CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

A Multi-Objective Model for Enterprise Cash Flow Management

Shiha, Ahmed[1,2], and Hosny, Ossama[1,3]
[1] Department of Construction Engineering, the American University in Cairo, Parcel 8, 74 S El-Teseen St, New Cairo, 11835, Cairo, Egypt
[2] e-mail: ahmedshiha@aucegypt.edu
[3] e-mail: ohosny@aucegypt.edu

Abstract: Research on Finance-based scheduling has been receiving increased interest from construction contractors to support them in managing their projects' cash flow. Failure to efficiently manage cash flow, on a project level, diminishes the Contractor's profitability and undermines project's viability. Moreover, Construction contractors usually work on multiple projects concurrently which need careful analysis of the effect of each project on other projects. Management of cash flow includes both management of cash inflows and outflows, as well as administration of positive and negative cash requirement. The most challenging issue for the enterprise is to properly schedule cash inflows and outflows to cover any shortage and ensure smooth execution of projects. Such reliance implies different parameters such as interest rates as well as when to apply for loans that eventually affect the Contractor's profitability. This paper highlights Employer's payments to contractor, Contractor's payments to subcontractors and suppliers, as well as Contractor's financial arrangements with banks as the main payment conditions relied upon in accurate modelling of portfolio cash flow management. A multi-objective optimization model that uses genetic algorithm is presented to support decision makers in construction companies to reach the optimum projects' schedules' that minimizes the total interest paid by the Contractor for a portfolio of projects as well as minimizing the maximum negative cash flow, while accounting for various payment conditions between multiple involved parties. Many researches concentrated on modelling finance-based scheduling highlighting Owner-Contractor payment terms only at a project level. The novelty in the proposed model is the inclusion of different financial terms such as advance payments, and retention between Contractor-subcontractor interest rates between Contractor-bank as well as the flexibility of the model to include any number of projects within a portfolio, number of activities within a project, and any number of predecessors for each activity. The proposed improved model targets enhanced cash flow management of Contractors to maximize their profitability and internal rate of return at a company level.

1 INTRODUCTION & LITERATURE REVIEW

Construction contractors are often challenged by providing cash to finance projects during periods when the project's cash outflow is exceeding project's cash inflow. These periods are often the result of owner's delayed payments and contractors would work under cash-constrained conditions as a result (Elazouni and Abido 2011). Procurement of such cash is often through external sources as financial institutions or banks. This procurement is usually in the form of loans/open credit which entail financing costs. Incurring financing costs during the project is an additional burden that contractors are forced to bear and will decrease their profitability. Construction projects involve multiple parties that affect the cash flow: Contractors, Owners, sub-contractors, suppliers, and banks. Contractual and financial arrangements between these different parties affect cash flow obligations. Contractors often rely on loans from banks to finance a portfolio at certain stages (Gajpal and Elazouni 2015).

Genetic algorithms are optimization procedures that mimic the biological systems. The genetic algorithm offers a string of feasible solutions called chromosomes. Each chromosome is member of the population. To achieve best feasible solutions, crossover between solutions occur to produce offspring and the survival in the end is for the fittest solution (A. M. Elazouni and Metwally 2005). Genetic algorithm is population-based iterative computation process that rely on survival of the fittest through several stages including initialization, selection, crossover, mutation, evaluation and stoppage criteria (Ding, Su, & Yu, 2011). Advantages of genetic algorithm over traditional optimization algorithms include GA's ability to reach global optimum solutions through population-based searching strategy, rather than point to point searching, and adaptability to complex and nonlinear problems through reliance on fitness of individual solutions, rather than gradient information of objective function (Ding et al., 2011). Complex problems in the context of the construction industry include finance-based scheduling (Ali & Elazouni, 2009; A. Elazouni, 2009; A. M. Elazouni & Metwally, 2005; Gajpal & Elazouni, 2015), site layout improvement (Lam & Oshodi, 2016; Mawdesley, Al-jibouri, & Yang, 2002; Wong, Fung, & Tam, 2010), time-cost tradeoff (Lee, Yi, Lee, & Arditi, 2015), and maximum resource utilization (Hegazy & Wassef, 2001; Kaiafa & Chassiakos, 2015). Most of these problems have been tackled by researchers over years relying upon genetic algorithm due to its superiority over traditional methods.

