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Maximizing expected contractor profit using an integrated model

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Abstract

Purpose – Planning for increased contractor profits should start at the time the contract is signed because low profits and lack of profitability are the primary causes of contractor failure. The purpose of this paper is to propose an integrated profit maximization model (IPMM) that aims for maximum expected profit by using time-cost tradeoff analysis, adjusted start times of activities, minimized financing cost and minimized extension of work schedule beyond the contract duration. This kind of integrated approach was never researched in the past.

Design/methodology/approach – IPMM is programmed into an automated system using MATLAB 2016a. It generates an optimal work schedule that leads to maximum profit by means of time-cost tradeoff analysis considering different activity acceleration/deceleration methods and adjusting the start/finish times of activities. While doing so, IPMM minimizes the contractor's financing cost by considering combinations of different financing alternatives such as short-term loans, long-term loans and lines of credit. IPMM also considers the impact of extending the project duration on project profit.

Findings – IPMM is tested for different project durations, for the optimality of the solutions, differing activity start/finish times and project financing alternatives. In all cases, contractors can achieve maximum profit by using IPMM.

Research limitations/implications – IPMM considers a deterministic project schedule, whereas stochastic time-cost tradeoff analysis can improve its performance. Resource allocation and resource leveling are not considered in IPMM, but can be incorporated into the model in future research. Finally, the long computational time is a challenge that needs to be overcome in future research.

Practical implications – IPMM is likely to increase profits and improve the chances of contractors to survive and grow compared to their competitors. The practical value of IPMM is that any contractor can and should use IPMM since all the data required to run IPMM is available to the contractor at the time the contract is signed. The contractor who provides information about network logic, schedule data, cost data, contractual terms, and available financing alternatives and their APRs can use an automated IPMM that adjusts activity start times and durations, minimizes financing cost, eliminates or minimizes time extensions, minimizes total cost and maximizes expected profit.

Originality/value – Unlike any prior study that looks into contractors' profits by considering the impact of only one or two factors at a time, this study presents an IPMM that considers all major factors that affect profits, namely, time-cost tradeoff analysis, adjusted start times of activities, minimized financing cost and minimized extension of work schedule beyond the contract duration.

Keywords Scheduling, Interest, Construction, Project management, Construction projects

Paper type Research paper

Introduction

One of the primary threats to a construction company is lack of profitability (Mahamid, 2012; Peterson, 2013). Construction companies generally operate with low profits (Senouci and Mubarak, 2014). Low profit is the primary cause of contractor failure (Arditi *et al.*, 2000). Planning for increased contractor profits should start at the time the contract is signed. A contractor can capitalize on the efficiency of its operations and explore the possibility of accelerating certain activities by using time-cost tradeoff analysis. A contractor can adjust the activity start times in its work schedule to ensure a convenient cash flow forecast of the operation. It is to the contractor's advantage to explore the use of combinations of different financing alternatives and minimize the financing cost. Finally, a contractor can explore the tradeoff between profit and extended contract duration.

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Time-cost tradeoff analysis can be performed to find the most cost effective work schedule that can be used by a contractor with minimum direct plus indirect cost. However, when the contractor has cash availability constraints, direct plus indirect cost is not the only parameter that affects profit. The contractor may need to borrow money because the cash inflows and outflows are unbalanced in every intermediate period during the project, mainly due to the retainage withheld by the owner and the delay in the intermediate payments made by the owner (Alavipour and Arditi, 2018a). It follows that the financing cost should also be considered as a factor that affects profit. The financing cost could be minimized if different combinations of financing alternatives are used (Alavipour and Arditi, 2018a), and if the start times of activities are adjusted. If the work schedule is extended beyond the duration specified in the contract, the contractor does not only incur liquidated damages, but also pays more indirect and financing cost, which results in lower profits. Therefore, the extension of the work schedule should be avoided or minimized to help the contractor obtain higher profits.

The models that have been developed to maximize the contractor's profit can be classified according to their considerations:

(1) Profit is maximized by minimizing the total cost where only time-cost tradeoff analysis is considered by taking into account direct and indirect costs (e.g. Ammar, 2011; He *et al.*, 2009; Jiang and Zhu, 2010; Shrestha and Shrestha, 2016). The profit that is generated by these models is not realistic since financing cost is not considered.

(2) Profit is maximized by minimizing the total cost where time-cost tradeoff analysis is considered alongside other parameters such as resource allocation (e.g. Kandil and El-Rayes, 2006), resource leveling (e.g. Chen and Weng, 2009), risk (e.g. Lakshminarayanan *et al.*, 2010) and quality (e.g. El-Rayes and Kandil, 2005). Although these studies considered these parameters in addition to time-cost tradeoff analysis, the profit that is obtained by these models is still not realistic since financing cost is not considered.

(3) Profit is maximized by reducing financing cost (e.g. Alghazi *et al.*, 2013; Elazouni *et al.*, 2015; Elazouni and Metwally, 2005; Fathi and Afshar, 2010). The profit that is obtained by using these models is not the maximum profit since time-cost tradeoff is not considered.

(4) Profit is maximized by minimizing total cost and reducing financing cost (e.g. Ali and Elazouni, 2009; El-Abbasy *et al.*, 2016, 2017; Elazouni and Metwally, 2007; Liu and Wang, 2008). Although these models consider time-cost tradeoff and adjust the start times of the activities, the profit obtained is not the maximum profit because the financing cost is not minimized, and the likelihood of incurring liquidated damages is high. It should be noted that profit can be maximized if financing cost is minimized and liquidated damages are avoided by using financing optimization considering combinations of different financing alternatives (Alavipour and Arditi, 2018a).

(5) Profit is maximized by minimizing total cost and financing cost. Although Alavipour and Arditi's (2018b) model uses time-cost tradeoff and financing optimization to maximize profit, it fails to consider different activity start times and ignores the situation where the project duration has to be extended beyond the duration specified in the contract.

The objective of this study is to develop an integrated profit maximization model (IPMM) that aims for maximum profit by using time-cost tradeoff analysis, adjusted start times of activities, minimized financing cost and minimized extension of work schedule beyond the contract duration.

Methodology

The IPMM that is proposed in this study calculates the maximum profit for every project completion time between the crash and extended durations so that the analyst can see the difference between the optimal outcomes for every project completion time, hence, performing a sensitivity analysis that allows the analyst to compare the results obtained in different scenarios. IPMM operates by performing time-cost tradeoff analysis, by adjusting the start times of activities, by minimizing financing cost, and by avoiding or minimizing the impact of extending the project duration beyond the duration specified in the contract. These approaches are briefly described in the following paragraphs.

