Proceedings of the 8th International Conference on Civil Structural and Transportation Engineering (ICCSTE'23)
Ottawa, Canada – June 04-06, 2023
Paper No. 204
DOI: 10.11159/iccste23.204

Schedule Optimization for Cash Flow Management of Owner Portfolios

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Abstract **-** Although new infrastructure has been widespread in many countries, the owners' main obstacle to complete new projects has been the cash flow problems. If cash flow problems are not appropriately addressed, projects will undoubtedly fail. The current study's goal is to help portfolio owners to avoid cash flow problems and achieve portfolios' goals. A modified finance-based scheduling method is proposed to optimize project schedules within owners' portfolios using genetic algorithms (GA). Finance-based scheduling helps owners to control portfolios' cash flow by balancing contractors' payouts during the fiscal years with the available budget amounts. The random key (RK) representation system of GA is used effectively to implement finance-based scheduling for multiple projects simultaneously.

Keywords**:** Cash flow, Scheduling, Evolutionary algorithms, Optimization, Financial planning, Portfolio management.

1. Introduction

While portfolio management has become a standard practice for owners [1], financial planning of portfolios is regarded as one of the essential portfolio management tasks. Project delays are commonly ascribed to owners' financial difficulties, especially in the public sector [2]. Portfolio owners often conduct financial planning using budgets allotted to budgetary periods, each of which spans multiple fiscal years. The amount of fund needed for projects or portions of projects scheduled for a certain fiscal year must be determined before additional projects can be scheduled during that year. The most accurate method to determine the amount of fund needed for projects within a given fiscal year is to use the projected payments the owner will make to the projects' contractors (contractors' payouts). The number of additional projects that can be scheduled depends on the amount of money still available in the budget to cover the costs of these projects. The owners' budget set aside for each fiscal year represents the cash in, and the contractors' payouts during that time reflect the cash out, so financial planning of portfolios fundamentally denotes a cash flow problem.

Two essential steps make up the portfolio cash-flow control process: (1) establishing the anticipated contractor payouts during each fiscal year within the budgetary period; and (2) ensuring that the budget is adequate during the same fiscal year to fund the contractors' payouts. Each project in the portfolio was taken into account as a component of the portfolio during the planning phase because the total amount of fund required for the project falls within the available budget for the entire budgetary period. Accordingly, all projects are supposed to start and finish promptly since the funds required for the portfolio's projects are available. However, when the two steps of the cash flow control process are carried out for projects overlapping some fiscal years, the budget available during those fiscal years could be inadequate. These circumstances point to potential cash flow problems that need to be appropriately addressed early on in the project planning phase.

During the project construction phase, the actual budgets allotted to the portfolios for certain fiscal years occasionally differ from those initially projected during the planning phase, leading to potential budget deficits for those fiscal years. Budget deficits will undoubtedly lead to cash flow problems, if the planned progress needs to be maintained. Budget deficits during certain fiscal years unquestionably hinder the owner from making contractors' payouts on time, resulting in cash flow problems and consequently delays in projects' completion. Furthermore, budget cuts made during financial crises may aggravate the cash flow problems. Owners will need to go over the two steps of the above cash-flow control process once more in these circumstances. Owners may opt to cancel, delay, or slow down some of the projects in their portfolios as a result of budget cuts. Moreover, changes and modifications made to projects during the construction phase may result in portfolio cash flow additional problems.

2. Literature Review

Numerous research efforts were conducted to forecast, plan, and manage project cash flow. Cao et. al. [3] proposed a model to optimize the two conflicting objectives of minimizing the project cost and maximizing the schedule robustness with the integration of cash flow. Tavakolan and Nikoukar [4] performed a sensitivity analysis to examine the effects of changes in the parameters of the project cash flow on the trade-off between project duration and financing cost. By identifying the feedback loops in the cash flow system, a dynamic model was developed by Dabirian et al. [5] to forecast, plan, and manage different policies, including prepayment, overbilling, loans, incentive payment, delay in payment and equipment lease. Andalib et al. [6] developed a simulation-based framework for forecasting the cash flow of construction projects considering the owners' payment history in previous projects and intertemporal correlation between successive progress payments. Alavipour and Arditi [7] presented a model, which creates cash flow forecasts, to minimize the financing cost considering different financing alternatives and based on un-extended work schedules. Su and Lucko [8] used singularity functions to precisely and efficiently calculate balances of project cash flow. Lee et al. [9] presented an automated tool to improve the reliability of project cash flow analysis while dealing with the uncertainties of the activities' durations and costs. Motawa and Kaka [10] introduced an IT system to help all supply chain members decide the most appropriate payment mechanism and cash flow. Tang et al. [11] employed a fuzzy and entropy-based mathematical approach to solve the weighting problem of the objective function in cash-flow models. Unfortunately, all of the previously reviewed research efforts were focused on the cash flow of the contractors and are not relevant to the portfolios of owners.

