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Research paper

An efficient algorithm to improve oil-gas pipelines path

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Abstract

Oil-gas pipeline is a complex and high-cost system in terms of materials, construction, maintenance, control, and monitoring in which it involves environmental, economic and social risk. In the case study of Iraq, this system of pipelines is above the ground and is liable to accidents that may cause environmental disaster, loss of life and money. Therefore, the aim of this study is to propose a new algorithm to obtain the shortest path connecting oil-gas wells and addressing obstacles that may appear on the path connecting any two wells. In order to show the efficiency of the proposed algorithm, comparison between ant colony optimization (ACO) algorithm and a real current method of linking is used for this purpose. Result shows that the new proposed algorithm outperformed the other methods with higher reduction in operational cost by 16.4% for a number of 50 wells. In addition, the shortest path of connecting oil-gas wells are able to overcome all the addressed obstacles in the Rumaila north field, which is located in the city of Basra in southern Iraq.

Keywords: *Shortest Path Algorithm; Ant Colony Optimization; and Oil-Gas Assembly Pipeline.*

1. Introduction

Oil is a crucial source of energy. It is used in many industries, transportations and electricity supplies. The oil is transferred from the oil fields to the main stations (oil refineries) that requires a network of pipes which includes a number of valves and pipes of different diameters and pumping stations. When oil passes through the pipelines, there occurs a loss of 3% of the total oil due to the evaporation process since the oil pipelines carry large quantities of oil. The oil pipelines are used to transport (import and export) petroleum products between different cities around the world with about 17.95 million barrels per day [1]. This has led to the development of large and extensive design as well as operations of pipelines which have become more complex in recent years [2]. The main issue discussed in this paper is using the proposed algorithm to find the shortest path that links the oil wells with the gathering facilities, hence, obtaining the least cost for the work of the oil-gas pipeline network.

In the past years, some optimization algorithms have been used such as the ant colony optimization algorithm (ACO) [3], the particle swarm algorithm (PSO) [4], and the genetic algorithm (GA) [5] which was applied to improve the oil-gas pipeline network. In 1992, PhD study by [3] used ACO for the first time to solve the travelling salesman problem. The algorithm was then developed and applied to solve many other problems such as vehicle routing problem [6], quadratic assignment problem (QAP)[7], scheduling problem [8], data encoding in telecommunication systems [9], garbage collection problem [10], network model problem [11], protein folding problem [12], personal placement in airline companies [13], and job-shop scheduling problem [14]. Besides that, it has been successfully applied in finding the best solution for the complex problem in life such as the design of large communication networks, the scheduling of traffic in major cities as well as creating the ideal locations and stores of energy plants [15].

Previous Related Works

Comparisons with genetic and evolutionary algorithms suggest that ACO is one of the best characteristics involving the problem of the shortest way among others. In addition, most issues of the shortest path are a key point in software engineering and algorithms on these issues are considered a functioning field [1], [2], [16], [17]. For these reasons, ACO is adopted in this current study. In 2001, Carter et al. [16] applied the Noisy algorithm, implicit filtering algorithms, direct and a new hybrid of these methods on gas transport pipelines to describe some of the noise improvement algorithms in the gas transportation industry issues. The results of the hybrid DIRECT-IFFCO algorithm were a combination of durability and low cost [18]. On the same type of transport pipelines, [19] employed the Bell-Ford algorithm and the shortest path algorithm to solve the splitting valve location problem in the transport pipelines of the Hydrocarbon in Colombia, in assumption that the shortest path problem minimizes the maximum size of the spill as well as the social and environmental risks which suffers the pipelines of transportation of oil industries. The results showed a 75% reduction in the maximum possible spillage, with less risk for all areas [19]. The original Dijkstra algorithm was developed by making a simple and useful change to the improved Dijkstra's shortest path algorithm, which works on large sparse networks, especially in road networks. The Dijkstra's shortest path algorithm avoids building heap and the algorithm execution is surprisingly easy and runs in $O(m + D_{max} \log (n!))$ time [20]. In 2012, graph theory was utilized to analyse the problem of pipeline optimal design. The candidate pump station locations were taken as the vertex and the total cost of the pipeline system between the two vertexes corresponded to the edge weight. An algorithm recursively known as the Dijkstra algorithm, was analysed and designed to obtain N shortest paths and avoid adjustments in the locations of the pump station [21]. Furthermore, in 2017, [22] proposed the design of a technique to automatically avoid obstacles using Laplace's smoothing algorithm to produce subsea pipeline paths that are more practical. The proposed algorithm was effective, fast and easy to use on simple clusters, but there is no effective way to

