



Optimizing the Duration of the Construction Projects in Egypt by Using Goal Programming

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ملخص البحث

تعتبر الطرق الحالية التي تتعامل مع مشكلة الوصول الى الحلول المثلى للزمن والتكلفة المقابلة لا تعبر عما يجري على ارض الطبيعة في المشاريع التنفيذية وتركز فقط على العوامل التقليدية المباشرة في الوصول للزمن والتكلفة المثالية. الغرض من البحث هو خلق وتطوير نموذج حسابي يأخذ في اعتباره العديد من العوامل التي تؤثر على زمن وتكلفة المشروعات التنفيذية مثل علاقات الانشطة ببعضها البعض وقيود خارجية لبعض ازمدة الانشطة والمعوقات والتحديات للانتهاء من بعض الانشطة في ازمدة محددة بالإضافة الى المكافأة والغرامات. الغرض هو دراسة هذه المشروعات مع الاخذ فب الاعتبار العوامل المذكورة بالأعلى والتي لم يتم اخذها من قبل فريق العمل الذي عمل بإنشاء البرنامج الزمني والتكلفة لهذه المشاريع. الطريقة المطروحة هي تطوير نموذج حسابي عن طريق فرض علاقة خطية في البرمجة وتنتج عنها الحلول المثلى للزمن والتكلفة باستخدام طريقة برمجة الهدف وهي البحث في اقل الحلول انحرافا عن الهدف سواء كان التكلفة او الزمن. مع تحليل والحكم على النتائج نستنتج انه يمكن التطبيق بالمشروعات التنفيذية في الحياة العملية. النموذج الحسابي اثبت ان هذه العوامل تؤثر على زمن وتكلفة المشروع والوصول لحلول أكثر واقعية وايضا في الوصول للحلول المثلى في البحث عن كل الاحتمالات الممكنة. متخذي القرار سيستطيع قراءة المنحنيات المنتجة من البرنامج في البحث عن حلول بديلة ومدى تأثيره بالمشروع من حيث الزمن والتكلفة ومدى انحرافه عن الحل المستهدف وهل يوجد حلول أفضل من الحل المستهدف ام لا. لقد تم دراسة مشروعان، الاول عبارة عن تطوير طريق قائم بحارتين مروييتين الى اربعة حارات ممرورية، اما الثاني هو انشاء مبنى السفر رقم ٣ بمطار القاهرة الجديد او ما يسمى بمبنى الرحلات الموسمية.

Abstract

Existing methods dealing with the time– cost trade-off problem, which is encountered in project planning, have focused on the solution of a basic problem that does not adequately represent actual engineering projects. The aim of this thesis is to develop a mathematical solution method considering additional realistic project characteristics such as generalized activity precedence relations and external time constraints and milestones for particular activities and also bonuses and penalty costs. The idea of the thesis is to develop a model to study all different factors as mentioned above. The construction management team for both projects already performed crashing analysis to reach optimum cost corresponding to the desired time. The construction team didn't take into their consideration all the factors mentioned above. The proposed method is formulated as a linear/integer program and provides the optimal project time– cost curve and the minimum cost schedule by using goal programming by looking for the minimum deviation from the target either time or cost. Evaluation results indicate that the method can be reliably applied to engineering projects. The proposed model proofed that it can be very useful in construction projects to find better solutions for crashing the activities. Solution curves also been generated to help the decision makers for taking the right decision and see how flexible they are in extending and reducing the time of the project and its corresponding cost. Two projects have been studied; first one is a project of upgrading an existing two-lane undivided highway to a four-lane divided motorway

with controlled traffic access. The second one is Construction of Cairo Airport terminal building 3. All decision makers will be able to see how each solution deviates from the target of the client in both time and cost. In our case any positive deviation means more than the target which means more days and more cost, so we are targeting in our model to find the minimum deviations from the target, which means any negative deviation means less time and cost than the client even wants and saves for him time and cost.

1. Introduction

Reducing both construction projects' cost and time is critical in today's market-driven economy. This relationship between construction projects' time and cost is called time-cost trade-off decisions. Reducing project duration can be done by adjusting overlaps between activities or by reducing activities' duration. What is the reason for an increase in direct cost as the activity duration is reduced? A simple case arises in the use of overtime work. By scheduling weekend or evening work, the completion time for an activity as measured in calendar days will be reduced. However, extra wages must be paid for such overtime work, so the cost will increase. Also, overtime work is more prone to accidents and quality problems that must be corrected, so costs may increase. The activity duration can be reduced by one of the following actions:

- Applying multiple-shifts work.
- Working extended hours (over time).
- Offering incentive payments to increase the productivity.
- Working on weekends and holidays.
- Using additional resources.
- Using materials with faster installation methods.
- Using alternate construction methods or sequence.

2. Problem Definition

Every scheduled project has number of activities (n) that gives a certain duration for the project. Many times the resulted duration from the scheduling does not satisfy the project requirement and the decision makers. Therefore, the alternative solution is to start crashing the activities and find the optimum solution for time and cost. Usually crashing occurs without taking in consideration many factors that will significantly affect the results and mainly take the Direct and indirect cost only while other factors may affect as the following:

- Different relationship between activities (FS, SS, SF & FF).
- Lags and Leads.
- Penalties and bonuses.
- Milestones.
- Holidays.
- Resources.
- Quality.

