Journal of Al-Nahrain University Vol.12 (1), March, 2009, pp.134-142 Science

TIME-CONSTRAINS PROJECT SCHEDULING PROBLEM WITH ACTIVITIES ALTERNATIVES, ANT COLONY OPTIMIZATION APPROACH

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Abstract

In this paper we handle the problem of scheduling/rescheduling project activities when there is more than one method (alternatives) available to execute the project activities, each method has its own time duration and resource requirements and also there is a dependency between the methods of execution the activities , A suggested method is presented here to deal with activities dependency and the ant colony optimization metaheuristic approach is used to find the best set of alternatives for the project activities in order to finish the project as soon as possible and identifying the critical path of the project.

Introduction

Project scheduling/ rescheduling (called scheduling in brief) is one of the most important topics in management many scheduling techniques have been developed and are widely used for projects like construction, research, maintenances,…,etc. Bar chart is one of the simplest scheduling techniques but it does not clearly show the dependency among activities specially when there is more than one method of executing the activities (i.e. alternatives) the critical path method (CPM) is also a popular scheduling technique and used in project scheduling when the duration of activities is well known, when there is uncertainty around activities duration or there is a probabilistic nature of activities duration the Project Evaluation and Review Technique (pert) is used.

A good start for the project management (or project scheduling problem) found in Rao [1] and a representation of the problem as a linear programming problem found in Phillips [2], recent directions and development of this topics found in Shih [3] Varizi [4] and Kolisch [6].

In general project scheduling is concerned with planning of activities over time subject to various constraints with the intension to reduce certain objective (cost or time), the main models for project scheduling are Kolisch [6]:

A. ***Time constrained*** project scheduling problem (TCPSP) in this model the objective is to reduce the time duration of the project (also called makes span), we make use of this models to answer questions like what is the earliest time to finish the project and if uncertainty take place in the project we use this models to find the probability of finishing the project at or before a given deadline.
B. ***Resource constrained*** project scheduling problem (RCPSP) these models concentrate on resource like budget, machines, workers,…, etc and try to reduce the cost to the minimum.
C. ***Time cost trade off models*** these models build to minimize both project duration and the over all cost.
D. ***Resource leveling models*** also known as resource leveling problem (RLP) these models search for the optimum usage of available resources and take into consideration variables like hire and fire of workers, available work space, how many project are executing at the same time and their priorities…..etc.

Problem definition

In planning phase for any project the planner (or scheduler) will always face the problem of alternatives, these alternatives may be found for the same activity when there is more than one method to execute the activity, and also found among project activities i.e. the executing of some activities will cancel (or require) the need of executing one or more activities.

Avoiding project activities alternatives from the beginning by choosing the least time or least cost alternative of each activity is not always possible for many reasons as shown below:

A. Price change during the project execution.
B. Unexpected events (storms, war, fire…etc).
C. Customer need and desire change during project duration.
D. Competition and market share considerations.
E. Progress of science and technology.
F. Maximizing profits.
G. Conflict between least cost /time alternatives.

As a result the management should always be ready to work and handle the alternatives in planning phase and also when executing the project, by saying the management should be ready we mean that:

A. The management listed all available alternatives for each activity in the project.
B. Collect the full information of each activity alternatives (time, cost, …,etc).
C. The dependency among activities of the project should be clear and understood by the management, and down in detail until the alternatives level.

In brief the problem here is to find the best feasible set of alternatives of project activities such that the project finished as soon as possible. This problem rise in two main places:

A. After the first draft of the project network and planning moves from general to details.
B. During the project execution and especially when there is a need for rescheduling.

Activities Relations

In addition to the known relations (before/after) among activities of project there are other relations that should be considered when handling activities with alternatives, we will explain these additional relations (known also as activity dependency) with a suggested notation to represent them on the project network and we will also use the activity on arc (AoA) to represent the project network Bartk [5]:

A. ***mode alteration*** this relation corresponds to change of time and/or resource requirements associated with changing an activity by it's alternatives for example we note in Fig.(1) bellow that activity (b) has two alternatives and activity (c) has three alternative.

