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The Project Scheduling by Using Ant Colony Algorithm

Researcher: Ali Fadhil Hayder Saddawi[1] , Assist. Prof. Shifa Balassim Hassan[2]

1 Technical College of Management, Baghdad, Iraq,

alialassady23@gmail.com

2 Technical College of Management, Baghdad, Iraq,
Dr.Shifa2018@gmail.com

Abstract

The study aims to schedule the project using the ant colony algorithm as one of the swarm intelligence algorithms as a smart search technique that derives its work from the natural behavior of ant colonies in reaching the optimal solution efficiently, by identifying the critical path in the shortest time and lowest cost.

The study problem is represented in the company's need to use modern technologies in scheduling its projects, and its reliance on experience and personal effort in scheduling projects and determining the times of completing activities and the total time to complete projects, which was reflected in exceeding the project completion time and cost from the plan.

Keywords: Ant colony algorithm, project scheduling, critical path method

Introduction

1) Study Problem

Project scheduling has some challenges and complications that cause the postponement of project implementation on their specified dates agreed upon with the beneficiary parties, which is reflected in the additional costs borne by the project implementing parties. Project implementing parties face the problem of determining a completion period that is not commensurate with the size of the project activities, which leads to delaying the completion of the project on the specified date, in addition to the difficulties of obtaining project equipment from raw materials and financial allocations necessary to complete the project. There is also a knowledge gap between theory and application, as a result of companies relying on personal experience in scheduling projects, without adopting modern scheduling techniques using discretionary algorithms.

2) The Importance Of The Study

A. It is an attempt to apply the ant colony algorithm in project scheduling, which is one of the modern techniques in project scheduling.

B. Good scheduling represents a competitive advantage that the company can benefit from to achieve the project objectives, as it is recognized that there is an increasing need for competition that requires companies implementing projects to compete on the basis of time and cost.

C. Helping the company in completing projects on time by scheduling the dates of completing activities, taking into account the imposed restrictions such as cost and the intersection of work with other projects.

3) Study Objectives

The study aims to present a modern topic represented by project scheduling through the application of the ant colony algorithm through the following:

A. Evaluating the method adopted in project scheduling in the company, the field of study.
B. Applying the ant colony algorithm in project scheduling, the field of study.
C. Comparing performance according to the scheduling method adopted in the company and the ant colony algorithm according to the specified criteria.

Literature Review

1) **Project Concept**

A project is a series of activities linked in a logical sequence to provide a unique product. Projects have become a new way to accomplish and manage activities, regardless of their type, whether service, commercial or industrial. This justifies the diversity of projects according to the activity they carry out, despite their sharing of many characteristics. All projects have a unique beginning and end, in addition to other characteristics that projects may have (Cander at al., 2007:33). Projects are also characterized by not being repeated, and if they are repeated, they are not a project, even if they are similar to another project in some stages of its life cycle (Najm, 2013: 85).

2) **Project Scheduling**

Scheduling represents the final stage in project planning, before starting the actual implementation of the project, and through it the duration of each activity and the resources required for each activity are determined, which achieves multiple and conflicting goals and determines the priority of completing the various activities (Stevenson, 2018: 689).

3) **Project Scheduling Objectives**

The objectives of project scheduling can be explained as follows (Heizer, at al., 2017: 65):

- Monitoring and controlling the project, by providing a general framework for displaying data, analyzing risks and presenting facts for decision-making, and helping management evaluate and choose the best alternatives to end the project.

- Clarifying the sequence of activities by identifying the relationship of each activity to the project as a whole and its relationship to other activities.
- Determining the precedence relationships between activities and the critical path of the project.
- Determining the time and cost of completing each activity within the project schedule.
- Achieving optimal utilization of financial, human and material resources and identifying bottlenecks in the project to address them.

4) Self-Organization Of Insects

Self-organization can be defined as "a set of dynamic mechanisms that show the structures at the global level of a system of interactions between the lower level of components and the rules that determine these interactions between the components of the system and the implementation is based on local information, through organized networks consisting of pheromone paths. Self-organization depends on four basic components, which are (Birattari & Dorigo, 2005: 107)

A. Positive feedback: represents simple behavioral capabilities that encourage the creation of structures. Searching for a food source is a positive feedback for competition. Ants searching for a food source have high quality, which allows the ant colony to choose the best decision.