3. Objectives and Scope

Proposing a model to solve TCT problems in real construction projects considering the most factors affected the planning process based on Linear TCT relationship using GOAL PROGRAMMING, which considers and includes the following factors:

- Direct and Indirect Costs.
- Different relationship between activities (FS, SS, SF & FF).
- Lags and Leads.
- Penalties and bonuses.
- Holidays.
- Milestones.

4. Literature Review

The linear relationship shown in the Figure (4-1) between these two points implies that any intermediate duration could also be chosen. It is possible that some intermediate point may represent the ideal or optimal trade-off between time and cost

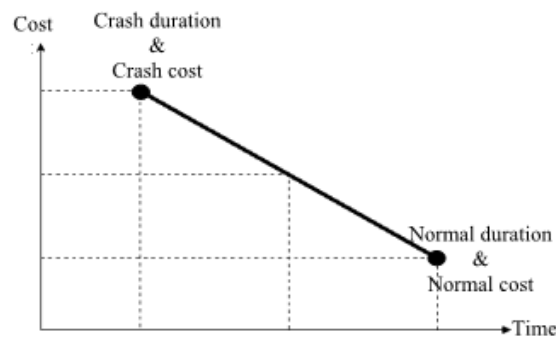


Figure (4-1): Illustration of linear time/cost trade-off for an activity [Chris Hendrickson, 1998]

The linear relationship shown in the Figure (4-1) between these two points implies that any intermediate duration could also be chosen. It is possible that some intermediate point may represent the ideal or optimal trade-off between time and cost for this activity. The slope of the line connecting the normal point (lower point) and the crash point (upper point) is called the cost slope of the activity. The slope of this line can be calculated mathematically by knowing the coordinates of the normal and crash points.

$$\text{Cost slope} = \frac{\text{crash cost} - \text{normal cost}}{\text{normal duration} - \text{crash duration}}$$

As shown in Figures (4-1), (4-2), and (4-3), the least direct cost required to complete an activity is called the normal cost (minimum cost), and the corresponding duration is called the normal duration. The shortest possible duration required for completing the activity is called the crash duration, and the corresponding cost is called the crash cost. Normally, a planner start his/her estimation and scheduling process by assuming the least costly option

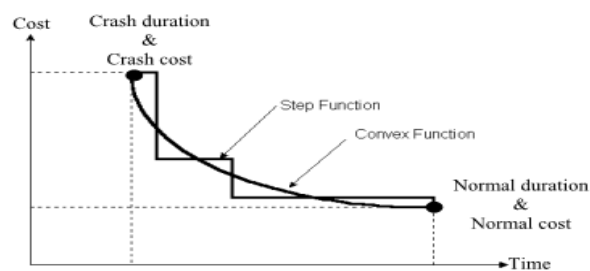


Figure (4-2): Illustration of non-linear time/cost trade-off [Chris Hendrickson, 1998]

In the traditional discrete time-cost trade-off problem, only certain values of the duration and cost of the options within an activity, usually the mean values, are used to evaluate the options as shown in Figure (4-3).

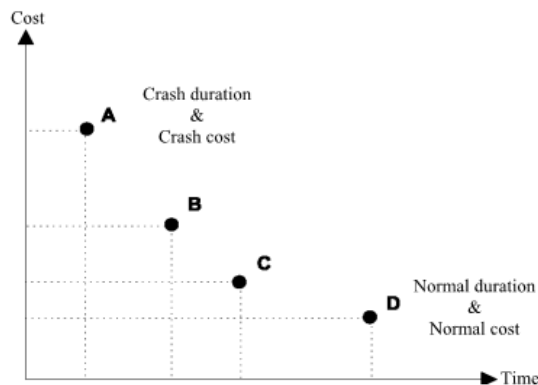


Figure (4-3): Illustration of discrete time/cost trade-off for an activity [Chung-Wei Feng, 2000].

The total cost sums the direct cost of a project and corporate overhead costs. Because overhead increases as the project continues off, there is a minimum point of the total cost curve as shown in Figure (4-4). The minimum point determines the “optimal duration” referred to as the length of the project consistent with the minimum total cost for the firm.

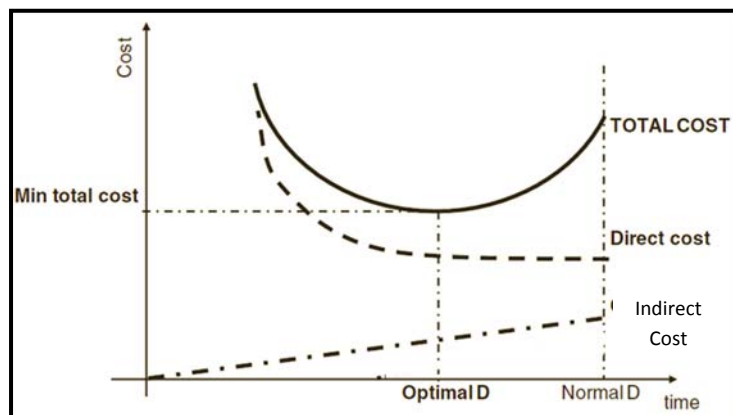


Figure (4-4): Optimal duration at the minimum total cost of the project [Marco,2011]

[Babu and Suresh 1996] illustrated that time and cost are among the important aspects considered for every construction project. It is always a complex and challenging task for the main contractor, to choose a correct bid which satisfies the time, cost and quality requirements of a project. In the present study, a differential evolution algorithm is used to solve this multi-objective time-cost-quality optimization problem.