Time-cost tradeoff analysis

IPMM recognizes that different activities can be performed with different acceleration/deceleration methods, each with a different duration and cost. When searching for maximum profit, an optimal work schedule should be identified by considering different acceleration/deceleration methods (i.e. normal, accelerated, crashed, and relaxed) for each and every activity throughout the project. Normal activity durations are specified by experienced managers considering the normal capabilities and productivity of their labor force and equipment, leading to a normal project duration and normal indirect and direct costs. Accelerated activity durations are obtained by allocating more resources, leading to shorter project duration and lower indirect cost at the expense of higher direct cost. Crashed activities are associated with the most accelerated durations and their associated costs, leading to minimum project completion time, maximum direct cost and minimum indirect cost, whereas relaxed activities that are associated with the most decelerated durations and their associated costs, leading to maximum project completion time, minimum direct cost and maximum indirect cost. Although crashed and relaxed activities result in two extreme boundaries, there are several intermediate alternatives between these two boundaries that represent accelerated and normal activities. Since financing cost depends on the schedule of construction activities, profit maximization involves selecting an optimal set of acceleration/deceleration methods for project activities after the optimized financing cost is incorporated in the model.

Adjusted start times of activities

The total cost (excluding financing cost) does not change when the start times of activities are adjusted within the available total floats, whereas the financing cost and profit do change. The financing cost, and hence profit depends on two parameters when the start times of activities are adjusted: the duration of keeping the money and the average of the cumulative net balance of the cash flow. It should be noted that when the start times of activities are pushed forward, one of two cases may occur based on the relative position of parallel activities in the work schedule: the duration of keeping the money goes down and the average of the cumulative net balance of the cash flow becomes less negative, resulting in a lower financing cost and higher profit; or the duration of keeping the money goes down, but the average of the cumulative net balance of the cash flow becomes more negative, in which case more money should be borrowed, which results in a higher financing cost and lower profit. Therefore, the effect of the duration of keeping the money and the average of the cumulative net balance of the cash flow on financing cost and profit should be considered simultaneously. However, regardless of whether the impacts of the duration of keeping the money and the average of the cumulative net balance of the cash flow coincide or conflict, if the minimum financing cost is obtained when different start times rather than the early start times of activities are adopted, the schedule becomes more critical since the total floats of some of the activities are used up. If the impacts of these two factors (i.e. the duration of keeping the money and the average of the cumulative net balance of the cash flow) conflict with each other, the impact of the average of the cumulative net balance of the cash flow on the financing

cost may cancel out the impact of delaying the start times of activities. IPMM detects such situations and considers the tradeoff between the effects of these two factors on the financing cost and profit. This analysis is vital in finding out when the activities should start so that minimum financing cost and maximum profit are achieved.

Financing optimization

The contractor will encounter deficits and the project duration will be extended if the contractor insists on using only the money received from the owner (Alavipour and Arditi, 2018a). If the contractor does not want to extend the project duration in order to avoid liquidated damages, the contractor has to finance the project. A construction project is rarely financed by the contractor's own savings because construction projects require large investments (Elazouni and Metwally, 2005). Regardless, using the company's capital or borrowing from a third party has a cost, and minimizing financing cost is of vital importance in maximizing profit (Alavipour and Arditi, 2018a). According to Alavipour and Arditi (2018a, b), financing cost can be minimized if combinations of different financing alternatives (e.g. short-term loans, long-term loans and lines of credit) are considered. IPMM adopts the financing optimization model proposed by Alavipour and Arditi (2018a) to maximize profit by minimizing financing cost.

Extension of work schedule beyond the contract duration

Contractors are advised to concentrate on construction time and reduce delays (Xiao and Proverbs, 2003). Although timely and adequate financing is important in preventing delays, borrowing a large amount of money can be difficult, especially for small contractors. This problem can be even worse in the absence of sufficient collateral since the financing alternatives offered by banks or other lenders can be limited (Nesan, 2012). If a contractor is not able to secure enough financing, the work schedule will have to be extended beyond the duration specified in the contract, the contractor is forced to reduce the maximum negative balance of the cash flow to a level that satisfies the availability of cash (Elazouni and Gab-Allah, 2004; Elazouni and Metwally, 2005). In such situations, a commonly used line of credit may not only force the contractor to extend project completion beyond the duration specified in the contract, but may also result in lower profit. The solution to this problem is to consider combinations of several financing alternatives. When a bank does not offer a large enough line of credit especially in the absence of adequate collateral, a contractor can obtain additional financing at a higher interest rate from alternative lenders in the form of short-term loans. When short-term loans with interest rates higher than the interest rate of the line of credit are considered in addition to a line of credit, not only does the project not need to be extended, but also higher profit may be obtained because the total cost and financing cost goes down, and liquidated damages are avoided.

If a contractor can secure the required financing, IPMM finds the maximum profit for a completion within the contract duration with no need to extend the project; if a contractor cannot secure the required financing and is forced to extend the work schedule, IPMM still finds the maximum profit for completion in the extended duration.

In addition, in past studies, the work schedule was extended beyond the contract duration by pushing forward the start times of activities rather than decelerating the activities (e.g. El-Abbasy *et al.*, 2017; Elazouni and Metwally, 2007; Liu and Wang, 2008). In other words, past studies consider the normal time and cost for both the normal duration (i.e. the contract duration) and the extended duration. In contrast to previous studies, IPMM considers relaxed activities when the project duration specified in the contract need to be extended. When decelerated durations are used in activities, fewer resources are allocated to the activities, which results in lower direct cost. Considering decelerated durations instead of using the normal durations in slowed-down activities reduces the direct cost and financing cost, and increases profit.

Proposed integrated profit maximization model (IPMM)

A hybrid algorithm is proposed to optimize financing variables using linear programming inside a genetic algorithm that is used to find the optimal activity acceleration/deceleration methods and start times of activities that lead to the highest profit. This algorithm of IPMM differs from Alavipour and Arditi's (2018b) hybrid algorithm in three respects. First, this algorithm considers the impact of changes in the start times of activities; second, it can handle the extension of the work schedule beyond the contract time; third, it considers four activity acceleration/deceleration methods including decelerated methods during the extension time in addition to crash, accelerated and normal conditions.

