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CONSTRUCTION PROJECT CASH FLOW PLANNING USING THE PARETO OPTIMALITY EFFICIENCY NETWORK MODEL

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Abstract. Cash flow is crucial for ensuring the viability of a project. It consists of a complete history of all cash disbursement, cash shortage, loans, cost of money, and all earnings received. Although significant research work has been conducted on cash flow forecast, planning, and management, the objective is constantly the maximization of profit/final cash balance, or minimization of total project cost. Moreover, cash flow forecasting needs to be effective and fast. The paper develops multiple-objective cash flow planning model – Pareto optimality efficiency network model, which considers typical banking instruments, the constraints of the financial market, the budget constraints, and retention of money. A case study illustrates the multi-objective project cash flow management approach by applying the proposed model to a real world problem. A what-if-analysis depicts the tradeoff between profitability and loan interests, which are major issues in project cash flow planning and management. The model presents an effective decision making tool to be used by industry practitioners with reasonable accuracy.

Keywords: cash flow planning, pareto optimality, network model, multiple-objective.

1. Introduction

Cash is the most important resource for a construction company, because more companies become bankrupt due to lack of liquidity for supporting their day-to-day activities, than because of inadequate management of other resources (Singh, Lakanathan 1992). Many construction projects have negative net cash flows until the very end of construction when the final payment is received or advanced payment is received before starting the project. It is very difficult to convince creditors and potential lenders that these inadequacies in cash flow are only temporary. Perhaps this is one of the main reasons that insolvency is more likely to occur in this industry than any other (Kaka, Price 1993). Moreover, the construction industry is a sector where significant uncertainties arise in many aspects of the problem, including the business and the financial environments. The financial risks come from several sources, encompassing the need for intensive capital, cash retainage from clients, the exposure to interest rate changes during the period between the contract closing and the end of the payment plan, leading to difficulties in good cash flow forecasting (Barbosa, Pimentel 2001). Inaccurate cash forecasts and inadequate cash flow management incurs financial stress (Kaka, Price 1991). Companies of different sizes face this kind of problem which requires distinct approaches and proper tools according to the nature and complexity of the operations (Barbosa, Pimentel 2001).

Cash flow at the project level consists of a complete history of all cash disbursement, cash shortage, loans, cost of money, and all earnings received as a result of project execution. A firm with higher cash flow variability increases the level of expected external financing costs, which incurs high cost of money and accordingly high project cost. Although significant research work has been conducted on cash flow forecast, planning, and management, the objectives of most of research is to maximize profit/final cash balance, or minimizing total project cost, or more accurately forecast the cost-in flow or cost outflow. Furthermore, cash flow forecasting needs to be effective and fast, considering the short time available and the associated cost at the tendering stage. Contractors rarely prepare a detailed construction plan at this stage, and usually wait until being awarded the contract. Therefore an effective and fast technique for forecasting cash flow is required, which is with reasonable accuracy and which takes into consideration the tradeoff of greater profitability and the cost of money.

This paper addresses cash flow management at the project level for the tendering and construction stages. The proposed model considers the typical instruments and constraints of the financial market, including earnings from depositing excess cash, long term and short term loans from banks. The budget constraints and minimum cash reserves for a project are also taken into account. The significance and useful potential attributed to the proposed Pareto optimality efficiency network model lies in: (a) considering the impact of external financial constraints and project parameters on cash flow transaction forecast; (b) providing decision alternatives through scenario analysis by changing these external constraints and parameters; (c) trading-off profitability/final cash balance and loan interests, which are two of the most important issues in project cash flow planning and management; (d) the effective cash flow forecasting technique with reasonable accuracy and without time-consuming data collection. The model developed in this paper provides a decision making tool for use by project managers with an analytical and consistent 'what if' analysis.

2. Models for cash flow management

Due to the importance of cash flow management, therefore, numerous researchers (Barbosa, Pimentel 2001; Chiu, Tsai 2002; Elazouni, Gab-Allah 2004; Elazouni, Metwally 2005; Park *et al.* 2005; Liu, Wang 2008, 2009, 2010) employed various techniques for cash-flow planning and management, differing in their levels of accuracy and detail, the degree of automation in compiling them (Navon 1995), the method they use to integrate the time and the money elements to assist contractors in assessing overall performance when minimizing project duration or maximizing project profit (Liu, Wang 2010). The paper is not allowed to describe all of the cash-flow modeling techniques due to space limitation.

Probably the earliest work was conducted by Gates and Scarpa (1979). They described a simple approximation method for developing cash flow analysis – income and expenses, surplus and deficit, as a function of time-over the life of the project. The simpler techniques are useful tools that allow contractors to achieve a quicker cash flow forecast with reasonable accuracy. Significant research efforts have been developed towards improving the accuracy of the simpler techniques. Kaka and Price (1991) improved the accuracy of cash flow forecast by using cost commitment curves. Hsu (2003) established statistic models to forecast control or assess of construction project cash flow by S-curve contains. Park *et al.* (2005) adopted moving weights of cost categories in a budget that are variable depending on the progress of construction works, aiming to provide a tool that can be applicable during the construction phase based on the planned earned value and the actual incurred cost on a jobsite level. Blyth and Kaka (2006) produced a multiple linear regression model that predicts S-curves for individual projects, aiming at standardizing activities, and forecasting the duration, cost and end dates of these activities.