[H. J. Weng and P. H. Chen, 2005] proposed a two-phase GA (genetic algorithms) in which both the effects of time-cost trade-off and resource scheduling are taken into account. A GA-based time-cost trade-off analysis was adopted to select the execution mode of each activity through the balance of time and cost, followed by utilization of a GA-based resource scheduling method to generate a feasible schedule, which may satisfy all the project constraints.

[Venkat R. Lakshminarayanan, 2011] When making choices between risky options, human decision-makers exhibit a number of framing effects. One of the most prominent framing effects is the tendency for decision makers to evaluate gambles relative to a reference point, and to act risk-seeking when prospects are framed as losses but risk-averse when identical prospects are framed as gains. This tendency for risk-preferences to reverse between loss and gain frames has been termed the reflection effect and is one of the primary predictions of Prospect Theory.

[S. Sakellariopoulos, A.P. Chassiakos, 2004] Existing methods dealing with the time–cost trade-off problem, which is encountered in project planning, have focused on the solution of a basic problem that does not adequately represent actual engineering projects. The aim of this paper is to develop a solution method considering additional realistic project characteristics such as generalized activity precedence relations and external time constraints for particular activities. The proposed method is formulated as a linear/integer program and provides the optimal project time–cost curve and the minimum cost schedule. Evaluation results indicate that the method can be reliably applied to engineering projects.

[Hassan, Mohammed, 2013] Time cost trade-off analysis has been developed by using bounded objective function for time and cost and obtaining optimum solution for both, by taking into consideration different factors in construction project (Activities relationship, milestones, lags, Leads and holidays).

[Abdelkrim Yahia-Berrouiguet, 2014] The objective of this paper is to apply one of the techniques of multiple objective programming (goal programming) to a project management problem. Mubiru proposed a goal programming model for allocating time and cost in project management. In order to test this model, a case study was accomplished in the company of construction, SEROR, Algeria

[Hillier and Liberman, 1967] using computer for scheduling projects and how to optimize several objectives with several constraints and overlapping between activities

[Kerzner, 1979] defines the project management as the planning, scheduling, directing and controlling of company resources for relatively short-term project which has been established for the completion of specific goals and objectives.

5. Methodology

The methodology used in this research to reach final proposed model which can be summarized into the following stages:

1. Developing a base model using Premium Solver Engine application and define all the activities for the project with their normal time and cost and link them together with the normal constraints and relationship.
2. Develop a base model using Primavera for the same project activities with its different relationships and constraints.
3. Verification for the base model has to be done (without any crashing yet) to make sure that the basic relationships and constraints are represented in the right way in the Premium Solver model, verification for time and cost has to be taken in place.

4. After making sure that the model is verified and its result matches with the Microsoft Project output, crashing should take place for the activities and add new constraints to match the client or the decision maker requirement for either time or cost.
5. After crashing the premium solver will generate results for which activities should be crashed and by how many days to suit the criteria for the project requirement.
6. Results should be reflected through Microsoft Project to make sure if it will give the same result or not as a verification for the model.
7. Analyzing the results based on one of the mathematical methods for multi-objective optimization, Goal programming will be followed in this case.

6. Modeling of multi-objective optimization problems

Assumptions for the proposed model are summarized in the following:

1. The proposed model solves scheduling issues related to network project not to repetitive projects.
2. Time and cost relationship for each activity is linear as a general case, however Non-linear relationship also is valid and applicable if needed.
3. Duration for each activity (i) in the project is defined and known.
4. Crashing approaches are determined by the project team by any of the available solutions as increasing overtime or resources, thus the impact for cost and time is defined.

- Model Functions

Two main functions are introduced in our model, which is Time (Z1) which is introduced in equation no.(6-1) and Cost (Z2) which is introduced in equation no.(6-3). Both equations are presented by Hendrickson.

- Time Function

Time function equation is introduced by the following:

$$\text{Min}Z_1 = T_{fn} - T_{s1} \quad (6-1a)$$

Where: T_{fn} is the finish time of the project or can be considered the last performed activity (n), T_{s1} is the start time of the project and can be considered the start of first activity which is not necessary being zero and Z1 is the total project duration.

- Real time Factor α

In equation (6-1a) it was considered that the working days per week are 7 continuously days without any weekends holidays so we had to modify our model to suit and matches what happens in reality. We introduced in our model real time factor α which equals the following equation (6-2).

$$\alpha = \frac{\text{Total number days per week (7 days)}}{\text{Number of working days per week}} \quad (6-2)$$

So the real total project duration considering the presence of weekends holidays.

$$Z_1 = (T_{fn} - T_{s1}) * \alpha \quad (6-1b)$$

- Cost Function

Time function equation is introduced by the following:

$$Z_{dc} = \sum_{i=1}^n C_{ni} + \sum (C_{sli} * T_{sci}) \quad (6-3a)$$

Z_{dc} Is the total direct cost

$\sum_{i=1}^n C_{ni}$ Is the sum of normal costs of all activities

C_{sli} Is the cost slope

T_{sci} Is the number of crashed days and it is equal $(D_i - d_i)$.

T_{sci} Is considered as a design variable for the objective function.