Elazouni and Gab-Allah (2004) used integer programming in proposing an optimization model for finance-based scheduling. The aim for their model is to minimize the total extension of the project duration to satisfy the cash available to finance the project. Elazouni and Metwally (2005) utilized genetic algorithm by producing a model to maximize the profit of a single project. The objectives of the genetic algorithm-based model were to minimize the total project duration as well as minimize the financing costs which will finally reflect in the project's profit. The authors followed finance-based scheduling techniques by producing an initial schedule, then allowing the optimization model to shift the project's activities within their floats as well as beyond them with a certain extension criterion. A. Elazouni and Abido (2011) proposed a model that utilizes Strength Pareto Evolutionary Algorithm to manage the cash flow of multiple projects executed concurrently. The authors used financial terminology proposed by Au and Hendrickson (1986). The objective of their model is to maximize the profit of each project within the portfolio. Although the authors included multiple projects, their cash flow management model still can be considered on a single project level as it did not consider the interrelationship between the concurrent projects. Their paper considered that each project can have its separate credit limit and separate impact on the financing costs. Their model follows finance-based scheduling by shifting the activities of each project within their total floats and allowed each project to be extended for a certain limit beyond its duration. The variables in their model is the start date of each activity in each project. They demonstrated their model through optimization application of one 25-activtiy project and one 30-activity project that are executed simultaneously. The authors concluded that their model produced similar results to those models that utilize Genetic Algorithms.

Tabyang and Benjaoran (2016) modified the finance-based scheduling models provided by many researchers by including contractor-subcontractor payment arrangements. The authors found that while comparing with other existing models, this inclusion result in reduced financing costs and improved profitability as a result. However, their model was not expanded to be utilized as an optimization model for multiple projects and was only limited on a single project level.

In a recent study, Alavipour and Arditi (2018) developed a cash flow model that minimizes the financing costs paid by the contractor during the project. The authors followed a different route than other researchers by allowing their model's user to select from different financial offers by different institutions. Also, the durations and start dates of the activities in their research are fixed. The authors followed similar approach in building the model to that of A. Elazouni (2009) by starting with creating a schedule using critical path method. However, as many researchers did not, they did not include the effect of subcontracted works on the contractor's cash flow. Through a case study of a single project of 20 activities, linear programming was used to minimize the total financing cost. Although their research followed a different route, it has the same limitations of not including subcontracting and management of cash flow was limited to a single project level.

Although many researchers attempted to model cash flow of multiple projects, such as (A. Elazouni 2009), (Lam et al. 2001), and (A. Elazouni and Abido 2011), while others have tried to include the impact of subcontracting on the contractor's cash outflow, such as (Tabyang and Benjaoran 2016), limited research efforts have integrated both concepts. This paper is an effort to fill this gap by following the works in finance-based scheduling to propose an optimization model for contractors' cash flow on the enterprise level as well as considering different subcontracting options.

2 MODEL DEVELOPMENT

2.1 Portfolio of construction projects

Construction contractors often manage a portfolio of multiple projects concurrently rather than a single project. Hence, managing the cash flow at the enterprise level provide a more realistic insight into construction projects (Lam et al. 2001). Contractors will face the challenge of ensuring that the required cash to be procured for each project within the portfolio is less than the credit limit established in their agreements with the financial institutions such as banks. Finance based scheduling of projects constituting a portfolio will ensure that surplus cash in for some projects may be utilized in other projects to reach the overall profitability of the portfolio (Elazouni and Abido 2011).

2.2 Scheduling using Critical Path Method (CPM)

Finance based scheduling is based on shifting the activities without affecting the project's deadline to meet certain financial objectives (A. Elazouni and Abido 2011). First, to schedule activities within a project, Critical Path Method (CPM) was used to determine the project's activities' times. Following CPM scheduling, this paper concentrates on early start, early finish, late start, late finish, total float and free float among the activity times. The proposed model in this paper require the user to input only the activity names, their predecessors, and the start date of the first activity in any project. The model will perform the CPM calculations for each activity. The user of the model will need to specify the start date of the first activity in each project as although the projects are performed simultaneously, they do not necessarily start at the same date. Each project will be constrained by a certain deadline and changing the activity start dates will only be within each activity's free float. Hence, each activity will have start and finish dates as well as delayed start and delayed finish dates that will be determined through the optimization model to satisfy contractor's financial objectives.