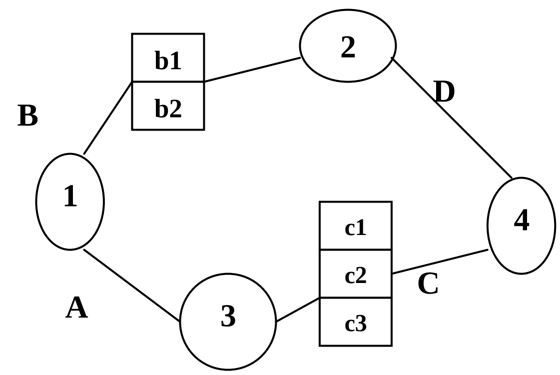

Fig. (1) : The Rectangular Shape Used As Annotation for The Mode Alteration Relation.

B. ***Insertion/removal relation*** This relation shows the dependency whenever activity (i) is considered dependent on activity (j) if (j) has to be executed whenever activity (i) is scheduled for example activity (b) many have two alternatives (b1 and b2) but (b1) is dependent on execution of activity (c1) while (b2) is not, this relation need not to be represented on the network diagram of the project but should be represented in the activity information table this is achieved if we add two columns to the usual activities information table these columns are (Must column & Forbidden column) so for the above example we can list the information table of activity (b) as shown below.

Table (1)
Represent Must / Forbidden Relation between the Alternative Activities b1, b2, c1, c2 and c3.

Activity	General information about time, cost and before / after relation	Must	Forbidden
b1		c1	
b2			
c1		b 1	
c2			b 1
c3			b 1 ,b 2

The must column shows which alternatives should be executed while the forbidden column pointed which alternative should not so. Table (1) above shows that activity (c1) can not be executed unless we first execute activity (b1), and activity C2 should be cancelled or removed from our calculation if we execute activity (b1) executing activity (c3) means that we cancel all the alternatives of activity (b i.e. both b1 and b2) to handle this case we change activity (b) to a dummy activity, so it is a good idea to assume always the first alternative of any activity a dummy alternative.

C.*Partial order change* This relation can be described by alternative sequence of (before/ after) relation between activities alternative for example in a sequence a, b, c and d with two alternatives for b i.e. (b1 and b2) and d i.e. (d1 and d2) the original sequence may be (a,b1,c,d1) and the alternative (a,d2,c,b2) this relation can be handled easily with the suggested method described in insertion/ removal relation. i.e. (Must/ Forbidden) and treated as a special case ,the network of the above example is shown bellow in Fig.(2).

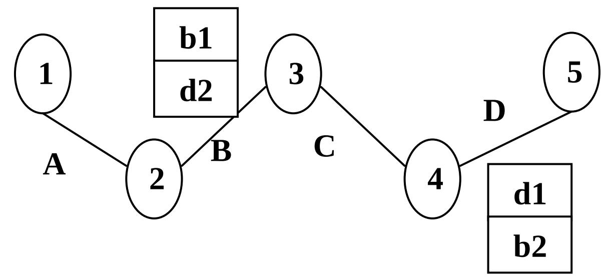

Fig. (2): Representation of Partial Order Change Relationship between Project Activities and Their Alternatives.

From Fig.(2) above we can see that activity between nodes 2&3 may be (b1 or d2) and activity between nodes 4&5 may be (b2 or d1), and suppose we have the following project activity information Table:

Table (2)
Project Information Table for Network of Fig (2).

Acclivity	Must	Forbidden
a		
b1	d1	b2
b2	d2	b1
c		
d1	b1	d2
d2	b2	d1

The sequence of activities might be (a, b1, c, d1) or (a, d2, c, b2) so we change the sequence of activities when we go down to alternative level.

D. ***The serialization / parallelization*** This relation of operations is based on two or more alternatives with different precedence relation associated with each alternative, as in Fig.(3) shown bellow:

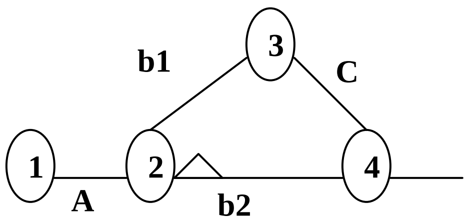

Fig. (3) : The Serial/Parallel Relation.

The relation of activities between nodes (2) and (3) is that we can execute alternatives (b2) or (b1) but (b1) need to execute another activities (c) in serial ,this relation can be described as parallel execution of alternatives (b2) and (b1 plus activity c in serial).

We think it is a good idea to pinpointed the parallel alternatives this can be archived by replacing a small triangle to the right of the node where parallel alternatives emerged and put into this triangle the number of the parallel operation in case there are more than one serial/parallel relation in the project so one can easily notice them, we can notice also that without the serial activity we have the mode alteration relation described earlier.