The linear cost slope for an activity i can be calculated as:

$$C_{sli} = C_{cmaxi} / T_{cmaxi} \quad (6-4)$$

C_{cmaxi} is the maximum crashed cost for activity i:

$$C_{cmaxi} = \text{crash cost}(C_{ci}) - \text{normal cost}(C_{ni}).$$

T_{cmaxi} is the maximum crashed time for activity i:

$$T_{cmaxi} = \text{normal time}(T_{ni}) - \text{crash time}(T_{ci})$$

Expression $\sum (C_{sli} * T_{sci})$ in equation (6-3a) is the total crashed cost Z_c ,

so $Z_c = \sum (C_{sli} * T_{sci})$ and consequently equation (6-3a) can be rewritten as:

$$\text{Min } Z_{dc} = \sum C_{ni} + Z_c \quad (6-3b)$$

As mentioned earlier that cost impact through any project is divided into several items, which is illustrated in the following:

- Total indirect cost (indC):

Here two types of indirect costs are considered: the variable indirect cost ($indC_v$) and the fixed indirect cost ($indC_f$). So, the total indirect cost can be calculated as:

$$\text{indC} = \text{indC}_f + \text{indC}_v \quad (6-5)$$

- Penalty Cost (PC):

In most construction project contracts, the penalty cost (PC) can take place for a project completion date later than a certain time (PT). In the proposed model, two types of

penalty costs are considered. The variable penalty cost (PCv) and the fixed penalty cost (PCf), so penalty cost is calculated as:

$$PC = PC_f + PC_v \quad (6-6)$$

- Bonuses Cost (BC):

Some contracts might include bonuses for early project completion date. Same concept as in penalty cost, bonuses cost can be variable (BCv) or fixed (BCf).

$$BC = BC_f + BC_v \quad (6-7)$$

Based on equations illustrated above, the total project completion cost (Z2) can be calculated as:

$$Z_2 = Z_{dc} + indC + PC - BC \quad (6-8)$$

- Variable Constraints

Two design variables in the model are exist: the start time (Tsi) and the number of crashed days (Tsci) for each activity i. During the optimization process, the values of these variables will be changed iteratively under the applied following constraints to obtain the optimum solution:

1. The start time of each activity must be bigger than or equal to zero $T_{si} \geq 0$
2. Number of crashed days per activity must be bigger than or equal to zero $T_{sci} \geq 0$
3. Number of crashed days for each activity must be equal or less than the maximum possible crashed days for this activity. $T_{sci} \leq T_{cmxi}$
4. The start time and the number of crashed days of each activity i are integer numbers ($T_{si} = integer, T_{sci} = integer$).

- Activities Relationships Constraints

Activities-relationship constraints are related to the types of relationships among activities. Four types of these relationships are considered in the proposed model (FS, SS, SF and FF). The model will schedule activities based on these constraints.

1. For FS relationship, the start time of activity j (successor) is bigger than or equal to the finish time of activity i (processor) plus lags (or leads) between j and i (lags have positive values, while leads have negative ones):

$$T_{sj} \geq T_{fi} + L_{ij}$$

2. For FF relationship, the finish time of activity j is bigger than or equal to the finish time of i plus lags (or leads) between j and i:

$$T_{fj} \geq T_{fi} + L_{ij}$$

3. For SS relationship, the start time of activity j is bigger than or equal to the start time of i plus lags (or leads) between j and i:

$$T_{sj} \geq T_{si} + L_{ij}$$

4. For SF relationship, the finish time of activity j (successor) is bigger than or equal to the start time of activity i (processor) plus lags (or leads) between j and i

$$T_{fj} \geq T_{si} + L_{ij}$$

In these constraints, T_{fi} is the calculated finish time of activity i: $T_{fi} = T_{si} + T_{ni} - T_{sci}$

- General Activity Constraints

The following generalized activities-constraints are considered in the proposed model:

- | | |
|---|----------------------|
| 1. Activity i must finish before time (t): | $T_{fj} < t/\alpha.$ |
| 2. Activity i must start before time (t): | $T_{si} < t/\alpha.$ |
| 3. Activity i must start at a certain time (t): | $T_{si} = t/\alpha.$ |
| 4. Activity i must finish at a certain time (t): | $T_{fj} = t/\alpha.$ |
| 5. Activity i must finish after a certain time (t): | $T_{fj} > t/\alpha.$ |
| 6. Activity i must start after a certain time (t): | $T_{si} > t/\alpha.$ |

- Other Activity Constraints

Total project completion cost must be equal or smaller than the available budget:

$$Z_2 \leq \text{budget}.$$

.If the available project budget is predetermined, therefore, this constraint will prevent the model to get solutions with total project completion cost bigger than the available budget.

- Model Solution Method

As mentioned earlier that we are going to use Goal programming as a method for solving multi-objective optimization.

We have two functions which are time and cost and we have two targets for each one of them thus, we need to target our solution to minimize the deviation from exceeding this level and maximize the deviation that improves our target as shown in the following equations.

- First function $f_1(x)$ refers to Time function.
- b_1 is the aspiration level or the target for time function we need as a maximum requirement for time. For example we need the project to be completed not more than 1 year so we will provide a constraint $f_1(x) \leq 1 \text{ year}$
- d_1^+ is the over achievement deviation target for time function.
- d_1^- is the under achievement deviation target for time function.

