A Comprehensive Cash Management Model for Construction Projects Using Ant Colony Optimization

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ABSTRACT: Cash management is a major concern for all contractors in the construction industry. It is arguable that cash is the most critical resource of all. A contractor needs to secure sufficient funds to navigate the project to the end, while keeping an eye on maximizing profits along the way. Past research attempted to address such topic via developing models to tackle the time-cost tradeoff problem, cash flow forecasting, and cash flow management. Yet, little was done to integrate the three aspects of cash management together. This paper, as such, presents a comprehensive model that integrates the time-cost tradeoff problem, cash flow management, and cash flow forecasting. First, the model determines the project optimal completion time by considering the different alternative construction methods available for executing project activities. Second, it investigates different funding alternatives and proposes a project-level cash management plan. Two funding alternatives are considered; they are borrowing and company own financing. The model was built as a combinatorial optimization model that utilizes ant colony search capabilities. The model also utilizes Microsoft Project software and spreadsheets to maintain an environment that incorporates activities, their durations, and other project data, in order to estimate project completion time and cost. Ant Colony Optimization algorithm was coded as a Macro program using VBA. Finally, an example project was used to test the developed model, where it acted reliably in maximizing the contractor's profit in the test project.

Keywords: Cash Management, Cash Flow, Time-Cost Tradeoff, Optimization, Ant Colony Optimization

1. INTRODUCTION

The construction industry utilizes a multitude of resources for the execution of its projects. Money is widely considered the most critical resource of all due to its limited availability and essentiality for the completion of every single activity in a project. Statistics-wise, construction companies tend to fail due to deficits in their budgets rather than inadequacy of other resources [1]. It was estimated that over 60% of contractors' failures are due to economic factors [2]. Thus, cash management becomes a mandatory practice for all contractors as it serves many purposes, such as: 1) maximization of the contractor's profit through the minimization of project costs; 2) forecasting of the cash outlay throughout the project time span and determination of the break-even points; and 3) assessment of the funds needed to complete the project based on the estimated cash overdraft amounts [3].

Many models have been developed to address different aspects of cash management in construction projects. Some focused on determining the project minimum cost through finding the optimal completion time, which is referred to as the time-cost-tradeoff problem [1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. Other studies proposed models for forecasting and generating the project cash flow [13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27]. Fewer studies were directed toward the management of the cash flow in construction projects[3, 28, 29].

The majority of these models addressed each aspect of the cash flow management problem individually without taking into consideration the interrelationship between optimization of project time, overdraft requirements, and available funding options. Hegazy and Ersahin [28] developed a spreadsheet-based model that schedule the project with respect to one of four aspects, which are: time-cost tradeoff (TCT) analysis, resource allocation, resource leveling, and cash flow management. However, the model optimizes the project schedule with respect to each aspect individually rather than integrating all of them in one comprehensive objective function.

As such, there is a need for a comprehensive cash optimization model with the objective of maximizing the contractor's profit through the minimization of project different cost components. The model presented in this paper determines the optimal completion time (minimum cost) taking into consideration the tradeoff between project time and cost, cash overdraft requirements, and the different funding alternatives available for the contractor. The model utilizes the ant colony algorithm for optimization.

2. RESEARCH SCOPE AND METHODOLOGY

The methodology adopted in this research attempted to overcome the main shortcomings of previous models reviewed in the literature. To achieve this goal, a comprehensive model was built that integrates all three problems, which are: (1) time-cost tradeoff, (2) cash flow forecasting, and (3) cash flow management. The model is composed of two modules; the first determines the project optimal completion time by solving the TCT problem while the second provides a cash flow management strategy for the results obtained by the first module. The main objective of the model is to maximize the contractor's profit through the minimization of project costs.

The model is computer-based and has two main subsystems of different attributes and functions that collaborate to integrate and solve the aforementioned cash problems. The first subsystem is a user interface that utilizes MS Project and spreadsheets, where the project essential data are collected, inferred, stored and processed. MS Project is used to maintain various relationships between activities, identify critical paths, assign cost indices, level resources, and process all necessary project data obtained by different computational operations. Spreadsheets then display the model output data, and the details needed for executing the proposed cash management plan. The second subsystem is the optimization unit, which is responsible of finding the optimum values according to a predefined objective function. Ant colony algorithm was used for optimization and was coded as macro program through MS Project, as shown in Figure 1.

3. ANT COLONY OPTIMIZATION

Ant Colony Optimization (ACO) was introduced by Marco Dorigo as a multi-agent approach to different combinatorial problems and the quadratic assignment problem [30]. ACO simulates the foraging behavior of real ants. Although ants are almost blind, they can find the shortest path between their nest and a source of food [31]. This is achieved through the pheromone trails that ants use to mark paths while traveling as a form of indirect communication [9].

Ants start searching for food in a stochastic manner; the ant traveling through the shortest path tends to deposit more pheromone, which consequently attracts other members in the colony. The process continues with more ants joining the shortest path until the majority of the colony converges to the shortest path [32], as shown in Figure 2.

The ant colony algorithm incorporates six main steps as follow [3]:

1. Construction of Trial Solutions: This is done by creating a colony of ants (M). Each ant ($z \in \{1, 2, 3\ldots M\}$) starts moving randomly in the search space from one decision point ($i \in \{1, 2, 3\ldots V\}$) to another until all points are visited. The decision points represent the problem variables. For every decision variable, there is a number of available options (N). At each decision point (variable), an option ($j \in \{1, 2, 3\ldots N\}$) is randomly selected, which has a value (lij), as represented in Figure 3.