B. Negative feedback: negative feedback that balances positive feedback and helps in achieving stability. Competition in the case of searching for food has negative feedback consisting of a limited number of available relationships, crowding on the food source, or competition between food sources.

C. Randomness: Self-organization depends on randomness in following paths with a low error rate, because it enables the discovery of new solutions for these sources Food.

D. Interactions: All cases of self-organization depend on multiple interactions. Although the individual can generate a self-organizing structure, successfully reaching the goal requires mutual social relationships between individuals. To be able to benefit from their results and activities.

5) Definition Of The Ant Colony Algorithm

It is one of the most successful and widely recognized algorithmic techniques based on ant behavior. These algorithms have been applied to many problems; moreover, ACO algorithms are among the current high-performance algorithms for many problems. The first ant colony optimization (ACO), called the ant system, was by (Dorigo) and was inspired by a study of ant behavior in 1991 (Dorigo & Stützle, 2004). The ant colony is highly organized, with one ant interacting with others through pheromones in perfect harmony. Optimization problems can be solved by simulating ant behavior. Since the first ant system algorithm was proposed, there has been a lot of development in ACO. Since its invention, ACO has been successfully applied to a wide range of NP-hard problems such as the traveling salesman problem (TSP) or the quadratic allocation problem (QAP), and is gaining increasing interest in solving real-world engineering and scientific problems.

6) The Mechanism Of Action Of Ant Colonies

The pheromone helps ants explore the way back, and the way back is the same as the way out. It also helps other ants discover the way from the colony to the source through the sense of smell of the volatile chemical substance (pheromone). The more concentrated this substance is in a certain path, the better this path is, which makes the rest of the ants take it as a way to go and return between the colony and the food source. Therefore, the pheromone substance is the main controller or indicator that natural ants rely on in choosing the path (and by natural ants we mean ants found in nature) (Rahim, 2017: 28).

7) Ant Colony Algorithm Application Functions

The Ant Colony Algorithm includes objective functions that represent the areas of its use as follows (Rahim, 2017: 33-35)

A. Guidance information function

It is symbolized by the symbol η, which is the function of the desired goal to be achieved or what is preferred to be obtained, and it is according to the nature of the problem under study, as it may be achieving the shortest distance or reducing the completion time. Its value is the opposite of the length of the side, and a special formula must be developed for this function, which differs from one problem to another. This function shares with the pheromone matrix in calculating the value of the probability function, which must meet the constraints of the function specific to the problem, and any value that does not meet these constraints, the guidance function for that side is not calculated, and the node connecting that side is excluded, which can be expressed by the following equation: -

$$\eta(i,j) = 1/d(i,j) \qquad \dots (1)$$

where d(i,j) is the time taken on side i,j.

B. Probability function

A discrete distribution probability function that guides the artificial ant in choosing the next node to move to, and the probability value is calculated for all nodes allowed to move to, and the node that has the highest probability value is the candidate for the ant to move to according to the following equation:

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$$p_{(k,i,j)} = \frac{\eta(\text{i,j})^{\beta}\tau(\text{i,j})^{\alpha}}{\sum_{r\in \Gamma}\eta(\text{i,j})^{\beta}\tau(\text{i,j})^{\alpha}} \qquad \dots (2)$$

Where:

(i,j) The value of the pheromone present in the path (i,j)

(i,j)η The numerical value of the intuitive function and is calculated as the inverse of the distance between nodes i,j, and d(i,j) represents the length of the path i,j.

Γ The set of paths that the ant actually took so that they are not chosen again during the same round.

β,α: Numerical constants that represent the relative weight of the amount of pheromone and intuitive information, respectively, which is called the necessary guidance information in the solution-building phase and is an optimal value when applying the algorithm, and each type of problem has optimal values to achieve the optimal solution (Johnny & Chang, 1991:194).