Another important approach contributing to the accuracy of the cash flow forecast modeling is computer simulation models that integrate cash flow forecast model and project estimating database. Navon (1995) proposed a resource-based computerized cash-flow forecasting model which solves the compatibility problem caused by the different data structures of the cost and the schedule items. The model automatically integrated the bill of quantities (BOQ), the estimate and the schedule, based on a non-project specific database which facilitates the linkage between resources and schedule items. The cash flow is compiled on the basis of the resource and schedule integration. Kaka (1996) also introduced stochastic simulation model which uses more than fifty variables to calculate the cash flow of individual contracts.

Karshenas and Haber (1990) are among those who first introduced optimization models in cash flow management. Their model aimed at minimization of the total project cost through cash flow forecast. Binary variables are used to formulate a linear integer model which minimizes the sum of the cost of all resources. Specific functions are formulated for equipment costs, labor costs, material costs, and cost of time. The resultant schedule has an optimal duration at minimization of the total project cost. Elazouni and Gab-Allah (2004) introduced an integer-programming finance-based scheduling method to produce financially feasible schedules that balance the financing requirements of activities at any period with the cash available during that same period. The proposed method offers twofold benefits of minimizing total project duration and fulfilling finance availability constraints. Liu and Wang (2008) applied combinatorial optimization algorithms based on constraint programming (CP) to integrate the issues involving resource-constrained problems and cash flow. Contractors thus can evaluate appropriate project schedules under associated constraints, and arrange activities and resources to maximize project profit. Liu and Wang (2009) also present a two-stage profit optimization model for linear scheduling problems using constraint programming (CP) to optimize the primary objective – project profit – and minimize total interruption time, given the optimized value of the primary objective. Their most current research (Li, Wang 2010) present an optimization model considering cash flow for multi-project scheduling problems and determines schedules and periodical cash flow using the proposed model in an effort to maximize overall profit.

Barbosa and Pimentel (2001) conducted significant research in proposing a linear programming model which is designed for optimal cash flow management, addressing maximizing final cash balance. Their model included typical financial transactions, possible delays on payments, use of available credit lines, the effect of changing interest rates, and budget constraints that often occur in the construction industry. The proposed model considers typical banking instruments and the constraints of the financial market. Elazouni and Metwally (2005) finance-based scheduling provides a tool to control the credit requirements. This control enables contractors to negotiate lower interest rates which reduce financing costs. Thus, finance-based scheduling enables contractors to reduce project indirect costs and financing costs. This paper utilizes genetic algorithm technique to devise finance-based schedules that maximize project profit through negotiating interest rates with financial institute.

Despite the relative success of many models and applications, construction companies continue to face challenges in implementing procedures for cash flow management, as determined in surveys conducted by Navon (1996). In many cases collecting the detailed tendering data to achieve reliable results is very time consuming and not feasible even with computerized tools. Linear cash flow optimization models either emphasize minimizing total cost versus time or maximizing final cash flow balance available at the end of the time horizon by ignoring the cost of money, which is a serious concern in construction companies. Cash flow analysis and management at the tendering stage, considering typical banking instruments and trading off the cost of money and final cash balance without time-consuming data collection, has a strategic role as a tool for decision-making. This is the perspective assumed for the potential use of the proposed Pareto Optimality Efficiency network model. Cash forecasts and other financial and project parameters are used as input to the model. Once they are defined, the optimality efficiency algorithm serves as an analytical tool for various scenarios by changing the project parameters and financial constraints (e.g. front money, minimal periodic cash balance, etc.) to manipulate the cash transactions over the planning horizon, aiming at achieving a greater profitability and less cost of money level for the project.

3. Methodology

Our model assumes cash flow forecast on a periodic basis with compound interest rates from period to period. The user defines the planning horizon, as well as the objective functions to some extent. Despite the deterministic nature of the model, sensitivity analysis provides insights on the uncertainties and variations about parameters or input data. Progressive updating is recommended whenever more accurate data or forecasts become available along the tendering stage of the project.

The network in Fig. 1 shows the basic components of the model. The objectives of this model are to maximize final cash balance (FC) and minimize the total cost of money (R) by determining such variables as the long term loan (LTL) and the periodic short term loans (STL_i) for a project. There are some pre-defined values for some external inputs and parameters. The pre-defined external inputs to the network are the periodic expense forecasts (E_i), owner's progress payment (P_i) as defined by the payment plan, and front money as the initial capital (IC). Pre-defined parameters include retainage rate, profit percentage, periodic minimum cash balance requirement (V), the contractor's borrowing capacity (W), and all kinds of interest rates associated with the cost of money from long term loan and short-term loans, and related to earnings from excess cash balance. These external inputs and parameters affect the decision making process.