As shown in Figure 1, IPMM consists of two processes. Process 1 (i.e. Steps 1–5) maximizes the profit by optimizing activity acceleration/deceleration methods and financing variables where only the early start times of activities are considered. In Step 1, the schedule information (i.e. activity ID, activity name, predecessors and the durations of accelerated/decelerated activities and associated costs), project cost data and contract terms

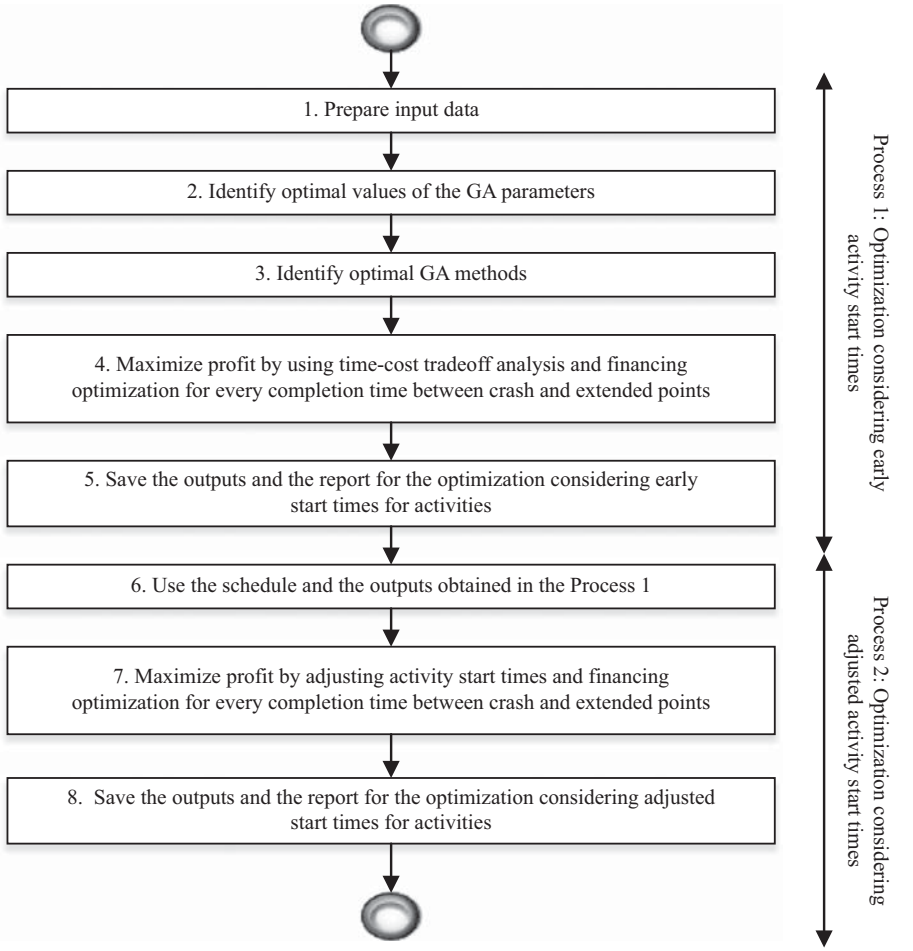

Figure 1.
The IPMM algorithm

(i.e. weekly fixed overhead cost, variable overhead percentage, mobilization cost percentage, profit percentage, bond premium percentage, early completion bonus percentage, weekly liquidated damages, advance payment percentage, retained percentage, number of months between submitting pay requests, lag in paying payment requests, and lag in making the final payment and return the retainage), and financing data (i.e. financing alternatives, annual percentage rates (APRs), interest payment times and borrowing limits) are read by an automated system programmed in MATLAB 2016a to calculate the contract price and to set up the financing flow, constraints and variables for every project completion time. The schedule information and financing data are read by MATLAB 2016a from the two separate Excel sheets while the project cost data and contract terms are sought from the user.

Steps 2 and 3 (Figure 1) are adopted from Lee *et al.*'s (2015) and Alavipour and Arditi's (2018b) method to identify the optimal values of the GA parameters (i.e. population size, crossover percentage, mutation percentage, mutation probability) and optimal GA methods (i.e. parent selection method, and crossover operation method). These practices eliminate the deficiencies of GA algorithms and add to their reliability and practicality. In Step 4, optimum results (i.e. optimum work schedule and optimum financing schedule) that lead to maximum profit are obtained for every project completion time using time-cost tradeoff analysis and financing optimization.

Process 2 (i.e. Steps 6–8) uses adjusted activity start times (not early start times exclusively, as was the case in Process 1) to maximize profit. The activity acceleration/deceleration methods that were obtained and saved in Step 5 of Process 1 are used in Step 6 to see whether there is a better solution that can be reached by adjusting the start times of activities in Step 7. Finally, the outputs of Process 2 are saved in Step 8. The outputs that are saved by IPMM are provided to the contractor in three categories for every project completion time: optimum work schedule that leads to maximum profit, optimum financing schedules (i.e. borrowing and repayment schedules) that lead to minimum financing cost, and the summary of optimum results (optimum financing cost, optimum total cost, maximum profit, optimum required limits for financing, percentage of critical activities, sum of the activities' total floats, liquidated damages, bonus and whether the project can be completed for the selected project completion time). These outputs are provided for early activity start times and for adjusted activity start times separately.

It should be noted that the reason why IPMM consists of two successive processes is to record the optimal results for early activity start times and for adjusted activity start times, allowing contractors to see the tradeoff between the cost of the impact and the level of criticality in the work schedule.

Decision variables

Three types of variables are considered in IPMM: activity acceleration/deceleration methods (X_1), start times of activities (X_2) and financing variables (X_3). The decision variables of activity acceleration/deceleration methods (X_1) are presented in Equation (1) where n is the number of activities, and m_i is activity acceleration/deceleration method relative to each activity that represents the duration and cost of the activity. The decision variables of start times of activities (X_2) are presented in Equation (2) where n is the number of activities and ST_i is the start time of each activity. The financing variables (X_3) are presented in Equation (3) where $FC_{i,j,k,t}$ represents financing cost relative to short-term loans, long-term loans and lines of credit:

$$X_1 = \{m_i\}, \tag{1}$$

$i = 1, 2, 3, \ldots, n$ activities; m = crashed, accelerated, normal, relaxed activities:

$$X_2 = \{\mathrm{ST}_i\}, \tag{2}$$

$i = 1, 2, 3, \ldots, n$ activities; ST, start time within total float:

$$X_3 = \left\{\mathrm{FC}_{i,j,k,t}\right\}, \tag{3}$$

i = time of taking the money (every 1, 3, 6, 9, 12 months); j = time of paying back the principal (after 3, 6, 9, 12 months); k = short-term loans, long-term loan or line of credit; $t = 0$, 1, 2, …, f months, where f is the time of the final payment.