Whereas many studies focused on cash flow management for construction projects from the contractors' perspective, few studies were conducted from the owner's perspective. Shalaby and Ezeldin [12] provided governments with a tool to select work packages for mega projects funded through the "Results-Based-Finance" mechanism so that projects' cash-in can be collected earlier. Liang et al. [13] created an expenditure cash flow forecasting model for design-build projects of transportation agencies based on case-based reasoning and a genetic algorithm. Huang et al. [14] employed a dynamic threshold cash flow based structural model that helps owners assess the credit quality score for each construction contractor during the prequalification phase. Jarrah et al. [15] analyzed TxDoT projects from 2001 to 2003 for creating mathematical models representing contractors' monthly payments. In planning for contractor payments, an owner faced with the problem of organizing the budget for multiple projects needs to estimate the payouts to contractors in coming months. Nevertheless, none of these research efforts compare contractor payouts to the owners' budget for each fiscal year to assist portfolio owners in avoiding cash flow problems.

In order to help owners avoid portfolios' cash flow problems and achieves portfolios' goals, the current research introduces scheduling techniques as effective tools to control cash flow. Using GA, a modified finance-based scheduling model is developed to control the cash flow of portfolios with multiple projects. Technically, projects' schedules are simultaneously optimized to balance contractors' payouts with the budgets available for individual fiscal years within budgetary periods. The proposed model adds to the body of knowledge regarding portfolio management by helping owners to avoid portfolio cash flow problems and achieves portfolios' goals. The proposed method optimizes schedules by minimizing potential project delays based on the owners' priority assigned to the individual projects for early completion and by maximizing owners' budget usage.

3. Model Formulation

This section introduces the owner's cash flow model, model objective function, and model constraints. Three time-indices are used to describe the model: (i) $t = 1,2, \dots, T$ is the time index used to schedule the activities, (ii) $b = 1,2, \dots, B$ is the time index of the billing periods, and (iii) $f = 1,2, \dots, F$ is the time index of the fiscal years. It is assumed that unit times used satisfy the condition of $t \leq b \leq f$. For example, t is measured in days, b is measured in months, and f is measured in years. For simplicity, it is assumed that indices used for longer time units are compatible with small time units. For instance, the first fiscal year correspond to $b = 12$, assuming that the billing periods are measured in months. In addition to these time indices, M is the set of projects in the managed portfolio, and each project $j \in M$ consists of a set of activities denoted by N_j.

3.1. Owner Cash Flow Model

The current scheduling problem consists of multiple projects within a portfolio. The projects' activities are of fixed durations and prices, and cannot be interrupted once started. The owner's cash-out represents the payouts to contractors, which are calculated based on the contract prices of the activities. The price of activity $i \in N_j$ is assumed to be uniformly distributed over the duration with a daily rate of c_i.

Typically, projects within portfolios are awarded to different contractors under contracts of different payment terms and commencement dates. The contractors' bills are submitted as of the ends of one-month billing periods. The start time of the beginning activity in a given project marks the project's commencement date and the start of the first billing period. The contractor's billed amount of the part of activity $i \in N_{j\in M}$, which overlaps with billing period b, is calculated using Eq. (1) below and is denoted as $Y_{i,b}$.

$$Y_{i,b} = \begin{cases} \sum_{t=s_i}^{t=F_b} c_i & if\ F_b \geq s_i \geq S_b\ and\ f_i \geq F_b \\ \sum_{t=S_b}^{t=f_i} c_i & if\ s_i < S_b\ and\ S_b \leq f_i < F_b \\ \sum_{t=s_i}^{t=f_i} c_i & if\ s_i \geq S_b\ and\ f_i < F_b \\ \sum_{t=S_b}^{t=F_b} c_i & if\ s_i < S_b\ and\ f_i \geq F_b \end{cases} \quad , \forall\, i \in N_j, j \in M, b = 1,2,\ldots,B \tag{1}$$

Where; c_i is the price per day of activity $i \in N_{j\in M}$; s_i, and f_i are the start and finish dates of activity $i \in N_{j\in M}$; and the start and end dates of billing period *b* are S_b and F_b, respectively.