It is important to notice that when dealing or scheduling activities with alternatives for a given project require no change to take place in the network representation of the project, and if changing take place then we are no more working with activities alternatives but instead we work with scheduling alternatives.

The solution Method:

The solution of project scheduling problem with time constrained consists of:

A. Finding the best alternative for each activity that minimize the time duration of the project.
B. Checking that the selected alternatives are feasible and there is no conflict between these alternatives.
C. Finding the critical path as in the usual project scheduling problem.
D. Finding the estimated time of finishing the project.

By tracking the literature Shih [3], Kolisch [6] we find that the project scheduling problem (PSP) defined as a combinatorial problem, NP-hard so we do not expect to find solution in polynomial time and many researchers use the simulation or the metaheuristic methods to find the critical path and time duration of the project, in our problem (activities with alternatives) the problem become more complex but still a combinatorial optimization problem and NP-hard.

We will use ant colony optimization metaheuristic to solve the problem and find the best feasible set of activities alternatives, the critical path and the time to finish the project.

Ant colony optimization

Ant colony optimization (ACO) is rather a new metaheuristic introduced in the early nineties Dorgio[7] and has successfully been applied to several combinational optimization problem.

The behavior of real ants when searching for food was the main motive for the search of new strategy to solve the combinatorial optimization problem that is known as ant colony optimization. Real ants are able to communicate information concerning food sources via what is called pheromone, depending on the distance and the quality of the discovered food source, they mark the path leading to that food source by laying down varying quantities of pheromone other ants observe pheromone trial and are attracted to follow it thus the path is marked again, reinforced and will attract even more ants to follow the trial paths leading to close ,rich food source, and it will be more frequently used and there fore the pheromone trials on such paths will grow faster. The described behavioral process of real ant colonies is used to solve the combinatorial optimization problem using simulation with artificial ants, and instead of searching their natural environment for food artificial ants search the solution space in order to generate high-quality solutions. The objective valves correspond to the quality of the food sources and an adaptive memory is the analogy of the pheromone trial.

To navigate through the set of feasible solution artificial ants are able to use a local heuristic function and for more details about ants colony optimization metaheuristic the reader is referred to Dorgio [8].

Generally speaking the (ACO) algorithm consists of four main steps which are:

A. ***Initialization*** where the initial or setup value of pheromone is assigned to each permissible path, the number ants to be used is initialized, the way they move from paint to paint is fixed ,total number of iterations is fixed, and the evaporation rate is also fixed.

B. ***probability calculations*** In this step the probability that an artificial ant will choose any one of the permissible path is calculated using the following formula

$$p_{ij}^{n} = \frac{[ph_{ij}^{(n-1)}]^{a}[Y_{ij}]^{b}}{\sum_{j=1}^{J}[ph_{ij}^{(n-1)}]^{a}[Y_{ij}]^{b}} \quad \text{.......................(1)}$$

Where

p_{ij}^{n} the probability that artificial ant found at point (i) will choose the path (j) in the iteration (n).

ph_{ij}^{n} the net pheromone value found in route or path (ij) at the end of iteration (n).

y_{ij} this is an index of how good is the food in the route (ij).

a ,b control variables which determine the relative influence of pheromone trial (ph_{ij}^{n}) and heuristic information (y_{ij}), so when a=0 we depend on heuristic value only but when b=0 we depend on pheromone information only.

C. ***Path Assignment*** in this step and after we calculate the probability that an artificial ant will choose one of the paths, we force the artificial ant to select a path from it's standing point (i) to a new point (j), this done by generating a random number [0,1] and the corresponding path is assigned as in Monte Carlo technique.

D. ***Pheromone Update*** after we force the artificial ant to choose and walk through a path in step (3) above the amount of pheromone assigned to that path is recalculated using the following equation.

$$ph_{ij}^{n} = (1-v)\,ph_{ij}^{n-1} + T^{n} \quad \text{..............(2)}$$

the above equation consist of two parts the left one $(1-v)ph_{ij}^{n-1}$ deals with the evaporation rate of pheromone where 0<v<1 we make this evaporation process in order to remove the early result of calculations, the second term T^{n} consist of adding pheromone by an amount (T) which depend on the food found by artificial ants at the end of iteration (n). The evaporation term applied to all permissible paths that artificial ants can use while the pheromone addition applied only to the selected path by artificial ants in the last iteration.