[1] $Activity\ delayed\ start = Activity\ start\ date + X$

Where: X= Shifted days within free float determined by the optimization algorithm

2.3 Cash flow calculations

Cash flow from the contractor's point of view has been heavily studied in many research efforts, and this research will utilize the financial terminology and equations used by Au and Hendrickson (1986) with some minor modifications. Figure 1 illustrates a typical construction project cash flow. Contractor's cash flow is affected by the payment terms between the contractor and the owner, loan terms with financial institutions such as banks, as well as contractor's payment terms with suppliers and subcontractors. From the contractor's point of view, payment terms with the owner, such as advanced payment, markup, taxes, and retention percentages will affect the contractor's cash inflow. Loan terms with banks will entail financing costs such as interest rates on loans which will affect the contractor's cash outflow. Interest to be paid on loans are also called financing costs that contractors incur during their projects and reduce their profitability (Elazouni and Abido 2011). Payment terms with subcontractors and suppliers will affect also the cash outflow through terms like contractor-owner terms such as advanced payment, retention, and when to repay the retention percentage. Finance based scheduling at the enterprise level makes inclusion of subcontracting more relevant as contractors managing multiple projects simultaneously are more likely to reach better terms through offering the opportunities for subcontractors in more projects. On a project level, Contractor's monthly expenses (E_t), excluding interest or financing costs, cover the weekly payments to subcontractors, portions of the activities' costs executed by own resources, and indirect costs allocated to this project.

[2] $E_t = Construction\ expenses\ during\ time\ period\ (t)\ excluding\ financing\ costs$

Many researchers have used the financial terminology and equations used by Au and Hendrickson (1986), however, the novelty in this paper's proposed model is expanding the monthly expenses to cover the concept of subcontracting and how the financial terms between contractor and subcontractor affect the overall cash flow of the individual project and the enterprise as a result. Cumulative cash flow before receiving the interim payment for $t \geq 1$ is:

[3] $F_t = N_{t-1} + E_t$

Where: N_{t-1} is the cumulative net cash flow from previous time periods up to time period (t-1). The cumulative net cash flow after receiving the interim payment is given by:

[4] $N_t = F_t + P_t$

Where: P_t is the interim payment received at the end of time period t. The gross profit for the project is given by the following equation:

[5] $G = \sum_{t=0}^{n}(P_t + E_t)$

Where: G is the gross profit and the expenses E_t is expressed in negative sign. Most often, contractors refer to loans from banks to finance the projects and incur financing costs that are affected by a certain annual interest rate (i) due to the fact that N_t is negative during the early periods of the project and become positive towards the end of the project (Au and Hendrickson 1986). Hence, financing costs or interest charges can be explained by equation 6 and the net cumulative cash flow before receiving the payment P_t and after receiving it in equations 7 and 8 respectively:

[6] $I_t = iN_{t-1}$

[7] $\hat{F}_t = F_t + \sum_{k=1}^{t} I_k(1 + i)^{t-k}$

[8] $\hat{N}_t = \hat{F}_t + P_t$

At a project level, the maximum negative value of the net cash flow $\hat{N}_t$ at any time period during the project is the maximum value that the contractor will need at any project to cover its financing. In this paper, these equations will be used from enterprise level rather than a project level. Loans or financing costs will be incurred by the contractor on the cumulative net cash flow resulting from the summation of expenses and payments of multiple projects executed concurrently. Hence, equations 2-8 will be used in this paper to cover the cash flow management of a portfolio of multiple projects rather than a single project.