design a pipeline path with algorithms to generate obstacles [22]. Chart technique was utilized to display a unique system to assess the supply dependability in natural gas pipeline systems where lists of the client part are partitioned into three viewpoints: likelihood, ampleness and time. The composed structure incorporates strategies to tend the issues from alternate point of view in regards of the ecological, utilitarian requirement, topology and dynamics.
Apart from that, the graph theory technique was utilised to evaluate the supply of natural gas pipeline systems, and analyses the results in detail. From a practical point of view, the methodology may aid engineers and managers in estimating safety margins to serve costumers reliably [23]. The common problem that exists in the design of the pipeline networks are to handle obstacles such as bridge, river, lake, residential areas and private properties. Removing or circumventing obstacles is considered an additional cost on the basic project. Thus, this study presents an algorithm for finding an alternative to avoid these obstacles, and at the same time in finding the shortest path.

2. A new proposed algorithm

This study proposes a new algorithm for oil-gas pipeline problem that is capable in avoiding all the obstacles addressed in the real situation. In this section, we present the following mathematical model:

$$\textbf{Minimize} \quad \sum_{i=1}^{n} TC_i = \sum_{i=1}^{n} (LSD_i \times CS) \tag{1}$$

Where LSD_i represents the length of the pipe connecting two wells (km) and CS represents the cost of one pipe per km. We now have the following definitions.

Definition 1: *There exists an obstacle between two wells, W_i and W_j, if the link between them is null as defined in (2) below. In this case, the distance between W_i and W_j is zero as stated in (3).*

$$Link(i,j) = \emptyset \tag{2}$$

$$D(W_i, W_j) = 0, \forall\ Link(i,j) = \emptyset \tag{3}$$

Definition 2: *The distance between W_i and W_j is zero for the same well given by*

$$D(W_i, W_j) = 0, \forall\ i = j \tag{4}$$

Definition 3: *The connection between two wells, W_i and W_j, is possible in one direction only given by:*

$$D(W_j, W_i) = 0, \forall\ D(W_i, W_j) = d_i, d_i \neq 0. \tag{5}$$

The distance between W_i and W_j defined in (5) is given by

$$D(W_i, W_j) = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \tag{6}$$

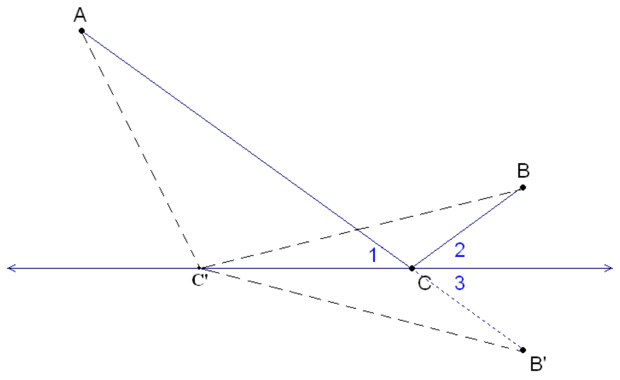
We present the new proposed algorithm as below which is programmed using MATLAB software.

