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DEVELOPING A COST-PAYMENT COORDINATION MODEL FOR PROJECT COST FLOW FORECASTING

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Abstract. Project operating cash flow forecasting techniques have evolved to enable detailed predictions relating to individual projects. These techniques, principally the cost-schedule integration (CSI) model, extensively use project cost estimates and schedule data. Despite CSI models having gained general acceptance, they have not been without criticism. Such criticism includes the problems of differential schedules between network and cost activities, ignoring the important information of payment conditions composed of payment lags, components, and frequency, and the combined adverse effects of payment irregularity and uniform distribution of cost over time. To resolve and alleviate these problems, this study develops a set of cost-payment coordination mechanisms for creating interaction among cost and payment activities. These mechanisms are then developed into a model. The accuracy of the model is assessed by comparing the historical flows on two case projects. The result shows that the patterns of predicted cost flows created with the model closely match those of the historical flows.

Keywords: project management, cost control, cost analysis, forecasting.

1. Introduction

Low and unreliably profitability characterize the construction contracting industry (Garnett, Pickrell 2000; Sorrell 2003). Levy (2009) and Teerajetgul *et al.* (2009) further noted that contractors work on slim profit margins due to fierce competition. While researchers continually develop methods and approaches for reducing engineering project costs (e.g., Dainty *et al.* 2001; Humphreys *et al.* 2003; Yeo, Ning 2002), some authors (e.g., Navon 1994, 1995; Kaka 1996; Kenley 1999) have focused on improving profitability of engineering projects by improving the efficiency of project cash flows. Since net positive project cash flows reduce the project working capital, smaller working capital needs indicate better profitability performance, defined as Net Profit/Net Investment, where Net Investment represents the working capital committed to the project to generate profits. Consequently, companies that predict and plan operating cash flows so as to slow cash outflows or reduce working capital needs will achieve higher ROI.

Among the models and approaches reviewed, the most information-intensive models for predicting operating cash flows are those based on the cost-schedule integration (CSI) techniques (e.g., Abudayyeh, Rasdorf 1993; Carr 1993; Chen, Chen 2005; Navon 1996). However, despite using extensive schedule and estimated data information as inputs to provide highly integrated models for predicting cash flows, existing CSI approaches still lead to large discrepancies between payment flows and cost flows. This discrepancy stemmed from the problems of differential schedules between network and cost activities, lags between applications for payment and actual disbursement of funds, payment components for materials and labor (payment split between labor and materials), and payment frequency, as well as the combined impacts of payment irregularity (the amount of a progress payment different from the actual accumulated activity cost, or the disbursement of that progress payment different from the projected schedule) and uniform distribution of cost over time (a key assumption of CSI models).

Research thus continues on extensions of CSI models to provide solution methods for these limitations. First, this study briefly discusses the background of methods and approaches for operating cash flows. Next, this study describes the development of the coordination mechanisms based on CSI models. Finally, this study validates the coordination mechanisms by two construction projects. Analysis of pattern matching logic using simulated cost flow data by coordination mechanisms indicates that while input parameters are based on the actual cost and schedule of the work performed, the coordination mechanisms are able to eliminate the difference between cost flows and payment flows. More broadly, this study provides a methodology and starting point for further refinement of CSI models to include future sales and overhead flows.

2. Background

This paper first offers some definitions: cash flows, generated by operating, investing, and financing activities, are the inflows and outflows of cash into and out of a business (Needles *et al.* 1999). Operating activities are defined as transactions other than investing or financing activities. Investing activities include purchasing and selling long-term productive assets and equity and debt investments that are cash equivalents, as well as making and collecting loans. Financing activities include issuing equity securities and long-term and short-term liabilities, paying dividends to stockholders, purchasing treasury stock, and repaying cash loans. Thus, operating activities that produce operating cash flows include sales, costs of goods sold or services rendered, and overhead costs. Operating cash flows are more important than investing and financial cash flows, as they reflect the financial health of a business and its value (Barth *et al.* 2001; Krishnan, Largay 2000).

Operating cash flows comprise the inflows and outflows of cash. Inflows consist of sales flows, whereas outflows are composed of payment flows and overhead flows. Sales flows are income realized on contractual agreements with clients relating to activity and project completion. Payment flows are the disbursement of costs of goods sold or services rendered as a function of time. Overhead flows are the disbursement of the overhead costs (field and main office) as a function of time. From a modeling perspective, cost flows are defined as forecasts of payment flows. Cost flow forecasting has proven to be more difficult to generate than that of sales flows and overhead flows for reasons of complexity, as there are typically many activities generating costs, and partial payments are made to vendors (Chen, Chen 2005). Therefore, this research focuses on improving the accuracy of cost flow predictions.

Though cash flow management is relatively well researched, those standard direct and indirect methods used for predicting operating cash flows that have been extensively addressed in previous studies (e.g., Barth *et al.* 2001; Krishnan, Largay 2000; Lorek, Willinger 1996) are not relevant in a project-based industry, especially one such as construction contracting. It is widely believed that in a project-based industry, a product (project) contributes a relatively large proportion of the overall level of sales volume that may destabilize these models (Chen, Chen 2005; Kaka, Lewis 2003). Several methods, principally the CSI techniques, thus are developed to meet the needs of project-based industries. These techniques focus on the project contracts rather than firm income statement and balance sheet, since the contracts determine both the timing and amount of the cash inflows and outflows.

CSI models forecast operating cash flows by using forecast work schedules and activities (e.g., Abudayyeh, Rasdorf 1993; Carr 1993; Chen, Chen 2005; Navon 1995). CSI models therefore produce cost flows either as a continuous function, or in more refined models, periodic function summing the costs of scheduled work as a function of time. While the costs of scheduled work are budgeted costs, CSI models produce the budgeted cost for work scheduled (BCWS), or the budgeted cost for work performed (BCWP) after the scheduled work is accomplished. When the scheduled work is accomplished and the corresponding actual cost is incurred, CSI models produce the actual cost of work performed (ACWP). BCWS serves as a time-phased budgetary baseline for the entire project, representing the standard or plan against which the performance (BCWP) and the cost (ACWP) of the project are compared. BCWS, BCWP, and ACWP, which are also called planned value (PV), earned value (EV), and actual value (AV), respectively, formulate earned value management (EVM) systems.

While based on different input data, CSI models produce EVM systems that evaluate a project's technical performance (i.e., accomplishment of planned work), schedule performance (i.e., behind/ahead of schedule), and cost performance (i.e., under/over budget), some authors further refine CSI models for use in cost flow predictions. For example, Abudayyeh and Rasdorf (1993) designed the basic approaches and computer implementations for cost flow predictions using CSI techniques. Carr (1993) provided refinements to accounting for schedule variance in cost flow predictions. Building upon this work, Navon (1995, 1996) refined the CSI technique to account for time lags between application for payment and actual disbursement of funds, providing a model that assumes monthly dates for application of vendor payment. Building on this level of detail, Fayek (2001) further discusses fusing CSI techniques with firm accounting systems.

Hwee and Tiogn (2002) developed a sophisticated S-curve profile model from CSI that is equipped with progressive construction data feedback mechanisms. Kaka and Lewis (2003) further devised a company-level (CL) S-curve model that accounts for both known and unknown individual projects at the time of the forecast. Subsequent work by Park (2004) developed a project-level cash flow forecasting model using moving weights of cost categories in a budget over project duration based on the planned earned value and the cost from a GC's view on a jobsite. He concluded that the proposed model is more accurate, flexible, and yet simpler than traditional models from the validation results of four real projects.

Mavrotas *et al.* (2005) further modeled cash flows based on a bottom-up approach starting from the level of a single contract (project) towards the level of the entire organization, where each contract's cash flow is approximated and updated with an appropriate S-curve that is based on a conventional non-linear regression model.

Recently, Jiménez and Pascual (2008) modeled cash flow components by incorporating preferences and expectations in the form of specific projection criteria for each of the components (e.g., sales and debts.), such as the use of ratios and rates of change. Cheng *et al.* (2009) developed a cash flow model from a set of artificial intelligence (AI) approaches and CSI to predict project cash flow trends. Görög (2009) presented a comprehensive model for planning and controlling contractor cash flows, based on the expansion of EVM to include new performance measurements and indicators, such as PVWP

(Price Value of Work Performed) and IVWS Invoiced Value of Work Scheduled. More recently, Cheng and Roy (2011) proposed an evolutionary fuzzy decision model for cash flow prediction using time-dependent support vector machines and historical S-curve data by CSI.