- Second function $f_2(x)$ refers to Cost function.
- b_2 is the aspiration level or the target for Cost function we need as a maximum requirement for cost. For example we need the project to be completed with a budget not exceeding one million dollar so we will provide a constraint

$$f_1(x) \leq 1 \text{ million}$$

- d_2^+ is the over achievement deviation target for Cost function.
- d_2^- is the under achievement deviation target for Cost function.

In order to get better results for time and cost we need to maximize the over achievement deviation $d_{1,2}^+$ While we need to minimize the under achievement deviation $d_{1,2}^-$ This means the less results generated for $(d_{1,2}^- - d_{1,2}^+)$ for time and cost the more will achieve the target and even may better than required if a solution was found.

Table (6-1) shows how we will translate these expression into equations and constraints for time and cost.

Table 6-1 Model Analysis Philosophy

Function	Time $f_1(x)$	Cost $f_2(x)$
Target	$f_1(x) \leq b_1$	$f_2(x) \leq b_2$
Deviations to be maximized	d_1^+	d_2^+
Deviations to be minimized	d_1^-	d_2^-
General Equation	$f_1(x) + d_1^- - d_1^+ \leq b_1$	$f_2(x) + d_2^- - d_2^+ \leq b_2$
Objective	Minimize $d_1^- - d_1^+$	Minimize $d_2^- - d_2^+$
Conditions	$d_1^-, d_1^+ \geq 0$	$d_2^-, d_2^+ \geq 0$

7. Model validation using actual projects

The proposed Model is applied to two actual projects. The first represents a highway construction project, while, the second represents a Construction flights terminal building in Egypt. The aim of this Chapter is to validate the proposed model by applying it to the mentioned projects.

The data related to the studied projects is used by the proposed model to get TCT solutions for the two projects problems.

In this paper we will only show the first project due to it's simplicity and limited number of activities.

The second project is illustrated in the thesis itself.

Table (7.1a): Activities data

Activity		(T _{ni})	(T _{ci})	(C _{ni})	(C _{ci})	Relatio	Lij
Service road A							
1	Rock excavation	5	4	2030	2300	0	0
2	Embankment construction	8	6	1020	1510	1(FS)	-3
3	Sub base and base layers	8	6	1700	2090	1(FS)	0
4	Asphalt layer	4	3	590	730	3(FS)	0
5	Temporary marking and	2	-	90	-	4(SS)	+1
Service road B							
6	Earth and semi-rock	4	3	910	1100	1(FS)	0
7	Embankment construction	2	-	250	-	2(FS)	0
8	Subbase and base layers	7	5	1490	1830	3(FS)	0
9	Asphalt layer	4	3	520	750	4(FS)	0
10	Temporary marking and	2	-	90	-	5(FS)	0
Main road							
11	Traffic diversion	1	-	50	-	5(FS)	0
12	Rock excavation	8	6	3260	3710	11(FS)	0
13	Earth and semi-rock	5	3	1140	1720	12(SS)	+2
14	Sub grade stabilization,	4	3	300	450	13(SS)	+2
15	Embankment construction	8	5	1020	1430	12(FS)	-4
16	Drainage pipe construction	9	6	790	1180	15(FS)	-6
17	Drainage layer	13	11	3340	4060	15(SS)	+4
18	Planting at roadway verges	9	7	470	830	15(FS)	+4
19	El. installations at roadway	6	4	460	810	15(FS)	0
20	Ditches	6	5	1280	1430	17(SS)	+3
21	Sub base layer	14	10	1090	1560	20(SS)	+2
22	Base layer	14	9	900	1400	21(SS)	+2
23	Median island (New Jersey)	14	11	2220	2690	22(FS)	-9
24	Elect. installation in median	3	-	230	-	23(SS)	+6
25	Asphalt layer #1	6	4	1590	1990	23(FS)	-4
26	Asphalt layer #2	10	8	2630	3240	25(SS)	+4
27	Friction course overlay	8	6	2060	2660	26(FS)	0
28	Final marking and signing	10	8	320	610	27(FS)	-3
29	Traffic restoration	1	-	50	-	28(FS)	0

An external constraint is set for the completion time of the service roads. In particular, the latest finish time of activity 11 is 23 days after the beginning of the project. The variable indirect project cost (indCv) is 150 units per day. Further, a variable penalty (PCv) at a rate of 200 units per day of delay applies after the 80th day (PT = 80 days), While a variable bonus (BCv) of 100 units per day is given for project completion before the 80th day (BT = 80 days).

In this application, The holiday days were not taking into account (7 working days per week), so in our model, this can be expressed by giving a value equal to (1) for the real time factor (α).

- Developing Microsoft Project model for verification

The first step we need to develop a Microsoft Project model that includes all the given data from the contractor in order to judge on the results obtained by the mathematical model developed.

We have to first make an initial model without crashing to get results from the normal assumed timetable so that we can later see how differences and improvement we have made. After that we compare it with the initial mathematical model for verification and then repeat the same steps after crashing and getting results from the mathematical model. After that, we implement the results obtained from the mathematical model through the Microsoft Project model so that we can verify our results.

We can see the following data that after developing the Microsoft Project model and without crashing results is shows that the project duration $Z1 = 85$ days.

So first we need to make sure that the mathematical model matches with the same result.

As we can see that the normal scheduling from Microsoft project gave us end date of 24/12/11 at activity number 29 which is equivalent to $Z1=85$ Days.