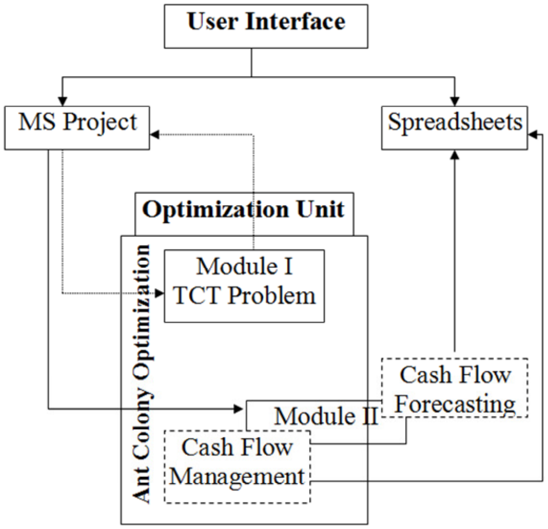


Figure 1. Main Components of the Cash Management Model

2. Providing Heuristic Information: This is a piece of information available about the problem from a source different from the ant. For example, in construction projects with high indirect cost, the preference might be given to the construction method with the shortest duration. In this case the heuristic value for each construction option (l_{ij}) will be calculated as the inverse of construction method duration [9].

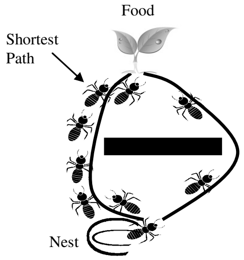


Figure 2. Foraging Behavior of Ants Using Pheromone Trails

3. Evaluating Trial Solutions: Each ant (z) is evaluated with respect to a predefined objective function. This is done by substituting the variable values (l_{ij}) in the corresponding decision variable (i).

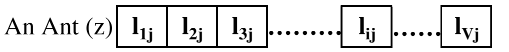


Figure 3. Representation of Candidate Solutions in ACO [10]

4. Updating Pheromone Trails: At the end of each trip (iteration ($t \in \{1, 2, 3 \ldots X\}$)), the pheromone trails (τ) deposited by each ant (z) is updated. Shorter routes (better objective function values) tend to have higher concentration pheromone. Pheromone is updated according to Equation 1:

$$\tau_{ij}(t) = \rho\tau_{ij}(t-1) + \Delta\tau_{ij} \quad (1)$$

Where τ_{ij} (t): new pheromone concentration assigned to at iteration (t); τ_{ij} (t-1): pheromone concentration associated with option (j) of variable (i) at previous iteration (t-1); ρ: pheromone evaporation rate; and $\Delta\tau_{ij}$: change in pheromone concentration.
The change in pheromone concentration is calculated in accordance to Equation 2:

$$\Delta\tau_{ij} = \sum_{z=1}^{M} \begin{cases} R/f(\varphi)_z & \text{If option } l_{ij} \text{ is selected by ant (z)} \\ 0 & \text{Otherwise} \end{cases} \quad (2)$$

Where R: pheromone reward factor; $f(\varphi)_z$: value of objective function using ant (z); and M: total number of ants created [9]
It should be noticed that the change in pheromone concentration for each option is a function of the value of objective function obtained. The higher the quality of the solution obtained, the higher the concentration of pheromone added. This reinforces the selection of good in the next iterations. The evaporation rate ($\rho < 1$) is used to avoid premature convergence by allowing ants to explore new routes (options).

5. Updating Selection Probability: The probability of selecting options (j) at different decision points (i) by the ants in the next iterations is calculated according to a predefined equation that incorporates both the updated pheromone concentration and the heuristic value. The options are selected by the ants probabilistically according to the Equation 3.

$$P_{ij}(z,t) = \frac{[\tau_{ij}(t)]^{\alpha} + [\eta_{ij}]^{\beta}}{\sum([\tau_{ij}(t)]^{\alpha} + [\eta_{ij}]^{\beta})} \quad (3)$$

Where P_{ij} (z, t): probability that option (j) is selected by ant (z) for decision variable (i) at iteration (t); $\tau_{ij}(t)$: pheromone concentration associated with option (l_{ij}) at iteration (t); η_{ij}: heuristic value that favors options according to a preset criteria; α & β: are exponent parameters that distribute weight between pheromone concentration and the heuristic value according to their relative importance [10].

6. Termination: A termination condition should be set. It can be either a period of time or after a specified number of iterations.

4. MODEL DESCRIPTION AND OPTIMIZATION USING ACO

In this model, the time-cost tradeoff and cash flow management problems have been formulated as combinatorial optimization problems. Ant colony algorithm is used to solve these problem by determining the project minimum cost (optimal time). The project cash flow can then be forecasted with respect to the optimal project duration determined in the previous steps.

4.1 Module I: Time-Cost Tradeoff

In construction projects, there is a relationship between the project activity time and cost. In general, as the activity duration decreases, its direct cost increases, and vice versa. The assumption is that executing a construction activity in a shorter duration will necessitate the use of more resources to complete it on time; this in turn will increase the direct costs. At the same time, there might be a saving in the project indirect costs as the total project duration may decrease. This relationship is referred to as the time-cost tradeoff, as shown in Figure 4.

