Expanding Finance-Based Scheduling to Devise Overall-Optimized Project Schedules

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Abstract: Construction contractors often finance projects using bank credit lines that allow contractors to withdraw money up to certain credit limits. Finance-based scheduling provides schedules that ensure that the contractor's indebtedness at any time during the construction stage does not exceed the credit limit. Generally, constricted credit limits tend to yield prolonged schedules. Provided that credit limits can be adequately relaxed, compressed schedules of compressed-duration activities can be attained. Devising a compressed schedule calls for the incorporation of time-cost trade-off (TCT) analysis to strike a balance between the decreased overhead costs and the increased direct costs of the activities. Since employing TCT analysis usually causes great fluctuations in the daily resource requirements by mixing compressed-duration activities of high resource demand with others of low resource demand, therefore, the need for resource management techniques becomes inevitable to ensure efficient utilization of resources. This note used genetic algorithms to expand finance-based scheduling to devise schedules for relaxed credit limits. A prototype system was developed and coded using VISUAL BASIC, then demonstrated using a five-activity example project. The prototype was validated by comparing the results with those obtained by using the integer programming. Expanding finance-based scheduling to handle the whole spectrum of credit limits helps devise overall-optimized schedules that consider cash, time, cost, and resources.

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Introduction

Contractors often procure the necessary cash to finance projects by establishing bank credit lines. It is not uncommon that bankers set a limit on the credit allocated to an established credit line. Contractors often deposit the interim progress payments made by the projects' owners in their credit-line accounts to avoid exceeding the credit limits and to minimize the financing costs on the outstanding debt. Finance-based scheduling specifies activities' start times such that the contractor's indebtedness due to subsequent cash outflows and inflows do not exceed the specified credit limit. Besides, finance-based scheduling maintains the demand of project time minimization.

Elazouni and Gab-Allah (2004) developed an integer programming model to device finance-based schedules. Another study (Elazouni and Metwally 2005) used genetic algorithms (GAs) technique to revise critical-path method (CPM) schedules so as to fulfill the constraints of limited credit as well. In addition, the developed technique maximizes project profit through minimizing financing costs and project duration. These two studies were concerned mainly with developing project schedules financed by constricted credit limits which tend to prolong project duration.

When contractors manage to relax the credit limits, the availability of cash enables contractors to investigate the feasibility of devising compressed schedules. Compressed schedules can be obtained by deploying compressed-duration activities. The basic task of finance-based scheduling remains to devise schedules that yield contractors' indebtedness below the relaxed credit limits. Once compressed-duration activities were introduced, the time-cost trade-off (TCT) analysis must be incorporated to strike a balance between the reduced overhead costs and the increased direct costs of the activities. As crashed-duration activities are often of higher daily resource requirements, mixing crashed-duration activities of high daily resource demand with others of low daily resource demand may cause great fluctuations in the daily resource requirements (Karshenas and Haber 1990). This makes an inevitable need for resource management techniques including resource allocation and leveling to ensure efficient utilization of resources.

This technical note utilizes compressed activities to broaden the scope of the GAs, finance-based scheduling prototype introduced in Elazouni and Metwally (2005). The broadened finance-based scheduling enables schedulers to schedule under relaxed credit limits. In addition, this note employs resource allocation and leveling techniques to schedule under resource limitations and ensures the efficient use of resources. The objective of the

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optimization in this context is to minimize the total project costs. The constraints to the cost minimization represent the credit limit and resource availability. The demand of efficient utilization of resources was fulfilled by imposing resource unleveling penalty.

Project Cash-Flow Modeling

Au and Hendrickson (1986) modeled the contractor's cash inflows and outflows and charted these transactions at ends of periods which could be weeks or months. The model, which is introduced in detail in Elazouni and Metwally (2005), considers all different cash outflows and inflows. Starting at the beginning of the project and proceeding with time, the model consecutively adds cash inflows and subtracts outflows at due times. The completed model yields the contractor's indebtedness at the end of the project periods. At the end of the project, the positive outcome of all the additions and subtractions represents the profit.

The common practice to prepare progress payments in unit-price contracts is through determining the worth of the completed work items based on the unit prices. The unit price of a work item includes the direct costs plus a pro rata share of the project overhead, financing costs, tax, profit, and bond. As the project duration in the context of this note is a decision variable, the progress payments were estimated using a multiplier to add the pro rata share to the periodical disbursements. This procedure allows the contractor to figure out the exact overheads, financing costs, and taxes and adjust the unit prices before bid submission.

Adjustments to the profit are required to account for completion penalties/bonus and resource unleveling penalty which was introduced by Hegazy and Ersahin (2001) and explained in the rest of this section.