Ant Colony Optimization for Project Scheduling

In this section we will show how can we applied the ant colony optimization metaheuristic to project management with activities alternatives, the main idea is to allocate an artificial ant to each activity and forcing this ant to choose one of the available method to finish the activity so that at the end we will have a set of alternatives for project activities, if this set is feasible then we will continue as usual and calculate the project finish time and compare it with best previous results and if the new set of alternatives is better (less project duration time) then we fixed it as the best found (yet) set of activity alternatives but if not we simply neglect it, in both cases above the pheromone update calculations carried out and the new valves of pheromone will be used in the next iteration until the predefined number of generation (iteration) is reached, the best value found will be considered the solution.

If the set of activity alternatives was not feasible this may be due to violation of (must /forbidden) relation explained earlier we simply neglect the result of this iteration and go to step one without increasing the counter of iterations.

The main steps of calculation can be summarized as bellow

A. ***Initialization***

In this step we set values for:

I. Number of ants =number of activities =k.
II. Number of ants at any node = number of activities emerging from that node.
III. Initial value of pheromone to each alternatives = (**T_0**).
IV. Number of iterations.
V. Value of evaporation rate v.
VI. Control variables a &b

B. ***Probability Calculations***

At this step we find the probability that an artificial ant (k) allocated to activity (i) will choose the alternative (j) to execute this activity and use the ph^{n}_{kij} notation to represent it and since the number of ants will always equal the number of activities then we can simplify the notation to ph^{n}_{ij} and (n) will represent the iteration number, then ph^{n}_{ij} will no more represent the probability that an ant will go from point (i)to (j) but will mean probability that ant (i) will choose method (j) to execute the activity (i). Equation (1) will be used with

$$y_{ij=1/d_{ij}} \quad \text{..(3)}$$

Where d_{ij} is the duration time of activity (k) when using alternative method (j) to complete it.

C. ***Path Assignment***

We assign an artificial ant to each activity this artificial ant have to decide which alternative should be used to finish this activity, at the same time it should mark use of previous iterations information this is done by the a mount of pheromone previous ants laid is each possible path. A random number between [0, 1] is generated and by using Monte Carlo technique the ant choose the alternative for each activity.

D. ***Pheromone Update***

By combining the alternatives chosen by the ants we construct a project network, if there is no conflict between the chosen alternatives the project can be treated in the usual way and we can find the project finishing time (project makes pan) and. By comparing the result of this set of alternatives with best set that found previously we can either use this set if it is best or neglect the result if it's not best than the previous, in both cases the pheromone trial update take place using equation (2), and T will be the inverse of the total project duration. But if there was a conflict or (infeasibility) between the set of alternatives chosen by artificial ants such as must relation or forbidden relation didn't satisfied the whole iteration neglected and we regenerate another set of random number between [0, 1].

One can list the following main advantageous of the suggested method and modified model of project scheduling

A. More general model has been build, and by taking one alternative only for each activity we will have the usual project scheduling network..
B. Ability to take more options into consideration when calculating project duration (planning phase), analysis., and when monitoring the project execution
C. By introducing the ant colony optimization metaheuristic we over come the problem of NP_hard which associated with combinatorial optimization.
D. More flexibility available for the management if unexpected events happen so it can react more quickly and correctly.
E. More general software can be build and easily updated with new alternatives and their necessary time and dependency relations with other activities / alternative

Example

Suppose we have the following project that consist (5) activities (A, B, C, D and E) each with alternatives and must/forbidden relation shown is Fig. (4) and Table (3).

In this project activity (A) represent ordering time of three machines for a manufacture, these machines can be single phase (alternative a1) or three phase electricity machines (a2). Activity (B) represent type of basement should be build for machines (b1 for ordinary, b2 for iron enforced and b3 for double layer). Activity (C) represent how to wiring the electrical circuits in the manufacture alternative (c1) represent the single phase wiring option and (c2) the 3 phase option, it is clear that alternative (c1) associate with single phase machine only (a1) and wont work with three phase machine(a2) and this constraints represented in the (must / forbidden) columns of Table (3) for alternative (c1), also we note that alliterative (c2) dose not has this constraints since wiring the manufacture with three phase will allow both machines type to work properly. Activity (d) represents the action of checking the wiring system of the manufacture which can be through method (d1 or d2). At last activity (E) represent the time needed to get the workers ready to work on machines, these workers of two types low skill (e1) which can work only on single phase machine, and high skill workers which can operate three phase machines (e2), we see there is a dependency between activities (A & E) this dependency and its effect on project scheduling listed in (must/forbidden) columns of activity (A).