C. Local update function for pheromone

After the ant completes the current step and before performing the next step, the pheromone value is updated at time t+1 based on the pheromone value at time t, and the amount of pheromone released by ant k on the path (i,j) according to the following equation:

t) + φ(k,i,j) ...(3) $(_{\text{i,j}})(\tau)$ = ∂t+1$(_{\text{i,j}})(\tau$

Where:

∂: pheromone evaporation coefficient and its value lies between (1,0).

φ (k,i,j): The amount of secretion by ant k on path i,j, which is calculated according to the following equation:

$$\varphi(\text{k,i,j}) = \begin{cases} 0 \ if\ ant\ select\ trial\ i \neq j \\ \frac{Q}{L} if\ ant\ select\ trial\ i = j \end{cases} \qquad \dots (4)$$

Where Q: numerical constant L: total sum of times of the path.

D. Global update function

The second update (global) is done after all ants have finished building all solutions within the same iteration, according to the amount of pheromone lost by path i,j as a result of evaporation and the amount of pheromone added to it as a result of the other ants' pheromone release during their passage through the same path. Here, the update is done on the best solution that resulted from each round (solution) performed by the ant and during the single iteration and for all ants according to equation (3).

The best solution is chosen within the single iteration after comparing the complementary time for the work and the optimal solution is the one that gives the least complementary time (Makespan), which is the same matching function.

5. Matching function

A test function that measures the efficiency of the solution obtained through the ant's movement (because the ant's movement between two nodes represents an experimental solution), and the lower the value of the matching function, the greater the efficiency of the solution, and the matching function is equal to the objective function, i.e. the least complementary time for all work or has the lowest value for the minimum.

Findings

1- Study Field

The Fourth Dimension Company for General Contracting and Tourism Investments Limited is one of the Fourth Dimension Group, which was established in 2002 in Iraq / Baghdad, and includes several branches in most of the governorates of Iraq. The company works in various fields such as the construction of residential complexes, bridges and infrastructure. The company has partners from Germany, Jordan, the United Arab Emirates and Turkey. It has several projects in the field of reconstruction, rehabilitation and investment projects in all residential, commercial, entertainment and service fields throughout Iraq.

The company owns its own factories in Baghdad and Najaf, such as the ready-made casting factory, warehouses and factories for aluminum, paints and adhesives, workshops, maintenance centers and heavy equipment. The company has completed a number of projects, including Al-Ghadeer Village (1) / Najaf Al-Ashraf, Al-Ghadeer Village (2) / Najaf Al-Ashraf, Al-Shaab Central Markets Bridge / Baghdad, Al-Hamza Al-Sharqi Complex / Diwaniyah Governorate, and the Ministry of Education Project No. (1) to build schools in all governorates of Iraq.

2- Al-Ghadeer Village Project (2)

The company has built several projects, including Al-Ghadeer Village Project (2) in Najaf Governorate, for the period from 1\1\2019 to 1\1\2023. The project consists of (1293) houses distributed over several residential units (blocks), the number of which is (48) residential units (blocks). The number of houses in each residential unit varies according to the area of the residential unit, as shown in Table (1) .

Table (1) Number of Residential Units and Their Affiliated Houses

N	Number Units	Number of Houses in Units	Total
1	1	12	12
2	4	14	56
3	3	17	51
4	10	18	180
5	2	20	40
6	3	22	66
7	2	24	48
8	5	26	130
9	1	28	28
10	2	30	60

11	4	32	128
12	2	36	72
13	1	42	42
14	1	44	44
15	7	48	336
T	48	413	1293

Table (1) indicates that the number of houses varies according to the number of residential units. There are (48) residential units, each of which includes a number of houses. There is one residential unit consisting of (12) houses, and there are 4 residential units, each of which consists of (14) houses. Thus, the total number of houses in it is (56) houses, and so on for the rest of the residential units. Thus, the project includes (1293) houses distributed over (48) residential units.

3- Description Of Activities And Times

The project consists of (48) housing units, each housing unit was built according to a number of activities, which are the same activities necessary to complete all housing units. The activities were divided into (17) activities starting from establishing the electricity, water and sewage network and ending with the completion of the project as shown in Table (2).