Pseudocode for New Proposed Algorithm

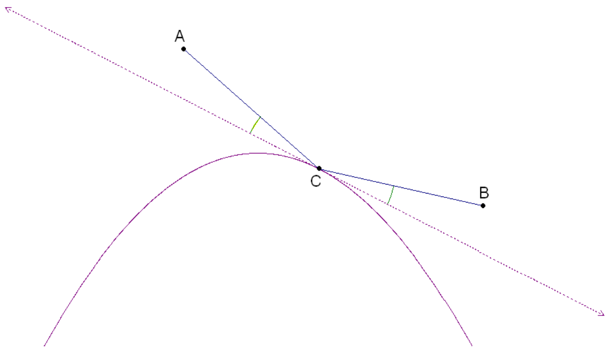
Inputs : WLT $(X,Y) \in R^{2\times n}$// Location Table for all wells
Output: $\underline{ShortPathTable}$
Begin:
Calculate $D_{Table} \in \mathrm{R}^{n\times n}$
For $i = 1{:}n$ Do // i=1, 2,n ;
For $j = 1{:}n$ Do
If Obstacles(i,j) == 1 THEN
$D(i,j) = \infty$
ELSE
D(i,j)= $SQR\left[(x_i - x_j)^2 + (y_i - y_j)^2\right]$
End IF
Next
Next
For $Well.Id = 2{:}n$ Do
Determine Short path for Well ($Well.Id$).
SET $X \leftarrow Well.Id$
S_ID = $ShortPath(Well.Id, \{D\})$, S_ID $\in R^{1\times 1}$,
SET Well($Well.Id$).Links= S_ID
SET $D(Well.Id, \text{S\_ID}) = \infty$
SET $Y \leftarrow$ S_ID
Z = $ShortPath(Y, \{D\})$
SET $D(X, Z) = \infty, D(Z, X) = \infty$
$\underline{ShortPathTable(Well.Id) = \text{Well}(Well.Id).\text{Links}}$
NEXT
END Algorithm

3. Shortest path theory

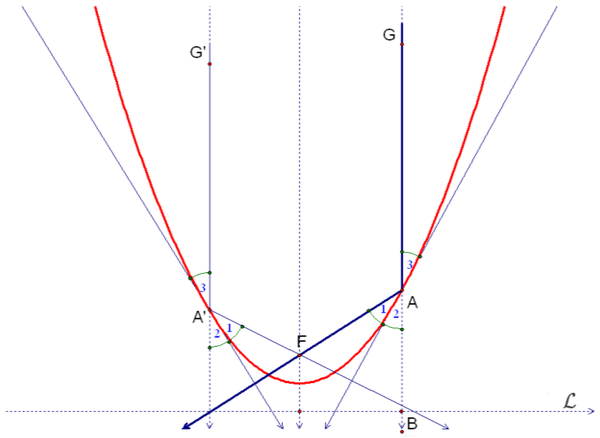
Given two points, A and B, on one side of a line, find C which is a point on the straight line that minimizes AC + BC. Here is the mathematical approach used by Heron. He noticed that if B is reflected across the line, to some point B', then for any point C on the line, |CB|=|CB'|, and hence minimizing |AC|+|CB| is equivalent to minimizing |AC|+|CB'| . The shortest path from A to B' is a straight line, so the point C that minimizes |AC|+|CB'| should be on the line AB'. Any other position of C will increase |AC|+|BC|.



In addition, $m\angle 2 = m\angle 3$ because C is at an equal angle to B and B'. Also, $m\angle 1 = m\angle 3$ since these are vertically opposite angles. Therefore, $m\angle 1 = m\angle 2$. This is the equal angle law of reflection. It was Euclid who, over three hundred years earlier, had noted the now well-known Reflection Law for light:
"Euclid's Law of Reflection states that if a beam of light is sent towards a mirror, then the angle of incidence equals the angle of reflection".
This, as we have found, is true when the value of |AC|+|BC| is at its lowest, so light always takes the shortest path!
In fact, the mirror in the Equal Angle Law of Reflection need not be flat. We may replace the line in Heron's problem by any concave curve (a curve is concave if it lies entirely on one side of any tangent line). In this case, the angles are measured with respect to the tangent line, and the same argument used by Heron shows that if C is such that the angle of incidence equals the angle of reflection, then |AC|+|BC| is minimized.