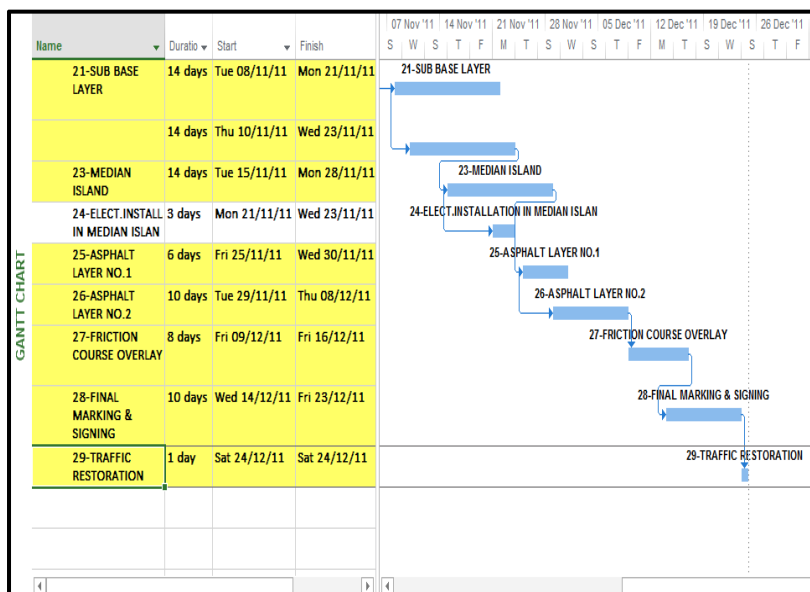


Figure 7-1 Sample of output data from Microsoft Project before Crashing

- Developing Mathematical model

Table(7-2)Output Data Table from The Premium Solver Model before Crashing

Activity	T_{cmaxi}	C_{sli}	T_{si}	T_{sci}	T_{fi}
1	1	270.00	0	0	5
2	2	245.00	2	0	10
3	2	195.00	11	0	19
4	1	140.00	19	0	23
5	0	0.00	20	0	22
6	1	190.00	7	0	11
7	0	0.00	10	0	12
8	2	170.00	19	0	26
9	1	230.00	26	0	30
10	0	0.00	29	0	31
11	0	0.00	22	0	23
12	2	225.00	23	0	31
13	2	290.00	25	0	30
14	1	150.00	27	0	31
15	3	136.67	29	0	37
16	3	130.00	31	0	40
17	2	360.00	33	0	46
18	2	180.00	41	0	50
19	2	175.00	37	0	43
20	1	150.00	36	0	42
21	4	117.50	38	0	52
22	5	100.00	40	0	54
23	3	156.67	45	0	59
24	0	0.00	51	0	54
25	2	200.00	55	0	61
26	2	305.00	59	0	69
27	2	300.00	69	0	77
28	2	145.00	74	0	84
29	0	0.00	84	0	85

As per first run for the model and by adjusting an extra constraint that all time reduction for all activities equals zero $\sum T_{sci} = 0$ as shown in table (7-2) to guarantee that no crashes occurs for calibrating the model first and to check if it matches with the normal planning of Microsoft project or not. Also to avoid discovering the issue in later stages where the crashes occurs.

As shown in the output data in table (7-2) for the premium solver engine it shows without crashing generates 85 days ($T_{f29} = 85$)

According to the normal cost of each activity it produces 31890 LE as direct cost.

Also we can easily say that the indirect cost depends on the total duration which equals 85 days multiply the rate for the indirect cost per day which produces 12750 LE.

An extra factor interferes with the total cost which are penalty costs as a result for not maintaining the desired duration for the project so according to 85 days we will have to charge extra 1000 LE.

So that's in total 45640 LE. As a result from the first Run from the model.

- Optimizing and crashing activities

After running the initial mathematical model without any crash it can be found through the report of the solver that the minimum number of days without crashing activities shows to be $Z1 = 85$ days which matches the Microsoft Project model. Now we can start crashing the activities safely without any worries about the constraints assignment.

First we need to run the model to get the minimum number of days that can be achieved according to the given activity durations and their relation to each other. So there is two variables need to be optimized and according to the requirement of the client the client needs to know what is the optimum solution and then he can choose after that what solution he needs and how much deviation from his requirement to the optimum solution.

The target is that we need to minimize the deviation from the client's target.

Goal B1 = 77 day & Goal B2 = 44500 \$

As we can see in table (7-3) that the target of 77 days is satisfied with a negative cost deviation $d_2^- - d_2^+ = -0.94\%$ which is equivalent to $Z2=44080$ \$ which is even less than required.