However, despite the panoply of approaches to generating project cash flow forecasts, there still exist several potential limitations. First, CSI models do not consider important information of payment conditions, including differential payment lags, components for materials and labor (payment split between labor and materials), and payment frequency. Second, CSI models appear not to consider the problems of differential schedules between network and cost activities. Third, research on construction has mainly focused on studying how to improve the integration of cost activities and their corresponding resources (e.g., Abudayyeh, Rasdorf 1993; Chen 2007; Fayek 2001; Navon 1994). Relatively little research has addressed relationships between cost and progress payment activities. Thus, little research has provided methods of alleviating the influences of progress payment irregularity (the discrepancy between a progress payment and the actual accumulated activity cost, or the disbursement of that progress payment at a time different from the projected schedule) and uniform distribution of cost over time (a key assumption of CSI models) on the creation of cash flows.

3. Development of the model and the algorithm

The previous section criticized the ability of the CSI techniques. The primary objective of this study is to develop coordination mechanisms that are capable of resolving and/or alleviating the problems of existing CSI models, and hence, enhance the accuracy and reliability of forecasts of future cost flows produced by CSI models. Development of the coordination mechanisms are described in several parts, including rectifying differential schedules between network and cost activities, extending CSI models to include payment conditions, and alleviating the combined effect of payment irregularity and uniform distribution of cost over time.

3.1. Rectification of differential schedules between network and cost activities

CSI models assume that schedules between network and cost activities are identical; nonetheless, differential schedules between them often occur in practice. For instance, two subcontractors follow each other around fabricating a main structure of a building. The slab formwork must be installed before the concrete subcontractor can do its work; the slab formwork acts as a sustainer for concrete weight. Hence, there is a finish-to-start relationship between the work of the formwork subcontractor and that of the concrete subcontractor. However, the general contactor will not approve the cost of the formwork work until the concrete is placed, which acts as a *verifier activity* used to confirm whether or not the quality (or safety) requirements of the formwork work are achieved. Therefore, not only the relationship between the activities of slab formwork and concrete is transformed to a finish-to-finish relationship, but the cost of the formwork activity is viewed as being incurred on the very last day of the verifier activity.

When differential schedules exist in a project activity, the activity is defined as a scheduling conflict activity. The rectification for a scheduling conflict activity is as follows:

$$f_{SCA}\left(\mathrm{PCE}_{ij}\right)=\left\{Dur,\ Dep_{v}\left(Dur=1,\ \ Dep_{v}=F_{V}F_{SCA}\right\}\right.,\tag{1}$$

where: i is project contracting entity (PCE) index, $i = 1,\ldots, N$, where PCE is defined as a subcontractor, supplier, or as the general contractor itself, and N is the total number of entities; j is activity index, $j = 1,\ldots, M$, where M denotes the total number of activities of each PCE, for example, PCE_{ij} means the jth activity of the ith project contracting entity; $f_{SCA}(\mathrm{PCE}_{ij})$ is function of transforming PCE_{ij} while having the scheduling conflict attribute; Dur is duration of PCE_{ij}; Dep_V is dependency of PCE_{ij} on its verifier activity.

Before applying Eq. (1), a condition must be met: the activity cannot be partially examined and, thus, the activity cannot be partially invoiced. If an activity with the scheduling conflict attribute can be partially examined and billed, that activity needs to be further broken down until the condition is met.

3.2. Extending CSI models to include payment conditions

Since the cost occurs earlier than the payment of an activity, the cost flows are ahead of the payment flows of an activity. In practice, predictions of cost flows are verified by payment flows (the disbursements of payments as a function of time). Thus, while the effect of payment conditions on payment flows is significant (Chen, Chen 2005), there is a need to extend CSI models to include the information of payment conditions. The information of payment conditions include time lags between applications for payment and actual disbursement of funds, components for materials and labor (payment split between labor and materials), and monthly payment frequency for suppliers and subcontractors. The following assumptions must be made before extending CSI models to include payment conditions:

1. The network activity schedule and cost activity schedule are identical except scheduling conflict activities.
2. A cost loaded activity of a project can only be assigned to a PCE of that project.
3. The quantity of an activity's progress payment application is accumulated up to the day before the application date.

The first assumption gives the position of PCE_{ij} relative to time (dates) of application in the future in the time axis; the second provides the basis for calculating the cumulative quantity of PCE_{ij} in relation to time (dates) of application in the future in the time axis. Collectively, these two assumptions generate several possible scenarios of the relevant pay amount of PCE$_{ij}$'s *k*th payment application, conceptually expressed in Fig. 1. In this Figure, the relevant pay period of PCE$_{ij}$'s *k*th payment application is the time between TA_{ijlk} and $TA_{ijl(k-1)}$, indicated by the shaded portion of these scenarios. Scenarios A to L depict the possible range of PCE$_{ij}$ starting and finishing across multiple times of applications. These scenarios can be further grouped into four different types according to the relevant pay period of each scenario. Such grouping is expressed in Fig. 2 by showing the split among possible scenarios as a dotted lines perpendicular to the time axis.

More details of the four different types are addressed as follows:

Type 1: $TA_{ijlk} \geq ef_{ij} \geq TA_{ijl(k-1)} \geq es_{ij}$.

Under this Type, the *p*th payment application for activity *i* of PCE*j* is the last payment application. During the pay period, the *p*th cumulated activity cost is the multiplication of $ef_{ij} - TA_{ijl(k-1)} + 1$ and $pc_{ijl}bq_{ij}buc_{ij}(1-r_{ij})/(ef_{ij} - es_{ij}+1)$. Type 1 includes scenarios A and B.

Type 2: $TA_{ijlk} \geq ef_{ij} \geq es_{ij} \geq TA_{ijl(k-1)}$.

Under this Type, the *p*th payment application for activity *i* of PCE*j* is the first and last payment application.

During the pay period, the *p*th cumulated activity cost is the multiplication of $ef_{ij} - es_{ij} + 1$ and $pc_{ijl}bq_{ij}buc_{ij}(1-r_{ij})/(ef_{ij} - es_{ij} + 1)$. Type 2 includes scenario C. Type 3: $ef_{ij} \geq TA_{ijlk} \geq es_{ij} \geq TA_{ijl(k-1)}$.

Under this Type, the *p*th payment application for activity *i* of PCE*j* is the first payment application. During the pay period, the *p*th cumulated activity cost is the multiplication of $TA_{ijlk} - es_{ij}$ and $pc_{ijl}bq_{ij}buc_{ij}(1 - r_{ij})/(ef_{ij} - es_{ij} + 1)$. Type 3 includes scenarios D, E, and F.

Type 4: $ef_{ij} \geq TA_{ijlk} \geq TA_{ijl(k-1)} \geq es_{ij}$.

Under this Type, the *p*th payment application for activity *i* of PCE$_j$ is betweem the first and the last payment application. During the pay period, the *p*th cumulated activity cost is the multiplication of $TA_{ijlk} - TA_{ijl(k-1)}$ and $pc_{ijl}bq_{ij}buc_{ij}(1 - r_{ij})/(ef_{ij} - es_{ij} + 1)$. Type 4 includes scenarios G to L.

Based on theses scenarios, cost flow forecasting of a project can be modeled as follows:

$$\sum_{ij}\sum_{lk} f_{ijlk}\left[\frac{pc_{ijl}bq_{ij}buc_{ij}\left(1-r_{ij}\right)}{ef_{ij}-es_{ij}+1}N_{ijlk},\left(T_{ijl}+TA_{ijlk}\right)\right] \qquad (2a)$$