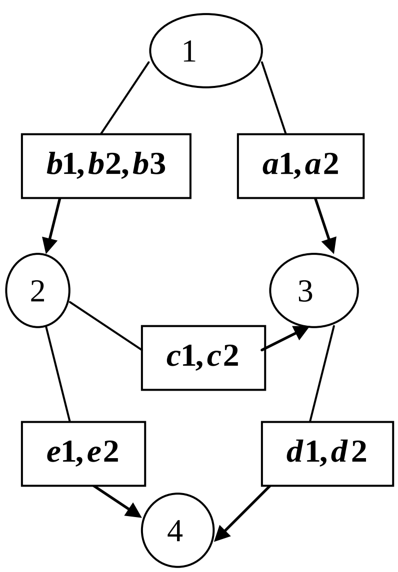

Fig. (4): The Example Project Network.

Table (3)
Project Information Table.

Activity	Duration	Must	Forbidden
a1	10	e1	
a2	15		e1
b1	5		
b2	7		
b3	8		
c1	6	a1	a2
c2	8		
d1	4		
d2	3		
e1	5		
e2	2		

A**. Initialization**

I. Number artificial ants = number of project Activities =5.
II. The following table show number of ant at each node of the project = number of emerging activities of that node.

Table (4)
Distribution of Artificial Ants on The Project Nodes.

Node	Number of artificial ants
1	**2**
2	**2**
3	**2**
4	**zero**

III. $\mathbf{T_0}$ = initial pheromone =10 i.e.
$ph_{a1} = ph_{a2} = ph_{b1} = \cdots = 10$.
IV. Total number of iterations=100.
V. Evaporation rate **V=**0.1.
VI. a=b=1.0

B**. Iteration (1)**

I. **Probability Calculation**

Table (5)
Probability Result for Iteration (1) When Applying Equation (1).

alternative	probability
a1	**0.6**
a2	**0.4**
b1	**0.427**
b2	**0.305**
b3	**0.267**
c1	**0.571**
c2	**0.429**
d1	**0.429**
d2	**0.571**
e1	**0.282**
e2	**0.715**

II. ***Path Assignment***

With following set of random numbers (0.918, 0.629, 0.717, 0.617, 0.089), we find the artificial ants choose the following alternatives to finish the project (a2, b2, c2, d2, e1).

This set alternative don't violate any must/forbidden relation shown in Table (3), so it will be accepted and the earliest time of finish the project can be found to be (18) days.

III. ***Pheromone Update***

By using equation (2) the pheromone can be updated and the result shown in Table (6) bellow:

Table (6)
The Pheromone After Updating It.

Alternative	Pheromone
a1	9
a2	9.056
b1	9
b2	9.056
b3	9
c1	9
c2	9.056
d1	9
d2	9.056
e1	9.056
e2	9

After that we go back to probability calculation step and repeat the calculations until the (100) iteration carried out, then the best solution (the minimum project make span) can be considered as the best or optimum solution and the set of activity alternatives that lead to the optimum will be considered as the optimum alternative set.

Using other techniques like decision tree or dynamic programming one can find the optimum solution for this simple example is (14) days and the optimum set of alternatives is (a1, b1, c1, d2, e1) which we found in the 4th iteration.

Conclusion and Future Work

In this paper we take the well known problem of project scheduling but under the assumption that activities (all or some of them) have many method of execution which we called in brief alternatives, also there is a relation between these alternatives which we call the must /forbidden relation that should be satisfied to finish the project, we show first how the information of must/forbidden can be added to the project network and to the information table.

We suggest also a solution method for this combinatorial optimization, NP- hard problem based on ant colony optimization metaheuristic.

We suggest following direction for further work:

A. Studying the effect of changing the value of a and b.
B. Trying advanced metaheuristic algorithms like simulated annealing or max-min ant colony optimization.
C. Studying the resource constrain project scheduling problem with alternative activities.

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الخلاصة

تم هنا تناول مشكلة جدولة/ اعادة جدولة للمشاريع التي تتألف من فعاليات تتوفر لها اكثر من طريقة لتنفيذ تلك الفعاليات (بدائل) ولكل طريقة زمنها وكلفتها الخاصة بها، تم اقتراح طريقة لتمثيل تلك البدائل واستخدام اسلوب مستعمرة النمل لايجاد افضل مجموعة بدائل بهدف انجاز المشروع باقصر وقت ممكن وتحديد المسار الحرج.