Table (7-3) Optimizing and Crashing Activities Results for Project No.1

B2	B1	TIME Z1	C_{ni}	$Indc$	BC	PC	TOTAL COST Z2 W/T P/B	TOTAL COST Z2 WITH P/B	$(d_1^- - d_1^+)$	$(d_2^- - d_2^+)$	$(d_1^- - d_1^+) / b_1\%$	$(d_2^- - d_2^+) / b_2\%$
		Days	\$	\$	\$	\$	\$	\$				
77	44500	85	3189	1275	0	1000	44640	45640	8	1140	10%	2.56%
		84	3199	1260	0	800	44590	45390	7	890	9%	2.00%
		83	3209	1245	0	600	44540	45140	6	640	8%	1.44%
		82	3219	1230	0	400	44490	44890	5	390	6%	0.88%
		81	3229	1215	0	200	44440	44640	4	140	5%	0.31%
		80	3239	1200	0	0	44390	44390	3	-110	4%	-0.25%
		79	3253	1185	-100	0	44385	44285	2	-215	3%	-0.48%
		78	3268	1170	-200	0	44380	44180	1	-320	1%	-0.72%
		77	3283	1155	-300	0	44380	44080	0	-420	0%	-0.94%
		76	3298	1140	-400	0	44387	43987	-1	-513	-1%	-1.15%
		75	3314	1125	-500	0	44393	43893	-2	-607	-3%	-1.36%
		74	3330	1110	-600	0	44400	43800	-3	-700	-4%	-1.57%
		73	3360	1095	-700	0	44550	43850	-4	-650	-5%	-1.46%
		72	3390	1080	-800	0	44700	43900	-5	-600	-6%	-1.35%
		71	3420	1065	-900	0	44855	43955	-6	-545	-8%	-1.22%
70	3451	1050	-1000	0	45010	44010	-7	-490	-9%	-1.10%		

And because the target that we need is already achieved we will start looking for the less cost solution which is $Z1=74$ Days which results a negative cost deviation

$$d_2^- - d_2^+ = -1.57\% \text{ which is equivalent to } Z2=43800 \$.$$

- Duration Verification

By applying the crashing output corresponding to $Z1 = 74$ days, we will start crashing these activities as per figure (7-2) and check whether the Microsoft project will give us same results or not.

It can be seen in figure (7-2) which represent the output from Microsoft project that project starts at 1/10/2011 and finishes at 13/12/2011 (74 days). Also, activity 11 finishes at 23/10/2011 (23 days after project start) and this means full agreement with model solution.

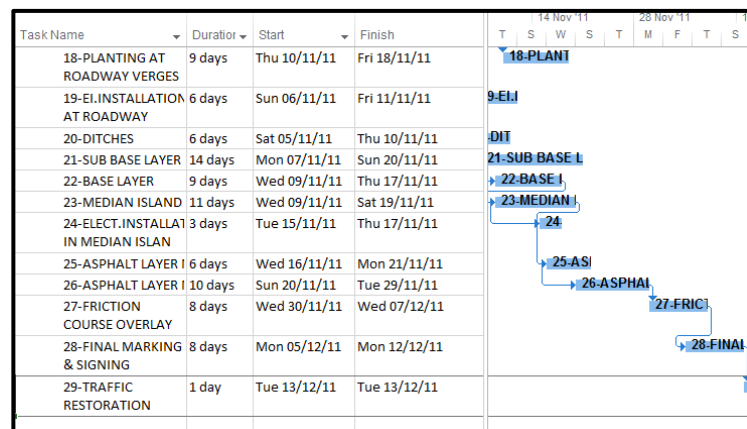


Figure (7-2) Sample of Output Data for Microsoft Project after Crashing

- Cost Verification

Table 7-4 Summary Cost for Verification

Activity	C_{ni}	C_{sli}	T_{sci}	C_{ci}	Activity	C_{ni}	C_{sli}	T_{sci}	C_{ci}
1	2030	270	0	0	16	790	130	0	0
2	1020	245	0	0	17	3340	360	0	0
3	1700	195	0	0	18	470	180	0	0
4	590	140	0	0	19	460	175	0	0
5	90	0	0	0	20	1280	150	0	0
6	910	190	0	0	21	1090	117.5	0	0
7	250	0	0	0	22	900	100	5	500
8	1490	170	0	0	23	2220	156.6666667	3	470
9	520	230	0	0	24	230	0	0	0
10	90	0	0	0	25	1590	200	0	0
11	50	0	0	0	26	2630	305	0	0
12	3260	225	0	0	27	2060	300	0	0
13	1140	290	0	0	28	320	145	2	290
14	300	150	1	150	29	50	0	0	0
15	1020	136.6666667	0	0					

DIRECT COST $\sum_{i=1}^n C_{ni}$	31890	Crash cost $\sum (C_{sli} * T_{sci})$	1410
TOTAL INDIRECT COST IndC = 150 X 74 = 11100			
TOTAL BONUS BC		TOTAL PENALTY PC	
6 X 100 = -600		0	
TOTAL COST Z2			
31890 + 1410 + 11100 -600 = 43800			

The calculations presented in Table (7-4) gives the same costs presented in Table (7-3) for the model solution “Z1= 74days and Z2 = 43800 units”

- Total Cost with Penalties and Bonuses

We can see that Z1=74 days produces the best solution Z2=43800\$.