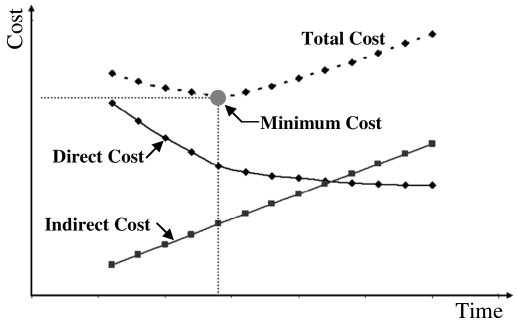


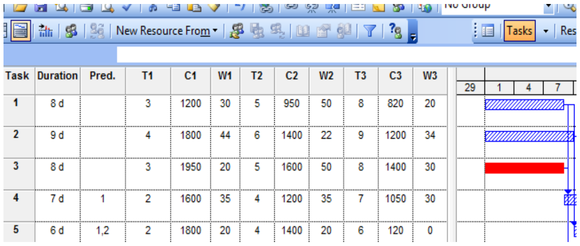
Figure 4. Time-Cost Tradeoff in Construction Projects

In most cases, there are multiple construction methods available to execute a single activity. Each method has a different cost and time depending on the quantities, costs, and productivity rates of the resources used. As such, there are multiple scenarios for executing a single project. Each scenario represents a possible combination of the construction methods available for the project activities. Consequently, there is a different project time and cost associated with each scenario.

TCT problem can have different objectives. For example, the objective can be crashing the project duration to meet the deadline with the possible minimum cost. Another objective is finding the project minimum cost regardless of the time needed to complete it [12].

The TCT was modeled based on previous attempts as presented in [5, 9, 10]. Microsoft Project software is used as a primary interface where all project activities are stored and scheduled. The construction methods available for executing different activities are then entered with their duration, cost, and weights. The weight reflects the contractor's preference for using a given construction method compared to other methods available, as shown in Figure 5. The total of the weights of all methods for a single activity should add up to 100.

A number of ants (M) are then created representing different scenarios for executing the project. Each ant (z) is represented by a number of variables (V) corresponding to the number of project activities (decision points). For each variable (i) an index (l_{ij}) is assigned to refer to the construction method (j) selected for this specific activity (route selected). The indices are used to retrieve information about the durations, costs, and weights of the construction methods selected by a given ant, as shown in Figure 6. The ants are then evaluated with respect to a predefined objective function, see Equation 4.



Task	Duration	Pred.	T1	C1	W1	T2	C2	W2	T3	C3	W3
1	8 d		3	1200	30	5	950	50	8	820	20
2	9 d		4	1800	44	6	1400	22	9	1200	34
3	8 d		3	1950	20	5	1600	50	8	1400	30
4	7 d	1	2	1600	35	4	1200	35	7	1050	30
5	6 d	1,2	2	1800	20	4	1400	20	6	120	0

Figure 5. Times, Costs, and Weights of Different Construction Methods Available for the Project Activities

$$\text{Minimize: Total Cost} = DR + \sum_{i=1}^{V} C_{ij} + C_l + P - W \qquad (4)$$

$$\text{subject to: } D, R, C_{ij}, C_l, P, W \geq 0$$

where: D: project total duration; R: indirect cost/unit time; C_{ij}: direct cost of construction method (j) assigned for activity (i); V: number of activities; C_l: total liquidated damages; P: total penalty; and W: total bonus for fast performance. It should be noted that in construction projects, the contract agreement usually stipulates either liquidated damages or penalty/incentive. The two conditions do not coexist.

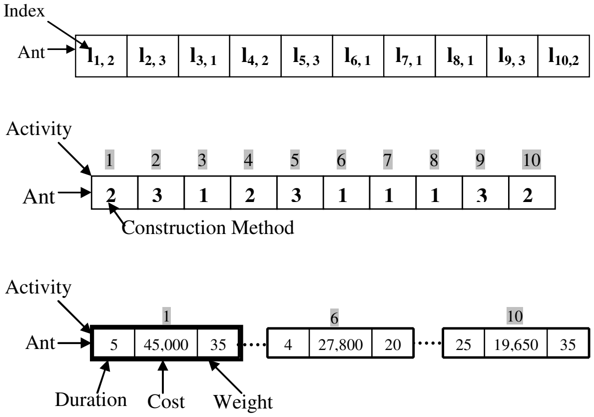
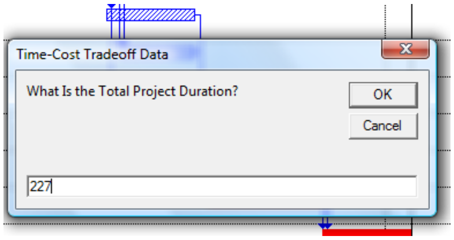


Figure 6. Generation of Trial Solutions Represented by Ants

The pheromone concentration associated with each route (construction method) is then updated with respect to its performance compared to other options according to Equation 2. Finally, the probabilities of selecting construction methods for new ants are updated with respect to the current pheromone concentration associated with each method, and its relative weight compared to other methods according to Equation 3. The process of creating, evaluating, and terminating the ants is repeated up to a specific number of iterations determined by the user.

Additional data regarding contractual aspects part in the objective function such as: the project deadline, liquidated damages, penalty and bonus, as well as, different optimization parameters such as: number of ants and number of iterations are set by the user using message boxes, as shown in Figure 7. Once the project optimal completion (minimum cost) is determined, the optimum combination of construction methods is exported to a spreadsheet, and the process of forecasting and managing the project cash flow starts using the second module.



Time-Cost Tradeoff Data

What Is the Total Project Duration?

