Construction project planning using integration of crashing and concurrency techniques

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Abstract. Construction Project planning process is considered an essential area in the field of organization and implementation of projects, particularly those needing coordination, great effort and long implementation time. Moreover, project managers are focusing on achieving predetermined objectives. This paper aims to attain certain objectives; cost, time, and number of labourers, in a way that reaches the best satisfied results depending on the importance of each objective. A multi-objective model construction based on project planning in two techniques; crashing technique and concurrency is presented, additionally a new proposed mixed technique titled as Concurrency Partitioning with Crashing Techniques (CPCT). The proposed model is implemented on a Substation of Electrical Power for Transformation plant as a case for studying. The suggested mixed approach (CPCT) provides more desirable results with the multi-objective problem, where both project time and cost are decreased by 19.5% and 2.6%, respectively, while the total number of labourers is increased by 8.8%

1. Introduction

With the progress of project and when more issues start to happen, project management becomes a significant necessity. This process management may meet possible restrictions, which may have their effects on attaining particular objectives. Accordingly, it is important for project manager to make predetermined scheduling and plan processes for project activities.

In other words, each project has specific objectives to be satisfied, like time, cost, scope, resources and performance. Projects might fulfil single or multi-objective through planning, scheduling and control processes. For project management, following are some of the planning techniques and tools:

- Gantt chart: is the most familiar technique used for project scheduling (Jun-yun 2012). It is a graphical project scheduling tool through which the time of performing a certain activity could be determined. It represents each activity as a horizontal bar beginning with its start date to its end date. Hence, this chart is used to depict a project schedule against a calendar (Maley 2012).

- Critical Path Method/Program Evaluation and Review Technique (CPM/PERT): are the most important planning techniques used to assist project administrator in the process of evolving a representative timetable as well as to monitor project progress. The two tools are closely related to each other (Hillier 2012). Using CPM, the project duration could be reduced in a less costly way, hence the project could be accomplished by a due date or in the shortest time. PERT provides a way to estimate the possibility of completing a project in a certain date, by considering only the critical path regardless of all noncritical paths that could become critical (Nicholas and Steyn 2017).
• Crashing Technique: crashing refers to compression of activity duration (Badiru, Badiru, and Badiru 2007). Crashing technique is a compression technique used in project scheduling. This technique includes reducing the overall time of project preparation related to any activity by taking number of options and analysing them to determine a way of getting maximum compression time of schedule for the minimum added cost. Decreasing the time of schedule activity and increasing the resources assigned are some of the approaches used for crashing a project schedule (Badiru, Rusnock, and Valencia 2016).

• Concurrent Engineering: is a systematic technique that merges the main ideas of a project applied in research, design, production, development, marketing, distribution, and sales. This method yields more effective and shorter design cycle while keeping product reliability and improves its quality by compressing the schedule to permit simultaneous or overlapping performance of many activities (Angus, Gundersen, and Cullinane 2000).

2. Literature Review
Some of the previous studies dealt with project planning and project objectives achievement using different techniques for planning and scheduling. However, in this research, two techniques are combined together to produce a new planning approach. Pollack-Johnson and Liberatore (2006) extended the problem of time-cost trade-off, where each task was specified by three goals; quality, cost and time. A mixed integer using linear programming model with goal programming is used (Pollack-Johnson and Liberatore 2006). Hebert and Deckro (2011) combined contemporary and traditional project management techniques to resolve the problem of scheduling in slab construction project. The contemporary technique is represented by Microsoft project while the traditional technique used is a linear programming model for time-cost trade-off problem (Hebert and Deckro 2011).

Xu and Hua (2011) utilized the time-cost trade-off curve from a proposed crashing algorithm to determine the change of cost with the change of time (Xu and Hua 2011). Kim et al. (2012) proposed a mixed linear programming model that takes into account the potential quality loss cost (PQLC) that occurs in time-cost trade-off problems for extreme crashing of activities (Kim, Kang, and Hwang 2012).

Lee et al. (2015) presented an advanced stochastic time-cost trade-off (ASTCT) method for analysing the problem of time-cost trade-off based on CPM-guided genetic algorithm (GA) (Lee et al. 2015). Haj and Sayegh (2015) offered a nonlinear integer programming model for solving a problem optimization associated within time-cost trade-off by considering an impact of whole loss float (Haj and Sayegh 2015). Koo et al. (2015) introduced an integrated model of multi-objective optimization for solving the time-cost trade-off problem in construction project (Koo, Hong, and Kim 2015). The study used pareto front concept for providing the optimal solution set.