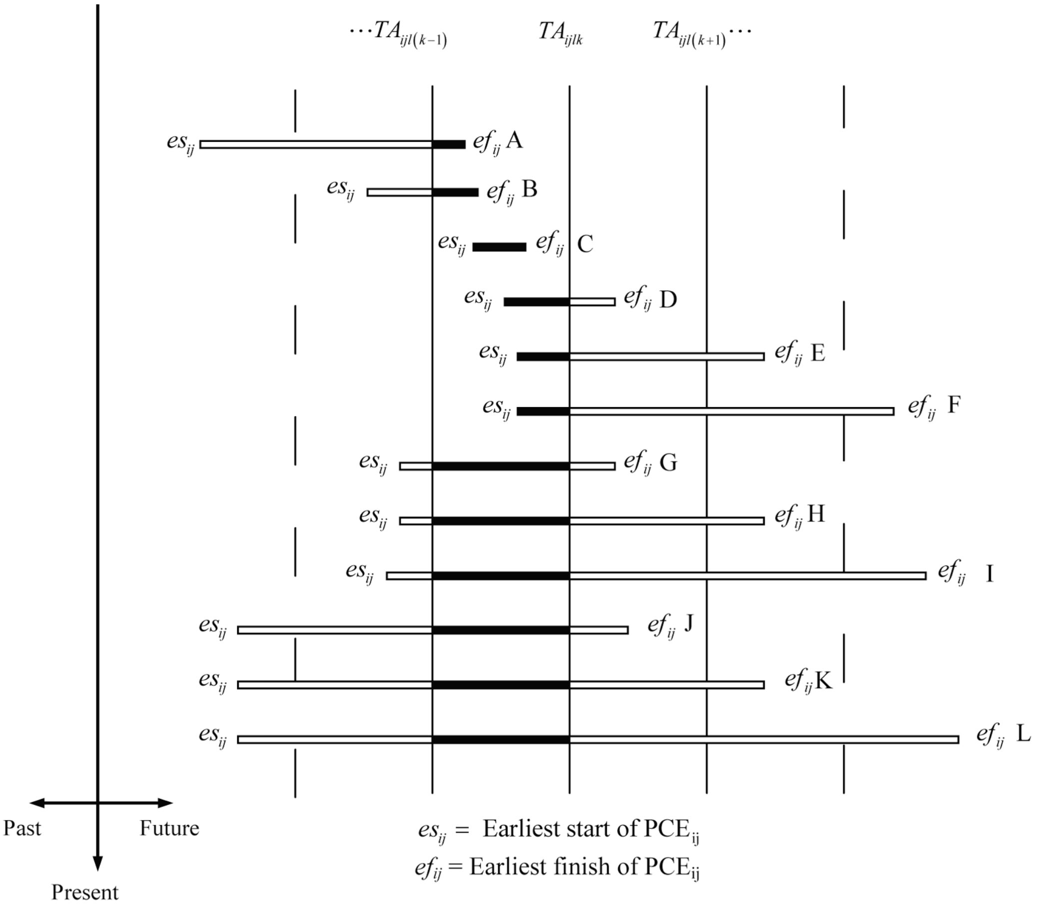

Fig. 1. Possible scenarios (A–L) of the relevant pay period of PCE$_{ij}$ (a hypothetical project activity)'s *k*th payment application relative to time (dates) of application (TA_{ijlk}) in the future

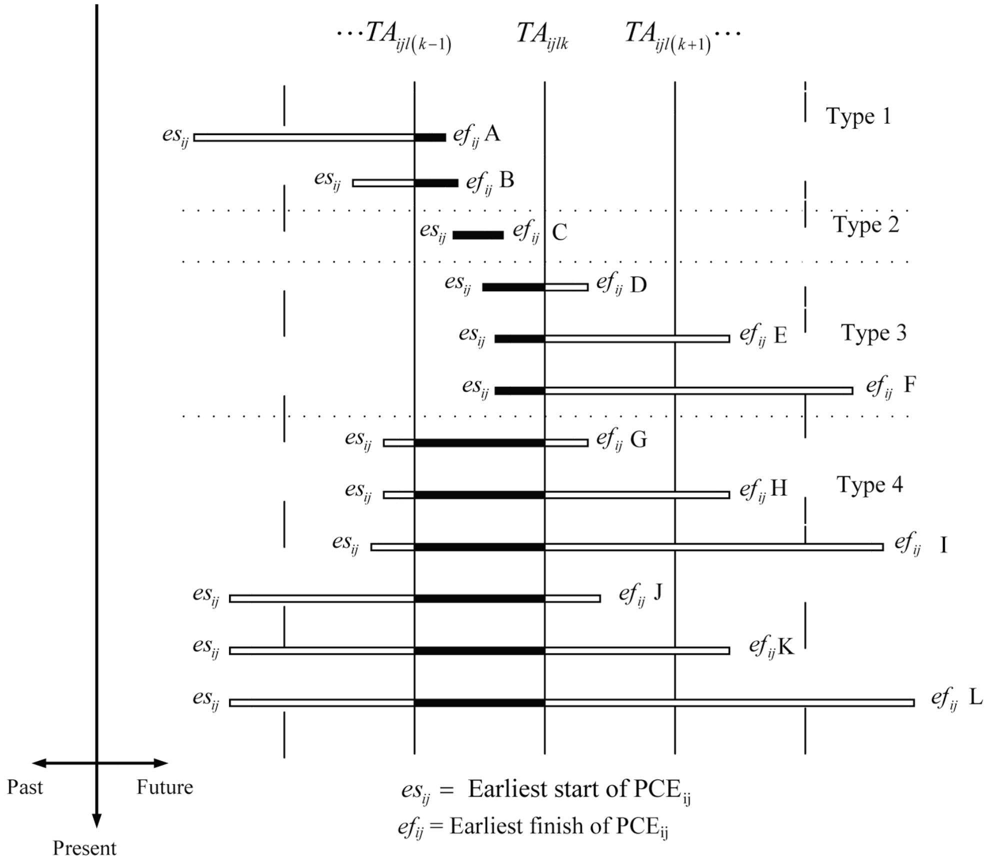

Fig. 2. Categorizing possible scenarios (A–L) of the relevant pay period of PCE_{ij}'s *k*th payment application relative to time (dates) of application (TA_{ijlk}) in the future into Types 1, 2, 3, and 4

and

$$N_{ijlk} = \begin{cases} ef_{ij} - TA_{ijl(k-1)} + 1 & \text{if} \quad TA_{ijlk} \geq ef_{ij} \geq TA_{ijl(k-1)} \geq es_{ij}, \\ ef_{ij} - es_{ij} + 1 & \text{if} \quad TA_{ijlk} \geq ef_{ij} \geq es_{ij} \geq TA_{ijl(k-1)}, \\ TA_{ijk} - es_{ij} & \text{if} \quad ef_{ij} \geq TA_{ijlk} \geq es_{ij} \geq TA_{ijl(k-1)}, \\ TA_{ijlk} - TA_{ijl(k-1)} & \text{if} \quad ef_{ij} \geq TA_{ijlk} \geq TA_{ijl(k-1)} \geq es_{ij}, \end{cases} \tag{2aa}$$

where l is component index, $l = 1$ to 2, where 1 denotes the labor ratio while 2 represents the material ratio. For example, when subcontracting the formwork of a project to a third party, the contract agreement may specify that all progress payments should be split between labor and materials, where the corresponding labor and materials ratios are 0.4 and 0.6 of a progress payment; k is *p*ayment frequency index, $k = 1,\dots, P$, where P is the total payment frequency of an activity. For example, if the value of P of a project activity such as laying foundation rebar is 3, this means that there are 3 progress payments for the laying foundation rebar activity; pc_{ijl} is ratio of component l of PCE_{ijis}; bq_{ij} is budgeted quantity of PCE_{ij}; buc_{ij} is budgeted unit cost for PCE_{ij}; r_{ij} is retainage of PCE_{ij}. Retainage is a portion of a project contracting entity's earned funds withheld from each progress payment until the project work is indeed completed under contract; T_{ijl} is payment time lag for component l of PCE_{ij}; TA_{ijlk} is time (or date) of application for the kth time progress payment of component l of PCE_{ij}; ef_{ij} is earliest finish date of PCE_{ij}; es_{ij} is earliest start date of PCE_{ij}; N_{ijlk} is relevant pay period for the kth time progress payment of component l of PCE_{ij}.

The term, f_{ijlk}, used in Eq. (2a) is designed to project the budgeted cost of the relevant pay period, $pc_{ijl}bq_{ij}buc_{ij}(1 - r_{ij})/(ef_{ij} - es_{ij} + 1)\times N_{ijlk}$, into the time axis in accordance with lags and the time of application, $(T_{ijl} + TA_{ijlk})$. The summation of k of PCE_{ij}, where $k \in \{1,\dots,P\}$, generates cost flow prediction at the activity level, and the summation of all cost-loaded activities of the project produces the project-level cost flow prediction, expressed as Eq. (2a). However, when PCE_{ij} is a scheduling conflict activity, future cost flows for this activity is modified from Eq. (2a) as follows:

$$\sum_{ij}\sum_{lk} f_{ijlk}\left[\frac{pc_{ijl}bq_{ij}buc_{ij}\left(1-r_{ij}\right)}{ef_{ij}-es_{ij}+1}N_{ijlk},\left(T_{ijl}+TA_{ijlk}\right)\right] =$$
$$\sum_{ij}\sum_{lk} f_{ijlk}\left[\frac{pc_{ijl}bq_{ij}buc_{ij}\left(1-r_{ij}\right)}{1}1,\ \left(T_{ijl}+TA_{ijlk}\right)\right] =$$
$$\sum_{ij}\sum_{lk} f_{ijlk}\left[pc_{ij}bq_{ij}buc_{ij}\left(1-r_{ij}\right),\ \left(T_{ijl}+TA_{ijlk}\right)\right]. \tag{2b}$$

3.3. Combined effect of payment irregularity and uniform distribution of cost over time

Following the initiation of a project activity, the actual activity cost simultaneously increases. Due to uncertain variables such as resource availability, on-site workability, worker skills, field support for timely responses, and construction management competency that cause variations in productivity, the actual accumulated cost of an activity during a period is unlikely to be the same as the predicted cost of the activity during that period based on assuming a uniform cost distribution over time. Additionally, because of payment irregularity, not only might the progress payment differ from the actual accumulated activity cost, but also the disbursement of the progress payment may differ from the projected schedule owing to late application for payment or quantity- and quality-related problems in activity and trade completion. That is, progress payment is not necessarily equivalent to the actual accumulated cost on the project construction site, nor is it necessarily equivalent to its projected schedule.