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Figure 7. Collection of Additional Data Required for the Optimization Process

4.2 Module II: Cash Flow Forecasting and Management

Although the minimum project cost is determined using the TCT module, the costs may increase once again due to the additional costs associated with the project different funding alternatives. The second module proposes a cash management plan for the optimal construction scenario - determined by the first module - through the exploration of different possible methods of funding, and utilization of different activities start times.

There are several alternatives used for funding a construction project; however, the most common ones are: (1) borrowing, and (2) company own financing. When borrowing is considered as a funding option for the project, additional costs are usually incurred due to the different types of interests charged by financial institutions. Alternatively, the company-own-financing option requires the contractor to have a big sum of money of their own to be able to start the project. Consequently, a slight deficit in the contractor’s budget may risk him work stoppage, which in turn incurs extra costs due to exceeding the project deadline and paying liquidated damages.

The second module considers borrowing and company own financing as funding alternatives for the contractor. In both cases, the objective is to minimize the additional costs expected to be incurred by attempting minimizing: (1) the cash overdrafts in case of borrowing, and (2) work stoppage periods in the company financing option. Hence, maximum profit can be attained. This is achieved by minimizing the monthly cash requirements by shifting the non-critical activities within the limits of the available float.

For example, the hypothetical construction project illustrated in Figure 8, shows that the monthly cash requirement for the 5th, 6th, and 7th months is $20,300K (see Figure 8a). By shifting activity B (the only non-critical activity) within the limit of its float, the cash requirements for the same period of time went down to $13,370K, as shown in Figure 8b [33].

The cash management process starts by setting the project to its optimal duration as determined by the first module. The borrowing option is first considered; and in this case, the project duration remains fixed while various scenarios are created suggesting different start times for the project non-critical activities utilizing the available float. For each generated scenario, the cash flow is forecasted and the required credit limit is determined. For simplicity, the model utilizes spreadsheets to tabulate the forecasted cash flow data, and draw the cash in flow and out flow curves, as shown in Figure 9.

Each scenario is then evaluated with respect to an objective function based on the credit limit needed and the interest accumulated, see Equation 5. All credit limits determined allow finishing the project within the optimal time limit; however, only the least credit limit guarantees maximum profit.

In the company own financing option, the contractor specifies an amount of money available to start the project. Similarly, multiple scenarios are then generated suggesting different possible starting times for the non-critical activities. Each scenario is evaluated with respect to the objective function (Equation 5) in search of the optimum solution.

$$\mathrm{Min:Cost} = DR + \sum_{i=1}^{V} C_i + i_1 \sum_{s=1}^{T} B_s t_s + i_2 \sum_{s=1}^{T} U_s t_s + C_l + P - W \qquad (5)$$

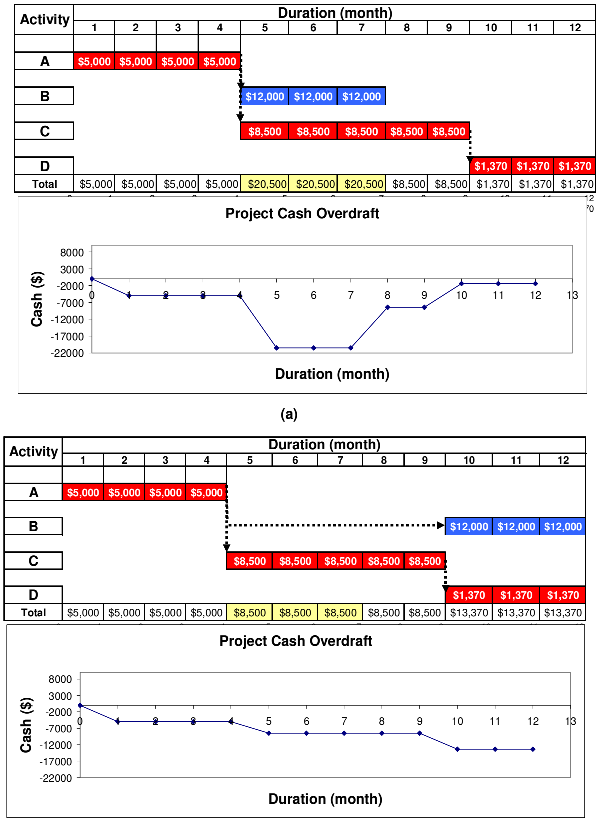
subject to: $D, R, C_i, i_1, i_2 B_s, U_s, C_l, P, W \geq 0$

where: C_i: direct cost of activity (i); i_1: interest rate/ day on the used amount of credit; i_2: penalty fee/ day on the unused portion of credit; B_s: total amount of money borrowed on day “s”; U_s: unused portion of credit; t_s: time difference between project total duration and day “s”.

It should be noted that when the borrowing option is considered, the liquidated damages, penalty, incentive for speedy construction parameters will be set to zero. This is due to the fact that the project will be financed within the optimal duration, i.e. the duration determined by the first module. On the other hand, parameters concerning interest rate on used and unused portions of credit were considered in the objective function. In reality, financial institution usually establishes an account for the contractor up to a certain credit limit with a monthly plan for money withdrawal. However, the contractor may only use a portion of his available monthly credit. As such, the financial institutes usually charge an interest on the withdrawn sum and a penalty fee on the unused portion of the allocated monthly credit.

Considering the company-own financing option, there is no money borrowing and thus there is no interest to be charged. However, there is a probability that the contractor might be penalized for exceeding the project deadline due to possible work stoppage.