Arrows and nodes of the network are associated with financial transactions. In the network shown in Fig. 1, a node is a particular point in time when all preceding cash flow and all immediately succeeding cash flow are computed. Arrows pointing to a node indicate cash inflows. Arrows shooting out of a node mean cash outflows. Take a typical node i in the Fig. 1 as an example. Node i is the end of period i and the start of period i+1. At this particular point in time, short term loan (STL_{i+1}), owner's progress payment (P_i), and periodic cash balance ($CB_i^{'}$) at the end of period i are cash inflows for period i+1. The project expense (E_{i+1}) for period i+1, paid-off short term loan for period i (STL_i), and cost of money (R_i, including long term loan and short term loan) are cash outflows. The cash balance at the beginning of the period i+1(CB_{i+1}) is equal to the mathematical sum of all cash inflows and outflows at the time node I (for node i = 1, 2, …n – 1):

$$CB_{i+1} = STL_{i+1} + P_i + CB_i^{'} - E_{i+1} - STL_i - R_i . \quad (1)$$

In Eq. (1), the computation of interest earnings ($CB_i^{'}$) occurs on the horizontal arrows of the network. The horizontal arrows are used to represent excess cash at the beginning and the end of a period. A small interest rate is assumed for deposits of excess cash. An output flow cash balance at the beginning of a period i (CB_i) will be converted into an input flow $CB_i^{'}$ that reaches the end node of the same arc, with the corresponding computation of the interest earning between time nodes (i–1) and i, calculated as follows:

$$CB_i^{'} = (1 + r_1)CB_i , \quad (2)$$

where r_1 is the interest rate for excess cash. There are minimum cash flow balance specifications (V) for deposits, which is set as a constraint in the model (Eq. 12), depending on requirements from the bank, or based on existing financial policies of the company.

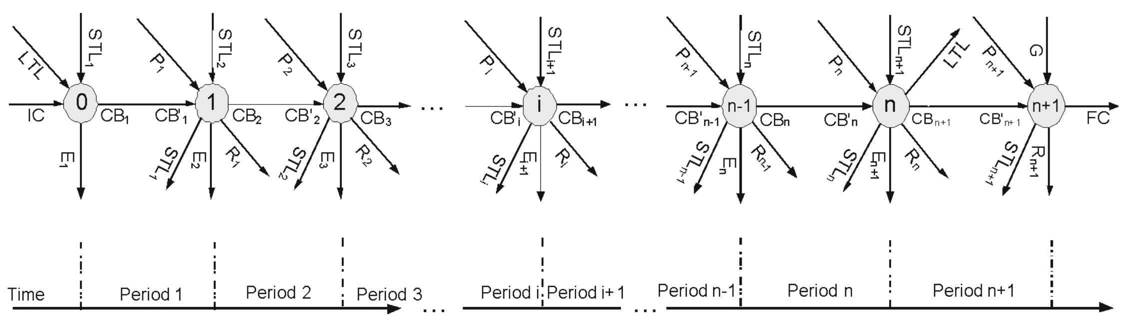

Fig. 1. Network for Cash Balance and Cost of Money Trade-off Model

In Eq. (1), the prevailing interest rate for loans is applied (for node $i = 1, 2, \ldots n$) using:

$$R_i = (LTL)r_2 + (STL_{i+1})r_3, \quad (3)$$

where R_i is the interests paid to the banks or cost of money at the end of period i or at the beginning of period $i+1$. LTL is the long term loan issued to the project when the project starts. The interest of LTL is paid periodically and the principle should be paid off when the project finishes at the time node n. STL_i is the short term loan cash flow at the beginning of the period i. STL_i and its interests should be paid off at the end of period i or at the beginning of the period $i+1$. Otherwise, the contractor is not entitled to further short term loans or is charged additionally depending on existing terms between the bank and the contractor. SLT is the available credit lines. Certainly, there are upper bounds to the amount of cash from these sources (W), which is set as another constraint, in the model (Eq. 13). r_2 and r_3 are the interest rates for long term loans and short term loans.

The cash inflows and outflows in the first node 0, the node n, and the node $n+1$ are different from a typical node i in Fig. 1 to some extent. Node 0 indicates the beginning of the project. It has three cash inflows – initial capital (IC), long term loan (LTL), and short term loan (STL_1) – and one cash outflow – the first periodic project expense (E_1). CB_1 is the mathematical sum of all cash inflows and outflows in node 0. Initial capital or front money is required which is assumed as available at the beginning of the planning horizon. STL_1 is the short term loan issued at the beginning of the project. LTL can be a construction loan or other kinds of loans. It represents a developer's or a contractor's borrowing capacity. It is assumed that the LTL is only available at the beginning of the planning horizon. Long term loans in this model are supposed to be paid off at the completion of the project (node n). Node n in Fig. 1 is the point in time to pay the principle of LTL back to the banks. Therefore, there is one more cash outflow coming from node n comparing to the typical node i.

The last node $n+1$ in the model indicates the time for final payments defined by contract, when the total money retained by the owner (G) is supposed to be returned to the contractor (Eq. 11). The final cash balance (FC) is calculated at this point in time:

$$FC = G + P_{n+1} + CB'_{n+1} - STL_{n+1} - R_{n+1}, \quad (4)$$

where P_{n+1} is the owner's full payment for the project expense which occurs in the period $n+1$. The computation of cost of money R_{n+1} is different from R_i in a typical node i. It only contains the interest from STL_{n+1} and its interest as follows:

$$R_{n+1} = (STL_{n+1})r_3. \quad (5)$$

Therefore, the final cash balance and cost of money trade-off problem can be formulated as: given the initial amount of capital allocated for the project (IC) from the company, the forecast expense flow E_i for each time period i along time horizon, the planned income flow supply P_i (progress payment), the interest rates for excess cash and loans(r_1, r_2, r_3), the retainage rate (r_4), profit percentage rate (r_5), the minimum cash flow balance requirements(V), and the upper boundary of the credit line (W), the model will maximize the final cash balance (FC) available and minimize the cost of money (R) for the planning horizon.