Table (2) Al Ghadeer Project Activities (2) and Start and End Times

N	Activity	Code	Start	End	planning Time	Real Time	Delay In Completing Each Activity/Day
1	Electricity network	A	2019\1\1	2022\9\7	937	1345	408
2	Water network	B	2019\1\1	2022\09\29	940	1367	427
3	Sewage network	C	2019\1\1	2022\9\7	937	1345	408
4	Roads	D	2019\1\1	2022\9\7	937	1345	408
5	Foundation and treatment works	E	2019\1\1	2022\9\1	904	1339	435
6	Ground floor walls	F	2019\1\5	2022\9\3	902	1337	435

	installation						
7	Ground floor ceiling installation	G	2019\1\6	2022\9\6	904	1339	435
8	Ground floor ceiling pouring and electrical installation	H	2019\1\10	2022\9\11	905	1340	435
9	First floor walls installation	I	2019\1\12	2022\9\13	905	1340	435
10	First floor ceiling installation	J	2019\1\13	2022\9\14	905	1340	435
11	First floor ceiling pouring and electrical installation	K	2019\1\15	2022\9\18	907	1342	435
12	Ground and first floor balconies installation	L	2019\1\16	2022\9\17	905	1340	435
13	Corridors	M	2019\1\16	2022\9\27	915	1350	435
14	External fence and parking lot	N	2019\1\16	2022\9\22	910	1345	435
15	Finishing works	O	2019\1\16	2022\10\6	924	1359	435
16	Finishing mechanical works	P	2019\1\16	2022\10\6	924	1359	435
17	Finishing electrical works	Q	2019\1\16	2022\10\6	940	1359	419

Table (2) shows the project completion activities, the planned time and the actual time to complete each activity. The total planned time was (940) days, the total actual time was (1375) days, and the total delay time was (435) days.

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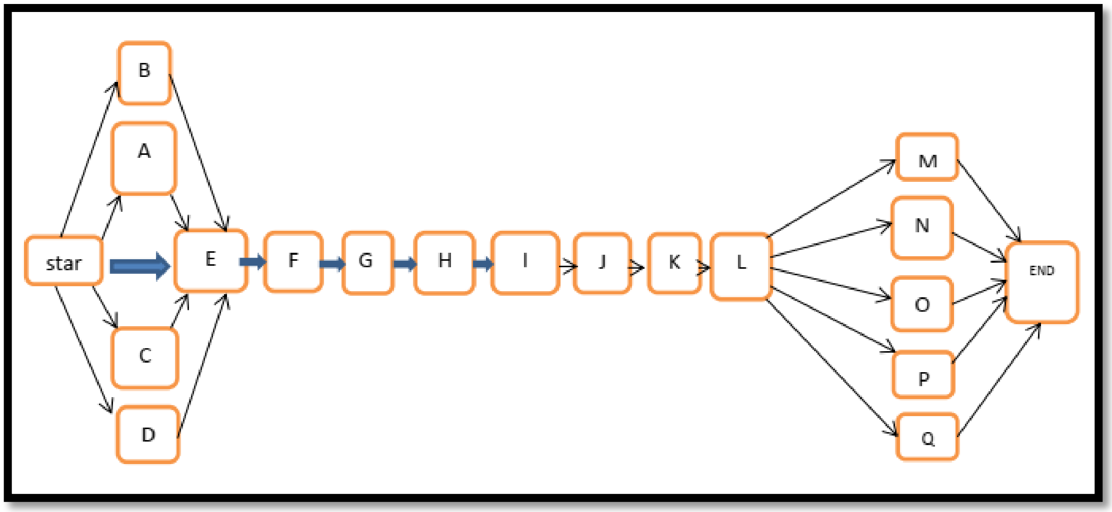

Figure (1) Al-Ghadeer Village Project Network (2)

4- Fourth: Calculating the costs required for each activity

Due to the difference in the number of houses in each housing unit in the project, as we indicated in Table (2), the time required to complete each housing unit will vary accordingly depending on the number of houses, with the same activities required to complete in each housing unit, i.e. the activities are fixed, but the time required to complete the housing units will vary depending on the number of houses, as well as the costs required to complete each activity, as shown in Table (3) and Figure (2).

