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Optimizing the Project Delivery Time with Time Cost Trade-offs

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***Abstract*—**While to minimize the overall project cost is always one of the objectives of construction managers, to obtain the maximum economic return is definitely one the ultimate goals of the project investors. As there is a trade-off relationship between the project time and cost, and the project delivery time directly affects the timing of economic recovery of an investment project, to provide a method that can quantify the relationship between the project delivery time and cost, and identify the optimal delivery time to maximize economic return has always been the focus of researchers and industrial practitioners. Using genetic algorithms, this study introduces an optimization model that can quantify the relationship between the project delivery time and cost and furthermore, determine the optimal delivery time to maximize the economic return of the project. The results provide objective quantification for accurately evaluating the project delivery time and cost, and facilitate the analysis of the economic return of a project.

***Keywords*—**Time-Cost Trade-Off, Genetic Algorithms, Resource Integration, Economic return.

I. Introduction

ALTHOUGH to minimize the construction cost following a pre-planned schedule is important for both the owner and contractors in the course of investment, it is more important to select a construction duration, which produces the highest economic return on the total investment plan. In real-world situations, unpredictable events often affect the schedules of construction projects, forcing contractors to alter and re-allocate the durations of activities. Therefore, evaluating the benefit of the investment cannot produce meaningful results unless the trade-offs between the times and costs of activities for a construction project are considered [1]. As such, there is a need to develop a practical technique which incorporates the time-cost trade-off of activities and can assess the optimal construction duration in an investment plan. This paper first introduces Genetic Algorithms (GAs) optimization model and then, use a project case to demonstrate that the proposed algorithms can quantify the relationship between project time and cost, and subsequently, identify the optimal project delivery time with the maximum economic return.

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II. Method

By using genetic algorithms (GAs), an optimization model was developed to assess the optimal delivery time of a construction project. Owing to the work of John Holland [2] in 1970s, GAs in particular became popular and has been widely adopted to find a near optimal solution to a problem with many solutions. There are three basic operators in GAs (Reproduction, Crossover, and Mutation) [3] which are used to reproduce a subsequent generation that is more suitable to the current environment. GAs simulate the natural ‘‘survival of the fittest’’ process, as best genes exchange information to produce offspring that are evaluated in turn and can be retained only if they are fitter than the others in the population. Usually the process is continued for a large number of generations until an optimal gene is obtained. Using genetic algorithms to solve optimization problems with an enormous range of possible solutions has proved to be a very effective and feasible approach.

III. Project Costs and Resource-Use Efficiency

Project costs include direct and indirect costs. Indirect cost is composed of the expenditure on management during project implementation and usually increases linearly with project duration and is represented as a single cost per time period, thus it depends heavily upon the project duration, the longer the duration, the higher the indirect cost, and can be calculated as follows:

$$IC = T \times U_d \tag{1}$$

where IC=total indirect cost of a project and U_d= daily cost rate for indirect cost in $/day.

The direct cost (DC) includes the costs required to execute activities directly (TC_d) and the resource handling cost caused by the mobilization/demobilization (TC_m). For a feasible project duration, there always is a set of time and cost arrangement for each activity that will produce the project duration with the lowest total project cost. Moreover, each activity has its own time-cost trade-off curve, which is defined by a minimum cost point, also known as normal point, and a minimum time point, also known as crash point, and estimated based on the relationships between the time and cost and the resource arrangements. Previous studies have suggested nonlinear resource-time relationships for an activity [4], [5] and a quadratic efficient model has been proposed to examine this [6]. The proposed model supposes that there always is an optimal crew combination for a specific activity, which can complete the activity in an optimal duration with the highest efficiency and lowest cost. When the assigned work duration deviates from the optimal duration, the efficiency will decline and the cost will increase. The relationship between efficiency and duration with regard to the resources needed for an activity is shown in Fig. 1, when the activity duration changes, the efficiency of each activity will change and affect the cost. The efficiency of the activity can be calculated as follows:

$$E_i = \frac{1}{a_i \times (T_i - Tn_i)^2 + 1} \tag{2}$$

where E_i= the efficiency of activity i; T_i = the duration of activity i; Tn_i = the normal duration of activity i; a_i = a positive constant.

Therefore, project direct costs required to execute activities are the sum of all activity costs, and can be expressed as follows:

$$TC_d = \sum_{i=1}^{M} \frac{Cn_i}{E_i} \tag{3}$$

where TC_d = the total direct costs of construction project with M activities, and Cn_i = cost of activity i at normal duration.