Based on the model in Fig. 1, the decision variables to be found are LTL and STL_i. In other words, the model finds the optimal final cash balance (FC) and cost of money (R) by varying the amount of long term loan and short term loans. The problem can be written in mathematical terms as follows:

$$\text{Max } FC = G + P_{n+1} + CB'_{n+1} - STL_{n+1} - R_{n+1}; \quad (6)$$

$$\text{Min } R = \sum_{i=1}^{n+1} R_i = \sum_{i=1}^{n} (LTL \times r_2)_i + \sum_{i=1}^{n+1} STL_i r_3; \quad (7)$$

subject to:

$$CB_1 = STL_1 + LTL + IC - E_1 \quad \text{(for Node } i = 0\text{)}; \quad (8)$$

$$CB_{i+1} = STL_{i+1} + P_i + CB'_i - E_{i+1} - STL_i - R_i$$
(for Node i=1, 2, ..i..., n–1); (9)

$$CB_{n+1} = STL_{n+1} + P_n + CB'_n - E_{n+1} - STL_n - R_n$$
(for Node $i = n$); (10)

$$G = \sum_{i=1}^{n} r_4 \times E_i \times (1 + r_5); \quad (11)$$

$$CB_i > V$$
(Periodic minimal cash balance requirements, i=1, 2, … n+1); (12)

$$STL_i < W$$
(Upper bound on credit line, i=1, 2, …, n+1), (13)

where: CB_i is the cash balance at the beginning of period i (i = 1, 2, … n+1); CB'_i is the cash balance at the end of period i (i = 1, 2, … n+1); E_i is the forecast expense for the period i (i = 1, 2, … n+1); FC is the final cash balance, at the end of the planning horizon; G is the total money retained by the owner; IC is the initial capital allocated to the project; LTL is long term loans; P_i is the owner's periodic payment for the work done in period i (i = 1, 2, … n+1); R is the total cost of money (interest) paid to the banks for the forecasting horizon; R_i is the periodic cost of money paid to the banks i (i = 1, 2, … n+1); r_1 is the interest rate for excess cash deposited; r_2 is the interest rate for long term loan; r_3 is the interest rate for short term loan; r_4 is the retainage rate according to the terms of the contract; r_5 is the profit percentage; STL_i is the money periodically borrowed from the bank under the available credits (i = 1, 2, … n+1); V is the monthly minimum cash balance requirement based on a bank's or company's financial policy; W is the upper bounds of cash credit available.

We get two pairs of values on the cost of money and final cash balance – (R_{min}, FC_R) and (R_{FC} , FC_{max}) – by minimizing the cost of money and maximizing the final cash balance. The value ranges of the cost of money and final cash balance are (R_{min}, R_{FC}) and (FC_R, FC_{max}) in Fig. 2. Given the various R within the range of (R_{FC}, R_{min}) as an upper limit of the cost of money (constrain), the maximal values of FC are found by running the network model. If all optimal solutions are graphed in the x-y plane with the y-axis being the values on Objective 1 (maximizing final cash balance) and the x-axis being the values on Objective 2 (minimizing interest paid), the graph is called a trade-off curve or efficient frontier. To illustrate, suppose that the set of feasible solutions for the bi- objective problem is the shaded region bounded by the curve AB and the first quadrant in Fig. 2, then the curve AB is the set of Pareto optimal points under pre-defined parameters and external inputs.

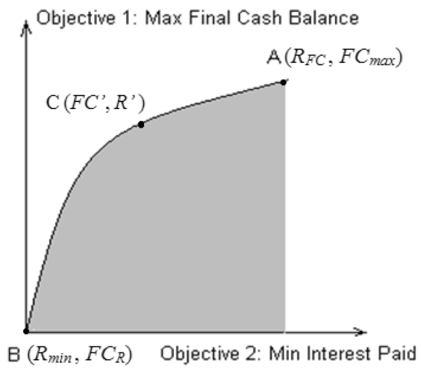

Fig. 2. Pareto Optimality Trade-off Curve in Max-Min Problems

The steps for finding a Pareto optimality trade-off curve are as follows:

1. Choose Objective 1 – maximizing final cash balance – and use the proposed network model to determine its maximal value FC_{max}. For the solution FC_{max}, find the value of cost of money and label it R_{FC}. Then A (R_{FC}, FC_{max}) is a point on the trade-off curve in Fig. 2.
2. In step 1 we obtained one "endpoint" of the trade-off curve. If we choose Objective 2 – minimizing the cost of money, use the proposed network model to determine its best value R_{min} that can be attained. For the solution R_{min}, find the value of final cash balance and label it FC_R, then the other endpoint B (R_{min}, FC_R) of the trade-off curve in Fig. 2 is obtained.
3. For values R that are better (smaller) than R_{FC} and worse (larger) than R_{min}, solve the optimization problem in step 1 with the additional constraint that the cost of money is at least as good as R. Varying R yields other points on the trade-off curve. Take any point C (FC', R') on the curve AB as an example, the FC' and R' are determined by maximizing the final cash balance with the additional constraint $R' \le R$.