When PCE$_{ij}$ is initiated and not completed yet, the combined effect of payment irregularity and uniform distribution of cost over time on projected future cost flows following each time of payment application can be conceptually summarized in Fig. 3. The total area of a scenario bar activity is the budgeted cost of PCE$_{ij}$, while the shaded black and gray portions of the area are the relevant payment amount and payment variance of PCE$_{ij}$ for the *k*th payment application, respectively. Scenario A' (or A") shows that the predicted cost of PCE$_{ij}$ for the *k*th pay period is the same as the relevant payment amount of that activity for that period, and likewise scenarios B' (or B") and C' (or C") are less and more, respectively. Scenario D' (or D") illustrates that the relevant payment amount of PCE$_{ij}$ for the *k*th pay period is zero regardless of whether the cost of that activity is incurred.

To alleviate the combined effect, adjustment for predicted cost flows following each time of payment application occurs becomes necessary. When PCE$_{ij}$ is still being constructed following its *k*th payment application (i.e., $TA_{ijlk}<ef_{ij}$), the payment flows of PCE$_{ij}$ can be modeled as follows:

$$\sum_{ij}\sum_{lk} f_{ijlk}\left[pc_{ijl}\Delta q_{ijk}auc_{ij}\left(1-r_{ij}\right),\left(T_{ijl}+TA_{ijlk}\right)\right] \qquad (3a)$$

and the adjusted future cost flows of PCE$_{ij}$ can be modeled as follows:

$$\sum_{ij}\sum_{lk} f_{ijlk}\left[\frac{\left(bq_{ij}-\sum_k \Delta q_{ijk}\right)auc_{ij}\,pc_{ijl}\left(1-r_{ij}\right)}{ef_{ij}-TA_{ijlk}+1}\right. \qquad (3b)$$
$$\left. N'_{ijl(k+1)},\left(T_{ijl}+TA_{ijl(k+1)}\right)\right],$$

$N'_{ijl(k+1)}$ is calculated as follows:

$$N'_{ijl(k+1)}=\begin{cases} ef_{ij}-TA_{ijlk}+1 & \text{if} \quad TA_{ijl(k+1)}\geq ef_{ij}, \\ TA_{ijl(k+1)}-TA_{ijlk} & \text{if} \quad TA_{ijl(k+1)}<ef_{ij}, \end{cases} \qquad (3ba)$$

where aq_{ij} is accumulated quantity of PCE$_{ij}$; auc_{ij} is actual unit cost of PCE$_{ij}$; Δq_{ijk} is payment quantity for the *k*th time progress payment of PCE$_{ij}$; $\sum_{ijk}\Delta q_{ijk}$ is Accumulated payment quantity up to the *k*th time progress payment of PCE$_{ij}$; N'_{ijlk} is relevant pay period for the (*k*+1)th time progress payment of component *l* of PCE$_{ij}$.

However, when the activity is completed prior to its relevant time of payment application ($TA_{ijlk}\geqq ef_{ij}$), the adjusted future cost flows of the activity can be modeled as follows:

$$\sum_{ij}\sum_{lk} f_{ijlk}\left[\left(aq_{ij}-\sum_k \Delta q_{ijk}\right)auc_{ij}\,pc_{ijl}\left(1-r_{ij}\right),\right. \qquad (3c)$$
$$\left.\left(T_{ijl}+TA_{ijl(k+1)}\right)\right].$$

Besides the previous three assumptions, Eq. (3c) assumes that the amount of deferral payment caused by a payment irregularity is postponed to the next term of payment application, if the payment irregularity involves an already completed construction activity.

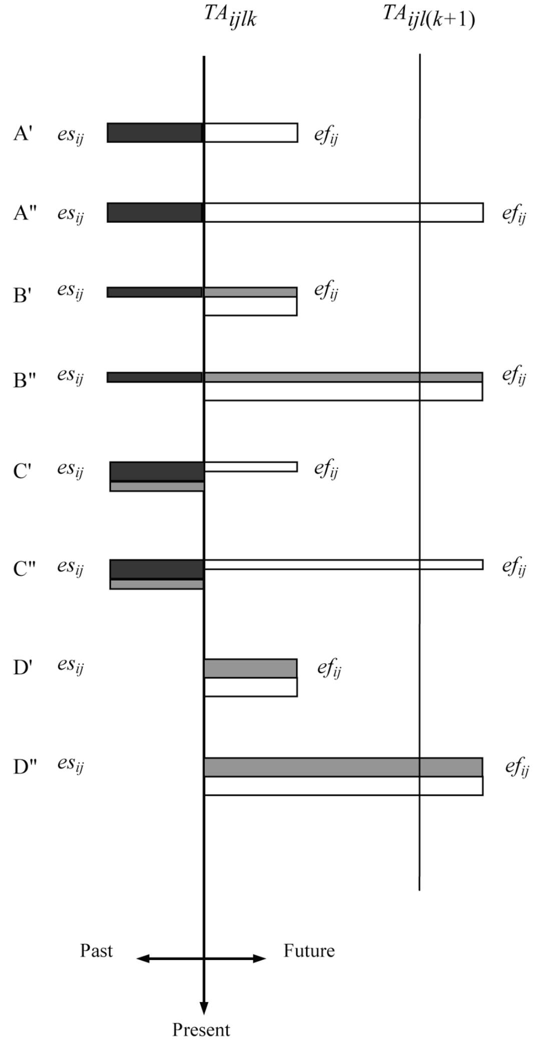

Fig. 3. The combined effect of payment irregularity and uniform distribution of cost over time on PCE$_{ij}$ (a hypothetical project activity) subsequent to each time of payment application

3.4. Coordination mechanisms

The reorganization of Eqs (1) to (3c) forms the coordination mechanisms capable of projecting payment flows and future operating cost flows. More specifically, before a project activity starts, i.e., both $aq_{ij} = 0$ and $\sum_{ijk} \Delta q_{ijk} = 0$ are met, cost flow forecasting of the activity is created with Eqs (2a) and (2aa) if the activity is not a scheduling conflict activity. However, if the activity is a scheduling conflict activity, its cost flow forecasting is generated by Eq. (2b). Together, Eqs (2a), (2aa), and (2b) form the first part of the mechanisms (4a) and (4aa).

After the activity starts, i.e., $aq_{ij} = 0$ and $\sum_{ijk} \Delta q_{ijk} = 0$ are not met, the payment flows of the activity is created with Eq. (3a). The adjusted future cost flow of the activity is created with Eqs (3b) and (3ba) when $TA_{ijlk}<ef_{ij}$ exists; however, the adjusted future cost flow is created with Eq. (3c) when $TA_{ijlk}>=ef_{ij}$ exists. Together, Eqs (3a), (3b), (3ba), and (3c) form the second part of the mechanisms (4b), (4ba), and (4c).