Lee et al. (2017) developed a project management model for creating a renewable energy plant. Total duration time under normal condition and Aggregate project cost are calculated using PERT technique. (Lee, Kang, and Huang 2017). Zareei (2018) applied CPM technique for analysis of biogas plant construction project. (Zareei 2018).

3. Proposed Model
The suggested model presents an approach for solving multi-objective problem using the previously mentioned project planning techniques and tools. The framework involves four steps as shown in figure 1.

3.1. Step one: Scheduling Defining and Inputs for Planning
In step one data definition of the case is included, which are: Activities series; Symbol of action (where = (1,2, 3, …, )); Duration of activity; Precedencies of activity; Cost of activity; Cost of material; the
Indirect Cost for a day; the Direct Cost for a day; the Employee salary for a day; Equipment Charge for a day; Estimation for the budget of the plant; Duration of plant; Laborers activity’s Figure: unskilled, skilled practical, engineer; Working Duration in days for equipment and laborers associated with the category of the job; working time per day per shift; Total Plant Duration; Total Cost of Plant; Total count of Laborers figure.

Figure 1. The proposed model

3.2. Step two: Plant Planning Objective Identification

Generally, each project targets to attain one or several objectives such as number of laborers, performance, quality, time, cost and resources. In this research, the objectives taken are time, cost and number of laborers.

3.3. Step three: Inputs Representation Using CPM Network and GANTT Chart

GANTT chart and Critical Path Method are used for project activities representation and according to the steps shown in figure 2. Symbols and equations shown below are used to calculate total time, cost, and number of laborers for the project.

\[ TW_j = L N_j L W_j / d W_D \]  
(1)

where \( L N_j \) is the Number of Laborers related with the type of job; \( L W_j / d \) is the Laborer Wage per day related with the type of job; \( W_D \) represents the figure for Working Duration for equipment or laborers associated with the form of job.

\[ \sum_{i} (SW_j) = \sum TW_j \]  
(2)

\[ (TE) = EN_j ER_j / d WD \]  
(3)

where \( EN_j \) is the Number of Equipment and \( ER_j / d \) represents Equipment Rent per day.

\[ \sum (SC) = \sum TE \]  
(4)

\[ (DC_{/ i}) = SW_j + SC + MC_{/ i} \]  
(5)
where $MC_i$ represents Material Cost.

Regular Employees and Equipment Fee ($LEC_{ni} = SW_j + SC$) (6)

The Indirect Price per Activity $IC_{i/d} = IC_i D_i$ (7);

where $D_i$ represents Duration of activity.

Direct and Indirect Cost per Activity ($DI_{i} = DC_{i} + IC_{i}$) (8)

Whole Cost of Project ($TC = \sum DI_i$) (9)

Whole Laborers Number for CPM ($TL_{CPM} = \sum LN_{i}$) (10);

where $LN_{i}$ represents the Laborers Number per activity: unskilled, skilled, technical, engineer.

Figure 2. steps of Critical path, laborers number and cost calculation

3.4. Step four: Applying of Techniques for Project Evaluation

The Technique of Crashing: The primary stages for the technique of crashing are depicted in figure 3. Symbols and equations shown below are used to calculate the total of the predefined objective for the project after crashing the critical activities.

$Nt_i$: Normal time per activity

$Ct_i$: Crashing time per activity

$Nc_i$: Normal cost per activity
Crashing cost per activity

\[ Cc_{i} \]  
Change in Time per Activity \( (\Delta T_{i}) = Nt_{i} - Ct_{i} \) \hspace{1cm} (11)  
Change in Cost per Activity \( (\Delta C_{i}) = Cc_{i} - Nc_{i} \) \hspace{1cm} (12)  
Cost Slope per Activity \( (CS_{i}) = \Delta C_{i}/\Delta T_{i} \) \hspace{1cm} (13)  
Indirect Project Cost \( (IPC) = PD_{new}C_{d} \) \hspace{1cm} (14);  
where \( PD_{new} \) is the New Duration of project, and it is calculated through the critical path of the crashed activity. \( IC_{d} \) represents the Indirect Cost per day.  