An interesting application of the Law of Reflection arises in the case of a light beam sent towards a parabolic mirror, where the light beam is parallel to the axis of the parabola. A parabolic mirror is one whose surface is generated by rotating a parabola about its axis. Suppose the parabola has focus F and directrix ℓ, and that the light beam $\overline{GA}$ hits the parabola at A. Recall from Roberval's construction of tangent lines to parabolas that the tangent line at A bisects the angle $\angle FAB$. Hence $m\angle 1 = m\angle 2$. Since $\angle 2$ and $\angle 3$ and are vertical angles, then $m\angle 2 = m\angle 3$. Hence, $m\angle 1 = m\angle 3$. So by the Equal Angle Law of Reflection, the light beam will be reflected in the direction $\overrightarrow{AF}$. This will be true for any point A on the parabola.



4. Ant colony algorithm

The ACO algorithm is an exploratory method capable of solving complex problems by looking for optimal solutions in the graphs within a range of possibilities. This algorithm mimics the natural behavior of the ants in the search for food where ants come out to find food, and when it does, a chemical known as pheromone is released on the way back to the colony. The rest of the ants will pick up the scent and follows the same path. The more ants follow the path, the greater the concentration of the pheromone, which causes the long path to disappear as this material rapidly evaporates. In the end, there is only one path followed by the ants, which is the shortest path. On this basis, this algorithm is chosen for comparison purpose with the proposed algorithm.

The standard ACO rule p_{ij}^{k} mentioned in (7):

$$p_{ij}^{k} = \frac{[\tau_{ij}]^{\alpha}[\zeta_{ij}]^{\beta}}{\sum_{z \in allowed_y}[\tau_{ij}]^{\alpha}[\zeta_{ij}]^{\beta}} \quad (7)$$

Where:

k: The number of ant $k \in \{1,2,3,\dots,m\}$, at node i.

p_{ij}^{k}: The probability with which ant k chooses to move from node i to node j,

τ_{ij}: The amount of pheromone along the transition from node i to j.

$\alpha \geq 0$: The parameter that controls the influence of τ_{ij},

ζ_{ij}: The desirability of node transition ij (a priori knowledge, typically 1/ d_{ij}, where d is the distance),

$\beta \geq 1$: A parameter that controls the influence of ζ_{ij},

τ_{ij}, ζ_{ij}: represents the attractiveness and trail level for the other possible node transitions.

Pheromone update.

When all the ants have completed a solution, the trails are updated by:

$$\tau_{ij} \leftarrow (1-\rho)\,\tau_{ij} + \sum_k \Delta\tau_{ij}^{k} \quad (8)$$

With

$$\Delta\tau_{ij}^{k} = \begin{cases} \frac{Q}{L_k} & if\ ant\ uses\ curve\ ij\ in\ its\ tour \\ 0 & otherwise \end{cases} \quad (9)$$

Where

L_k: The cost of the K_{th} ant's tour,

Q: a constant.

Now, we present the steps in ACO which is written in MATLAB software.

Pseudo code for ACO Algorithm

```
Inputs : WLT (X,Y) ∈ R^(2×n)// Location Table for all wells
Output: ShortPathTable
Begin:
Calculate D_Table ∈ R^(n×n)
For it = 1:MaxIt
For k = 1:nAnt
ant(k).Tour=randi([1 nVar]);
for l=2:nVar
i=ant(k).Tour(end);
P=tau(i,:).^alpha.*eta(i,:).^beta;
P(ant(k).Tour)=0;
P=P/sum(P);
j=RouletteWheelSelection(P);
ant(k).Tour=[ant(k).Tour j]
end
ant(k).Cost=CostFunction(ant(k).Tour);
if ant(k).Cost<BestSol.Cost
BestSol=ant(k);
end
end
Update Phromones
for k=1:n Ant
tour=ant(k).Tour;
tour=[tour tour(1)]; %#ok
for l=1:nVar
i=tour(l);
j=tour(l+1);
tau(i,j)=tau(i,j)+Q/ant(k).Cost;
end
end
NEXT
END Algorithm
```

5. Results

a) Ant colony algorithm

Table 1 below shows the number of oil-gas wells and the best cost for constructing a pipeline network connecting these wells, as well as the execution time by the ACO algorithm to reach the results as shown in Figures 1-5.