The AB curve indicates that the final cash balance increases as the cost of money increases and FC and R change at different rates under predetermined parameters and external inputs. In real world the initial capital is always limited. Project management favors initiating a project with as little initial capital as possible to achieve more final cash balance. FC and R vary by changing the initial capital (IC). Fig. 3 shows the four functions of IC – R_{FC}, R_{min}, FC_{max}, and FC_R. The pair of the curves R_{FC} and FC_{max} is determined by the model which maximizes the final cash balance FC by changing IC. These two curves intersect at point A where FC_{max} equals R_{FC}. Similarly, the other pair of curves R_{min} and FC_R is drawn by the model which minimizes the cost of money R by changing IC. These two curves intersect at point B where FC_R equals $R_{min.}$ On the other hand, R_{FC} and R_{min} decrease while more IC is available. However, the rate of decreasing R_{FC} and R_{min} are not the same till both curves R_{FC} and R_{min} arrive at point D. It indicates that R_{min} equals R_{FC} – calculated by minimizing R and maximizing FC – no matter how much IC are available ($IC \ge IC_E$). However, FC_{max} and FC_R increase as more IC *is* available. The FC_{max} equals FC_R after both curves arrive at point C. It indicates that FC_{max} equals FC_R – computed by maximizing FC and by minimizing R – when $IC \ge IC_E$.

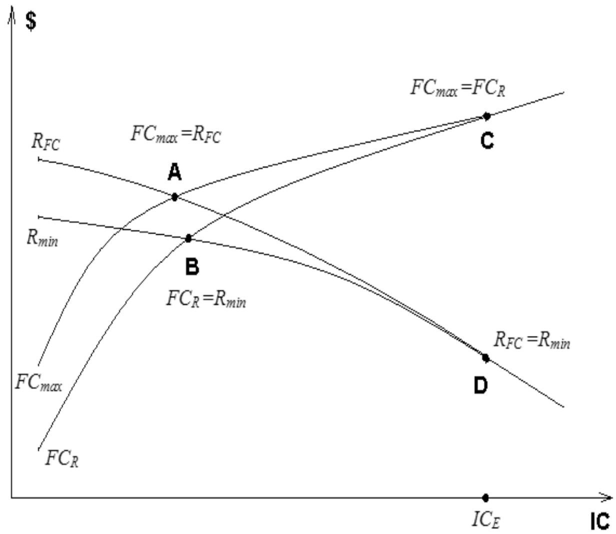

Fig. 3. R_{FC}, R_{min}, FC_{max}, and FC_R Curves when IC Changes

Except for the FC and R analysis based on various initial capital inputs, the proposed node network bi-objective trade-off model can be used as a tool for providing very interesting and relevant analysis, such as: (a) the amount of initial capital (IC) necessary to guarantee reliable cash flow management for the project as a whole, along the planning horizon; (b) the effect of the periodic minimum cash balance required on the final solutions; (c) the effect of the credit line (W) on the final optimum solution; and (d) the effect of interest rates and retainage rate (r_1, r_2, r_3, and r_4) on the objective functions; (a) and (b) are the two factors controlled by project management and the other factors are determined by the financial institutions and the project owners. Therefore, the case study mainly illustrates the impacts of IC and the periodic minimum cash balance required on the final cash balance and the cost of money.

4. Case study

The methodology described above is applied to data collected from a small-scale project located in the city of West Palm Beach, Florida, which will be designated as Case A. All data, contractual arrangements and interest rates adopted in this case study are based on interviews undertaken with practitioners. The following monthly interest rates, retainage rate, and profit percentage were adopted: $r_1 = 1.25\%$, $r_2 = 6\%$, $r_3 = 7.5\%$, $r_4 = 10\%$ and $r_5 = 5\%$. The initial capital (*front money*) is IC = \$1,000,000 and the upper bound of credit line is W_{max} = \$600,000. A basic structure of monthly expenses and a payment plan were assumed, based on the original plan for this project, as shown in Table 1. The optimal results from the input data (Table 1) are presented in Table 2.

Table 2 shows the long term loan and short term loans when optimizing one objective and ignoring the optimization of the other objective function. The two end points on the trade-off curves are found in this way. In other words, *FC* can get as high as \$140,800 by ignoring the cost of money or as low as \$131,700 by focusing entirely on the cost of money, and the cost of money can get as low as \$1,877,851 by ignoring *FC* or as high as \$1,883,342 by focusing entirely on *FC*. These establish the extremes. Now the points in between are determined. According to step 3 described in the model, an additional constraint is set on the model with the objective of maximizing *FC* with an upper limit on the cost of money (the same effect is obtained by minimizing the cost of money and putting a lower limit on *FC*). The only upper limits on cost of money are those between \$1,877,851 and \$1,883,342. The two right most columns in Table 3 show the set of points on the trade-off curve by varying the upper limits (column 1). The final cash balance tie after the upper bound of the cost of money is greater than \$1,883,342. It also displays the *LTL* and monthly *STL*s per a pair of values of *FC* and *R*. Fig. 4 shows the *FC* and *R* values. A Pareto optimality trade-off curve is generated by trending the values of *FC* and *R*. The function between *FC* and *R* displayed in Fig. 4 is obtained by using the least square fitting trend line.