Collectively, the coordination mechanisms are expressed as follows:

If aq_{ij}=0 and $\sum_{ijk} \Delta q_{ijk} = 0$ are true, then:

$$CF = \begin{cases} \sum\limits_{ij} \sum\limits_{lk} f_{ijlk} \left[pc_{ijl} bq_{ij} buc_{ij} \left(1 - r_{ij}\right),\ \left(T_{ijk} + TA_{ijlk}\right) \right] & \text{If } f_{SCA}(\text{PCE}_{ij}) \text{ is applied} \\ \sum\limits_{ij} \sum\limits_{lk} f_{ijlk} \left[\dfrac{pc_{ijl} bq_{ij} buc_{ij} \left(1 - r_{ij}\right)}{ef_{ij} - es_{ij} + 1} N_{ijlk},\ \left(T_{ijk} + TA_{ijlk}\right) \right] & \text{otherwise} \end{cases} \tag{4a}$$

with:

$$N_{ijlk} = \begin{cases} ef_{ij} - TA_{ijl(k-1)} + 1 & \text{if} \quad TA_{ijlk} \geq ef_{ij} \geq TA_{ijl(k-1)} \geq es_{ij}, \\ ef_{ij} - es_{ij} + 1 & \text{if} \quad TA_{ijlk} \geq ef_{ij} \geq es_{ij} \geq TA_{ijl(k-1)}, \\ TA_{ijk} - es_{ij} & \text{if} \quad ef_{ij} \geq TA_{ijlk} \geq es_{ij} \geq TA_{ijl(k-1)}, \\ TA_{ijlk} - TA_{ijl(k-1)} & \text{if} \quad ef_{ij} \geq TA_{ijlk} \geq TA_{ijl(k-1)} \geq es_{ij}. \end{cases} \tag{4aa}$$

Otherwise:

$$CF = \begin{cases} ACF = \sum\limits_{ij} \sum\limits_{lk} f_{ijlk} \left[\dfrac{\left(bq_{ij} - \sum_k \Delta q_{ijk}\right) auc_{ij}\, pc_{ijl} \left(1 - r_{ij}\right)}{ef_{ij} - TA_{ijlk} + 1} N'_{ijl(k+1)}, \left(T_{ijl} + TA_{ijl(k+1)}\right) \right] \\ \text{and } PF = \sum\limits_{ij} \sum\limits_{lk} f_{ijlk} \left[pc_{ijl} \Delta q_{ijk} auc_{ij} \left(1 - r_{ij}\right), \left(T_{ijl} + TA_{ijlk}\right) \right] \end{cases} \text{If } TA_{ijlk} < ef_{ij}\,; \tag{4b}$$

with:

$$N'_{ijl(k+1)} = \begin{cases} ef_{ij} - TA_{ijlk} + 1 & \text{if } TA_{ijl(k+1)} \geq ef_{ij}, \\ TA_{ijl(k+1)} - TA_{ijlk} & \text{if } TA_{ijl(k+1)} < ef_{ij}, \end{cases} \tag{4ba}$$

or:

$$CF = \begin{cases} ACF = \sum\limits_{ij} \sum\limits_{lk} f_{ijlk} \left[\left(aq_{ij} - \sum_k \Delta q_{ijk}\right) auc_{ij}\, pc_{ijl} \left(1 - r_{ij}\right), \left(T_{ijl} + TA_{ijl(k+1)}\right) \right] \\ \text{and } PF = \sum\limits_{ij} \sum\limits_{lk} f_{ijlk} \left[pc_{ijl} \Delta q_{ijk} auc_{ij} \left(1 - r_{ij}\right), \left(T_{ijl} + TA_{ijlk}\right) \right] \end{cases} \text{If } TA_{ijlk} \geq ef_{ij}\,. \tag{4c}$$

CF denotes cost flow forecasting of a project, ACF denotes adjusted future cost flows, and PF denotes payment flows. To illustrate how to compute the value of payment flows and predicted cost flows by using the coordination mechanisms, this paper provides an algorithm in Fig. 4. In the algorithm, it first searches all PCEs (*N* together) and obtains their relevant cost-loaded activities and the activities' scheduling and payment term data. The algorithm then reads the accumulated quantity (aq_{ij}) and accumulated payment quantity ($\sum_{ijk} \Delta q_{ijk}$) of each cost-loaded activity, creating two scenarios: If aq_{ij}=0 and $\sum_{ijk} \Delta q_{ijk} = 0$ are true, the algorithm computes future cost flows using Eqs (4a) and (4aa); otherwise, the algorithm creates cost flow forecasting and payment flows with two scenarios. If PCE$_{ij}$ is not completed yet ($TA_{ijlk} < ef_{ij}$), Eqs (4b) and (4ba) are used to compute cost flow forecasting and payment flows; otherwise, Eq. (4c) is used to compute cost flow forecasting and payment flows.

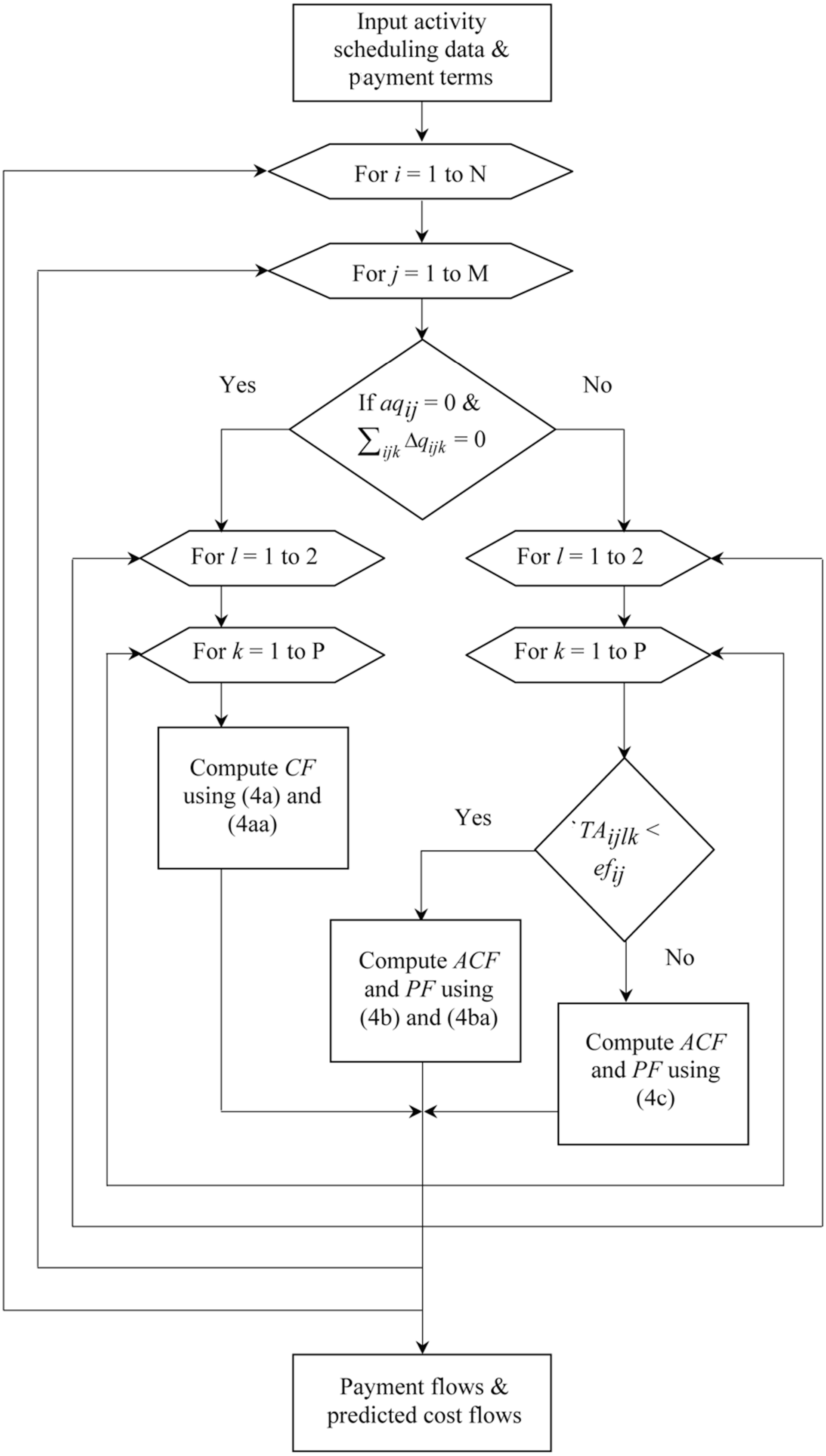

Fig. 4. Algorithm for Computing Payment Flows and Future Cost Flows

4. Model validation

4.1. Projects used for validation

Data to support model validation was gathered on two projects: the Cambridge project and the Yangkong project. The project names have been changed at the request of the firms involved. The Cambridge project was located in central Taiwan and had a total cost of NT105 million (~$3 million). Cambridge is a typical residential project comprising three, four-story residential buildings constructed of reinforced concrete and with a total floor area of around 5,400 square meters. Cambridge was designed completely before the start of construction although customers buying homes were allowed to specify certain custom particulars, such as flooring finishes and interior wall coatings. The Yangkong project, located in south Taiwan, is a NT2.5 billion (~$74 million) refuse resource recovery plant. The waste-to-energy operating capacity for the Yangkong project is 900 tons per day, with daily electrical power generation of approximately 22,000 kilowatts. The Yangkong project was completed within schedule, and the total project duration was five years.