Project Direct Cost \( (DC) = \sum DC_{i} \) \hspace{1cm} (15);  
where \( DC_{i} \) is the Direct Cost per Activity.  

Change in Time of the New Activity \( \Delta T_{n} \)  
Cost Slope of the New Activity \( CS_{n} \)  
Crashing Cost Slope of each critical crashed activity; where \( Cc_{slope/i} \) for the first critical crashed activity that has the minimum \( CS_{i} \) is calculated as:  
\[ Cc_{slope/i} = \Delta T_{i}/CS_{i} \] \hspace{1cm} (16);  
where \( \Delta T_{i} \) and \( CS_{i} \) represent the change in time and cost related with the first critical crashed activity respectively. For the rest activities:  
\[ Cc_{slope/new} = Cc_{slope/i} + (\Delta T_{n}CS_{n}) \] \hspace{1cm} (17)  
Total Project Crashed Cost \( (TC_{c}) = DC + IPC + Cc_{slope/i} \) \hspace{1cm} (18)  
Number of Employeess after crashing \( (TL_{crashed}) = TL + TL_{a} \) \hspace{1cm} (19);  
where \( TL \) is the Total Number of E and \( TL_{a} \) is the Laborers Number added for each activity.  

Equipment Figure is to be add to every action  
Equipment and Employeess Cost after Crashing \( (LEC_{c}) = SWj + SC \) \hspace{1cm} (20);  
where \( SWj \)is the Sum of Laborers Wage and \( SC \) represents the Sum of Equipment Cost.  

Concurrent Method after Separating (CP): Together, concurrency method and Gantt chart are applied in project planning process; wherever an overall plant implementation duration is decreased within the plan and implementing some of plant actions in a concurrent manner and past separating selected actions, with no impact on the remaining actions concerning the pre actions, then implementation duration. The actions are then implemented with their predetermined duration. Figure four illustrates steps of this technique. The total number of laborers for concurrency technique with partitioning \( TL_{cp} \) is calculated as follows:  
\[ (TL_{cp}) = (\sum TL + TL_{a}) \] \hspace{1cm} (21)
Figure 3. Crashing technique

Figure 4. (CP) method block diagram
Concurrency-Partitioning and Crashing Technique: in this paper, a new approach is suggested that combines two techniques, concurrency and crashing after partitioning some of project activities. This method is named as Concurrency-Partitioning and Crashing Technique (CPCT), where the main steps are illustrated in figure 5.

4. Model Implementation
The suggested method is implemented applied on the Substation of Electrical Power Transformation plant as an application. The following objectives are considered as objectives for the process of project planning (possible cost, duration and laborers minimization). Budget of the plant was 4,613 MIQD, involving the elements of direct price of 3,855 MIQD, but the indirect price of 1 MIQD/ day. The scheduled duration for the plant is seven hundred and fifty eight days, but number of labourers is six hundred and thirty two within 6 hours for work in a day for 7 working days in each week. The table 1 displays, in detail, the needed data for all actions. Another data is shown in table 2 including laborers’ competence and their wages per day, type of equipment and the payments for each day, engaged in the plant.
Table (1): Activities Cost and Duration