A second case study, Case B, differs from Case A only in the initial capital. A lower initial capital of IC = \$800,000 was assumed in case B. The two end points of Pareto Optimality trade-off curves for case B are shown in Table 4. Since the total of initial capital IC = \$800,000

Table 1. Input Data for the Case Study

Month (1)	Contractor's Expenses (2)	Monthly Payment Application (3) = (2)×5%	Owner's Payment (4) = (3)×90%	Minimal Cash Balance Requirements (5) = 50%×(2)
1	\$771,000	\$811,000	–	\$385,000
2	\$788,000	\$829,000	\$730,000	\$394,000
3	\$1,113,000	\$1,172,000	\$747,000	\$557,000
4	\$1,644,000	\$1,731,000	\$1,055,000	\$822,000
5	\$1,713,000	\$1,803,000	\$1,558,000	\$856,000
6	\$1,953,000	\$2,056,000	\$1,623,000	\$976,000
7	\$2,364,000	\$2,488,800	\$1,850,000	\$1,182,000
8	\$2,210,000	\$2,326,000	\$2,240,000	\$1,105,000
9	\$1,713,000	\$1,803,000	\$2,093,000	\$856,000
10	\$1,182,000	\$1,244,000	\$1,623,000	\$591,000
11	\$994,000	\$1,046,000	\$1,120,000	\$497,000
12	\$685,000	\$721,000	\$941,000	\$343,000
13	–	–	\$2,452,000	–
Total	\$17,130,000	\$18,031,000	\$18,031,000	–

Table 2. Optimal Solutions for Maximizing *FC* and Minimizing Cost of Money

Month	Maximize Final Cash Balance (*FC*)		Minimize Cost of Money (*R*)	
	Long–term Loan (*LTL*)	Short–term Loan (*STL*)	Long–term Loan (*LTL*)	Short–term Loan (*STL*)
1	\$826,000	\$0	\$231,000	\$0
2	–	\$0	–	\$0
3	–	\$0	–	\$539,000
4	–	\$898,000	–	\$1,441,000
5	–	\$1,194,000	–	\$1,742,000
6	–	\$1,772,000	–	\$2,326,000
7	–	\$2,662,000	–	\$3,221,000
8	–	\$2,789,000	–	\$3,355,000
9	–	\$2,405,000	–	\$2,978,000
10	–	\$1,918,000	–	\$2,498,000
11	–	\$1,884,000	–	\$2,471,000
12	–	\$1,658,000	–	\$2,254,000
13	–	–	–	–
	FC_{max} = \$140,800;	R_{FC} = \$1,883,342	FC_R = \$131,700;	R_{min} = \$1,877,851

Table 3. Pareto Optimal Solutions for Case A (unit is in $100,000)

Upper bound ($)	Long-term Loan ($)	Monthly Short-term Loan ($)												R ($)	FC ($)
		1	2	3	4	5	6	7	8	9	10	11	12		
18.778	No Feasible Solutions													–	–
18.780	2.47	0.00	0.00	5.24	14.26	17.27	23.11	32.06	33.40	29.62	24.82	24.55	22.38	18.7800	1.320
18.785	3.01	0.00	0.00	4.75	13.77	16.77	22.60	31.55	32.88	29.10	24.29	24.02	21.84	18.7850	1.328
18.790	3.55	0.00	0.00	4.26	13.27	16.27	22.10	31.04	32.37	28.58	23.77	23.48	21.29	18.7900	1.340
18.795	4.10	0.00	0.00	3.77	12.78	15.77	21.59	30.53	31.85	28.06	23.24	22.95	20.75	18.7950	1.344
18.800	4.64	0.00	0.00	3.28	12.28	15.27	21.09	30.02	31.34	27.54	22.71	22.41	20.21	18.8000	1.350
18.805	5.18	0.00	0.00	2.79	11.79	14.77	20.59	29.51	30.82	27.02	22.18	21.88	19.67	18.8050	1.361
18.810	5.72	0.00	0.00	2.30	11.29	14.28	20.08	29.00	30.31	26.49	21.65	21.34	19.12	18.8100	1.370
18.815	6.26	0.00	0.00	1.81	10.80	13.78	19.58	28.49	29.79	25.97	21.13	20.81	18.58	18.8150	1.377
18.820	6.81	0.00	0.00	1.32	10.31	13.28	19.07	27.98	29.28	25.45	20.60	20.27	18.04	18.8200	1.390
18.825	7.35	0.00	0.00	0.83	9.81	12.78	18.57	27.47	28.76	24.93	20.07	19.74	17.50	18.8250	1.394
18.830	7.89	0.00	0.00	0.34	9.32	12.28	18.06	26.97	28.25	24.41	19.54	19.20	16.95	18.8300	1.400
18.833	8.22	0.00	0.00	0.04	9.02	11.98	17.76	26.66	27.94	24.10	19.23	18.88	16.63	18.8334	1.410
18.835	8.26	0.00	0.00	0.00	8.98	11.94	17.72	26.62	27.89	24.05	19.18	18.84	16.58	18.8334	1.410

Table 4. End Points of Pareto Optimality Trade-off Curves by Varying Initial Capitals