The table below shows the execution time for the algorithm using the MATLAB program, the best cost and different number of wells using ACO algorithm.

Table 1:

No. of	Best cost ($)	Execution time (in

wells		second)
10	3.535363320166086e+04	19.48
20	4.588008572572926e+04	22.85
30	5.971085544455865e+04	26.29
40	6.669880728808713e+04	29.62
50	7.610282208287528e+04	32.97

Figure 1 shows the shortest path linking the locations of 10 oil wells, without obstacles. Assuming the total cost of constructing oil-gas assembly pipelines by length 1 km and diameter 5" is $100,000.

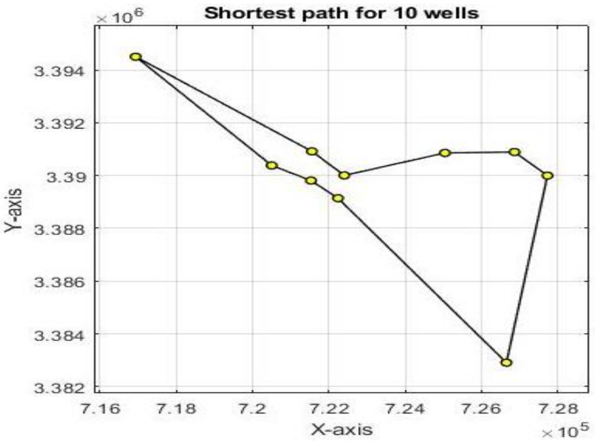


Fig. 1: Shortest Path for 10 Wells without Obstacles.

Figure 2 shows the shortest path linking the locations of 20 oil wells, without obstacles.

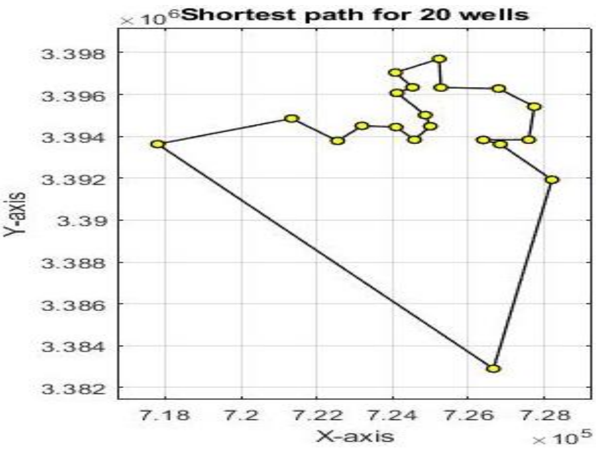


Fig. 2: Shortest Path for 20 Wells without Obstacle.

Figure 3 shows the shortest path linking the locations of 30 oil wells, without obstacles.

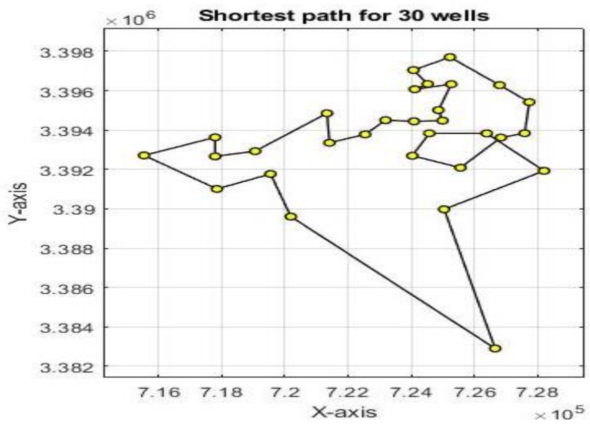


Fig. 3: Shortest Path for 30 Wells without Obstacles.

