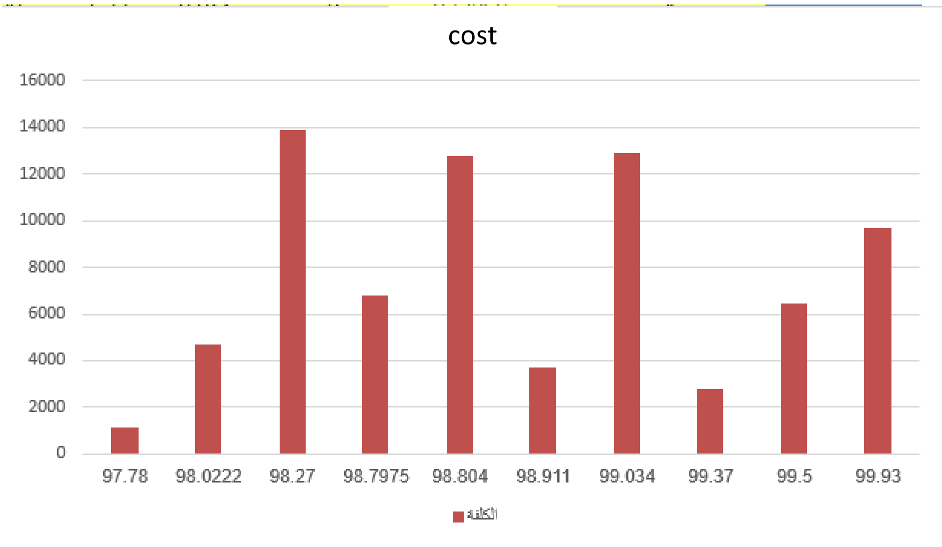

Figure (3) the values of the maximum cost to achieve the reliability of the sections

6. RESULTS AND DISCUSSION

A set of superior algorithms was relied upon to derive the cost and quality function of the Jableh city water network, where the genetic algorithm, Tabu search, and the ant colony algorithm were used. Each of the previous algorithms allows access to what is known as the optimal solution on the principle of Pareto Front, where each algorithm determines the best solutions in terms of the target function represented in the first stage by cost. Ten ideal solutions were selected that won the selection process at each of the stages, and the following figure (4) shows the difference of solutions with the results provided by each algorithm.

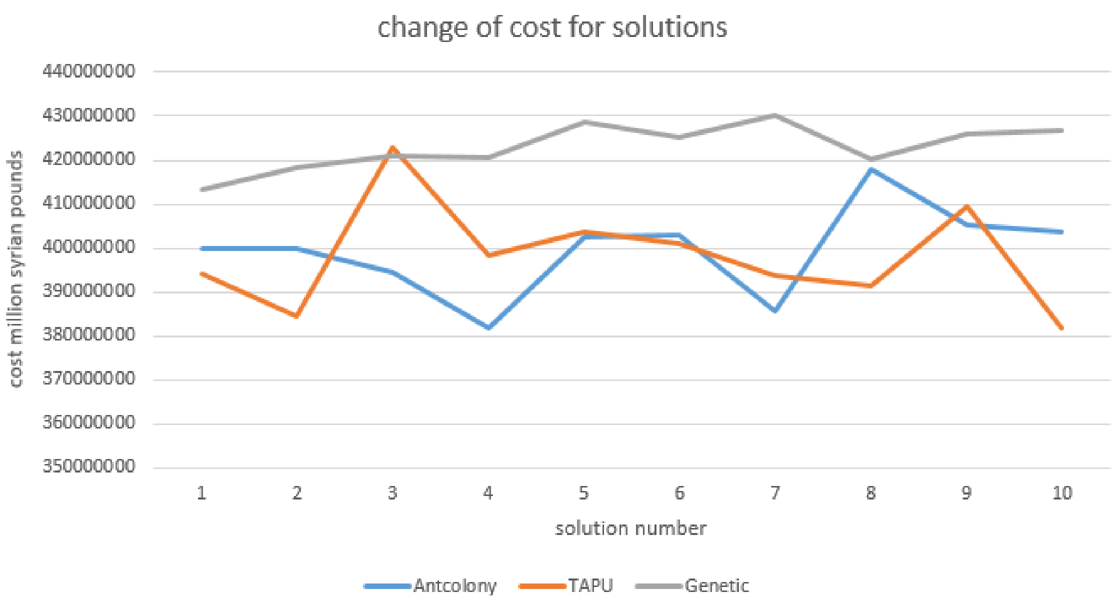

Figure (4) Costs of the ten best solutions for each of the genetic algorithms - ant colony - Tabo's research

We notice from Figure (4) the superiority of the ant colony algorithm, where the ant colony was able to give the least expensive solutions compared to the solutions provided by other algorithms, while the genetic algorithm gave the highest cost solutions compared to the rest of the competing algorithms. Thus, the ant colony algorithm is distinguished from other algorithms by its ability to reach effective optimal solutions and can be proposed as an ideal algorithm that can be used to build water distribution networks.