Case	*IC*	Maximize *FC*		Minimize *R*	
		FC_{max} (in $100,000)	R_{FC} (in $100,000)	FC_R (in $100,000)	R_{min} (in $100,000)
B	$800,000	–2.784	21.02977	–2.876	20.97356
A	$1,000,000	1.408	18.83342	1.317	18.77851
B–1	$1,100,000	3.503	17.73524	3.414	17.68098
B–2	$1,200,000	5.599	16.63707	5.511	16.58345
B–3	$1,300,000	7.695	15.53889	7.621	15.49407
B–4	$1,400,000	9.790	14.44071	9.734	14.40634
B–5	$1,500,000	11.886	13.34254	11.847	13.31862
B–6	$1,600,000	13.982	12.24436	13.959	12.2309
B–7	$1,700,000	16.077	11.14619	16.072	11.14317
B–8	$1,800,000	18.098	10.15202	18.098	10.15202
B–9	$1,900,000	20.088	9.19995	20.088	9.19995
B–10	$2,000,000	22.078	8.24789	22.078	8.24789

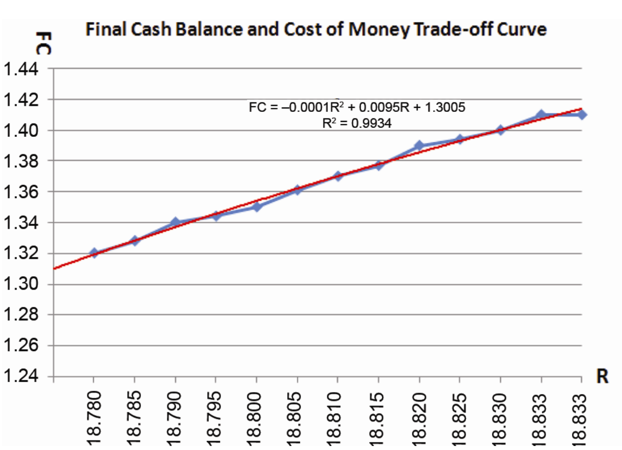

Fig. 4. Pareto Optimality Trade-off Curve for Case A (units in $100,000)

is not large enough, the contractor has to borrow more money (*LTL* and *STL*) from financial institutions, which incurs a high cost of money and accordingly leads to negative *FC* values(–$287,600 and –$278,400) in this project even though the model is run by minimizing the *R* ($2,097,356). We increase initial capital (*IC*) through case B–1 to case B–10 by observing the *FC* and *R*. Table 4 indicates that the more *IC* is allocated at the beginning of the project, the more *FC* and the less *R* are, which makes sense. Since the more money is invested, the less money would be borrowed from the bank which results less *R* and higher *FC*.

One finding is that FC_{max} and FC_R are less than R_{FC} and R_{min} respectively in the cases from A to B–5. However, FC_{max} and FC_R are greater than R_{FC} and R_{min} respectively in the cases from B–6 to B–10. By further running the model, it shows that FC_{max} = R_{FC} = $1,284,200 when *IC* = $1,545,600 (between the amounts

Table 5. Various V and IC When FC_{max}=FC_R and R_{FC} =R_{min}

% of Required Minimal Periodic Cash Balance	IC (in \$100,000)	FC_{max}=FC_R (in \$100,000)	R_{FC}=R_{min} (in \$100,000)
20%	\$14.030	\$14.019	\$9.56820
30%	\$15.115	\$14.924	\$9.98020
40%	\$16.205	\$15.799	\$10.40647
50%	\$17.290	\$16.685	\$10.82799
60%	\$18.375	\$17.570	\$11.24950
70%	\$19.460	\$18.456	\$11.67107
80%	\$20.550	\$19.351	\$12.08777

from case B–5 and B–6) and FC_R = R_{min} = \$1,281,833 when IC = \$1,545,994 (between amounts from case B–5 and B–6). The other finding is that the two extreme end points of (FC_{max}, R_{FC}) and (FC_R, R_{min}) are overlapped in case B–8 (IC = \$1,800,000), B–9 (IC = \$1,900,000), and case B–10 (IC = \$2,000,000). In other words, more IC does not have impact on FC and R after it attains a certain amount. By conducting more trials between \$1,700,000 and \$1,800,000, a more accurate IC is found at \$1,729,000 when FC_{max} equals FC_R and R_{FC} equals R_{min}. Of course, the initial capital is limited in practice. It changes along with other factors such as minimal periodic cash balance requirements (V). Accordingly the FC_{max}(=FC_R) and R_{FC}(=R_{min}) change with various IC and V. Table 5 and Fig. 5 display the sensitivity analysis of FC_{max} = FC_R and R_{FC} = R_{min} to V and IC.

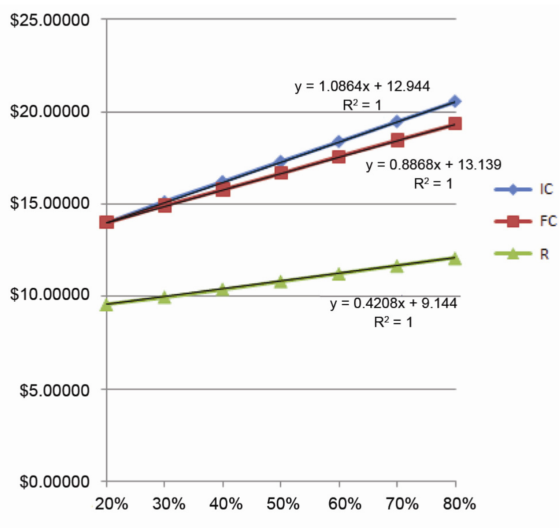

Fig. 5. Relationship of IC, FC and R with V

Other factors affecting the FC and R in Case B include the interest rates for LTL and STL, the retainage rate, the interest rate for excess cash, and the available credit lines. In order to provide a better appreciation of the potential of the model for such analysis, it is interesting to compare the benefits of using the model by changing all of the factors. The model represented in the network (Fig. 1), the corresponding equations, and the case study gives insight concerning the relationships among the variables in the decision-making problem.