Figure 4 shows the shortest path linking the locations of 40 oil wells, without obstacles.

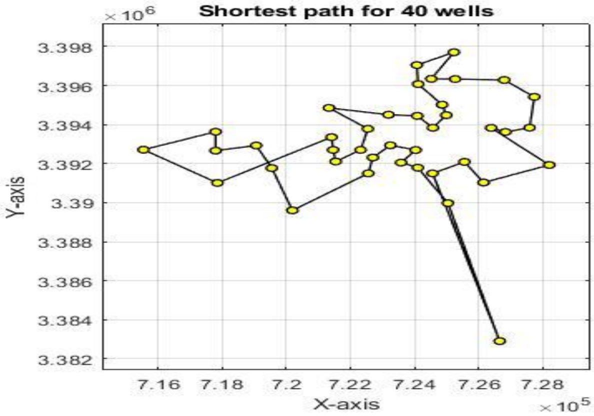


Fig. 4: Shortest Path for 40 Wells without Obstacles.

Figure 5 shows the shortest path linking the locations of 50 oil wells, with obstacles.

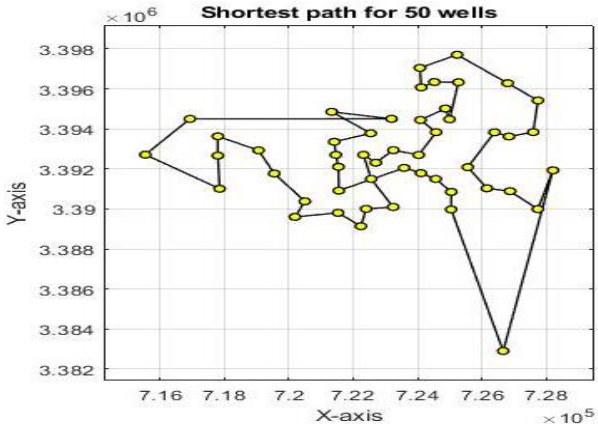


Fig. 5: Shortest Path for 50 Wells with Obstacles.

b) A new proposed algorithm

Table 2 below shows the various number of oil-gas wells and the best cost for constructing a pipeline network connecting these wells, as well as the execution time by the new proposed algorithm to reach the results as shown in Figures 6-10.

The table below shows the execution time for the algorithm using the MATLAB program, the best cost, and various number of wells using the new proposed algorithm.

Table 2:

No. of wells	Best cost ($)	Execution time (in second)
10	2.830483810509105e+04	0.643
20	2.231077578819970e+04	1.629
30	0.394613729618506e+05	2.125
40	0.423122375499187e+05	2.265
50	0.498650479761757e+05	2.781

Figure 6 shows the shortest path linking the locations of 10 oil wells, without obstacles.

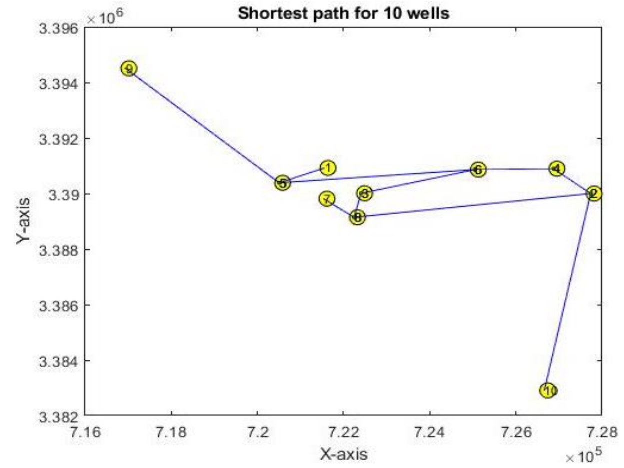


Fig. 6: Shortest Path for 10 Wells without Obstacles.