Objective function

The objective is to maximize expected profit (P). The maximum profit is obtained with a selected combination of activity acceleration/deceleration methods using Equation (4). Expected profit depends on the contract price (CP) as calculated by the contractor, plus bonus (weekly early completion bonus (O_{bs}) multiplied by the number of weeks that the project is completed ahead of the project duration that is mentioned in the contract (W_e)), minus liquidated damages (liquidated damages per week (O_{lq}) multiplied by number of weeks of delay caused by the contractor that pushes project completion beyond the project duration specified in the contract (W_l)), direct cost (C_{dc}), fixed overhead cost (C_{foc}), variable overhead cost (C_{voc}), mobilization cost (C_{mob}), cost of bonding (C_{bond}) and optimized financing cost (C_{fin}). It should be noted that for every combination of activity acceleration/deceleration methods, first, the financing cost is optimized using Equation (5), and is used to maximize expected profit using Equation (4):

$$\text{Maximize } P = \mathrm{CP} + (O_{bs} \times W_e) - (O_{lq} \times W_l) - \left(C_{dc} + C_{foc} + C_{voc} + C_{mob} + C_{bond} + C_{fin}\right), \tag{4}$$

where:

$$C_{fin} = \text{ Min}\left\{\mathrm{FC}_{i,j,k,t}\right\}, \tag{5}$$

$\mathrm{FC}_{i,j,k,t}$ = financing cost relative to short-term loans, long-term loans and lines of credit; i = time of taking the money (every 1, 3, 6, 9, 12 months); j = time of paying back the principal (after 3, 6, 9, 12 months); k = short-term loans, long-term loan or line of credit; $t = 0$, 1, 2, …, f months, where f is the time of the final payment.

Constraints

The constraints of the optimization are twofold:

(1) The cumulative net balance of the cash flow (N'_t) is the first constraint. It should never be in the red. In other words, the contractor should always be able to pay its creditors, implying that the cumulative net balance of the cash flow should never go below zero. However, given the uncertainties in the construction activity, many contractors prefer having a balance that is always a little higher than zero. If the contractor wishes to have some extra funds as a contingency ($N_{\min}$), the minimum cumulative net balance of the cash flow (N'_t) is set up as such (see the following equation:

$$N'_t \geqslant N_{\min};\ \ t = 0, 1, 2,\ \ \ldots,\ \ f \text{ months}, \tag{6}$$

where f is the time of the final payment.

(2) The second constraint is the higher limit on the amount of borrowed money relative to short-term and long-term loans, and lines of credit. The total amount of borrowed money relative to short-term and long-term loans, and lines of credit ($B_{i,j,k,t}$) should be less than or equal to the limits negotiated with lenders ($L_{i,j,k,t}$) (see the following equation):

$$\{B_{i,j,k,t}\} \leqslant \{L_{i,j,k,t}\}, \tag{7}$$

where $L_{i,j,k,t}$ = limits negotiated with the lenders; i = time of taking the money (every 1, 3, 6, 9, 12 months); j = time of paying back the principal (after 3, 6, 9, 12 months); k = short-term loans, long-term loan, or line of credit; $t = 0, 1, 2, \ldots, f$ months, where f is the time of the final payment.

Testing the model

IPMM is tested using an example project that is shown in Figure 2. This network is a modified version of the network used by Alavipour and Arditi (2018a), in which some activities and a new path are added and some predecessors and successors are modified. This network is simple enough for illustration but complex enough to display a multitude of activities with varied precedence relationships. The schedule data including activity acceleration/deceleration methods, and cost data including contractual terms are shown in Tables I and II, respectively. The CPM network that is presented in Figure 2 is solved using the schedule information presented in Table I, and the cash flow forecast is created using the cost and contractual data presented in Table II. The project costs and contract price are calculated using normal time and normal cost for all activities and are shown in Table III. In this study, the network (Figure 2), the schedule data including activity acceleration/deceleration methods (Table I), and cost data including contractual terms (Table II) are created by the user by considering the realities of the project. Past studies (e.g. Ali and Elazouni, 2009; El-Abbasy *et al.*, 2016; El-Abbasy *et al.*, 2017) used a similar approach to create an activity network, cost data, contractual terms and schedule inputs. It should also be noted that the network (Figure 2), the schedule data including activity acceleration/deceleration methods (Table I), and the cost data and the contractual terms (Table II) are identical in all three scenarios that are considered in this research, hence having no effect on the outcomes of these three scenarios.

In Table III, the direct, fixed overhead, variable overhead, mobilization and bonding costs, as well as profit are calculated using normal activity durations and costs.

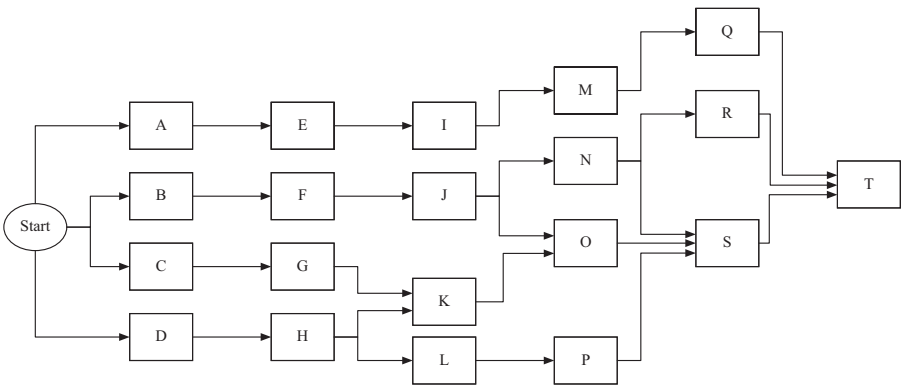

Figure 2.
Network schedule of the example project

Table I.
Project schedule data and activity acceleration/deceleration method inputs