Compared with existing cash flow planning models, this case study proves that the proposed model provides the project manager (1) optimal solutions by maximizing final cash balance and minimizing the cost of money respectively; (2) maximum final cash balance by setting the upper bound of the total cost of money; (3) optimal solutions through what-if analysis by changing the amount of initial capital, required periodic minimum cash balance, and other variables such as the credit line, the interest rates and the retainage rate. The proposed model provides reasonable accuracy on the cash flow management with limited data inputs during the project tendering stage.

5. Conclusions

The Pareto optimality efficiency network model shown in Fig. 1 is aimed at providing cash flow management for projects in the tendering and construction stages. The model assumes cash flow management on a monthly basis with compound interest rates from one month to the next. The proposed model considers typical banking instruments, the constraints of the financial market, budget constraints, and retention of money. The corresponding equations allow more insight concerning the relationship between the external inputs and the variables in the problem. The tradeoff procedure for the final cash balance and total cost of money is illustrated in a small size case study. A better view of the whole cash flow management for a project is provided when using the model. Despite the deterministic assumption adopted in this version of the model, what-if analysis on the uncertainties about parameters or input data are possible and are discussed in this study. The wide range of commercial software packages for linear programming available in the market at low prices (e.g. add-ins for MS Excel) enables any construction company to have this tool in its office for fast and effective cash flow forecast and planning with reasonable accuracy.

Although the model considers a good deal of external and internal variables and tradeoff of decision objectives, it is still a limited representation of the complex real world of the construction management environment. The other external and internal factors, such as delay of the client's progress payment, and penalty on delayed payment have not been represented in the model. In addition, more decision objectives may become additional concerns in the decision making process for this full-of-uncertainty industry. The formulation proposed is a good decision making tool when the project duration is defined. However, there is a progressive computational burden as the number of scenarios is increased. To make the decision making model closer to the real project management environment, further research needs to incorporate more external and internal project variables into the model to simulate the tradeoff of more objectives.

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Appendix: Nomenclature

CB_i	the cash balance at the beginning of period i (i=1, 2, ... n+1)
$CB_i^{'}$	the cash balance at the end of period i (i=1, 2, ... n+1)
E_i	the forecast expense for the period i (i=1, 2, ... n+1)
FC	the final cash balance, at the end of the planning horizon
FC_{max}	the final cash balance by maximizing the objective function FC
FC_R	the final cash balance by minimizing the objective function R
$FC^{'}$	the final cash balance between FC_{max} and FC_R
G	the total money retained by the owner
IC	the initial capital allocated to the project
LTL	the long term loans
P_i	the owner's periodic payment for the work done in period i (i=1, 2, … n+1)
R	the total cost of money (interest) paid to the banks for the forecasting horizon
R_i	the periodic cost of money paid to the banks i (i=1, 2, … n+1)
R_{FC}	the total cost of money by maximizing the objective function FC
R_{min}	the total cost of money by minimizing the objective function R
$R^{'}$	The total cost of money between R_{FC} and R_{min}
r_1	the interest rate for excess cash deposited
r_2	the interest rate for long term loan
r_3	the interest rate for short term loan
r_4	the retainage rate according to the terms of the contract
r_5	the profit percentage
STL_i	the money periodically borrowed from the bank under the available credits (i=1, 2, … n+1)
V	the monthly minimum cash balance requirement based on a bank's or company's financial policy
W	the upper bounds of cash credit available

STATYBOS PROJEKTO PINIGŲ SRAUTŲ PLANAVIMAS, NAUDOJANT PARETO OPTIMUMO EFEKTYVUMO TINKLO MODELĮ

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Santrauka

Projekto gyvybingumui pinigų srautai turi kritinę reikšmę. Pinigų srautus sudaro piniginės viso projekto išlaidos, pinigų trūkumas, paskolos, pinigų kaina ir visos gautos pajamos. Nors atlikta daug pinigų srautų prognozių, planavimo ir valdymo tyrimų, jų objektas paprastai yra pelno (galutinio pinigų likučio) maksimizavimas arba bendros projekto kainos minimizavimas. Be to, pinigų srautų prognozavimas turi būti veiksmingas ir greitas. Darbe kuriamas daugiatikslis pinigų srautų planavimo modelis – Pareto optimumo efektyvumo tinklo modelis, kuris apima įprastas bankų veiklos priemones, finansų rinkos suvaržymus, biudžeto suvaržymus ir pinigų išsaugojimą. Tiriant atvejį pristatomas daugiatikslis projekto pinigų srautų valdymo metodas, t. y. taikant siūlomą modelį sprendžiamas praktinis uždavinys. Galimų variantų analizė (angl. *What-if-analysis*) rodo, kaip suderinti pelningumą ir paskolos palūkanas, t. y. pagrindines problemas planuojant ir valdant projekto pinigų srautus. Modelis yra gana tiksli ir efektyvi sprendimų priėmimo priemonė, skirta sektoriaus praktikams.

Reikšminiai žodžiai: pinigų srautų planavimas, Pareto optimumas, tinklo modelis, daugiatikslis.

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