Figure 7 shows the shortest path linking the locations of 20 oil wells, without obstacles.

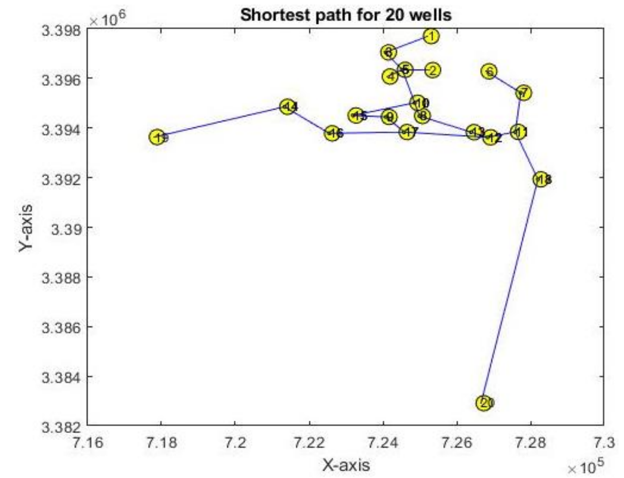


Fig. 7: Shortest Path for 20 Wells without Obstacles.

Figure 8 shows the shortest path linking the locations of 30 oil wells, without obstacles.

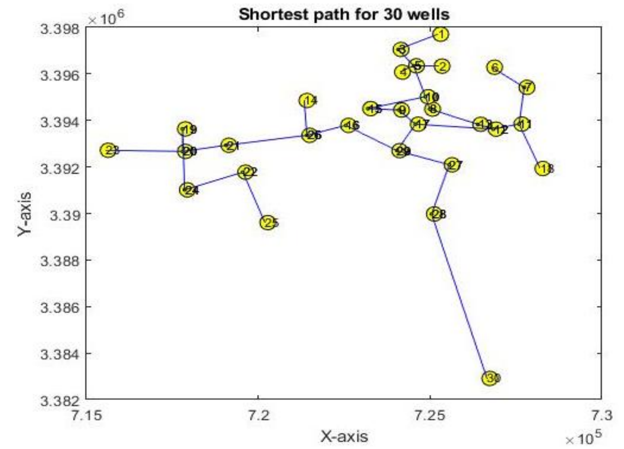


Fig. 8: Shortest Path for 30 Wells without Obstacles.

Figure 9 shows the shortest path linking the locations of 40 oil wells, without obstacles.

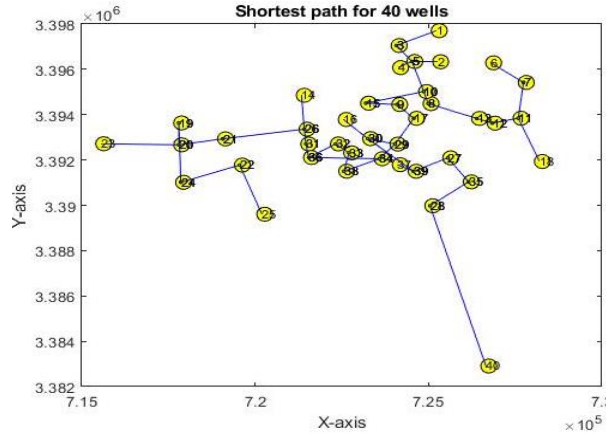


Fig. 9: Shortest Path for 50 Wells without Obstacles.

Figure 10 shows the shortest path linking the locations of 50 oil wells, without obstacles.