Table (3) Times and Costs Required to Complete the Housing Unit (42) Houses Before Applying the Ant Colony Algorithm

N	Activity	Code	Start	End	planning Time	Actual Time	N	Cost
1	Electricity network	A	-	2019\9\5	2019\10\4	30	30	14,100,000
2	Water network	B	-	2019\9\5	2019\10\5	30	31	14,570,000
3	Sewage network	C	-	2019\9\5	2019\10\4	30	30	14,700,000
4	Roads	D	-	2019\9\5	2019\10\6	31	32	21,120,000
5	Foundation and treatment works	E	A-B-C-D	2019\10\7	2019\11\7	32	32	21,120,000
6	Ground floor walls installation	F	E	2019\11\8	2019\12\8	30	31	8,680,000
7	Ground floor	G	F	2019\12\9	2020\1\7	30	30	7,800,000

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	ceiling installation							
8	Ground floor ceiling pouring and electrical installation	H	G	2020\1\8	2020\2\6	30	30	9,600,000
9	First floor walls installation	I	H	2020\2\7	2020\3\10	32	33	9,240,000
10	First floor ceiling installation	J	I	2020\3\11	2020\4\9	30	30	7,800,000
11	First floor ceiling pouring and electrical installation	K	J	2020\4\10	2020\5\9	30	30	9,600,000
12	Ground and first floor balconies installation	L	K	2020\5\10	2020\6\8	30	30	7,800,000
13	Corridors	M	L	2020\6\9	2020\7\8	30	30	19,200,000
14	External fence and parking lot	N	L	2020\6\9	2020\7\9	30	31	18,600,000
15	Finishing works	O	L	2020\6\9	2020\7\10	31	32	5,000,000
16	Finishing mechanical works	P	L	2020\6\9	2020\7\8	30	30	2,700,000
17	Finishing electrical works	Q	L	2020\6\9	2020\7\9	30	31	2,790,000
	Total					306	310	194,420,000

Table (3) shows that the total time to complete the residential units with (42) houses is (310) days, the delay time is (4) days, and the total cost is (194,420,000) dinars, as shown in Figure (2).