Activity ID	Activity name	Predecessors			Duration (weeks)				Direct cost ($/week)			
		Predecessor 1	Predecessor 2	Predecessor 3	Decelerated activities	Normal activities	Accelerated activities	Crashed activities	Decelerated activities	Normal activities	Accelerated activities	Crashed activities
1	Start	–	–	–	–	–	–	–	–	–	–	–
2	A	1	–	–	13	11	9	8	16,000	20,000	30,000	50,000
3	B	1	–	–	11	9	7	6	16,000	20,000	30,000	50,000
4	C	1	–	–	10	9	8	7	30,000	35,000	45,000	60,000
5	D	1	–	–	7	6	5	–	48,000	57,000	70,000	–
6	E	2	–	–	6	5	4	–	33,000	40,000	52,000	–
7	F	3	–	–	9	8	6	5	25,000	30,000	50,000	70,000
8	G	4	–	–	7	6	5	–	63,000	75,000	95,000	–
9	H	5	–	–	10	9	8	7	35,000	40,000	50,000	65,000
10	I	6	–	–	13	11	9	8	37,000	45,000	57,000	75,000
11	J	7	–	–	8	7	6	–	65,000	75,000	88,000	–
12	K	8	9	–	7	6	5	–	55,000	65,000	80,000	–
13	L	9	–	–	10	9	8	7	58,000	66,000	75,000	90,000
14	M	10	–	–	9	8	7	6	39,000	45,000	55,000	70,000
15	N	11	–	–	8	7	6	–	47,000	55,000	70,000	–
16	O	11	12	–	6	5	4	–	45,000	55,000	70,000	–
17	P	13	–	–	10	9	8	7	53,000	60,000	68,000	85,000
18	Q	14	–	–	9	8	7	–	55,000	65,000	80,000	–
19	R	15	–	–	10	9	8	7	35,000	40,000	50,000	75,000
20	S	15	16	17	12	11	10	9	54,000	60,000	70,000	90,000
21	T	18	19	20	11	10	9	–	72,000	80,000	90,000	–

Data type	Item	Amount
Cost data	Weekly fixed overhead cost	\$40,000/week
	Variable overhead percentage of direct cost	8%
	Mobilization cost percentage of (direct cost + variable overhead)	5%
	Profit percentage of (direct cost + fixed overhead + variable overhead + mobilization cost)	7%
	Bond premium percentage of (direct cost + fixed overhead + variable overhead + mobilization cost + profit)	1%
Contract terms	Early completion bonus percentage of contract price	\$0/week
	Weekly liquidated damages	\$40,000/week
	Advance payment percentage of contract price	0%
	Retained percentage of periodic payments	10%
	Number of months between submitting pay requests	1 month
	Lag in paying payment requests (months)	1 month
	Lag in making the final payment and return the retainage (months)	0 month

Table II. Cost data and contractual terms of the project

Type of cost/price	Calculation	Amount (\$)
Direct cost	Sum of activities' direct costs using normal activity duration and cost for all activities	8,211,000
Fixed overhead cost	Project duration × weekly fixed overhead cost 54 weeks × \$40,000/week	2,160,000
Variable overhead cost	Variable overhead percentage × direct cost 0.08 × \$8,211,000	656,880
Mobilization cost	Mobilization cost percentage × (direct cost + variable overhead) 0.05 × (\$8,211,000 + \$656,880)	443,394
Profit	Profit percentage × (direct cost + fixed overhead + variable overhead + mobilization cost) 0.07 × (\$8,211,000 + \$2,160,000 + \$656,880 + \$443,394)	802,989
Cost of bonding	Bond premium percentage × (direct cost + fixed overhead + variable overhead + mobilization cost + profit) 0.01 × (\$8,211,000 + \$2,160,000 + \$656,880 + \$443,394 + \$802,989)	122,743
Contract price	Direct cost + fixed overhead cost + variable overhead cost + mobilization cost + profit + cost of bonding (\$8,211,000 + \$2,160,000 + \$656,880 + \$443,394 + \$802,989 + \$122,743)	12,397,006

Table III. The project costs and contract price

This information is used to calculate the contract price (CP) considering the cost data and contractual terms of the project that are input by the contractor. The cost of bonding (C_{bond}) and the contract price (CP) that are calculated in Table III are known at the outset. After the contract is signed, the financing alternatives and conditions that are negotiated with lenders are used by IPMM to reduce cost and increase profit by minimizing financing cost.

Three scenarios are considered in testing IPMM to show that IPMM results in maximum profit and can be used in every situation regardless of whether the credit limit is adequate or inadequate; the start times of activities are variable or constant; only a line of credit or a combination of financing alternatives are considered; and the work schedule needs to be extended beyond the duration specified in the contract or not. The APRs and upper financing limits are the same in each scenario, whereas the available financing alternatives are different. It should be noted that the contractor can seek financing from two different types of lenders, namely, alternative lenders and traditional banks. If the contractor does not satisfy the requirements of traditional banks, alternative lenders can be the choice with higher APRs. It should also be noted that both

compounding and lending fees can be considered in APRs which causes APRs to be higher than interest rates. Accordingly, based on market conditions, the APR ranges between 2 and 28 percent for loans, and between 5 and 40 percent for lines of credit (Mclntyre, 2017; White, 2017), and are lower for loans when they are taken for a longer duration (Au and Hendrickson, 1986). In Scenario 1, i.e., the scenario used in all past studies, only a line of credit is considered. The APR is 15 percent, and the credit limit is $1,670,000. When the credit limit is $1,670,000 or less, the credit is not enough to finish the project between the crash and normal durations and the contractor is forced to extend the work schedule beyond the duration specified in the contract, simulating the conditions in past studies. In Scenario 2, in addition to the line of credit described for Scenario 1, it is also assumed that the contractor can obtain short-term loans with no upper limit, but with higher APRs than the APRs of the line of credit. Scenario 2 is specifically designed to see the changes in financing cost (and consequently in profit) when short-term loans with interest rates higher than the interest rate of the line of credit are considered in addition to a line of credit. The reason why no upper limit is considered for short-term loans in Scenario 2 is that alternative lenders usually allow borrowers to specify the required financing even when they do not provide enough collateral, but they seek higher APRs such as the short-term loans that are considered in Scenario 2:

- loans that are taken every three months and should be paid back after three months, with 21 percent APR;
- loans that are taken every three months and should be paid back after six months, with 19 percent APR;
- loans that are taken every six months and should be paid back after three months, with 20 percent APR; and
- loans that are taken every six months and should be paid back after six months, with 18 percent APR.