In modeling the cash flow management problem using ACO, a number of ants (M) are created representing different scenarios for starting the project activities. Each ant (z) is represented by a number of variables (V) corresponding to the project activities. Each activity (i) is randomly assigned a start date based on the available float, as shown in Figure 10. The ant is then exported to Ms Project to verify the logic in relationship and adjust them if any violation is detected. The ants are then exported to spreadsheets, where the project cash flow is forecasted, evaluated, and the values of each parameter in the objective function is calculated. The pheromone concentration and the selection probability of each activity start are then updated in a similar manner as discussed in Module I. The heuristic factor used in calculating the probability was set as the inverse of the activity start date.



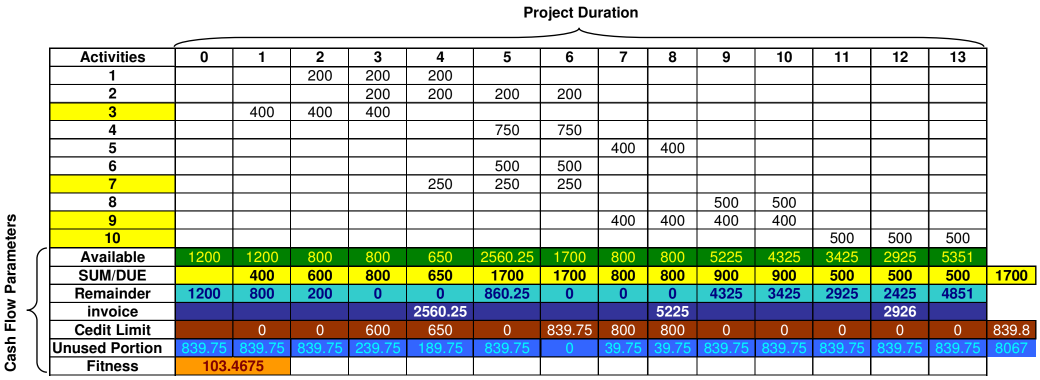
(b)

Figure 8. Minimization of the Monthly Cash Requirement [33]

5. VALIDATION AND RESULTS

5.1 Model Validation

To validate the model, it deemed essential to apply it to a benchmark optimization problem that has the optimal results known beforehand for comparison purposes. However, no comprehensive cash management problem could be found in the literature. As noted in previous sections, the majority of the work done in the area of cash management focused on solving one problem at a time.



Project Duration

Cash Flow Parameters

Activities	0	1	2	3	4	5	6	7	8	9	10	11	12	13	
1			200	200	200										
2				200	200	200	200								
3		400	400	400											
4						750	750								
5								400	400						
6						500	500								
7					250	250	250								
8										500	500				
9								400	400	400	400				
10												500	500	500	
Available	1200	1200	800	800	650	2560.25	1700	800	800	5225	4325	3425	2925	5351	
SUM/DUE		400	600	800	650	1700	1700	800	800	900	900	500	500	500	1700
Remainder	1200	800	200	0	0	860.25	0	0	0	4325	3425	2925	2425	4851	
invoice					2560.25				5225				2926		
Cedit Limit		0	0	600	650	0	839.75	800	800	0	0	0	0	0	839.8
Unused Portion	839.75	839.75	839.75	239.75	189.75	839.75	0	39.75	39.75	839.75	839.75	839.75	839.75	839.75	8067
Fitness	103.4675														

Figure 9. Cash Flow Forecasting Using Spreadsheets

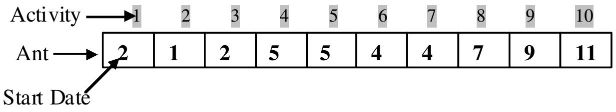


Figure 10. Representation of the Project Activities Start Dates Using ACO

As such, the methodology used in validating the model is to utilize a cash flow benchmark optimization problem from the literature, and expand it to integrate the time-cost tradeoff problem as will be described in the next sections.

A cash flow management problem originally described by Ahuja [34, 35] was used for this purpose. The problem is comprised of a nine-activity project; the activities relationships, costs, and duration are shown in Figure 11. The original duration of the project is 14 weeks. The contractor starts the project with an initial investment of \$4500. He expects to receive a series payment as follows: \$1000, \$5000, \$5000 on the 5th, 8th and, 12th weeks respectively. The contractor expects to receive the retention- \$5000- one week after the project completion. A sum of \$500/week was stipulated as liquidated damages for exceeding the project duration (14 weeks). Two funding options – borrowing and company own financing – were considered as possible alternatives for completing this project on time. The solution obtained for each option is given in [34, 35]. The objective is to complete the project with the minimum possible cost so that maximum profit can be attained.

To incorporate the time-cost tradeoff problem, a number of hypothetical construction methods were introduced to the problem. For each method, cost and duration were defined such that the optimal completion time of the project would be equal to the original duration. A relatively high indirect cost of \$500/week was assumed giving preference to construction methods with the shortest duration (original duration of the project). The costs and durations of the activities construction method is given in Table 1.

5.1 Validation Results

The project was initially set to its longest possible duration (49 weeks and cost of \$38900) by selecting the construction methods with the longest durations to make it difficult to determine the optimal solution. To complicate the problem even further, the contractor's highest preference (biggest weight) was given to the most economic construction methods (least cost and longest duration).