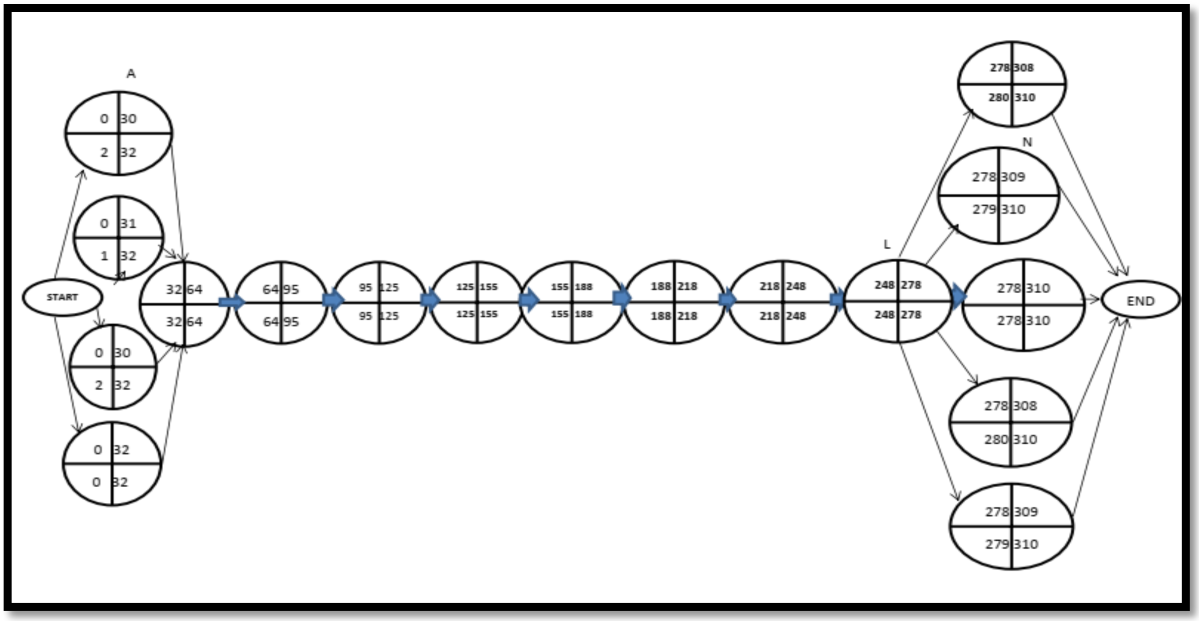

Figure (2) Plan of the Residential Unit With (42) Houses

5- Ant colony algorithm application for project scheduling

The algorithm's working mechanism

The algorithm was applied as follows:-

A. The problem was represented graphically according to the network diagram for each residential unit, where the activities represent the nodes and the edges represent the paths for moving between the nodes.

B. The values of the matrix (pheromone) (1) were represented at the beginning of the algorithm

C. The goal of applying the algorithm is to reduce the total completion time for each unit

D. Determine the critical path according to the conditions that included (the longest path with the shortest time and lowest cost)

E. Parameters were determined in the ant colony algorithm and the values were as follows (2 = α, 6 = β, 0.8 = ∂, p=0.5). The number of ants (10) and the number of iterations (50) were determined after trying the experimental numbers in the algorithm.

Table (4) shows the experimental numbers (random values) that were generated and that represent the times of completing the activities, which were generated based on the actual times of completing the activities shown in Table (3) for each housing unit.

Table (4) Experimental Numbers for the Housing Unit (42) Houses

N	Op1.	Op2.	Op3.	Op4.	Op5.	Op6.
1	30	30	30	30	30	30
2	31	31	31	31	31	31
3	30	30	30	30	30	30
4	31	30	31	31	32	32
5	32	32	32	32	31	32
6	31	31	31	30	31	31
7	30	30	30	30	30	30
8	30	30	30	30	30	30
9	31	32	33	33	32	33
10	30	30	30	30	30	30
11	30	30	30	30	30	30
12	30	30	30	30	30	30
13	30	30	30	30	30	30
14	31	31	31	30	31	31
15	31	32	32	30	32	32
16	30	30	30	30	30	30
17	31	31	31	31	31	31
Total	519	520	522	518	521	523

Table (4) shows that (6) possibilities were generated for the experimental numbers and after testing the possibilities, the fifth possibility (OP1) achieved the best results in terms of activity completion times and costs as shown in Table (5).

Table (5) Results of the Residential Unit (42) Houses After Applying the Ant Colony Algorithm

Code	Actual Time/Day	Actual Cost of Completion	Cost/Day	planning Time	planning Cost	Op1.	.Op1 Cost
A	30	14100000	470000	30	14100000	30	14100000
B	31	14570000	470000	30	14100000	31	14570000
C	30	14700000	490000	30	14700000	30	14700000
D	32	21120000	660000	31	19800000	31	21780000
E	32	21120000	660000	32	19800000	32	21120000
F	31	8680000	280000	30	8400000	31	8680000
G	30	7800000	260000	30	7800000	30	7800000
H	30	9600000	320000	30	9600000	30	9600000
I	33	9240000	280000	32	8400000	31	9800000
G	30	7800000	260000	30	7800000	30	7800000
K	30	9600000	320000	30	9600000	30	9600000
L	30	7800000	260000	30	7800000	30	7800000
M	30	19200000	640000	30	19200000	30	19200000
N	31	18600000	600000	30	18000000	31	18600000
O	32	5000000	156250	31	4687500	31	7932705
P	30	2700000	90000	30	2700000	30	2700000
Q	31	2790000	90000	30	2700000	31	2790000
	523	194420000		516		519	198,573,000

Table (5) shows that the time required to complete the activities according to the algorithm amounted to (519) days, which is less than the actual time of (523) and more than the planned time of (516) days. The total cost amounted to (198,573,000) dinars, which is more than the actual cost of (194,420,000) dinars, as reducing the time leads to increased costs. Figure (3) shows the project network for the residential unit (42) houses after applying the ant colony algorithm.