In Scenario 3, it is assumed that all financing alternatives can be considered and the contractor has access to short-term loans (with 9-21 percent APRs), a long-term loan (with 7 percent APR) and a line of credit (with 15 percent APR) with no upper limit.

Analysis of the results related to the duration of the project

The results of testing all scenarios are shown in Tables IV–VI. The duration specified in the contract is the normal duration of 54 weeks, but as seen in Table IV, the schedule can be accelerated to 44 weeks (crash duration), or relaxed to 61 weeks (extended duration). As shown in Table IV, in Scenario 1, the project cannot be executed in less than 55 weeks, because only one financing alternative is considered (i.e. only a line of credit with a credit limit of $1,670,000). In this scenario, the project has to be extended by one week from 54 to 55 weeks. In contrast, in Scenario 2, the project can be completed any time between 45 and 54 weeks (cannot be completed in the crash duration of 44 weeks) since short-term loans are considered in addition to the same line of credit used in Scenario 1. As seen on the left hand side of Table IV, in terms of the feasibility of the project, Scenario 2 has an advantage over Scenario 1, and Scenario 3 has an advantage over both Scenarios 1 and 2.

Analysis of the results related to the optimality of the solutions

Comparing the results of Scenario 2 to Scenario 1, one sees that the contractor can complete the project without extending the project and without paying liquidated damages (see Table IV). Less financing is incurred and more profit is generated in Scenario 2 if the project duration has to be extended (see Tables V and VI). In Scenario 2,

Completion of the project within contract duration				Sum of the activities' total floats					
				Scenario 1 (line of credit only)		Scenario 2 (line of credit + short-term loans)		Scenario 3 (line of credit + short-term loans + long-term loan)	
Project completion time (weeks)	Scenario 1 (line of credit only)	Scenario 2 (line of credit + short-term loans)	Scenario 3 (line of credit + short-term loans + long-term loan)	Early start times	Adjusted start times	Early start times	Adjusted start times	Early start times	Adjusted start times
44	No	No	Yes	–	–	–	–	0	0
45	No	Yes	Yes	–	–	0	0	0	0
46	No	Yes	Yes	–	–	0	0	0	0
47	No	Yes	Yes	–	–	0	0	0	0
48	No	Yes	Yes	–	–	0	0	0	0
49	No	Yes	Yes	–	–	0	0	0	0
50	No	Yes	Yes	–	–	1	1	1	1
51	No	Yes	Yes	–	–	5	5	5	5
52	No	Yes	Yes	–	–	9	9	9	9
53	No	Yes	Yes	–	–	12	12	12	7
54	No	Yes	Yes	–	–	15	15	15	10
55	Yes	Yes	Yes	27	27	16	16	16	11
56	Yes	Yes	Yes	24	24	25	25	25	18
57	Yes	Yes	Yes	38	38	22	22	22	19
58	Yes	Yes	Yes	47	47	31	30	31	27
59	Yes	Yes	Yes	47	47	31	30	31	25
60	Yes	Yes	Yes	47	47	31	30	31	27
61	Yes	Yes	Yes	62	62	46	45	46	40

(*continued*)

Table IV.
Schedules that lead to optimal profit considering three scenarios for every completion time

Table IV.

Percentage of critical activities					
Scenario 1 (line of credit only)		Scenario 2 (line of credit + short-term loans)		Scenario 3 (line of credit + short-term loans + long-term loan)	
Early start times	Adjusted start times	Early start times	Adjusted start times	Early start times	Adjusted start times
–	–	–	–	100%	100%
–	–	100%	100%	100%	100%
–	–	100%	100%	100%	100%
–	–	100%	100%	100%	100%
–	–	100%	100%	100%	100%
–	–	100%	100%	100%	100%
–	–	95%	95%	95%	95%
–	–	75%	75%	75%	75%
–	–	75%	75%	75%	75%
–	–	75%	75%	75%	85%
–	–	75%	75%	75%	80%
75%	75%	75%	75%	75%	80%
75%	75%	55%	55%	55%	65%
30%	30%	75%	75%	75%	75%
30%	30%	55%	60%	55%	65%
30%	30%	55%	60%	55%	70%
30%	30%	55%	60%	55%	65%
30%	30%	30%	30%	30%	40%

Table V.
Results of optimum costs considering three scenarios for every completion time

	Financing cost ($)						
	Scenario 1 (line of credit only)		Scenario 2 (line of credit + short-term loans)		Scenario 3 (line of credit + short-term loans + long-term loan)		Liquidated damages ($)
Project completion time (weeks)	Early start times	Adjusted start times	Early start times	Adjusted start times	Early start times	Adjusted start times	Scenarios 1 to 3
44	–	–	–	–	174,050	174,050	–
45	–	–	270,256	270,256	178,404	178,404	–
46	–	–	254,225	254,225	169,133	169,133	–
47	–	–	245,017	245,017	161,714	161,714	–
48	–	–	238,068	238,068	157,872	157,872	–
49	–	–	236,621	236,621	160,227	160,227	–
50	–	–	233,185	233,185	157,108	157,108	–
51	–	–	232,147	232,147	157,577	157,577	–
52	–	–	229,835	229,835	157,174	157,174	–
53	–	–	239,286	239,286	144,006	143,334	–
54	–	–	240,297	240,297	145,615	144,283	–
55	244,894	244,894	240,077	240,077	146,851	145,589	40,000
56	243,801	243,801	240,466	240,466	147,862	146,118	80,000
57	255,341	255,341	255,014	255,014	157,957	156,551	120,000
58	258,318	258,318	256,679	256,291	159,899	158,472	160,000
59	258,671	258,671	257,025	256,636	160,296	158,902	200,000
60	259,072	259,072	257,421	257,032	160,734	159,305	240,000
61	273,078	273,078	270,994	270,601	169,731	168,038	280,000

(*continued*)

Table V.