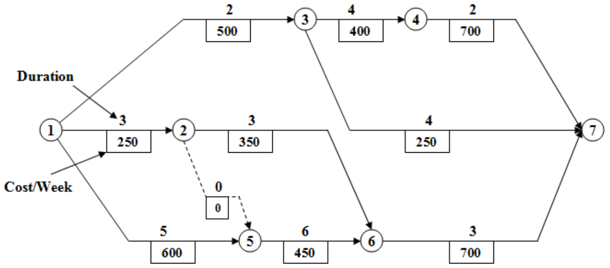


Figure 11. Project Network [34, 35]

Table 1. Different Construction Methods Available for Executing the Project Activities

Activity	M1			M2			M3			M4		
	T_1	C_2	W_1	T_2	C_2	W_2	T_3	C_3	W_3	T_4	C_4	W_4
1-2	3	\$750	30	7	\$400	70						
1-3	2	\$1,000	25	12	\$380	75						
1-5	5	\$3,000	5	8	\$2,600	15	10	\$2,250	30	14	\$1,750	50
2-6	3	\$1,050	10	13	\$350	30	17	\$120	60			
3-4	4	\$1,600	10	14	\$880	20	19	\$620	70			
3-7	4	\$800	35	14	\$250	65						
4-7	2	\$1,400	5	11	\$950	30	18	\$570	65			
5-6	6	\$2,700	15	9	\$2,530	20	13	\$2,300	25	17	\$1,900	40
6-7	3	\$2,100	20	5	\$1,900	35	8	\$1,620	45			

The first module was able to determine the optimal completion time of the project (14 weeks) using 20 ants and 40 iterations. The project minimum total cost is \$21400 (direct cost \$14400, indirect cost = \$7000). The setting of other optimization parameters are as follows: $\alpha = 1.2$, $\beta = 0.4$, R (pheromone reward factor) = 10, and ρ (pheromone evaporation rate) = 0.45.

The project is then set to its optimal duration, and the activities total floats are used to determine different possible start dates available for the project activities, as shown in Table 2. For the borrowing option, various credit limits are determined in search for the minimum credit limit that would allow completing the project within the desired duration. The second module was able to find the optimal solution for the borrowing option using 40 ants and 80 iterations. The solution obtained is identical to the one documented in the literature [34, 35], as shown in Figure 12.

Table 2. Different Start Dates Available for the Project Activities

Activity	Optimal Duration	Total Float	Start Dates								
			D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
1-2	3	2	1	2	3						
1-3	2	6	1	2	3	4	5	6	7		
1-5	5	0	1								
2-6	3	5	4	5	6	7	8	9			
3-4	4	6	3	4	5	6	7	8	9		
3-7	4	8	3	4	5	6	7	8	9	10	11
4-7	2	6	7	8	9	10	11	12	13		
5-6	6	0	6								
6-7	3	0	12								

For the company-own financing option, the project was scheduled in 15 weeks with a total cost of $21900 after including the liquidated damages ($500). It should be noticed that work has to stop during the 6th week due to the unavailability of funds. However, the solution obtained for the company-own financing option is better than the one documented in the literature. The original solution in [34, 35] schedule the project in 16 weeks with a total cost of $22900, as shown in Figure 13. The cash flow diagrams of the original project (before optimization), borrowing option, and company own financing option is shown in Figure 14.

6. CONCLUSION

Cash management is an essential task for all contractors in the construction industry. As such, there is a need for new cash management tools that would enable the contractor to manage the cash flow efficiently and to minimize their total cost.

This paper presents a comprehensive cash management model that is composed of two modules. The first module determines the project optimal completion time, while the second module proposes a cash managing plan for the optimized project. The model has been validated using benchmark optimization problem from the literature. The results have shown that the model proves to be a useful tool for managing the construction cash flow.

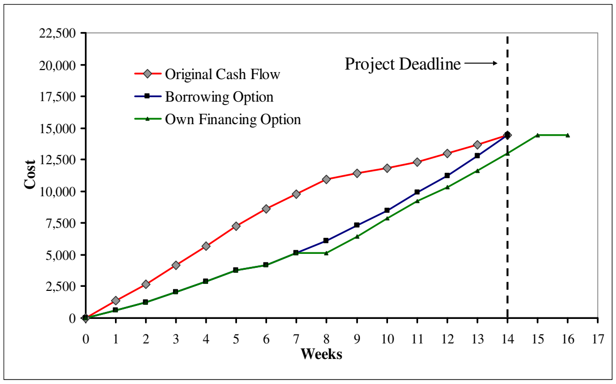
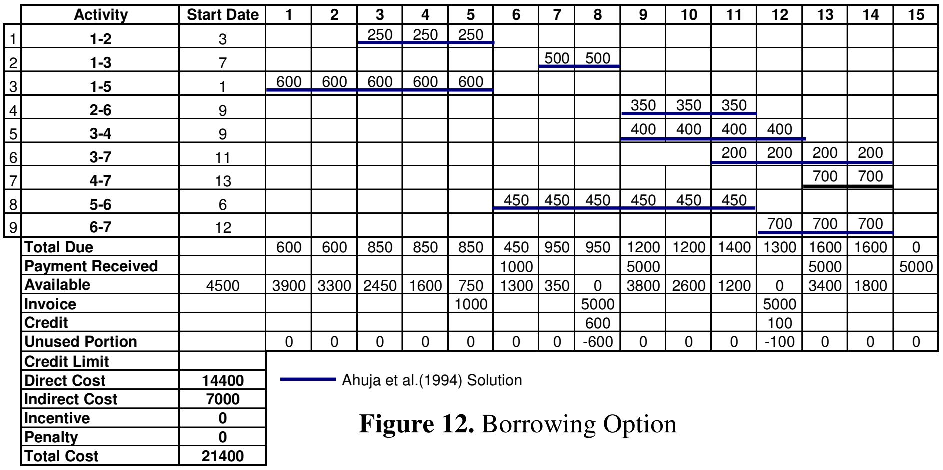