During billing period *b*, the contractor's billed amount, $Y_{j,b}$ from project $j \in M$ is equal to the summation of the billed amounts of all activities executed partially or totally during that period, as shown in Eq. (2) below.

$$Y_{j,b} = \sum_{\forall\, i \in N_j} Y_{i,b}, \forall j \in M \tag{2}$$

The contractor's payment in billing period b due to project $j \in M$,$E_{j,b}$, is less than the billed amount, $Y_{j,b}$, as shown in Eq. (3) below. Reduction factor r_j, which collectively adjusts for the retainage percentages and the repayment of the advance payment of project $j \in M$, is used. The contractor collects payment $E_{j,b}$ one month beyond the bill submission.

$$E_{j,b} = [1 - r_j] \times Y_{j,b}, \forall j \in M \tag{3}$$

During fiscal year *f*, the total amount O_f of the interim contractors' payments of all ongoing projects during fiscal year *f* is calculated as in Eq. (4) below. The first term in Eq. (4) represents the summation of any advance payments and/or repayments of the retained amounts of the projects, which possibly occurs during fiscal year *f*. The amount O_f in equation 4 represents the owner's cash-out during fiscal year *f*. For simplicity, it is assumed that fiscal years' starting and ending dates correspond with the billing periods shown in the inner summation in Eq. (4) below.

$$O_f = V_f + \sum_{j\in M} \sum_{b=f-1}^{b=f} E_{j,b}\, , f = 1,2,\ldots,F \tag{4}$$

The owner's budget, which represents the cash-in, is associated with defined budgetary periods of multiple fiscal years. The amount I_f represents the budget available for a fiscal year f, which is not necessarily constant for the individual fiscal years within the budgetary period. As the scheduling process proceeds sequentially from year to year, shifting start times of some activities might be inevitable to balance the budget amount I_f with the cash-out amount O_f. Situations might be that the budget amount available during a given fiscal year exceeds the cash-out realizing some amount of unutilized cash. The assumption in the current model is that the unutilized cash is moved forward to the following fiscal year. Thus, once all possible activities during a given fiscal year are scheduled with some unutilized cash, the cash-in available during the following fiscal year is updated. As of the end of a fiscal year f, the up-to-date cash-out is denoted R_f as in Eq. (5) below and the up-to-date cash-in is denoted G_f as in Eq. (6) below.

$$R_f = \sum_{w=1}^{w=f} O_w \tag{5}$$

$$G_f = \sum_{w=1}^{w=f} I_w \tag{6}$$

3.2. Objective Function

The objective of minimizing the total weighted projects' delays is adopted in the current optimization model. Delays in completion of the individual projects are calculated in working days. Each project $j \in M$ within the owner's portfolio encompassing $|M|$ projects is assigned a weight w_j that reflects the given priority to finish the project with minimum delay D_j. The larger the weight, the higher the urgency for early project completion. For the portfolio, the total weighted delay, $\mathcal{L}$, is shown in Eq. (7) below.

$$\mathcal{L} = \sum_{j \in M} w_j \times D_j \tag{7}$$

3.3. Model Constraints

The optimization model considers the fulfillment of the dependencies between the activities as well as the limited budgets available during the individual fiscal years. The predecessors of activity $i \in N_{j \in M}$ are stored in a set $P_{i \in N_{j \in M}}$. As in Eq. (8) below, activities can start when their predecessors are finished, i.e., the start time s_i of activity $i \in N_{j \in M}$ is greater than or equal to the finish times f_i of all its preceding activities. Besides, as of the end of fiscal year f, the R_f of the portfolio should not exceeds G_f as in Eq. (9) below.

$$s_i \geq s_{\hat{\imath}}, \ \forall \hat{\imath} \in P_i, \forall i, \hat{\imath} \in N_j, j \in M \tag{8}$$

$$R_f \leq G_f, \ f = 1,2,\ldots,F \tag{9}$$

4. Optimization using GA

This section describes the proposed GA optimization model, which involves the GA attributes including the chromosome representation system and serial decoder.

4.1. Representation System

In the current study, the indirect representation system of random key (RK) was adopted. The RK ensures that the feasibility of the chromosomes in the reproduction processes in maintained, which is often violated in the scheduling problems using the direct representation system. Special reproduction operators or feasibility-preserving operators are not required when the RK representation system is employed. GA with RK has been used to solve a variety of optimization problems including resource-constrained scheduling problems [16].