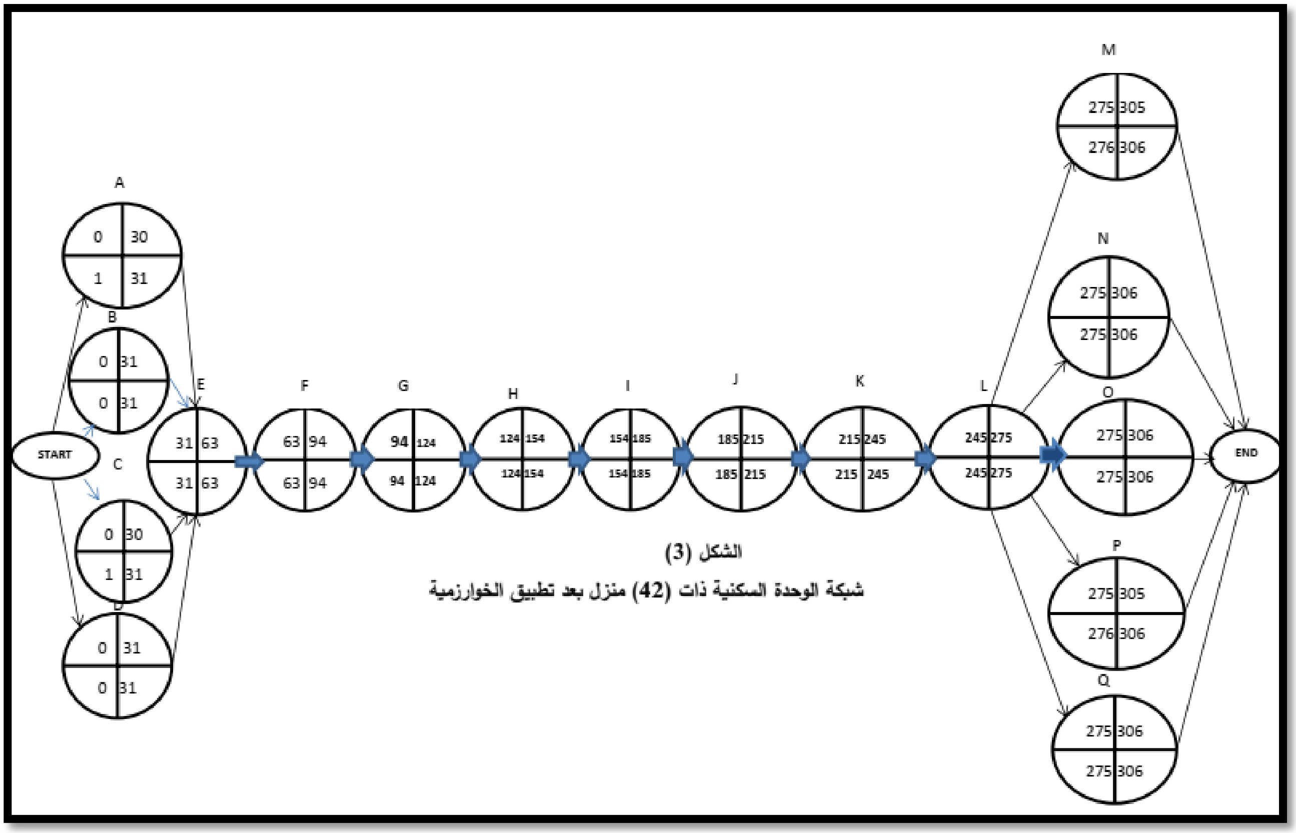

Figure (3) The Residential Unit Network With (42) Houses After Applying the Algorithm

<u>The critical path according to the algorithm is:</u>

B(31)+E(32)+F(31)+G(30)+H(30)+I(31)+J(30)+K(30)+L(30)+O(31)= 306

Thus, the critical path achieves the completion of the housing unit within (306) days compared to the critical path according to the company's method, which is (310) days, and thus (4) days were reduced.