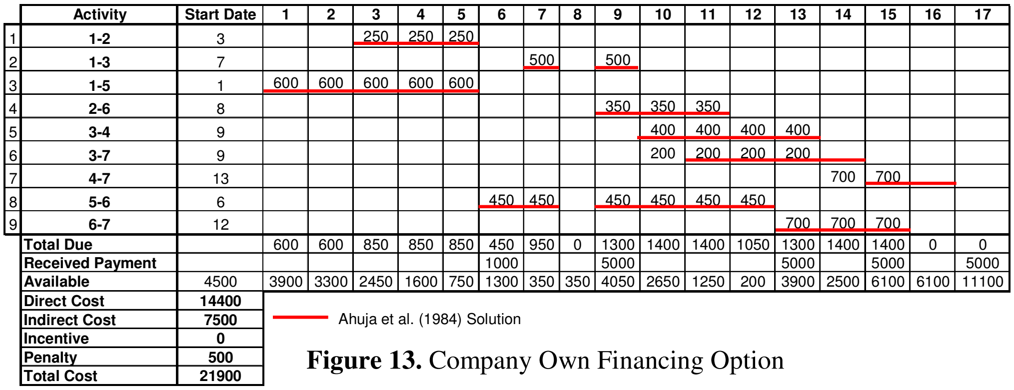
Figure 14. Project Cash Flow diagrams



	Activity	Start Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**1-2**	3			250	250	250										
2	**1-3**	7							500	500							
3	**1-5**	1	600	600	600	600	600										
4	**2-6**	9									350	350	350				
5	**3-4**	9									400	400	400	400			
6	**3-7**	11											200	200	200	200	
7	**4-7**	13													700	700	
8	**5-6**	6						450	450	450	450	450	450				
9	**6-7**	12												700	700	700	
	Total Due		600	600	850	850	850	450	950	950	1200	1200	1400	1300	1600	1600	0
	Payment Received							1000			5000				5000		5000
	Available	4500	3900	3300	2450	1600	750	1300	350	0	3800	2600	1200	0	3400	1800	
	Invoice						1000			5000				5000			
	Credit									600				100			
	Unused Portion		0	0	0	0	0	0	0	-600	0	0	0	-100	0	0	0
	Credit Limit																
	Direct Cost	**14400**															
	Indirect Cost	**7000**															
	Incentive	**0**															
	Penalty	**0**															
	Total Cost	**21400**															

Ahuja et al.(1994) Solution

Figure 12. Borrowing Option



	Activity	Start Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	**1-2**	3			250	250	250												
2	**1-3**	7							500		500								
3	**1-5**	1	600	600	600	600	600												
4	**2-6**	8									350	350	350						
5	**3-4**	9										400	400	400	400				
6	**3-7**	9										200	200	200	200				
7	**4-7**	13														700	700		
8	**5-6**	6						450	450		450	450	450	450					
9	**6-7**	12													700	700	700		
	Total Due		600	600	850	850	850	450	950	0	1300	1400	1400	1050	1300	1400	1400	0	0
	Received Payment							1000			5000				5000		5000		5000
	Available	4500	3900	3300	2450	1600	750	1300	350	350	4050	2650	1250	200	3900	2500	6100	6100	11100
	Direct Cost	**14400**																	
	Indirect Cost	**7500**																	
	Incentive	**0**																	
	Penalty	**500**																	
	Total Cost	**21900**																	

Ahuja et al. (1984) Solution

Figure 13. Company Own Financing Option

REFERENCES

[1] Park, H.K., and Russell, J.S., "Cash Flow Forecasting Model Using Moving Weights of Cost Categories for General Contractors on Jobsite", *First International Conference in the 21st Century, Florida International University, Miami, Florida*, 2002.

[2] Russell, J. S., "Contractor failure: Analysis", *Journal of Performance of Constructed Facilities*, Vol. 5(2), pp. 163–180, 1991.

[3] Abdel-Raheem, M, "Cash Management: A Computer-based Framework for Maximizing Profit Using Evolutionary Algorithms", *M.Sc. Thesis,* Cairo University, Egypt, 2007

[4] Burns, S., Liu, L., and Feng, C., "The LP/IP hybrid method for construction time-cost-tradeoff analysis", *Construction Management and Economics*, Vol. 14, pp.265-276, 1996.

[5] Feng, C.W., Liu, L., and Burns, S., "Using Genetic Algorithms to Solve Construction Time-Cost Trade-Off Problems", *Journal of Computing in Civil Engineering*, Vol. 11(3), pp. 184-189, 1997.

[6] Feng, C.W., Liu, L., and Burns, S., "Stochastic Construction Time-Cost Trade-Off Analysis", *Journal of Computing in Civil Engineering*, Vol. 14(2), pp. 117-126, 2000.

[7] Zehng, D.X.M., Ng, S., and Kumaraswamy, M.M, "Applying Pareto Ranking and Niche Formation to Genetic Algorithm-Based Multiobjective Time-Cost Optimization", *Journal of Construction Engineering and Management,* Vol. 131(1), pp. 81-91, 2005.

[8] El-Rayes, K., and Kandil, A., "Time-Cost-Quality Trade-Off Analysis for Highway Construction", *Journal of Construction Engineering and Management*, Vol. 131 (4), pp. 477-486, 2005.