The RK representation system was originally proposed by Bean [17], where schedules are represented indirectly by assigning a relative scheduling priority for each activity. The chromosome in RK representation has a fixed number of genes equals to the number of project's activities. Each gene has a random key of a value within the range from zero to one. This value represents the activity scheduling priority relative to the other activities. A larger RK value indicates a higher relative scheduling priority. However, a special decoder is required to obtain direct schedules from the RK chromosomes.

4.2. Serial Decoder

In the current study, schedules are obtained from the RK chromosomes using a serial decoder (scheduler). The decoding process is performed in two stages. First, the activities are ordered for scheduling based on the RK values. This stage is executed in *n* steps, where *n* is the number of activities. Two sets of unordered and ordered activities are established with all activities are initially included in the unordered set. The execution of each step involves identifying the eligible activities, selecting one activity, and moving the selected activity from the unordered set to the ordered set. The eligible activities can

be either the beginning project activity or the activities with predecessors that have already been moved in earlier steps to the ordered set. Among the eligible activities, the activity of the highest RK value is selected and placed in the next position in the ordered set. Second, the ordered activities are scheduled one by one while fulfilling both precedence and budget constraints. A pseudo-code of the RK serial decoder is shown in Fig. 1.

Fig. 1 Caption: Pseudocode for the RK serial decoder.

start
- Initiate two sets of activities, the empty ordered activity set, and the unordered activity set that initially contains all the activities.

for $i = 1$ to n
- Obtain all the eligible activities in the unordered activity set and save them in a temporary set.
- Obtain the corresponding RK values for all activities within the temporary set.
- Obtain the activity *a* of the highest RK value.
- Move the obtained activity *a* from the unordered to the position *i* in the ordered activity set.

do

for $i = 1$ to n
- Identify activity *a* in position *i*.
- Obtain the earliest start time s^p of activity *a* that preserves the precedence constraints.
  - The maximum finish time of all its precedence activities.
  - Zero, if it is the beginning activity of the project.
- Obtain the earliest start time s^b of activity *a* that fulfills the budget constraints.
- Obtain the earliest feasible start time s^f as the maximum of s^p and s^b.
- Update the available budget values

do

end

5. Illustrative Case Portfolio

To illustrate the application of the proposed scheduling model, a case portfolio is introduced in this section. The case portfolio consists of three road rehabilitation projects *A*, *B*, and *C*. These projects have the same three activities of "remove asphalt", "replace base layer", and "lay new asphalt" with road lengths of 5, 7, and 10 kilometers respectively. Table 1 presents the duration and prices of the activities of the three projects. For project *C*, the "Replace base layer" depends on "Remove asphalt" with a start-to-start relationship of 10-day lag, which is the time required to finish one kilometer of "Remove asphalt". Similarly, the "Lay new asphalt" depends on "Replace base layer" with a start-to-start relationship of 15-day lag, which is the time to finish one kilometer of "Replace base layer". For the purpose of applying the model to case portfolio, the linear schedules of projects *A*, *B*, and *C* were reconfigured as critical path method (CPM) schedules. The reason is that, the budget amounts, which represent the cash-in are allocated to the fiscal periods based on calendar dates. In addition, the billing periods and payment lags involved in the cash-out calculations are based on calendar dates. This makes the CPM scheduling process more convenient since calendars can be easily applied to CPM schedules. The owner awarded projects *A*, *B*, and *C* to three different contractors. The payment terms in the contracts between the owner and contractors of projects *A*, *B*, and *C* are presented in the last three columns in Table 2.

Table 1: Activities' description, durations, and prices of projects *C, D* and *E*.

Activity	Project *A*		Project *B*		Project *C*	
	Duration (day)	Price ($)	Duration (day)	Price ($)	Duration (day)	Price ($)
Remove asphalt	50	75,000	63	87,900	80	128,000
Replace base layer	75	125,000	105	147,000	100	180,000
Lay new asphalt	100	175,000	119	238,000	190	380,000

Table 2: Payment terms between the owner and contractors of projects *A, B, C*.