Quality study in the resulting networks:

After conducting cost studies, the least expensive solution was chosen for each of the previous algorithms, and the chlorine quality was studied for each of the networks resulting from the superior algorithms.

Figures (5-6-7-8) show the results of chlorine dissolution in both the basic tree network and the networks generated by the genetic algorithm, the ant colony, and the Tabo search. Simulations representing five days of chlorine distribution within the network took the time periods shown in Table 5:

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Table5. The time it takes to search the different algorithms

time	Algorithm
22.22s	normal
22.54	genetic
27.93s	Tabu search
35.28s	PSO

Despite the longer time taken by the ant colony algorithm (which is clearly reflected in a search field over a year (365 days)), the solution provided by the ant colony algorithm is the least expensive among all the resulting solutions, as in Table 6:

Table6. The cost of the tested algorithms.

PSO	Tabu search	genetic	algorithm
381929901.7	381656004.1	413412435.8	cost

By studying the dissolution of chlorine for the resulting less expensive solutions, the ideal solution for the ant colony presented a better spread of chlorine distribution within the network of the city of Jableh at the different nodes. When it needed beyond that period for the rest of the algorithms at the same node, this means that the solution provided by the ant colony algorithm allowed the free diffusion of concentrations at a higher speed than the solutions provided by other algorithms, taking into account the cost.
In addition, we notice stability in the chlorine concentrations at that node compared to other algorithms and the basic network, except for the solution provided by Tabo's research, which has the same degree of stability with a slightly higher cost.
We also notice from the resulting figures that the decay caused by radiation (which is the case in which a group of vertical random lines appears at the end of the analysis process) began to appear in all networks after the fourth day of the analysis process.

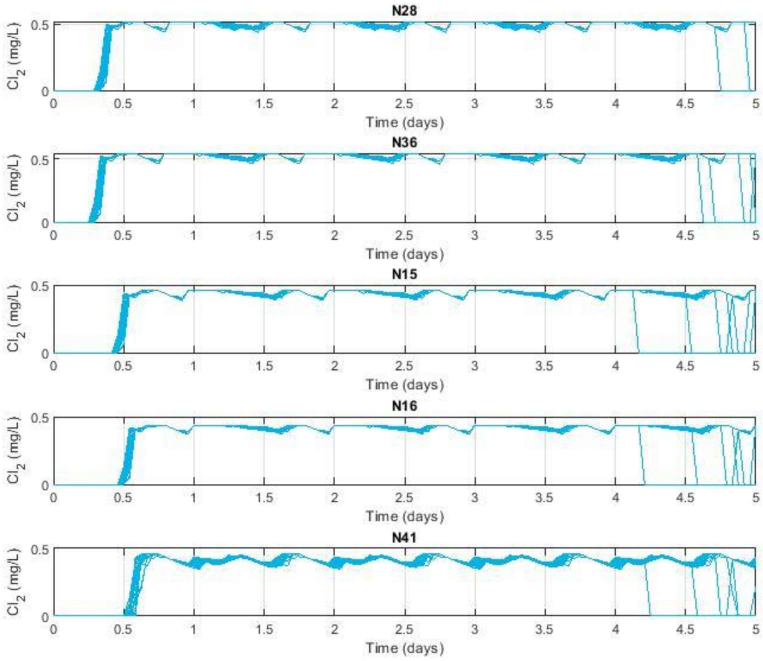

Figure (5) Chlorine concentrations for a group of nodes of the basic tree network

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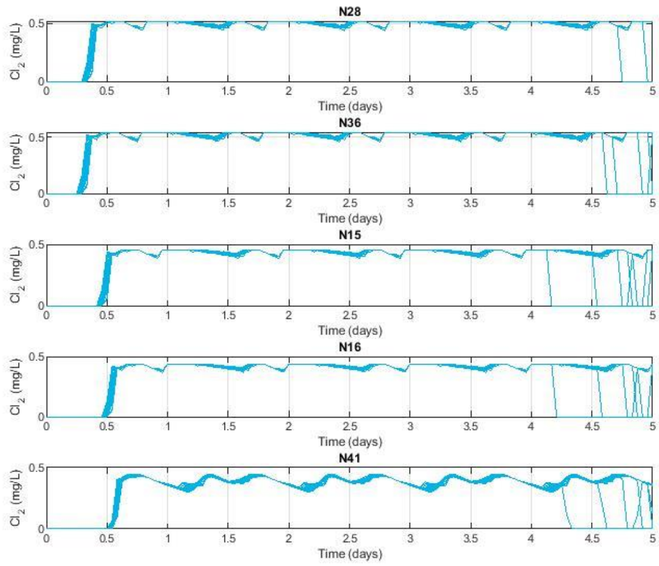