[9] Elbeltagi, E., "Using Ant Colony Optimization for Time-Cost Trade-Off in Construction", *Eleventh Colloquium on Structural and Geotechnical Engineering*, Ain Shams University, Cairo, Egypt, 2005.

[10] Elbeltagi, E., Hegazy, T., and Grierson, D., "Comparison among five evolutionary-based optimization algorithms", *Advanced Engineering Informatics*, Vol. (19), pp. 43-55, 2005.

[11] Geem, Z., "Multiobjective Optimization of Time-Cost Trade-Off Using Harmony Search", *Journal of Construction Engineering and Management*, Vol 136(6), pp. 711–716, 2010.

[12] Abdel-Raheem, M., and Khalafallah, A., "Using Electimize to Solve the Time-Cost-Tradeoff Problem in Construction Engineering", *Proceedings of 2011 ASCE International Workshop on Computing in Civil Engineering*, Miami, FL, pp 250-257, 2011.

[13] Ashley, D. B., and Teicholz, P. M., "Pre-estimate Cash Flow Analysis", *Journal of Construction Division*, Vol. 103(3), pp. 369–379, 1977.

[14] Singh, S. and Woon, P.W., "Cash Flow Trends for High-rise Building Projects", *Procedures of the 4th International Symposium on Organization and management of Construction*, University of Waterloo, Canada, 1984.

[15] Kenley, R. and Wilson, O., "A Construction Project Cash Flow Model - An Ideographic Approach" *Construction Management and Economics*, Vol. 4(3), pp. 213-232, 1986.

[16] Miskawi, Z., "An S-curve Equation for Project Control", *Construction Management and Economics*, Vol 7, pp. 115-124, 1989.

[17] Kaka, A. and Price, A., "Modeling Standard Cost Commitment Curves for Contractors' Cash Flow Forecasting", *Construction Management and Economics*, Vol. 11(4), pp. 271-283, 1993.

[18] Khosrowshahi, F., "Simulation of Expenditure Patterns of Construction Projects", *Construction Management and Economics*, Vol. 9, pp. 113-132, 1991.

[19] Skitmore, M.,, "Parameter Prediction for Cash Flow Forecasting Models", *Construction Management and Economics*, Vol. 10(5), pp 397-413, 1992.

[20] Kaka, A. P., "Towards More Flexible and Accurate Cash Flow", *Construction Management and Economics*, Vol. 14, pp. 35–44, 1996.

[21] Navon, R., "Company-level Cash-flow Management", *Journal of Construction Engineering and Management*, Vol. 122(1), pp. 22-31, 1996.

[22] Ranasinghe, M., "Total Project Cost: A Simplified Model for Decision Makers", *Construction Management and Economics*, Vol. 14(6), pp. 497 – 505, 1996

[23] Evans, R.C., and Kaka, A.P., "Analysis of the Accuracy of Standard/Average Value Curves Using Food Retail Building Projects as Case Studies", *Engineering, Construction and Architectural Management*, Vol. 5 (1), pp. 58 – 67, 1998.

[24] Skitmore, M., "A Method for Forecasting Owner Monthly Construction Project Expenditure Flow", *International Journal of Forecasting,* Vol 14(1), pp. 17-34, 1998.

[25] Hwee, N.G. and Tiong, R.L.K., "Model on Cash Flow Forecasting and Risk Analysis for Contracting Firms" *International Journal of Project Management*, Elsevier, pp. 351-363, 2002.

[26] Kaka, A. and Lewis, J., "Development of a Company-level Dynamic Cash Flow Forecasting Model (DYCFF)", *Construction Management and Economics*, Vol. 21(7), pp. 693-705, 2003.

[27] Liu, S., and Wang, C., "Resource-constrained Construction Project Scheduling Model for Profit Maximization Considering Cash Flow", *Automation in Construction*, Vol. 17 (8), pp. 966–974, 2008.

[28] Hegazy, T., and Ersahin, T., "Simplified Spreadsheet Solutions II: Overall Schedule Optimization", *Journal of Construction Engineering and Management*, Vol. 127(6), pp. 469-475, 2001.

[29] Elazouni, A.M., and Metwally, G., "Finance-Based Scheduling: Tool to Maximize Project Profit Using Improved Genetic Algorithms", *Journal of Construction Engineering and Management*, Vol. 131(4), pp. 400-412, 2005.

[30] Jalali, M.R., Afshar, A., and Marino, M.A., "Reservoir Operation by Ant Colony Optimization Algorithms," *Iranian Journal of Science & Technology*, Vol. 30 (B1), 2005.

[31] Dorigo, M., and Stutzle, T., *Ant Colony Optimization*, MIT Press, USA, 2004.

[32] Maier, H.R., Simpson, A.R., Zecchin, A.C., Foong, W. K., Phang, K.Y., Seah, H. Y., and Tan, C.L., "Ant Colony Optimization for Design of Water Distribution Systems," *Journal of Water Resource Planning and Management*, Vol. 129(3), pp. 200-209, 2003.

[33] Abdel-Raheem, M., "Electimize: A New Evolutionary Algorithm for Optimization with Application in Construction Engineering" *Ph.D Dissertation*, University of Central Florida, USA, 2011.

[34] Ahuja, H. N., *Project Management: Techniques in Planning and Controlling Construction Projects*, John Wiley & Sons, USA, 1983.

[35] Ahuja, H.N., Dozzi, P. and AbourRizk, S., *Project Management: Techniques in Planning and Controlling Construction Projects*, Wiley, 1994.