Payment terms	Projects		
	C	*D*	*E*
Initial start dates	0	0	0
Advance payment percentage	10	0	5
Retained percentage of interim pay requests	10	10	5
Billing period duration in month	1	1	1
Payment lag in month	1	1	1

Advance payment is made at the first day of the project; Retained amounts are paid with the last progress payment

The case portfolio adopts a budgetary period of eighteen months composed of six fiscal periods each period is of three months as presented in the first two columns in Table 3. Projects *A*, *B*, and *C* are initially assumed to start at day zero, as in the first row in Table 2, which is the first day in the eighteen-month budgetary period. Columns 5 and 6 in Table 3 present, the monthly and cumulative contractors' payouts respectively during the budgetary period based on the initial schedules of projects *A*, *B*, and *C*, which represent the owner's projected cash-out. Column 5 in Table 3 indicates that the initial cash-out spans a period of eleven calendar months. Columns 3 and 4 in Table 3 present owner's cash-in during the individual fiscal periods and the cumulative cash-in respectively. Projects *C*, *D*, and *E* were selected in the portfolio during the eighteen-month budgetary period based on the fact that the total cost presented in column 6 of the three projects, which amounts to $1,529,900, was exactly matching the owner's budget available during the eighteen-month budgetary period presented in column 4.

Table 39: Owner's cash-in during fiscal periods, and initial and optimized monthly cash-out.

Fiscal period	Month	Cash-in ($)		Initial cash-out ($)		Optimized cash-out ($)	
		Period	Cumulative	Month	Cumulative	Month	Cumulative
1	1	202,816	202,816	18,750	18,750	18,750	18,750
	2	0	202,816	153,720	172,470	0	18,750
	3	0	202,816	293,975	466,445	92,160	110,910
2	4	340,726	543,542	266,030	732,475	187,055	297,965
	5	0	543,542	224,325	956,800	146,550	444,515
	6	0	543,542	180,950	1,137,750	98,735	543,250
3	7	336,977	880,519	134,905	1,272,655	154,830	698,080
	8	0	880,519	84,045	1,356,700	113,355	811,435
	9	0	880,519	39,600	1,396,300	67,760	879,195

4	10	337,770	1,218,289	39,600	1,435,900	125,065	1,004,260
	11	0	1,218,289	94,000	1,529,900	106,920	1,111,180
	12	0	1,218,289	0	1,529,900	97,200	1,208,380
5	13	292,861	1,511,150	0	1,529,900	75,240	1,283,620
	14	0	1,511,150	0	1,529,900	46,080	1,329,700
	15	0	1,511,150	0	1,529,900	37,800	1,367,500
6	16	18,750	1,529,900	0	1,529,900	37,800	1,405,300
	17	0	1,529,900	0	1,529,900	39,600	1,444,900
	18	0	1,529,900	0	1,529,900	85,000	1,529,900

However, the owner's cumulative cash-in amounts presented in column 4 in Table 3 are inadequate to cover the cash-out amounts presented in column 6 in Table 3 starting from the third month. Therefore, the activities of the three projects were rescheduled simultaneously to balance the cash-in with the cash-out according to the code pseudo code shown in Fig. 2. Projects *A*, *B*, and *C* are assigned delay weights of 1.0 in the objective function to give the same priority for early completion. The problem was solved thirty times, the total weighted delay for projects *A*, *B*, and *C* averaged 136 days with a standard deviation of 1.2. The best solution obtained exhibited a total weighted delay of 135 days. The optimized monthly and cumulative cash-out of the best solution is presented in the last two columns in Table 3. The results in columns 4 and 8 in Table 3 indicate that optimized cumulative cash-out is balance with the cumulative cash-in.

6. Conclusion

This research contributes to the portfolio management body of knowledge by helping portfolio owners avoid cash flow problems. While portfolio management has become a standard practice for owners, the scheduling techniques has a lot of potential to help owners to avoid cash flow problems and achieve portfolios' objectives. The achievement of portfolios' objectives will unquestionably be compromised if cash flow problems are not adequately addressed during planning and construction phases. The FBS models in the literature optimize schedules to control contractors' cash flow while fulfilling the credit limit constraints. FBS has a lot of potential to optimize projects' schedules to control owner portfolios' cash flow. However, the FBS technique requires major modifications to accommodate for the owner portfolios' cash flow.

Using GA, a modified finance-based scheduling model was developed to control the cash flow of portfolios with multiple projects. Technically, finance-based scheduling method optimizes project schedules to balance contractors' payouts with the budgets available for individual fiscal years within budgetary periods. The random key (RK) representation system of GA is used effectively to implement finance-based scheduling for multiple projects simultaneously. The proposed method optimizes schedules by minimizing potential project delays based on the owners' priority assigned to the individual projects for early completion and by maximizing owners' budget usage. The robustness and scalability of the developed GA model were proven. The proposed model adds to the body of knowledge regarding portfolio management by helping owners to avoid portfolios' cash flow problems.

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