Total cost including financing cost and liquidated damages ($)					
Scenario 1 (line of credit only)		Scenario 2 (line of credit + short-term loans)		Scenario 3 (line of credit + short-term loans + long-term loan)	
Early start times	Adjusted start times	Early start times	Adjusted start times	Early start times	Adjusted start times
–	–	–	–	12,063,208	12,063,208
–	–	12,017,974	12,017,974	11,926,122	11,926,122
–	–	11,901,327	11,901,327	11,816,236	11,816,236
–	–	11,800,576	11,800,576	11,717,273	11,717,273
–	–	11,737,237	11,737,237	11,657,041	11,657,041
–	–	11,690,739	11,690,739	11,614,346	11,614,346
–	–	11,653,594	11,653,594	11,577,516	11,577,516
–	–	11,654,000	11,654,000	11,579,430	11,579,430
–	–	11,659,935	11,659,935	11,587,275	11,587,275
–	–	11,684,438	11,684,438	11,589,159	11,588,487
–	–	11,701,636	11,701,636	11,606,953	11,605,622
11,807,778	11,807,778	11,761,003	11,761,003	11,667,778	11,666,516
11,850,397	11,850,397	11,825,516	11,825,516	11,732,912	11,731,169
11,931,732	11,931,732	11,901,921	11,901,921	11,804,864	11,803,457
12,012,441	12,012,441	11,967,710	11,967,321	11,870,930	11,869,503
12,081,453	12,081,453	12,036,716	12,036,327	11,939,987	11,938,593
12,152,783	12,152,783	12,108,040	12,107,651	12,011,352	12,009,924
12,244,521	12,244,521	12,199,344	12,198,951	12,098,081	12,096,389

Project completion time (weeks)	Profit ($) Scenario 1 (line of credit only) Early start times	Scenario 1 (line of credit only) Adjusted start times	Scenario 2 (line of credit + short-term loans) Early start times	Scenario 2 (line of credit + short-term loans) Adjusted start times	Scenario 3 (line of credit + short-term loans + long-term loan) Early start times	Scenario 3 (line of credit + short-term loans + long-term loan) Adjusted start times
44	–	–	–	–	333,797	333,797
45	–	–	379,032	379,032	470,884	470,884
46	–	–	495,678	495,678	580,770	580,770
47	–	–	596,430	596,430	679,733	679,733
48	–	–	659,769	659,769	739,965	739,965
49	–	–	706,266	706,266	782,660	782,660
50	–	–	743,412	743,412	819,489	819,489
51	–	–	743,006	743,006	817,576	817,576
52	–	–	737,071	737,071	809,731	809,731
53	–	–	712,568	712,568	807,847	808,519
54	–	–	695,370	695,370	790,052	791,384
55	589,228	589,228	636,002	636,002	729,228	730,490
56	546,608	546,608	571,489	571,489	664,093	665,837
57	465,274	465,274	495,085	495,085	592,142	593,548
58	384,565	384,565	429,296	429,685	526,076	527,503
59	315,553	315,553	360,290	360,679	457,019	458,413
60	244,223	244,223	288,966	289,355	385,653	387,082
61	152,485	152,485	197,661	198,055	298,924	300,617

Table VI. Optimum profits considering three scenarios for every completion time

lower optimal financing cost and higher profit were obtained even though short-term loans had higher APRs than the APR of the line of credit (i.e. short-term loans with 21, 19, 20 and 18 percent APR, compared to 15 percent APR for the line of credit). When only a line of credit is considered in Scenario 1, the contractor cannot repay the debts fast enough because of the negativity of the cumulative net balance of the cash flow; as a consequence, the interest of the line of credit is compounded. In contrast, in Scenario 2, because short-term loans are available, the interest of the selected short-term loans can be lower than the compounded interest of the line of credit for longer durations. Meanwhile, when all financing alternatives are considered in Scenario 3, the financing costs are much lower and profits are much higher than in Scenarios 1 and 2 (see Tables V and VI). Therefore, while Scenario 2 generates lower financing costs and higher profits compared to Scenario 1, Scenario 3 generates lower financing costs and profits than both Scenarios 1 and 2 (see Tables V and VI). To conclude, Scenario 3 where all financing alternatives are considered is the best approach and Scenario 1 where only a line of credit is used is the worst approach in terms of the optimality of the solutions.

It should also be noted that considering different scenarios of financing alternatives not only results in achieving different financing costs and profits, but also results in different work schedules. For example, as shown in Table VI, in Scenario 1, the highest profit is obtained using a work schedule that results in a 55 week project completion time, whereas in Scenarios 2 and 3, the highest profit is obtained when the project duration is 50 weeks. However, sensitivity analysis is highly recommended before choosing the work schedule that leads to the highest profit. For instance, in Scenario 3, the highest profit of $819,489 is obtained when the project is completed in 50 weeks (see Table VI) with 95 percent of the activities being critical (see Table IV), whereas the next highest profit of $817,576 is obtained when the project is completed in 51 weeks (see Table VI) with 75 percent of the activities being critical (see Table IV). The contractor will have to decide which solution agrees better with the company's risk-taking policy.

Effect of early and adjusted start times of activities on the optimal profits

In Tables IV–VI, the results are shown for two conditions in each scenario, i.e., early and adjusted start times of activities. As shown in Tables V and VI, the optimal results are not affected by adjusting the start times of activities in Scenario 1, whereas changing the start times of activities does affect the optimal financing costs and profits at some project completion times in Scenarios 2 and 3, but negligibly and only for few completion times (between 53 and 61 weeks for Scenario 3), because the duration of keeping the money and the average of the cumulative net balance of the cash flow conflict with each other. It is true that the duration of keeping the money goes down when activity start times are shifted forward, but in this project example, the average of the cumulative net balance of the cash flow becomes more negative because of the changed combinations of parallel activities, which results in borrowing more money. The tradeoff between the duration of keeping the money and the average of the cumulative net balance of the cash flow is difficult to predict as it totally depends on the configuration of the activities in the network.

Although the changes in the financing costs and profits are negligibly small when adjusted activity start times are considered in both Scenarios 2 and 3, the variation is bigger in Scenario 3 compared to Scenario 2 (see Tables V and VI). For example, in Scenario 2, the profits for a project completion time of 61 weeks differ by \$198,055–\$197,661 = \$394 (0.2 percent), whereas in Scenario 3, they differ by \$300,617–\$298,924 = \$1,693 (0.4 percent). On the other hand, as shown in Table IV, when adjusted activity start times are considered, more total float is used in Scenario 3 compared to Scenarios 2, leaving less available total float for the project and making the schedule more critical. For instance, in Scenario 2, the sum of the total floats for a project completion time of 61 weeks differs by 46–45 = 1 (2 percent), whereas in Scenario 3, it differs by 46–40 = 6 (15 percent). In summary, when adjusted activity start times are considered, more total float is used in Scenario 3 compared to Scenario 2 (see Table IV). Therefore, the comparison between these three scenarios when adjusted activity start times are considered suggests that: lower optimal financing costs and higher profits are obtained when the schedule is more critical, and the effects of considering adjusted activity start times are more pronounced when all financing alternatives are considered (i.e. in Scenario 3). In other words, more risk results in more profit.