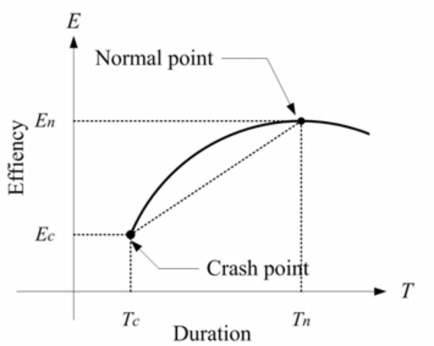

Fig. 1 Efficiency-duration curve

Besides, because of the variations of daily resource usage, the project would be mobilized and demobilized to re-allocate resources and the mobilization/demobilization cost of resources can be expressed as follows:

$$TC_m = \sum_{i=1}^{M} \sum_{t=1}^{T+1} \left| Q_{it} - Q_{i(t-1)} \right| \times U_i \times P_i \tag{4}$$

where Q_{it} and $Q_{i(t-1)}$ = the quantity of resource usage of activity i on day t and day t-1 respectively; U_i= unit cost of activity i; P_i= the ratio of mobilization/ demobilization unit cost over the cost for activity i.

Accordingly, the total cost of a project (TC) can be derived from (1) to (4) and expressed as follows:

$$TC = DC + IC = TC_d + TC_m + IC \tag{5}$$

IV. Objective Function

Implementing the GA technique involves five main steps: (1) Setting the gene structure; (2) deciding the gene evaluation criteria (objective function); (3) generating an initial population of genes; (4) selecting an offspring generation mechanism; and (5) coding the procedure in a computer program. Using genetic algorithms to solve optimization problems with an enormous range of possible solutions has proved to be a very effective and feasible approach.

The objective function in genetic algorithms is used to determine the suitability of the evolution of the chromosomes retained. By using the objective function the proposed model will eliminate inferior chromosomes through competition until the optimization process cannot evolve a better solution and all populations converge to a stable condition.

The objective function is a measure of the performance of the design variables and is used to determine the suitability of the evolution of the chromosomes retained in genetic algorithms. The objective function in this research is designed to obtain the maximum net present value (NPV) for an investment plan as follows:

$$F = Max\left\{ -TC(T_i, r) + \sum_{k=1}^{K} \frac{I_k}{(1+r)^k} \right\} \tag{5}$$

where TC(T_i,r)= the total project cost which will be calculated with various activity durations and periods; K = a positive integer, the total number of periods K; I_k= income of period k; r= discount rate of the investment; and F= the objective function value.

V. Case

The assumptions of the project are as follows:

1) The life cycle of the invested project is expected to be 50 years (period number = 200 quarters) after the construction is completed.
2) The income for each quarter is $75,000 after the construction project is completed.
3) The annual discount rate of the investment plan is assumed to be 2% (0.5%/ quarter), 5% (1.25%/ quarter) and 8% (2%/ quarter) to examine the simulation results.
4) The construction operation consists of seven activities (Activities A to G).

The details of the activity durations and costs are shown in Table I. The network schedule with the critical path B-E-G is as shown in Fig. 2. The indirect cost of the project was assumed to be $10,000 per day, and the project duration was assumed to be 2 years (8 quarters, 24 months) based on the normal duration provided for each activity. The total cost of the project calculated from the early-start schedule was $2,802,560. To simulate real-world projects while simplifying the complexities of the model, it is assumed that (a) project operations are assumed to be the best procedure, and will not change in the simulation process, (b) the relationship between work duration and the efficiency of resources for an activity is a quadratic function, (c) the working duration of each activity is adjustable within the range of (0.5 - 1.1) × Tn_i

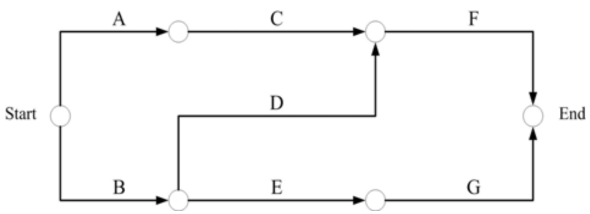

Fig. 2 Precedence network for the example project

TABLE I
PROJECT INFORMATION

Activity	Successors	Normal duration (months)	Total float (months)	Activity cost
A	C	6	8	119,400
B	D,E	9	0	192,000
C	F	5	8	309,000
D	F	5	5	548,100
E	G	8	0	142,000
F		5	5	525,600
G		7	0	43,200

First, the proposed algorithms successfully quantify the project delivery time and the construction cost as shown in Table II and the relationship is depicted as Fig. 3. Subsequently, the net present values (NPV) of the project at various delivery times are identified as shown in Table III and the relationships between the project delivery time and NPV is depicted as in Fig. 4. The results suggest that the optimal delivery time is compressed to 21 months instead of the original 24 months after the optimization and the value of the discount rate significantly affects the economic return of the project. It is logic to infer that as there is a trade-off relationship between the project time and cost, the optimal project delivery time may vary at different discount rate.