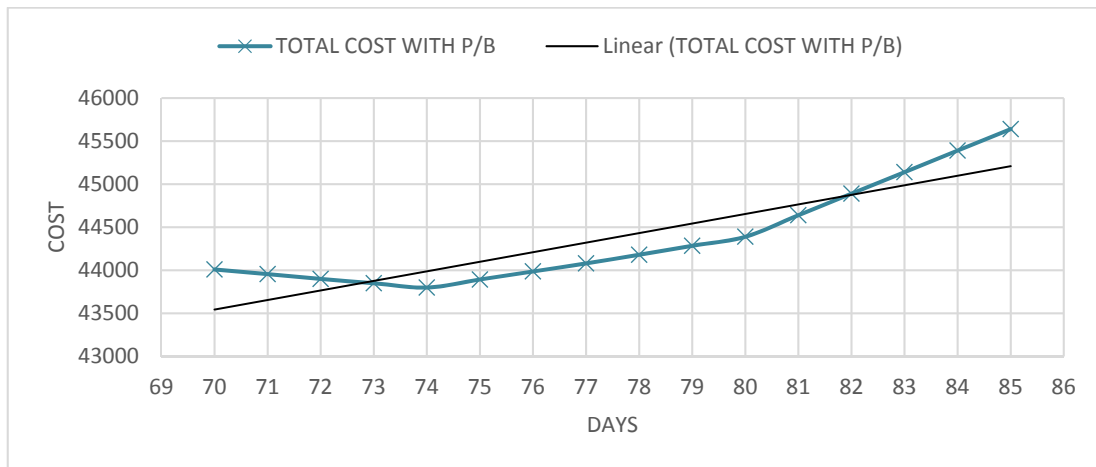


Figure 7-3 Relation Diagram between Total Cost and Time with Penalty and Bonuses

- Super position between Time D1 ($d_1^- - d_1^+$) & Cost D2 ($d_2^- - d_2^+$)

As we can see in figure (7-4) below we can see that the minimum deviation for cost at Day 74 produces as well a negative deviation for time. This means that the time cost trade off analysis produces optimum solution for both time and cost. Its also useful if we need to get the minimum deviation for time which means least number of days and as we can see that still even If we choose the least number of days Z1 = 70 days we will still have a minimum cost deviation that ensures meeting the budget with even saving. In terms of logical solution its never been a clever option to reduce the number of the project more than required specially if it will cost more money.

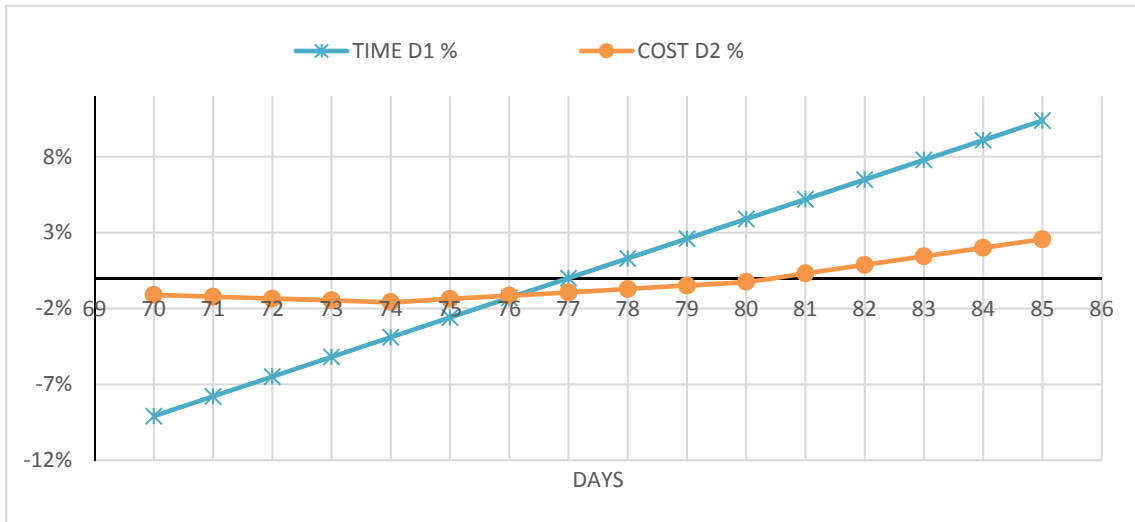


Figure 7-4 Relation Diagram between Deviation of Time D1 and Cost D2 with Time

8. General conclusions and recommendations

- Main Points of Conclusion

- 1) Time cost trade-off analysis are really effective for minimizing the cost and time through construction projects during planning and scheduling.
- 2) The basic approaches for optimizing doesn't consider a lot of factors which are essential in deciding the cost and time..
- 3) Considering more of these affected factors (such as: presence of holidays, milestones, different activities' relationships, indirect cost, penalty cost, bonuses cost, and project budget) will make the resulted TCT solutions more applicable in actual projects.
- 4) The proposed model generates optimum solutions for all possibilities for the project duration with its finish time, which is corresponding to the optimum solution.
- 5) Comparison took place between what the team in site have proposed and what the results of the proposed model shows and indicated that there was actually better ways in planning and scheduling which will generate better results.
- 6) These results can be imported through Primavera or Microsoft Project and gives better planning and scheduling with better strategies.
- 7) For the first project, the model solution could meet the desired project duration and budget, and even finds better solutions which found to be 3 days earlier which represents 4% of the project duration, while saving is about 700\$ which represents about 1.57 % of what the project team proposed for the completion cost.
- 8) For the second project, the model solution could meet the desired project duration and saves about 53011 L.E which represent about 1.32 % of what the project team proposed for the completion cost.

- Recommendations for future works

- 1) Developing a program that links with Primavera or Microsoft project planner Packages so that planners can use the engine of the solver for searching the optimum solutions and automatically reversed through planning programs.

- 2) Resource availability and limitations through the project was one of this project limitation, it was assumed that the resources are available through the project so it will be a good point to take into future researches consideration.
- 3) Modify the proposed model to use nonlinear and discrete activities is highly recommended.

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