Conclusions and Recommendations

- **Conclusions**

It includes the most important conclusions that were reached, which were as follows:

1. The activities necessary to complete the project are the ones approved in completing each housing unit.

2. It became clear that the company is working on building each housing unit separately and with the same activities required for each housing unit.

- **Recommendations**

The study recommends the following:

1. Adopting a special work schedule for each housing unit and according to the activities for each housing unit within the project.

2. Arranging activities according to priority in a way that provides the time necessary to complete each project.

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<u>Ant colony algorithm program</u>

```
clear
clc
close all
load('time.mat')
load('cost.mat')
CT=X.*C;
TC=sum(CT);
 TT=sum(X);
% Define data
tasks = {'A', 'B', 'C', 'D', 'E', 'F','G','H','I',' J ','K','L','R','M','N','O','P','Q'};
planned_duration = TT; % Planned duration for each task%
actual_duration = TC; % Actual duration for each task%
% Define task dependencies
dependencies = {[], [], [], [], {'A', 'B', 'C', 'D'},
{'E'},{'F'},{'G'},{'H'},{'I'},{'J'},{'K'},{'L'},{'R'},{'M','N','O','P','Q'},};
% Initialize parameters
num_tasks = numel(tasks);
pheromone_initial = 1; % Initial pheromone level
pheromone = ones(num_tasks, num_tasks) * pheromone_initial; % Initialize
pheromone matrix
num_ants = 10;
```

```
num_iterations = 50;
pheromone_evaporation_rate = 0.5;
% Calculate deviation heuristic
deviation = (actual_duration .* planned_duration);
 heuristic = 1 ./ deviation; % Inverse of deviation as heuristic
%
for i=1:100
    % Ant movement
    solutions = zeros(num_ants, num_tasks);
    for ant = 1:num_ants
        % Construct solution for each ant
        solution = construct_solution3(pheromone, heuristic,
dependencies,tasks);
        solutions = solution(2);
        solutions( solutions>5)=1;
    end

    % Update pheromone
    pheromone = update_pheromone(pheromone, solutions,
pheromone_evaporation_rate);

    % Track best solution
     best_solution (i,:)= calculate_durations(solutions,TT);
end
best_option=mode(best_solution);

for i = 1 : 6
    if best_option==TT(i)
        idx=i;
        break
    end
end

Z1=X(:,end);
Z2=X(:,idx);
D1= Z1-Z2;
total=Z1.*C;
DD1=D1.*C;
FinalCost= total+DD1
TotalDays= sum(Z2)
```

```
TotalCost= sum(FinalCost)
% G=GR(dependencies);
% for i = 1 : 17
% for j=1:17
%     if G(i,j)==1
%         H(i,j )= Z2(i);
%     else
%            H(i,j )= 0;
%     end
% end
% end
% graph = digraph(H, 'OmitSelfLoops');
%
% % Specify the source and target nodes
% source = 1;
% target = 17;
% shortestPath = shortestpath(graph, source, target);
%
% % Plot the graph with the shortest path
% h = plot(graph, 'Layout', 'force', 'EdgeLabel', graph.Edges.Weight);
% highlight(h, shortestPath, 'EdgeColor', 'r', 'LineWidth', 2);

s = [1 1 1 1 2 3  4  5  6  7  8   9  10 11 12  13 14 14 14  14  14 15 16 17 18
19] ;
t =  [2 3 4 5 6 6  6  6  7  8  9  10 11 12 13  14 15 16 17  19  18  20 20 20 20
20];
weights = [ 0 0 0 0 Z2' 0 0 0 0 0 ];
G = digraph(s,t,weights);
    p = plot(G,'EdgeLabel',G.Edges.Weight);
    path = longtestpath(G,1,20)
    highlight(p, path,'EdgeColor','red')
title(' Best solution by using ACO ')
```