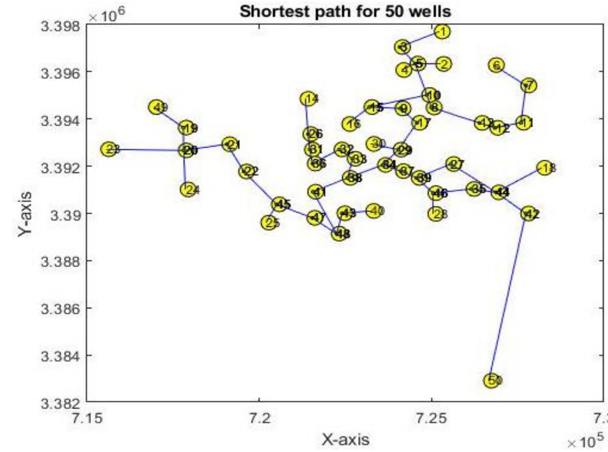


Fig. 10: Shortest Path for 50 Wells without Obstacles.

c) Comparison of results

In this section, we present the detailed simulation study that tests the performances of the proposed algorithm and ACO algorithm. The performance metric reduces the construction cost for oil-gas pipelines with MATLAB being used to write the code for the proposed algorithm. The evaluation is done based on numerous scenarios.

In Table 3 below, we show the number of wells and the best cost for three different methods which comprises of the new proposed algorithm, ACO algorithm, and a real current linking method. In addition, Figure 11 shows the superiority of the new proposed algorithm to the rest of the methods.

A comparison between the new proposed algorithm, ACO algorithm and the real current method of linking which shows that the higher the number of nodes, the greater the cost reduction which is clearly shown by the proposed algorithm.

Table 3:

No. of wells	Proposed Method ($)	ACO Method ($)	Current Method ($)
10	2.830483810509105e+04	3.535363320166086e+04	3.583464577620760e+04
20	2.231077578819970e+04	4.596788270523903e+04	8.119873954518900e+04
30	0.394613729618506e+04	0.612561509905572e+05	1.608440331710942e+05
40	0.423122375499187e+04	0.688198598129601e+05	2.223386365871008e+05
50	0.498650479761757e+04	0.801920813453712e+05	3.034852910011274e+05

Figure 11 shows that the new proposed algorithm is able to search for optimal solution that minimizes the operational cost of oil-gas pipeline problem. Nonetheless, the reduction in operational cost will highly benefit the management in future.

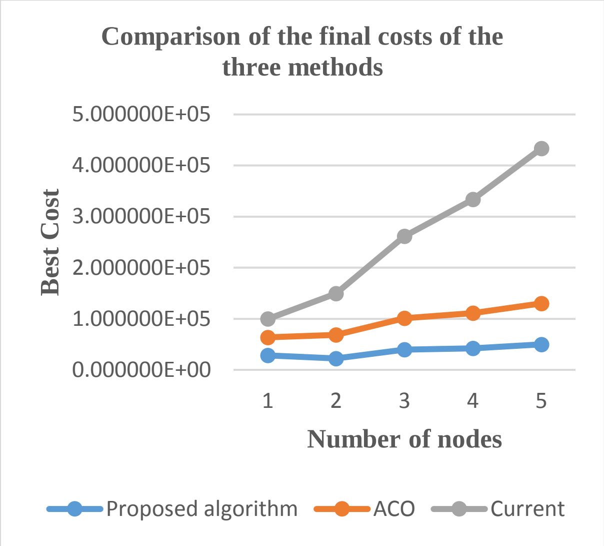


Fig. 11: Comparison of the Best Costs among All Three Methods.

Fig. 12: Some Oil-Gas Wells Which were Involved in This Study Situated in the Northern Rumaila Oil Field, Iraq.

6. Conclusion

The optimal design of the oil-gas pipeline is very difficult due to it being complex and diverse. The application of the traditional methods in improving the oil-gas pipeline system are challenging as well as time-consuming. Thus, the intelligent optimization has been widely used. In this study, the new proposed algorithm was applied which is based on finding the shortest path that links the oil-gas wells to the assembly plant. The improvement of the oil-gas pipeline network has been undertaken, taking into consideration the obstacles, the cost of operation as well as construction.

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