The fluctuation moment about the x axis M_x is calculated for a particular resource of daily demand R during a utilization period of n days using

$$M_x = \sum_{j=1}^{n} (R_j)^2 \tag{1}$$

The desired constant demand R_{avrg} during a utilization period of n days can be calculated, as in Eq. (2), by averaging the summation of the daily demands over n days

$$R_{\text{avrg}} = \frac{\sum_{j=1}^{n} R_j}{n} \tag{2}$$

An approximation of the desired minimum M_x that produces a leveled resource profile is calculated using

$$M_{x(\min)} = n(R_{\text{avrg}})^2 \tag{3}$$

Therefore, for this particular resource an unleveled-resource penalty value Q can be calculated using a user-specified penalty U, as in the penalty function presented in

$$Q = \frac{M_x - M_{x(\min)}}{M_{x(\min)}} \times U \tag{4}$$

This type of penalty can be viewed as fictitious cost needed to guide the optimization and may not be considered in the total cost after optimization. Thus the project adjusted profit can be represented by the fitness function given by

$$\text{Profit} = G \pm B/P - Q \tag{5}$$

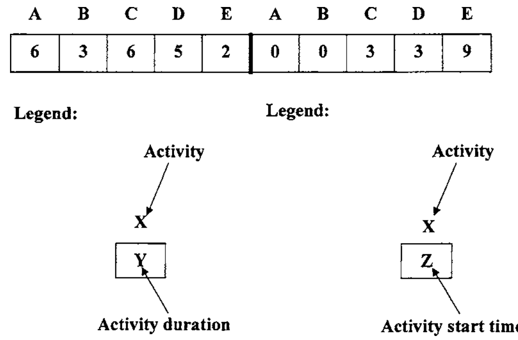

Fig. 1. Complete gene formation

where B=bonus for early completion; P=penalty for late completion; and Q=penalty for resource unleveling.

This adjusted profit is used in the GAs technique as the fitness value to identify the optimal schedule as explained in the next section. The objectives can be briefly stated as searching for a schedule that maximizes the project adjusted profit under the constraints of cash and resources.

Optimization Search Using Genetic Algorithms

Implementing the GA prototype for the problem in hand involved the operations of devising a schedule extension scheme which was described in Elazouni and Gab-Allah (2004), and setting the gene structure. The gene structure, as shown in Fig. 1 for the extension scheme of the 5-day extension increment in Fig. 2(b), was set as two strings of elements separated by a heavy line. The left-hand string represents the durations of activities' alternatives that make up the schedule. The right-hand string represents the assigned start times of the activities according to the improved crossover operation introduced in Elazouni and Metwally (2005) to avoid the violation of the precedence relationships.

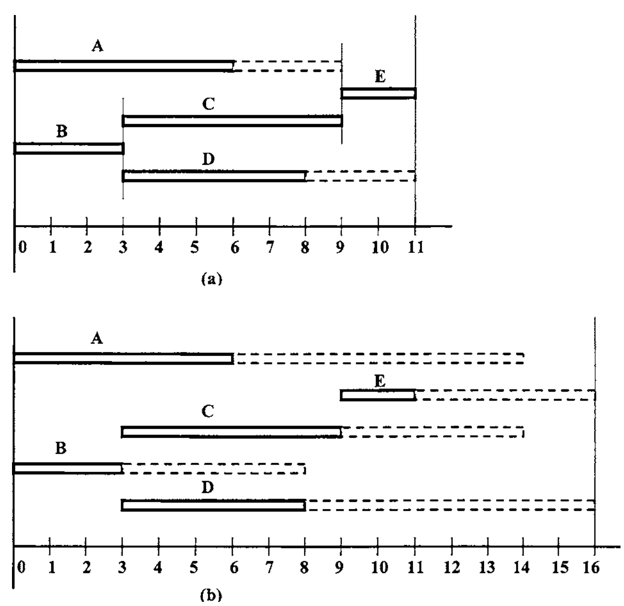

Fig. 2. Extension scheme of the example CPM schedule with 5-day increment

Table 1. Durations, Daily Direct Costs, and Resource Requirements of Activities

	Normal durations			Compressed durations		
Activity	Duration	Direct cost per day	Number of crews per day	Duration	Direct cost per day	Number of crews per day
A	6	2,000	6	4	4,000	9
B	3	3,000	7	2	5,000	8
C	6	4,000	4	4	7,000	7
D	5	2,000	5	3	4,000	8
E	2	3,000	6	1	7,000	8

The procedure of identifying the overall-optimized project schedule is initiated by generating a population of genes each compiles a randomly selected combination of activities' alternatives and assigns random start times as in Fig. 1. It is to be noted that genes have extension schemes of different duration although having the same extension increment. Cash-flow profile and resource-requirement histogram are charted for each generated gene. Genes of cash demand and resource requirements below the specified limits are exclusively accepted to the population. Then, the reproduction process among the population genes continues for a certain number of offsprings to ultimately identify the gene of the maximum adjusted profit.