| Ai | D_i - Day | LECn - MIQD | MC_i - MIQD | IC_{i,d} - MIQD |
|----|-----------|-------------|-------------|----------------|
| A  | 92        | 46,800      | 231,365     | 1              |
| B  | 61        | 29,350      | 155,085     | 1              |
| C  | 334       | 170,900     | 464,066     | 1              |
| D  | 31        | 11,470      | 47,464      | 1              |
| E  | 122       | 46,025      | 7,945       | 1              |
| F  | 120       | 63,000      | 110,475     | 1              |
| I  | 122       | 63,150      | 245,250     | 1              |
| J  | 365       | 59,700      | 5,835       | 1              |
| K  | 122       | 63,150      | 148,875     | 1              |
| L  | 92        | 48,900      | 164,473     | 1              |
| M  | 31        | 15,825      | 56,072      | 1              |
| N  | 61        | 31,940      | 45,160      | 1              |
| O  | 62        | 21,400      | 17,150      | 1              |
| P  | 62        | 47,590      | 68,060      | 1              |
| Q  | 31        | 9,145       | 30,036      | 1              |
| R  | 30        | 8,850       | 29,069      | 1              |
| S  | 61        | 28,975      | 9,575       | 1              |
| T  | 31        | 9,765       | 9,510       | 1              |
| U  | 91        | 33,565      | 159,185     | 1              |
| V  | 31        | 45,775      | 3,202       | 1              |
| W  | 30        | 44,950      | 2,448       | 1              |
| X  | 61        | 31,415      | 7,135       | 1              |
| Y  | 30        | 33,900      | 35,490      | 1              |
| Z  | 30        | 33,900      | 23,925      | 1              |
| A1 | 30        | 11,850      | 7,425       | 1              |
| B1 | 30        | 35,800      | 2,119       | 1              |
| C1 | 31        | 36,470      | 2,711       | 1              |
| D1 | 30        | 35,800      | 2,711       | 1              |
| E1 | 31        | 36,470      | 2,711       | 1              |
| F1 | 61        | 17,995      | 66,815      | 1              |
| H  | 31        | 10,075      | 16,910      | 1              |
| J1 | 61        | 25,315      | 13,235      | 1              |
| K1 | 92        | 64,400      | 50,060      | 1              |
| L1 | 92        | 50,060      | 10,750      | 1              |
| M1 | 31        | 8,525       | 10,075      | 1              |
| N1 | 59        | 16,520      | 41,305      | 1              |
| O1 | 59        | 27,140      | 140,630     | 1              |
| P1 | 91        | 18,655      | 620         | 1              |
| Q1 | 121       | 47,075      | 10,750      | 1              |

Table (2): Information of Laborers and Equipment

| Laborer                      | LW_{j,d} (IQD) | Equipment       | ER_{j,d} (IQD) |
|------------------------------|----------------|-----------------|----------------|
| Engineer                     | 75,000         | Shuffle         | 100,000        |
| Technical                    | 40,000         | Lorry           | 100,000        |
| Skilled Laborer/Building     | 100,000        | Steamroller     | 100,000        |
| Skilled Laborer/Reinforcing, | 50,000         | Autotransporter | 450,000        |
| timber,Concrete              |                |                 |                |
| Skilled Laborer/Finishing    | 35,000         | Winch           | 400,000        |
| Unskilled Laborer/ all       | 25,000         | Crane           | 2,250,000      |
| specializations              |                |                 |                |

4.1. Crashing Technique

Using crashing technique, the smallest cost and time are determined by crashing the actions for the six hundred and twenty three days and 4,524,840 MIQD correspondingly. Overall required number of laborers are calculated according to the steps mentioned in figure 3, and they were 677 laborers.
4.2. The Technique of Concurrent actions with Separating (CP)

Next to concurrency, partitioning, with overlapping processes in some activities, total project duration is 697 working days; overall price is 4,552 MIQD, while the total number of laborers is 646.

4.3. Concurrent Separating and Crash Procedure (CPCT):

Proposed approach (CPCT) is applied as stated in the flowchart in figure 5 by using concurrent method with the associated network and GANTT chart. Crashed cost with time are calculated for the divided activities. Duration is six hundred and ten working days and price is 4,492,465 MIQD. Implementing remain stages of the block diagram in figure no. 5, total number of labourers required is six hundred and eighty-eight.

Table no. 3 shows the variance of the plan for the plant considered by Critical path method, then proposed mix method (CPCT) that is found to be best of the further applied plants planning methods.

| Methods | Time (days) | Cost (MIQD) | Laborers No. |
|---------|-------------|-------------|---------------|
| CPM     | 758         | 4,613       | 632           |
| Crashing| 623         | 4,524,840   | 677           |
| CP      | 697         | 4,552       | 646           |
| CPCT    | 610         | 4,492,465   | 688           |
| % of Change from the original plan | 19.525 | 2.612 | 108.860 |

5. Conclusions and recommendation

This research presents a model that makes use of multi method for plant scheduling with planning for attaining multi objective. Three techniques are applied including CPM, crashing, and concurrency technique with partitioning, in addition to a new suggested mixed approach. This approach combined concurrency technique with partitioning and crashing technique, and it is called as Concurrency-Partitioning and Crashing Technique (CPCT). The results have shown that the suggested mixed approach (CPCT) provided more acceptable results compared with the other techniques; where both project time and cost have decreased by 19.5% and 2.6%, respectively, while the total number of laborers has increased by 8.8%. For future work, further objectives are to be considered like resources, risk in addition to quality besides assumed goals. Also, additional planning with scheduling techniques could be applied.

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