The Cambridge and Yangkong projects are representative of the impact of payment conditions and the combined effect of payment irregularity and uniform distribution of cost over time on operating cost flows. For both projects, certain payments to specialist contractors are split between labor and materials while others are not. The frequency of payments for suppliers and specialists varies from once to twice per month; and payment time lags differ between specialist contractors and suppliers. Payment irregularity in terms of dates and amounts to both specialist contractors and suppliers is occasionally incurred. Furthermore, each project is of a standard design and is administered using a typical general contracting arrangement. Consequently, both projects can be considered representative of numerous other projects globally.

To summarize, Table 1 lists the sample subcontractors and suppliers of the Cambridge and Yangkong projects. The time lags between application submission and approval for Cambridge and Yangkong projects are 7 days and 3 days, respectively. Both projects use unit-price contract. However, the Cambridge project uses unit-price including tax while the Yangkong project uses unit-price excluding tax. Table 2 illustrates the result of mapping sample activities of the cost loaded schedule to the PCEs of the projects. Table 3 details sample payment irregularities in the projects. The two projects involved a total of 77 subcontractors and suppliers generating over 900 data points used for the analysis; and a total of 45 payment irregularities were incurred.

4.2. Calculation illustrations

For project activity $j = 2$ (3rd F slab formwork activity) of project contracting entity $i = 2$ (the formwork subcontractor) of Cambridge, denoted as PCE_{22} (shown in Table 2), before it was initiated, i.e., both $aq_{22} = 0$ and $\sum_k \Delta q_{22k} = 0$ existed, Eqs (4a) and (4aa) were used to compute future cost flows. Table 1 shows that time of application for payments of Cambridge's formwork subcontractor (PCE_{2j}) were 1st and 15th of a month. For PCE_{22} in question, the value of the total payment frequency index, P, was 1.

The value of P equals (1+PAD), where PAD denotes the number of payment application dates included in the duration of PCE_{ij}. The duration of PCE_{22} was between 07/22/09 and 07/26/09 (shown in Table 2) computed by the critical path method (CPM), however, the schedule of the activity itself conflicted with that of the pouring 3rd F reinforced concrete activity, a verifier activity, completed on 07/31/09. Thus, the duration of PCE_{22} needs to be rectified by Eq. (1) as follows:

$$f_{SCA}(\mathrm{PCE}_{22}) = \{Dur, Dep_v \mid Dur = 1, Dep_v = F_v F_{SCA} = 07/13/09\}.$$

Following the rectification, the duration of PCE_{22} was located on 07/31/09, not containing 1st and 15th of that month; hence, P was equaled (1+0 = 1).

As also seen in Table 1, payment for the formwork subcontractor (PCE_{2j} (sub)) of the Cambridge project was split between labor and materials, where the labor is 40% and the materials is 60%, denoted as $pc_{ijl} = pc_{221} = 0.4$ and $pc_{ijl} = pc_{222} = 0.6$, respectively. Payment lags for the corresponding labor and materials of the subcontractor were 14 and 47 days following each time of application, denoted as $T_{ijl} = T_{221} = 14$ and $T_{ijl} = T_{222} = 47$, respectively. All additional data for computation of PCE_{22} could be found in Tables 1, 2, and 3. Because PCE_{22} had the scheduling conflict attribute, the cost flow was predicted by the first part of Eq. (4a) as follows:

$$\sum_{i=2,j=2lk} f_{22lk}\left[pc_{22l}bq_{22}buc_{22}(1-r_{22}),(T_{22k}+T_{22lk})\right]$$

$$=\sum_{1,1}^{2,1} f_{22lk}\left[pc_{22l}bq_{22}buc_{22}(1-r_{22}),(T_{22k}+T_{22lk})\right]$$

$$=\left[pc_{221}bq_{22}buc_{22}(1-r_{22}),(T_{221}+T_{2211})\right] \text{ for } l=1 \text{ and } k=1$$

$$+\left[pc_{222}bq_{22}buc_{22}(1-r_{22}),(T_{221}+T_{2211})\right] \text{ for } l=2 \text{ and } k=1$$

$$=\left[0.4\times 1,680\times 1,573\times(1-0.1),(14+08/01/09)\right]$$

$$+\left[0.6\times 1,680\times 1,573\times(1-0.1),(47+08/01/09)\right]$$

$$=(1,057,060,\ 08/15/09)+(1,585,584,\ 10/06/09).$$

As the construction progress to date was before 07/31/09, where the condition of $aq_{22} = 0$ and $\sum_k \Delta q_{22k} = 0$ was still met, the future cost flow of PCE_{22} was computed using Eqs. (4a) and (4aa). When the date was after 07/31/09 and ($TA_{ijlk} = TA_{2211} = 08/01/09$) $\geqq$ ($ef_{ij} = ef_{22} = 07/31/09$) existed, the condition of $aq_{22} = 0$ was no longer met, the adjusted cost flow and payment flows of PCE_{22} were calculated using Eq. (4c). In addition, the value of P increased by 1, i.e., $k \in \{1, ..., P\} = \{1, 2\}$. This phenomenon is according to a key assumption of the model: the amount of deferral payment resulting from a payment irregularity is postponed

Table 1. Sample Subcontractors and Suppliers of the Cambridge and Yangkong projects

Project	Firm	Application Dates of the Month	Time between Application Submission and Approval	Payment Frequency (Times of a month)	Payment Lags between Labor and Materials	Payment Split between Labor and Materials	Contract Type	Retainage
Cambridge	PCE_{1j} (sub)	1st and 15th	7 days	Twice	14 days	No payment split	Unit-price contract NT525 m^3/unit, including sales tax	No retainage
	PCE_{2j} (sub)	1st and 15th	7 days	Twice	14 (lab) and 47 days (mat)	40 (lab) and 60% (mat)	Unit-price contract NT1,573 m^2/unit, including sales tax	10%
	PCE_{3j} (supplier)	1st	7 days	Once	67 days	No payment split	Unit-price contract NT1,105 (3,000psi) m^3/unit NT1,027 (2,500psi) m^3/unit, including sales tax	No retainage
	PCE_{4j} (sub)	1st and 15th	7 days	Twice	14 days	No payment split	Unit-price contract NT3,800 t/unit, including sales tax	10%
	PCE_{5j} (sub)	1st and 15th	7 days	Twice	14 days	No payment split	Unit-price contract NT166.4 m^2/unit, including sales tax	10%
	PCE_{6j} (supplier)	1st	7 days	Once	67 days	No payment split	Unit-price contract NT9,300 t/unit, including sales tax	No retainage
Yangkong	PCE_{1j} (sub)	1st and 15th	3 days	Twice	17 (lab) and 93 days (mat)	50 (lab) and 50% (mat)	Unit-price contract NT20,342 per pile/unit (average unit price), sales tax excluded	10%
	PCE_{2j} (sub)	1st and 15th	3 days	Twice	17 (lab) and 93 days (mat)	30 (lab) and 70% (mat)	Unit-price contract NT95 m^3/unit (average unit price), sales tax excluded	10 %
	PCE_{3j} (sub)	1st and 15th	3 days	Twice	17 (lab) and 93 days (mat)	70 (lab) and 30% (mat)	Unit-price contract NT300 m^2/unit (average unit price), sales tax excluded	10 %
	PCE_{4j} (sub)	1st and 15th	3 days	Twice	17 days	No payment split	Unit-price contract NT3,800 t/unit (average unit price), including sales tax	15%
	PCE_{5j} (supplier)	1st	3 days	Once	93 days	No payment split	Unit-price contract NT9,300 t/unit (average unit price), sale tax excluded	No retainage
	PCE_{6j} (supplier)	1st	3 days	Once	93 days	No payment split	Unit-price contract 140 kg/cm^2, NT900 m^3/unit 210 kg/cm^2, NT1,300 m^3/unit, 280 kg/cm^2, NT1,570m^3/unit 350 kg/cm^2, NT1,900 m^3/unit, sales tax excluded	No retainage

Table 2. Mapping Sample Activities of Cost-loaded Schedule to PCEs of the Cambridge and Yangkong Projects