TABLE II
CONSTRUCTION COST VS. PROJECT DELIVERY TIME

Delivery time (Months)	Construction cost
12	3,094,947
15	2,733,372
18	2,642,653
21	2,543,844
24	2,560,520
27	2,594,638

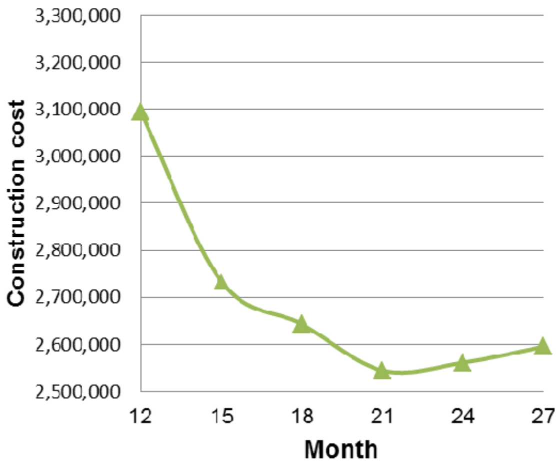

Fig. 3 Construction cost versus project delivery time

TABLE III
NPV VS. PROJECT DELIVERY TIME

Delivery time	Net present values		
	8%*	5%	2%
12	455,818	2,234,877	6,225,309
15	762,790	2,539,739	6,544,024
18	814,584	2,583,798	6,595,929
21	881,081	2,630,083	6,657,650
24	827,934	2,572,749	6,579,206
27	782,773	2,486,332	6,516,592

* Annual discount rate

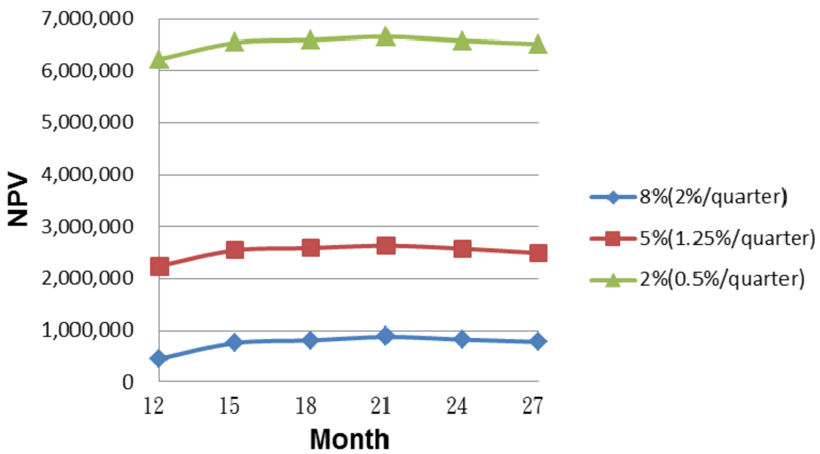

Fig. 4 NPV versus project delivery time

VI. Conclusions

To evaluate an investment project without considering the time cost trade-offs of its construction works is unrealistic and deviates from real-world practices. The proposed algorithm that incorporates the adjustable durations of activities and can analyze the trade-offs between the project deliver time and cost and subsequently, identify the optimal delivery time of an investment project. In addition, our research results indicate that the cost impact of float loss can be reduced through the effective integration of project resources. The proposed method provides an objective approach in which the project delivery time and overall project cost can be evaluated accurately and facilitate the analysis of the economic returns of the project with various delivery times.

Acknowledgment

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References

[1] C. W. Feng, L. Liu,and S. A.Burns, “Using genetic algorithms to solve construction time-cost trade-off problems,” *J. Comput. Civ. Eng*.,vol. 11, no. 3, 1997, pp. 184-189.
[2] Holland, J. H. Adaptation in natural and artificial systems. Univ. of Michigan Press, Ann Arbor, Mich.,1975.
[3] A. B. Senouci,and N. N.Eldin, “Use of genetic algorithms in resource scheduling of construction projects,” *J. Constr. Eng. Manage.* , vol. 130, no. 6, 2004, pp. 869-877.
[4] J. E.Kelly, “Critical-path planning and scheduling: Mathematical basis,”*Operational Res.*, 1961, pp. 296-320.
[5] R. Reda,and R. I. Carr,“Time-cost trade-off among related activities,”*J. Constr. Eng. Manage*., vol. 115, no. 3, 1989,pp. 475-486.
[6] B. Holt, L. M. Fu, “Rule generation from neural networks,” *IEEE Trans. on Sys., Man and Cybernetics*, vol. 8, no. 3, 1955, pp. 54-63.