Procedure Automation and Example Application

For implementation purpose, the detailed GA procedure was completely coded using VISUAL BASIC v.4. The input data of the example project, shown in Fig. 2, for the normal-duration and compressed-duration alternatives including direct costs, durations, and resource requirements, are presented in Table 1. The initial schedule that deployed the normal-duration alternatives of the project's five activities yielded an 11-day total duration. The result shows a maximum weekly indebtedness of 61,559, and an adjusted profit of 14,428 before applying the GAs technique. A population of 2,000 genes and 1,000 offsprings were used to run the GAs module. Table 2 presents the basic calculations of cash outflows, and inflows for the schedule at the credit limit of 47,000 with a total duration of 13 days. It is to be noted that the last payment which directly yields the profit amounted to 33,381 in Table 2 should be adjusted by subtracting an amount of 410.1 to account for a user-defined unleveled-resource penalty, plus an amount of 2,600 as a penalty for two-day extension in duration.

Since the maximum indebtedness at the initial solution amounted to 61,559, the credit limits above and below this value at increments of 1,000 were considered to determine the profits at project durations that range from 7 to 18 days. Adequate extension increments were allowed to give feasible solutions at the specified credit limits. The maximum number of crews per day was excessively specified to exclude the effect of the number of crews on time extension. Table 3 presents the schedules that maximized the adjusted profit and the associated credit limits, maximum indebtedness, and adjusted profit values. Results were such that as credit limit decreases, the project duration increases and vice versa. It can be noticed that while the initial schedule yielded a profit of 14,428, applying the GAs encountered another schedule of the same total duration but with a higher profit of 16,332.

Validation of the GAs Prototype

The developed GAs was validated by comparing the results of the example project in Fig. 2 with those obtained by using the integer programming (IP). Results of using the GAs were obtained at a weekly borrowing interest rate of 0.3%, overheads and taxes of 20%, markup percentage of 5%, a daily early completion bonus of 300, a daily delayed-completion penalty of 550, and an unleveled-resource penalty of 3,500. The other parameters were assigned zero values to secure identical modeling of cash inflows and outflows in GAs and IP, which is necessary for the purpose of comparing results. This was to circumvent the limited capability of the IP to model some modes of cash inflows and outflows. The application of the GAs at all possible credit limits encountered a

Table 2. Cash Outflow and Inflow Calculations of the Project at Credit Limit of 47,000

	Days																				
Activity	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	—	2,000	2,000	2,000	2,000	2,000	2,000	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B	—	5,000	5,000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C	—	—	—	—	—	—	—	4,000	4,000	4,000	4,000	4,000	4,000	—	—	—	—	—	—	—	—
D	—	—	—	—	—	—	—	—	2,000	2,000	2,000	2,000	2,000	—	—	—	—	—	—	—	—
E	—	—	—	—	—	—	—	—	—	—	—	—	—	7,000	—	—	—	—	—	—	—
Weekly direct costs	—			20,000					24,000					19,000						—	
Weekly overheads and taxes	4,400			3,400					4,080					3,230						—	
Weekly total costs	4,400			23,400					28,080					22,230						—	
Worth of work performed	5,280			28,080					33,696					26,676							
Payments at the end of weeks	9,200					1,685					22,205					27,259					33,381

Note: At the beginning of the project mobilization costs of 3,500, and bond costs of 900 add up to 4,400. Overhead and tax weekly rate of 17%. Weekly value of work performed equals the weekly total costs multiplied by a markup multiplier of 1.2. Advance payment at the beginning of the project equals 9,200. Weekly payment equals the weekly value of work performed after retaining 10% and one-third of the advance payment. Payments are paid one week later. All retained amounts are paid at the final payment.

Table 3. The Output Activities' Duration, Start Times, Maximum Negative Cash Flow, and Adjusted Profit for Investigating the Credit Limits That Cause the Total Project Duration to Change from 7 to 18 Days

Total duration	Credit limit	Activity A		Activity B		Activity C		Activity D		Activity E		Maximum negative cash flow	Adjusted profit
		Duration	Start	Duration	Start	Duration	Start	Duration	Start	Duration	Start		
18	30,000	6	0	3	0	6	10	5	4	2	16	29,767	4,662
17	33,000	4	0	2	3	6	9	5	8	2	15	32,650	6,873
16	40,000	4	0	2	0	4	11	3	7	1	15	39,613	9,344
15	41,000	6	0	2	0	6	8	5	3	1	14	40,443	9,622
14	44,000	6	0	2	0	4	9	5	2	1	13	42,329	11,405
13	47,000	6	0	2	0	6	6	5	7	1	12	45,242	12,335
12	55,000	6	0	2	0	4	7	5	6	1	11	53,318	14,512
11	67,000	6	0	2	1	4	4	3	7	1	10	66,332	16,332
10	68,000	6	0	3	0	6	3	5	5	1	9	67,770	22,972
9	72,000	6	0	3	0	4	3	5	4	2	7	71,313	31,661
8	76,000	6	0	2	0	4	3	3	5	1	7	75,997	40,427
7	81,000	4	0	2	0	4	2	3	4	1	6	80,743	49,606