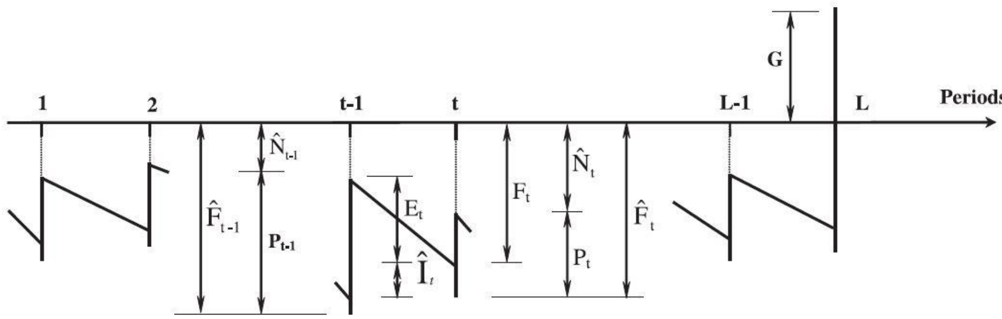

Figure 1- Typical cash flow from contractor's point of view (Elazouni and Abido 2011)

The objectives of finance-based scheduling for many researchers have been maximizing the profit (G) or minimizing the total interest paid (I). In this paper, finance-based scheduling of a portfolio of multiple projects through genetic algorithm aim at both minimizing the maximum negative cumulative net cash flow at any point during the portfolio's duration $\widehat{N}_t$ and maximizing the portfolio's overall profit (G).

2.4 Subcontractor offers and selection

The proposed model allows the user to select between several subcontractors for each activity in each project. Whether the same subcontractor can work in multiple projects simultaneously is determined initially by the user and the subcontractor's selection for each activity in each project will then be determined by the optimization algorithm. Selection of the subcontractor will coincide with the overall finance-based scheduling objectives of the model based on the subcontractor's financial terms with the Contractor. Financial terms in the proposed model include advance payment paid to the subcontractor, and the retained amount on each invoice. One of the reasons contractors often refer to subcontracting is using the mentioned financial terms to improve their own cash flow and mitigate the impact of delayed payments by the owner. Model assumptions also include the following: 1. After the advance payment, Subcontractors are paid by contractors on a weekly basis, 2. Activities included in the model can be only partially subcontracted by a certain percentage adjustable by the user, and 3. Contractor weekly expenses are payments to subcontractors, own resources incurred costs for each activity, and overall enterprise indirect costs that covers general overhead and site overhead for all the projects.

2.5 Optimization using Genetic Algorithm (GA)

Genetic algorithm, Ant colony, linear programming, integer programming, Strength Pareto Evolutionary Algorithm, and many other techniques for optimization have been used in previous studies. This paper proposes a model that utilize genetic algorithm to enhance cash flow management on an enterprise level. The objective function of the proposed optimization model is the following:

[9] $maximize\ \frac{G}{\widehat{N}_t}$

Here, two objectives of minimizing the negative overdraft of the portfolio $\widehat{N}_t$ as well as maximizing the portfolio's profit were combined in equation 9. Two sets of variables for the optimization model are presented in this paper:

1. Amount of shifted days (X), defined in equation 1, for each activity in each project
2. Indices from 1 to 10 for selection of subcontractor for each activity in each project: available for selection are 10 subcontractors for each activity each with an index

Constraints for the optimization model are the following:

1. The portfolio maximum negative cumulative cash flow $\widehat{N}_t \leq$ credit limit

2. X is integer
3. X ≤ free float
4. Subcontractor indices are integers ranging from 1 to 10

3 CASE STUDY

A sample case study of a portfolio of five projects is used to demonstrate the proposed model. The contractor has in this case study 10 different subcontractors offers for each activity in each project to select from. Each subcontractor financial offer for each activity entails the payment terms mentioned above. For each project, financial terms between owner and contractor as well as between banks and contractor are listed in table 1. Whether the same subcontractor's payment terms are the same for all projects is left for the model's user to decide. For months with a portfolio negative net cumulative cash flow $\widehat{N}_t$, the contractor will need a financial arrangement with the bank. In the case study, annual interest rate of 18% is used and can be adjusted by the user prior to optimization. The interest rate and the entailed financing cost is only referred to in months with negative cash flow of the portfolio not the single projects following the assumption that surplus cash from one project can be used to finance another project within the enterprise.