			$PCE_{ij} = PCE_{2j}$ (the formwork subcontractor) of Cambridge						
Act. ID	PCE_{ij}	Description	Budget Unit Price, buc_{ij} (m^2/unit)	Budget Quantity, bq_{ij} (m^2)	Actual Unit Cost, auc_{ij} (m^2/unit)	Actual Quantity, aq_{ij} (m^2)	Earliest Start, es_{ij}	Earliest Finish, ef_{ij}	Duration (Days)
13	PCE_{21}	1st F wall and 2nd F formwork	$buc_{21} = 1{,}573$	$bq_{21} = 1500.0$	$auc_{21} = 1{,}573$	$aq_{21} = 1506.7$	es_{21} = 06/23/09	ef_{21} = 06/25/09	3
20	PCE_{22}	3rd F slab formwork	$buc_{22} = 1{,}573$	$bq_{22} = 1680.0$	$auc_{22} = 1{,}573$	$aq_{22} = 1677.7$	es_{22} = 07/22/09	ef_{22} = 07/26/09	5
27	PCE_{23}	4th F slab formwork	$buc_{2\,3} = 1{,}573$	$bq_{23} = 1680.0$	$auc_{23} = 1{,}573$	$aq_{23} = 1677.7$	es_{23} = 08/08/09	ef_{23} = 08/14/09	7
34	PCE_{24}	Roof slab formwork	$buc_{24} = 1{,}573$	$bq_{24} = 860.0$	$auc_{24} = 1{,}573$	$aq_{24} = 851.0$	es_{24} = 09/05/09	ef_{24} = 09/9/09	5
			$PCE_{ij} = PCE_{4j}$ (the rebar subcontractor) of Yangkong						
Act. ID	PCE_{ij}	Description	Budget Unit Price, buc_{ij} (ton/unit)	Budget Quantity, bq_{ij} (ton)	Actual Unit Cost, auc_{ij} (ton/unit)	Actual Quantity, aq_{ij} (ton)	Earliest Start, es_{ij}	Earliest Finish, ef_{ij}	Duration (Days)
2	PCE_{41}	Foundation rebar	$buc_{41} = 3{,}800$	$bq_{41} = 30.00$	$auc_{41} = 3{,}800$	$aq_{41} = 29.78$	es_{41} = 05/02/07	ef_{41} = 05/05/07	4
5	PCE_{42}	Grade beam rebar	$buc_{42} = 3{,}800$	$bq_{42} = 26.00$	$auc_{42} = 3{,}800$	$aq_{42} = 24.70$	es_{42} = 05/08/07	ef_{42} = 05/10/07	3
9	PCE_{43}	1st F rebar	$buc_{43} = 3{,}800$	$bq_{4} = 15.00$	$auc_{43} = 3{,}800$	$aq_{43} = 15.10$	es_{43} = 06/03/07	ef_{43} = 06/08/07	6
12	PCE_{44}	1st F column and wall rebar	$buc_{44} = 3{,}800$	$bq_{44} = 8.00$	$auc_{44} = 3{,}800$	$aq_{44} = 7.50$	es_{44} = 06/10/07	ef_{44} = 06/10/07	1
15	PCE_{45}	2nd F slab and beam rebar	$buc_{45} = 3{,}800$	$bq_{45} = 50.00$	$auc_{45} = 3{,}800$	$aq_{45} = 46.77$	es_{45} = 06/26/07	ef_{45} = 06/26/07	1
19	PCE_{46}	2nd F column and wall rebar	$buc_{46} = 3{,}800$	$bq_{46} = 16.00$	$auc_{46} = 3{,}800$	$aq_{46} = 17.90$	es_{46} = 07/07/07	ef_{46} = 07/10/07	4
22	PCE_{47}	3rd F slab and beam rebar	$buc_{47} = 3{,}800$	$bq_{47} = 55.00$	$auc_{47} = 3{,}800$	$aq_{47} = 55.85$	es_{47} = 07/25/07	ef_{47} = 07/29/07	5
26	PCE_{48}	3rd F column and wall rebar	$buc_{48} = 3{,}800$	$bq_{48} = 13.00$	$auc_{48} = 3{,}800$	$aq_{48} = 12.95$	es_{48} = 08/02/07	ef_{48} = 08/06/07	5
36	PCE_{49}	Roof slab and beam rebar	$buc_{49} = 3{,}800$	$bq_{49} = 32.00$	$auc_{49} = 3{,}800$	$aq_{49} = 32.90$	es_{49} = 09/10/07	ef_{49} = 09/12/07	3

Table 3. Details of Sample Payment Irregularities

Project	PCE_{ij}	Description	Expected Date of Payment Application	Actual Date of Payment Application	Amount of Payment Irregularity
Cambridge	PCE_{22}	3rd F slab formwork	08/01/09	08/15/09	2,639,033
Yangkong	PCE_{43} PCE_{44}	1st F rebar 1st F column and wall rebar	06/15/07	07/01/07	77,292
	PCE_{48}	3rd F column and wall rebar	08/15/07	09/01/07	44,289

to the next term of payment application if the payment irregularity involves an activity that is already completed. Consequently, the adjusted cost flow prediction of PCE$_{22}$ on 08/01/09 was:

$$\sum_{i=2\,j=2lk} f_{22lk}\left[\left(aq_{22}-\sum\nolimits_k \Delta q_{22k}\right)auc_{22}\,pc_{22}\left(1-r_{22}\right),\left(T_{22l}+TA_{22l(k+1)}\right)\right]$$

$$=\sum_{1,1}^{2,2} f_{22lk}\left[\left(aq_{22}-\sum\nolimits_k \Delta q_{22k}\right)auc_{22}\,pc_{22}\left(1-r_{22}\right),\left(T_{22l}+TA_{22l(k+1)}\right)\right]$$

$$=\left[\left(aq_{22}-\sum\nolimits_1^1 \Delta q_{22k}\right)auc_{22}\,pc_{221}\left(1-r_{22}\right),\left(T_{221}+TA_{221(1+1)}\right)\right] \text{ for } l\text{=1 and } k\text{=1}$$

$$+\left[\left(aq_{22}-\sum\nolimits_1^1 \Delta q_{22k}\right)auc_{22}\,pc_{222}\left(1-r_{22}\right),\left(T_{222}+TA_{222(1+1)}\right)\right] \text{ for } l\text{=2 and } k\text{=1}$$

$$+\left[\left(aq_{22}-\sum\nolimits_1^2 \Delta q_{22k}\right)auc_{22}\,pc_{22}\left(1-r_{22}\right),\left(T_{221}+TA_{221(2+1)}\right)\right] \text{ for } l\text{=1 and } k\text{=2}$$

$$+\left[\left(aq_{2,2}-\sum\nolimits_1^2 \Delta q_{2,2k}\right)auc_{2,2}\,pc_{2,2}\left(1-r_{2,2}\right),\left(T_{2,2,2}+TA_{2,2,2(2+1)}\right)\right] \text{ for } l\text{=2 and } k\text{=2}$$

$$=[(1{,}677.7-0)\times 1{,}573\times 0.4(1-0.1),((7+7)+08/15/09]$$

$$+[(1{,}677.7-0)\times 1{,}573\times 0.6(1-0.1),((7+60)+08/15/09]$$

$$+[(1{,}677.7-1{,}677.7)\times 1{,}573\times 0.4(1-0.1),((7+7)+09/01/09]$$

$$+[(1{,}677.7-1{,}677.7)\times 1{,}573\times 0.6(1-0.1),((7+60)+09/01/09]$$

$$=(1{,}055{,}609,\ 08/29/09)+(1{,}583{,}413,\ 10/20/09)+(0,\ 09/15/09)+(0,\ 11/06/09)$$

and payment flows were:

$$\sum_{i=2\,j=2lk} f_{22lk}\left[pc_{22l}\Delta q_{22k}\,auc_{22}\left(1-r_{22}\right),\left(T_{22l}+TA_{22lk}\right)\right]$$

$$=\sum_{1,1}^{2,2} f_{22lk}\left[pc_{22l}\Delta q_{22k}\,auc_{22}\left(1-r_{22}\right),\left(T_{22l}+TA_{22lk}\right)\right]$$

$$=\left[pc_{221}\Delta q_{221}auc_{22}\left(1-r_{22}\right),\left(T_{221}+TA_{2211}\right)\right] \text{ for } l\text{=1 and } k\text{=1}$$

$$+\left[pc_{222}\Delta q_{221}auc_{22}\left(1-r_{22}\right),\left(T_{222}+TA_{2221}\right)\right] \text{ for } l\text{=2 and } k\text{=1}$$

$$+\left[pc_{221}\Delta q_{222}auc_{22}\left(1-r_{22}\right),\left(T_{221}+TA_{2211}\right)\right] \text{ for } l\text{=1 and } k\text{=2}$$

$$+\left[pc_{222}\Delta q_{222}auc_{22}\left(1-r_{22}\right),\left(T_{222}+TA_{2221}\right)\right] \text{ for } l\text{=2 and } k\text{=2}$$

$$=[0.4\times 0\times 1{,}573\times(1-0.1),((7+7)+08/01/09]$$

$$+[0.6\times 0\times 1{,}573\times(1-0.1),((7+60)+08/01/09]$$

$$+[0.4\times 1{,}677.7\times 1{,}573\times(1-0.1),((7+7)+08/15/09]$$

$$+[0.6\times 1{,}677.7\times 1{,}573\times(1-0.1),((7+60)+08/15/09]$$

$$=(0,\ 08/15/09)+(0,\ 10/06/09)+(1{,}055{,}609,\ 08/29/09)+(1{,}583{,}413,\ 10/20/09).$$

As shown from the computation examples, the predicted cost flows of PCE$_{22}$ were (1055609,08/15/09) and (1585584,10/06/09) before PCE$_{22}$ was initiated. After PCE$_{22}$ was initiated, the adjusted cost flow predictions of PCE$_{22}$ were (1055609,08/15/09) and (1583413,10/20/09) that matched the payment flows of PCE$_{22}$. Because the same logic can be used in computing the rest of the Cambridge and Yangkong project activities, this study decided not to present more calculations of the coordination mechanisms. Nonetheless, to further validate the performance of the coordination mechanisms, Microsoft Access and Visual Basic were used to program the mechanisms for simulations.