Effect of financing optimization on the optimal solutions

According to Table V, in Scenario 1, the lowest financing cost is \$243,801 that is obtained in a 56-week project, whereas the lowest financing costs in Scenarios 2 and 3 are \$229,835 and \$143,334 that are obtained in project durations of 52 and 53 weeks, respectively. Therefore, the results of the analysis of these three scenarios indicate that the lowest financing cost is obtained in Scenario 3 where all financing alternatives are available to the contractor. Although the lowest financing cost obtained in Scenario 3 proves the significance of having access to loans, it should be noted that the contractor is not able to find out which financing alternative to use and what amount of money to borrow each month, unless the contractor uses the financing optimization method coded in IPMM. The financing model used in this study has the ability to find optimum financing schedules and to provide both borrowing and repayment schedules considering different scenarios. Given the different financing alternatives, not only is the optimal financing cost different, but also the financing schedules are different.

Analyzing the IPMM algorithm

The project example is tested in three scenarios (i.e. Scenarios 1 to 3) using the IPMM algorithm proposed in this study. The advantage of IPMM is to integrate time-cost tradeoff analysis, adjusted start times of activities, minimized financing cost and minimized

extension of work schedule beyond the contract duration into a single model to achieve minimum financing cost and higher profit. In addition, the optimal results and computational time of each test are presented in Table VII. The reason why the optimum results are identical for both early and adjusted activity start times in this table is discussed in detail in the previous section. As shown in Table VII, when all financing alternatives are considered (Scenario 3), the computational time is longer than when only a line of credit (Scenario 1) or a line of credit with short-term loans (Scenario 2) are considered, because in Scenario 3, a larger number of financing combinations are possible. The reason why the computational time of IPMM is high is because: three types of variables (i.e. activity acceleration/deceleration methods, start times of activities, and financing variables) are considered; financing optimization is used; the algorithm performs for two conditions of early activity start times and adjusted activity start times separately; the optimal results are calculated and reported for every project completion time between crash and extended points (i.e. every project completion time between 44 and 61 weeks); and the optimal GA parameters and methods are identified to increase the reliability of the results.

Conclusion

IPMM integrates factors that affect the contractor's profit, namely: time-cost tradeoff, start times of activities, financing cost and extension of work schedule beyond the contract duration. IPMM is a distinct improvement over past models because:

(1) Higher profit is obtained if IPMM is used because IPMM considers time-cost tradeoff analysis, adjusted start times of activities, minimum financing cost and minimum extension of the work schedule beyond contract duration (if necessary). No past research has ever attempted to integrate these factors into a single model.

(2) IPMM finds the minimum financing cost because both financing optimization and adjusted start times of activities are considered. These two factors were never considered jointly in past studies. Although the example project that was tested in this study did not display significant reduction in the financing cost when adjusted activity start times are considered, the minimum financing cost could have gone down significantly if the average of the cumulative net balance of the cash flow had gone down when the activity start times were changed. There is no way to predict these effects unless IPMM is used.

Scenario	Activity start time alternatives	Maximum profit ($)	Optimal project duration based on maximum profit (weeks)	Total time with optimal GA identification process (seconds)
Scenario 1 (line of credit only)	Early activity start times	589,228	55	840,943
	Adjusted activity start times	589,228	55	
Scenario 2 (line of credit + short-term loans)	Early activity start times	743,412	50	854,148
	Adjusted activity start times	743,412	50	
Scenario 3 (line of credit + short-term loans + long-term loan)	Early activity start times	819,489	50	927,686
	Adjusted activity start times	819,489	50	

Table VII. Summary of the results of IPMM tests

(3) Sometimes contractors can secure the required financing to perform the project within the duration specified in the contract, whereas sometimes contractors cannot secure the required financing, resulting in an extended work schedule. IPMM can handle all situations and find the maximum profit according to the contractor's situation.

(4) IPMM is able to provide the optimum results using early activity start times and adjusted activity start times, whereas past studies do not. Contrary to past studies, the percentage of the critical activities, the total float of the project, and the average of the cumulative net balance of the cash flow are reported in each case (i.e. early activity start times and adjusted activity start times) to allow a contractor to make a decision whether it is worth to operate with a more critical work schedule or not.

(5) In IPMM, relaxed activities are considered when the work schedule is extended. Therefore, in the extension time, the optimal financing cost and profit are obtained not only by adjusting the start times of activities but also by changing the duration of activities, whereas this has been done in previous studies only by adjusting the start times of activities (with no change in activity duration) when the work schedule needs to be extended beyond the contract duration.

It should be noted that if any of the financing alternatives is different or the work schedule is changed, an updated optimum financing schedule and an updated optimum work schedule can be obtained. This study has also some limitations. The proposed model considers a deterministic project schedule, whereas stochastic time-cost tradeoff analysis can improve the proposed model. In addition, resource allocation and resource leveling are not considered in the proposed model, and can be incorporated into the model in future research. Moreover, the long computational time is a serious challenge that needs to be overcome in future research. Finally, the performance of the proposed model can be assessed under the effects of macroeconomic factors such as changes in government policies, and changes in market conditions caused by periodic recessions.

Profitability plays an important part in the survival and growth of a contractor. An informed contractor who is able to maximize profit by considering the relevant and salient factors is always ahead of the game. Contractors can obtain maximum profit using the proposed IPMM where the impacts of time-cost tradeoff, start times of activities, financing cost and extended work schedules are acknowledged. All the contractor needs to do is to provide information about network logic, schedule data, cost data, contractual terms and available financing alternatives and their APRs at the time the contract is signed. Based on this information, an automated IPMM adjusts activity start times and durations, minimizes financing cost, eliminates or minimizes time extensions, minimizes total cost, and maximizes expected profit. The IPMM model proposed in this study is likely to allow contractors to survive and grow better than their competitors.

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