Table 1: Financial terms between the contractor and projects' owners

	Project 1	Project 2	Project 3	Project 4	Project 5
Start date (week)	0	0	0	0	0
Duration (weeks)	63	59	41	55	49
Contract price ($)	257,084,022	298,987,765	166,500,818	206,391,072	245,644,540
Advance payment*	6%	5%	5%	2%	3%
Retention *	15%	20%	8%	20%	15%
Markup**	8%	10%	8%	8%	10%
Interest rate (i)	18%	18%	18%	18%	18%
Taxes and financial charges	12%	12%	12%	12%	12%

*Advance payment and Retention are percentages of the total contract price of the project

**Markup is a percentage of the total cost

4 RESULTS AND DISCUSSION

The model was used to reach the two objectives of minimizing the portfolio profit and maximizing the net profit. Table 2 shows the results before and after optimization of the profit, maximum negative overdraft, and the total financing costs. The results show significant reduction in the maximum negative overdraft from $91,003,865 to $82,751,672. The second objective was to maximize the portfolio's net profit which was through reduction in the financing costs by shifting activities in the projects constituting the portfolio. The contractor's profit was increased through the optimization from $170,665,024 to $173,450,140. Hence, the proposed model's results show potential in maximizing contractor's profitability at enterprise level. Figures 2, 3, and 4 illustrates the results of the portfolio cash flow. In Figure 2, the cash flow profile of project 2 shows a negative overdraft from week 48 to week 56, and in Figure 4, the cash flow profile of project 4 shows also negative overdraft from week 48 to week 56. However, in Figure 5, the cash flow profile of the portfolio of the five projects combined from week 48 to week 56, the overdraft is positive due to surplus cash from the other three projects. This observation demonstrates the significance of managing the cash flow financing problem on an enterprise level rather than a single project level. Week 48 to week 56 is also shown in Table 3 as month 12 to month 14 and it can be seen that negative overdraft in projects 2 and 4 are balanced by positive overdraft from projects 1,3, and 5. Also, as evident in Figures 2 and 3, from week 72 to week 80, although the contractors cash inflow has stopped from increasing, the cash outflow is still increasing since contractors' expenses in these weeks cover the retention money being repaid to subcontractors after the project is finished.

Table 2: results of profit and negative cash flow before and after optimization at enterprise level

	Before optimization	After optimization
Portfolio profit ($)	170,665,024	173,450,140
Maximum negative cumulative overdraft $\widehat{N}_t$ ($)	91,003,865	82,751,672
Financing costs ($)	13,316,157	12,707,072