maximum profit, which amounted to 4,826, at a credit limit of 84,000. The activities' durations were 6, 2, 4, 3, and 1 days of A, B, C, D, and E, respectively, with a total project duration of 7 days. The corresponding maximum indebtedness which amounted to 83,087 was identified.

However, obtaining the maximum profit using IP constitutes the accomplishment of two consecutive steps. The first step is to exhaustively enumerate all nonextended schedules which produced 32 initial schedules of durations ranged from 7 to 11 days. The enumerated initial schedules are presented in the first column of Table 4 wherein schedules were denoted for using the five activities' durations. For instance, Schedule 63652 represents a schedule of activities' durations of 6, 3, 6, 5, and 2 days that correspond to Activities A, B, C, D, and E, respectively. The second step involves providing extensions to allow 15-day extension schemes for all initial schedules identified in the first step. For instance, an initial schedule of 8-day duration receives a 7-day extension increment to allow a searching space of 15 days. The IP models were formulated for the 32 cases using the EXCEL macro developed in Elazouni and Gab-Allah (2004) to express the financial constraint that the maximum indebtedness should not exceed the limit of 83,087. Then, the IP formulations were solved using the Quantitative Systems for Business computer program (Cheng 1993) to output the required activities' shifts that fulfill the constraints.

The duration and the profit outputs of the IP were calculated for the 32 schedules and are presented in Table 4. The results indicate that some schedules were extended beyond 7 days to fulfill the constraints but no schedules were extended beyond the originally specified 15-day searching space. Then, the profit values were adjusted to account for the unleveled-resource penalty and completion bonus/penalty, as presented in the last column of Table 4. The schedule that produced the maximum profit value of 4,826 was 62431 of 7-day total duration. Thus, the GAs yielded, at one step, the same maximum profit that the IP technique obtained, and that was at the same activities' alternatives and start times. Therefore, this finding supports the validity of the GAs technique.

Table 4. Outputs of the IP Method

Alternative	Initial duration	Final duration	Profit	Resource penalty	Bonus	Adjusted profit
63652	11	11	3,345	460	—	2,885
63651	10	10	3,390	335	300	3,355
63632	11	11	3,455	997	—	2,458
63631	10	10	3,500	861	300	2,939
63452	9	9	3,555	267	600	3,888
63451	8	8	3,607	104	900	4,403
63432	9	9	3,665	698	600	3,567
63431	8	8	3,718	474	900	4,144
62652	10	10	3,392	505	300	3,187
62651	9	9	3,445	352	600	3,693
62632	10	10	3,503	602	300	3,201
62631	9	9	3,556	713	600	3,443
62452	8	8	3,609	274	900	4,235
62451	7	7	3,666	63	1,200	4,803
62432	8	8	3,720	570	900	4,050
62431	7	7	3,774	148	1,200	4,826
43652	11	11	3,565	659	—	2,906
43651	10	10	3,610	529	300	3,381
43632	11	11	3,675	1,048	—	2,627
43631	10	10	3,721	910	300	3,111
43452	9	9	3,773	305	600	4,068
43451	8	15	3,837	2,143	—	1,694
43432	9	11	3,891	1,589	—	2,302
43431	8	11	3,946	2,124	—	1,822
42652	10	10	3,284	768	300	2,816
42651	9	9	3,665	607	600	3,658
42632	10	10	3,723	1,310	300	2,713
42631	9	10	3,773	1,419	300	2,654
42452	8	11	3,838	2,068	—	1,770
42451	7	15	3,890	2,309	—	1,581
42432	8	11	3,947	2,224	—	1,723
42431	7	11	4,000	2,506	—	1,494

Conclusion

The objective of this note was to expand the concept and technique of the finance-based scheduling to device feasible schedules of cash surplus as well as cash shortage circumstances. This expansion necessitated the integration with the techniques of TCT analysis, resource allocation, and resource leveling. The integration of these four techniques was achieved through a GAs environment. The ultimate goal of the expanded technique is to maximize project profit through minimizing direct costs, overheads, financing costs, and resource fluctuations under credit and resource limits. The developed model was demonstrated and validated using a small example project of five activities by comparing its results to the results of the integer-programming technique. Finally, the developed model devises overall-optimized schedules that considered cash, time, cost, and resource aspects simultaneously.

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