Figure (6) Chlorine concentrations for a group of nodes of the genetic network

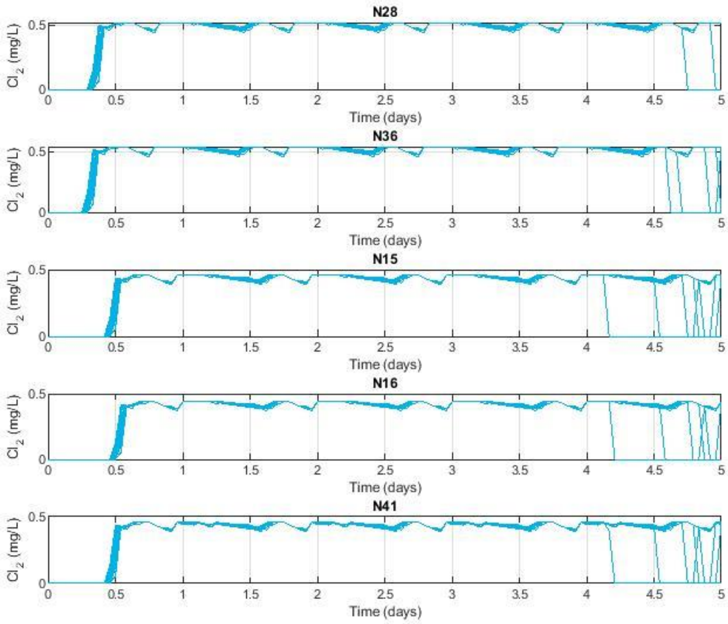

Figure (7) Chlorine concentrations for a group of nodes of the TABU search network

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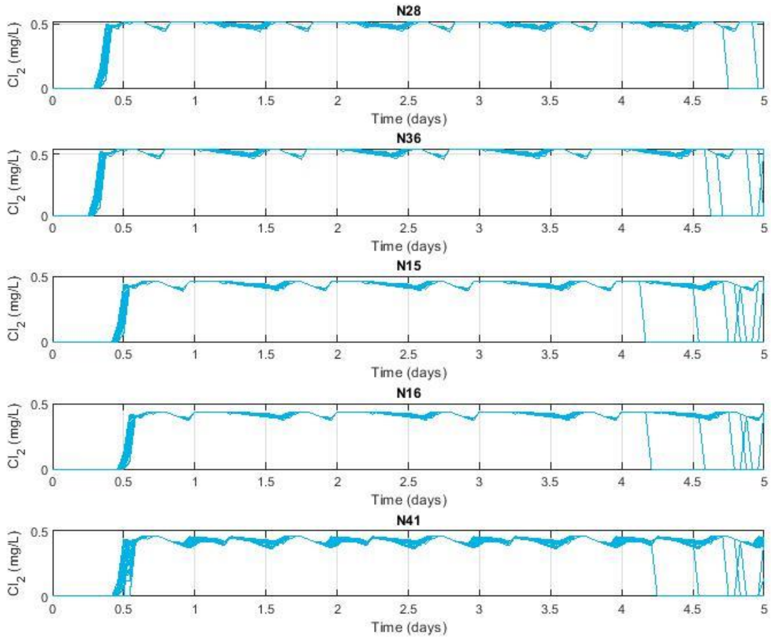

Figure (8) Chlorine concentrations for a group of nodes of the PSO network

7. CONCLUSIONS AND RECOMMENDATIONS

The results inspired by the study showed the effectiveness of superior algorithms to reach effective solutions in terms of cost and quality that are superior to the traditional network design, provided that the initial values for building the network are appropriate. From the results, we show the following:

• The algorithms of the ant colony and Tabo's research outperformed the genetic algorithm in terms of cost, as it gave solutions with a lower cost compared to the main or genetic network.

• The network resulting from the research of the ant colony gave high effectiveness in terms of chlorine concentrations, whether it spread quickly through the network or the stability of concentrations during the studied time period, as it maintained an acceptable concentration ratio within the permissible limits of about 0.5mg/L.

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