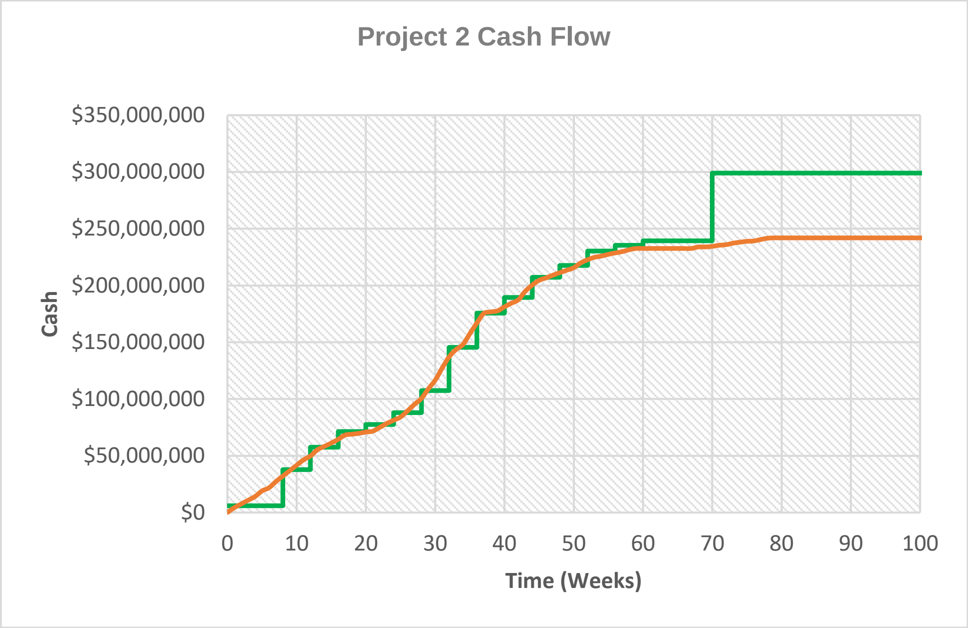

Figure 2- Project #2 cash flow profile

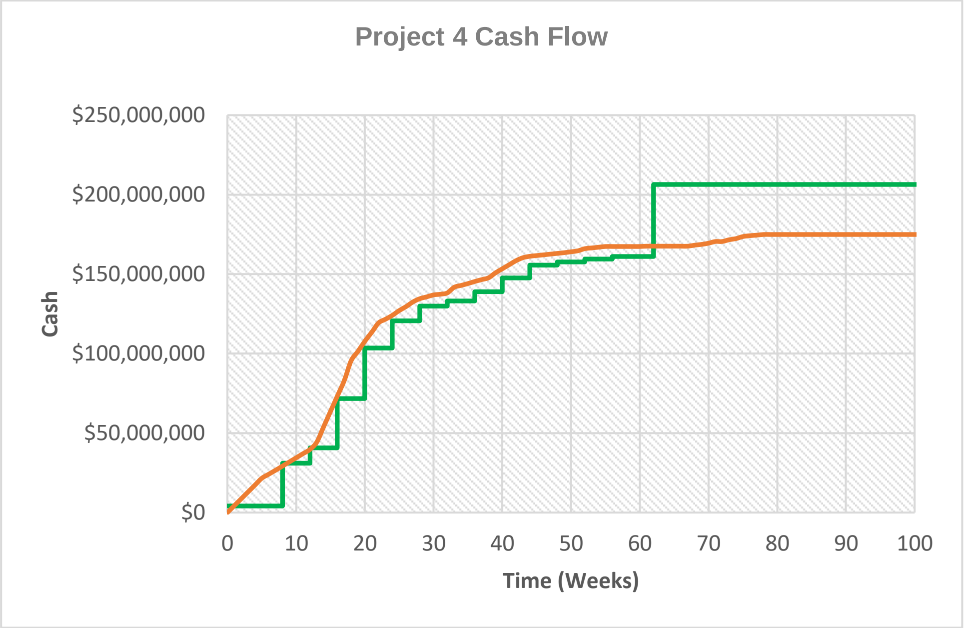

Figure 3- Project #2 cash flow profile

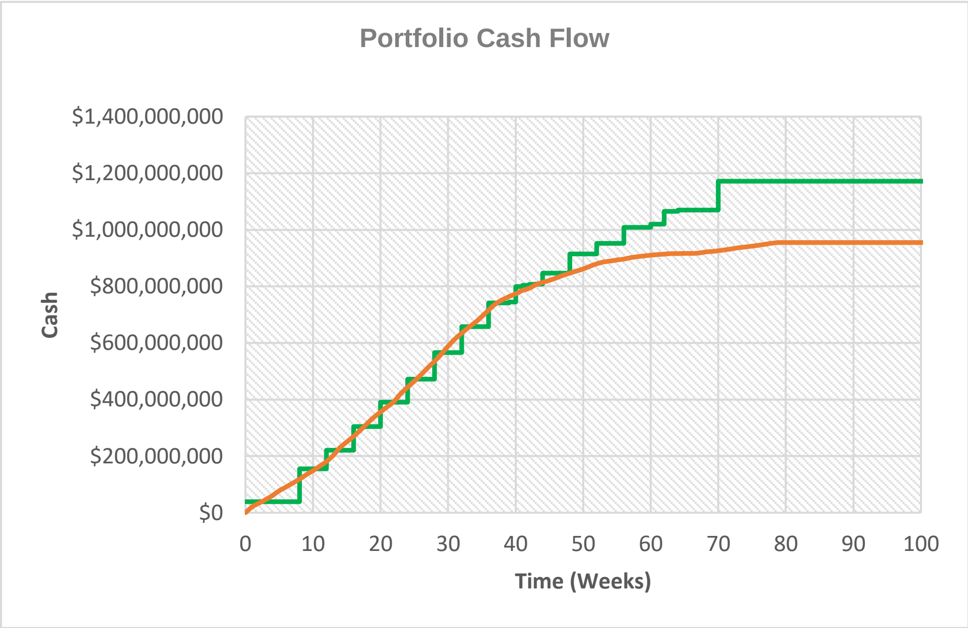

Figure 4- Cash flow profile of a Portfolio of five projects

Table 3: Negative cumulative overdraft $\hat{N}_t$ after optimization

End of month	Portfolio	Project 1	Project 2	Project 3	Project 4	Project 5
1	(24,368,009)	2,693,819	(8,311,079)	809,961	(13,374,455)	(6,250,491)
2	(82,751,672)	(5,350,215)	(26,713,698)	(4,860,763)	(25,786,908)	(20,040,088)
3	(30,169,408)	6,156,807	(13,408,450)	(4,624,033)	(9,479,146)	(8,927,462)
4	(57,301,009)	(1,652,569)	(5,289,744)	(6,172,657)	(34,123,925)	(10,062,113)
5	(66,444,959)	(4,436,545)	(3,063,903)	(12,715,099)	(37,902,446)	(8,326,967)
6	(80,571,195)	(10,797,519)	(4,817,263)	(22,184,669)	(28,368,597)	(14,403,148)
7	(81,834,391)	(20,438,866)	(12,171,719)	(22,664,984)	(21,840,116)	(4,718,706)
8	(80,728,246)	(11,127,057)	(28,670,130)	(15,321,535)	(14,045,153)	(11,564,371)
9	(70,346,487)	(6,329,618)	(28,440,008)	(9,059,413)	(10,651,059)	(15,866,389)
10	(52,235,206)	(9,133,023)	(11,647,101)	(11,450,896)	(11,124,454)	(8,879,733)
11	(43,658,183)	(18,536,898)	(10,544,244)	(8,256,481)	(13,261,816)	6,964,934
12	(35,411,335)	(16,810,710)	(5,924,042)	(7,735,891)	(11,952,657)	6,885,726
13	3,800,847	(14,078,955)	(9,317,263)	29,494,280	(12,183,568)	9,245,801
14	16,051,088	(10,360,887)	(1,402,641)	29,494,280	(11,829,514)	9,725,098
15	59,174,236	(13,870,067)	(259,744)	29,494,280	(10,576,137)	53,941,116
16	64,943,050	(11,465,230)	3,538,953	29,494,280	(10,969,976)	53,941,116
17	105,873,887	(11,773,855)	2,125,745	29,084,485	33,435,724	52,789,821
18	90,775,042	(15,163,911)	(744,422)	26,562,962	29,379,641	50,454,370
19	181,100,482	23,334,136	56,585,205	25,415,998	27,721,327	48,043,816
20	173,450,140	23,334,136	54,005,866	24,096,408	27,081,022	44,932,709

5 CONCLUSIONS

In conclusion, this paper proposes a model for cash flow management at enterprise level that utilizes genetic algorithm and takes subcontracting into consideration. The main aim of this paper is to capture the real-life situations in cash flow management by providing a tool for maximizing profitability of a portfolio of multiple concurrent projects rather than a single project. The model was demonstrated through an example of a portfolio of five projects that are executed simultaneously, and the model produced promising results by minimizing net cumulative cash flow of the portfolio and maximizing the overall profit of the portfolio. The model does not aim at maximizing the profit of a single project but of the whole portfolio, moreover surplus cash from one project's cash flow may be useful as financing cash for another project to enhance the enterprise's cash flow. This paper follows similar approach to researchers in finance-based scheduling, however, considering the subcontracting concept and its implications on the contractor's cash outflow as well as dealing with finance-based scheduling at enterprise level is an enhancement in the direction of full demonstration of real-life construction firm's cash flow management.

6 References

Alavipour, S. M. Reza, and David Arditi. 2018. "Optimizing Financing Cost in Construction Projects with Fixed Project Duration." *Journal of Construction Engineering and Management* 144 (4): 04018012. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001451.

Au, Tung, and Chris Hendrickson. 1986. "Profit Measures for Construction Projects." *Journal of Construction Engineering and Management* 112 (2): 273–86. https://doi.org/10.1061/(ASCE)0733-9364(1986)112:2(273).

Ding, S., Su, C., & Yu, J. (2011). An optimizing BP neural network algorithm based on genetic algorithm. *Artificial Intelligence Review*, *36*(2), 153–162. https://doi.org/10.1007/s10462-011-9208-z

Elazouni, Ashraf. 2009. "Heuristic Method for Multi-project Finance-based Scheduling." *Construction Management and Economics* 27 (2): 199–211. https://doi.org/10.1080/01446190802673110.

Elazouni, Ashraf, and Mohammad Abido. 2011. "Multiobjective Evolutionary Finance-Based Scheduling: Individual Projects within a Portfolio." *Automation in Construction* 20 (7): 755–66. https://doi.org/10.1016/j.autcon.2011.03.010.

Elazouni, Ashraf M., and Ahmed A. Gab-Allah. 2004. "Finance-Based Scheduling of Construction Projects Using Integer Programming." *Journal of Construction Engineering and Management* 130 (1): 15–24. https://doi.org/10.1061/(ASCE)0733-9364(2004)130:1(15).

Elazouni, Ashraf M., and Fikry Gomaa Metwally. 2005. "Finance-Based Scheduling: Tool to Maximize Project Profit Using Improved Genetic Algorithms." *Journal of Construction Engineering and Management* 131 (4): 400–412. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:4(400).

Gajpal, Yuvraj, and Ashraf Elazouni. 2015. "Enhanced Heuristic for Finance-Based Scheduling of Construction Projects." *Construction Management and Economics* 33 (7): 531–53. https://doi.org/10.1080/01446193.2015.1063676.

Kaiafa, S., & Chassiakos, A. P. (2015). A Genetic Algorithm for Optimal Resource-driven Project Scheduling. *Procedia Engineering*, *123*, 260–267. https://doi.org/10.1016/j.proeng.2015.10.087

Lam, K C, Tiesong Hu, S O Cheung, R K K Yuen, and Z M Deng. 2001. "Multi-Project Cash ¯ow Optimization: Non-Inferior Solution through Neuro-Multiobjective Algorithm," 16.

Lam, K. C., & Oshodi, O. S. (2016). Forecasting construction output: a comparison of artificial neural network and Box-Jenkins model. *Engineering, Construction and Architectural Management*, *23*(3), 302–322. https://doi.org/10.1108/ECAM-05-2015-0080

Lee, H.-G., Yi, C.-Y., Lee, D.-E., & Arditi, D. (2015). An Advanced Stochastic Time-Cost Tradeoff Analysis Based on a CPM-Guided Genetic Algorithm: Advanced stochastic TCTA using CPM-guided GA. *Computer-Aided Civil and Infrastructure Engineering*, *30*(10), 824–842. https://doi.org/10.1111/mice.12148

Tabyang, Wisitsak, and Vacharapoom Benjaoran. 2016. "Modified Finance-Based Scheduling Model with Variable Contractor-to-Subcontractor Payment Arrangement." *KSCE Journal of Civil Engineering* 20 (5): 1621–30. https://doi.org/10.1007/s12205-015-0581-z.

Mawdesley, M. J., Al-jibouri, S. H., & Yang, H. (2002). Genetic Algorithms for Construction Site Layout in Project Planning. *Journal of Construction Engineering and Management*, *128*(5), 418–426. https://doi.org/10.1061/(ASCE)0733-9364(2002)128:5(418)

Wong, C. K., Fung, I. W. H., & Tam, C. M. (2010). Comparison of Using Mixed-Integer Programming and Genetic Algorithms for Construction Site Facility Layout Planning. *Journal of Construction Engineering and Management*, *136*(10), 1116–1128. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000214