4.3. Simulation analysis and discussion

Pattern-matching logic compares the history of the payment flows with projections of expected cost flows (Trochim 1989). Since five factors needed to be investigated in combination, several scenarios must be generated. Each factor is either considered or not considered in each scenario, as follows:

Time lags considered (T) or not considered (NT); frequency (F, NF); payment components (C, NC); schedule conflicts (SC, NSC); and payment irregularities (PI, NPI). Some 64 different combinations exist; however, scenarios considered for the hypothesis test in accordance with the limitations of CSI modes are (NT, NF, NC, NSC, NPI), (T, F, C, NSC, NPI), (T, F, C, SC, NPI), and (T, F, C, SC, PI). The hypothesis test is: *When cost and schedule uncertainty do not exist, solutions to the problems of existing CSI models are capable of eliminating deviations between the projected cost flows and historical payment flows.*

Considering the hypothesis, this study decided to use the actual cost and schedule rather than the budgeted cost and estimated schedule of the Yangkong and Cambridge projects for the simulation input data. This decision eliminated deviations between the projected cost flows and historical payment flows owing to the cost and schedule variance (or uncertainty).

Table 4 lists a sample of the cost flow predictions for a specific combination of variables (T, F, C, SC, NPI) for the Yangkong project. Similar cost flow predictions were developed for the other three scenarios (not shown).

Table 4. Cost Flows of Yangkong Project Created with (T, F, C, SC, NPI)

Date (1)	Cost Flows (2)
April 17, 2007	0
April 30, 2007	495,000
May 17, 2007	3,074,946
May 30, 2007	3,033,659
June 17, 2007	2,935,119
June 30, 2007	3,304,358
July 17, 2007	3,539,871
July 30, 2007	5,153,393
August 17, 2007	6,247,868
August 30, 2007	7,338,106
September 17, 2007	7,989,253
September 30, 2007	11,445,118
October 17, 2007	10,531,096
October 30, 2007	12,841,651
November 17, 2007	8,318,521
November 30, 2007	11,121,052
December 17, 2007	10,244,278
December 30, 2008	16,973,524
January 17, 2008	11,925,418
January 30, 2008	15,030,393
February 17, 2008	7,974,296
February 28, 2008	13,826,885
March 17, 2008	7,681,574
March 30, 2008	16,547,551
April 17, 2008	7,367,968
April 30, 2008	16,221,932

Figs 5 to 8 plot the cost flow predictions against the historical payment flow data. Fig. 5 plots the scenario (NT, NF, NC, NSC, NPI), Fig. 6 plots (T, F, C, NSC, NPI), Fig. 7 plots (T, F, C, SC, NPI), and Fig. 8 plots (T, F, C, SC, PI). Figs 5 to 8 show that deviations between the projected cost flows and historical payment flows are gradually eliminated. Of the four scenarios, Fig. 5 is with the largest deviation while Fig. 8 is has the smallest one. In fact, the only one of the four combinations that matches the pattern of payment flows is the simulated pattern with the factor combination (T, F, C, SC, PI), shown in Fig. 8.

Pattern-matching was also performed on the Cambridge project. Figs 9, 10, 11 and 12 plot the cost flow predictions against historical payment data for the scenarios (NT, NF, NC, NSC, NPI), (T, F, C, NSC, NPI), (T, F, C, SC, NPI), and (T, F, C, SC, PI), respectively. Of all the scenarios for the Cambridge project, Fig. 9 is with the

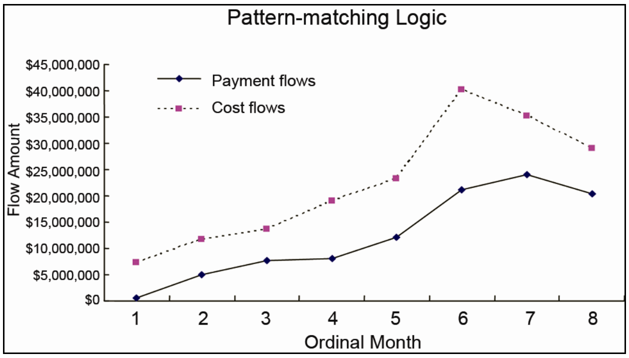

Fig. 5. Comparison between Payment Flows and Cost Flows Created with (NT, NF, NC, NSC, NPI) for the Yangkong Project

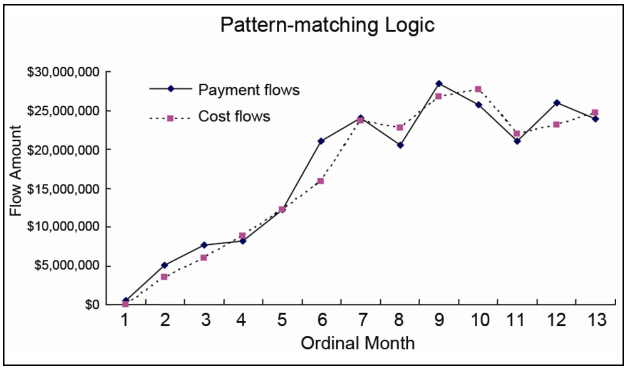

Fig. 6. Comparison between Payment Flows and Cost Flows Created with (T, F, C, NSC, NPI) for the Yangkong Project

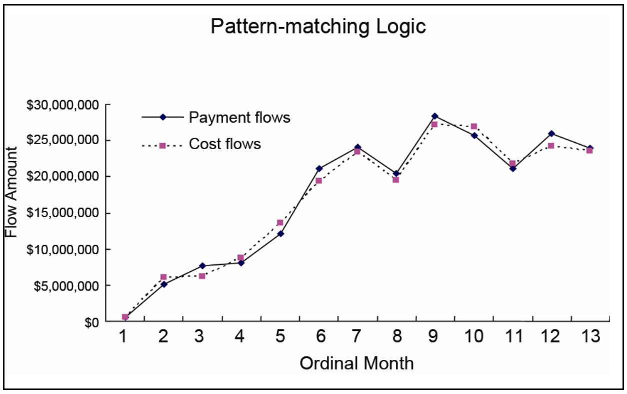

Fig. 7. Comparison between Payment Flows and Cost Flows Created with (T, F, C, SC, NPI) for the Yangkong Project

largest deviation while Fig. 12 is has the smallest one. Only the pattern of Fig. 12 (T, F, C, SC, PI) matches the historical pattern of payment flows, while other patterns progressively eliminate the deviations between the projected cost flows and historical payment flows.

For both projects, scenarios (T, F, C, SC, PI), (T, F, C, SC, NPI), (T, F, C, NSC, NPI), and (NT, NF, NC, NSC, NPI) rank from the first place to the fourth place, respectively, in terms of effectiveness of eliminating deviations between the projected cost and historical payment flows. Consequently, this study accepts the hypothesis and concludes that solutions the problems of existing CSI models are able to eliminate deviations between the projected cost flows and historical payment flows. Furthermore, the combination of (T, F, C, SC, NPI) on the Cambridge project indicates a larger deviation than the combination of (T, F, C, SC, NPI) on the Yangkong project. This phenomenon largely results from the varying size of the two projects. The Cambridge project is small and a late payment to a single vendor (or late application for payment) can cause significant deviations from expected payment flows. The larger Yankong project involves numerous vendors and thus the effects of late payments on individual vendors are correspondingly smaller.

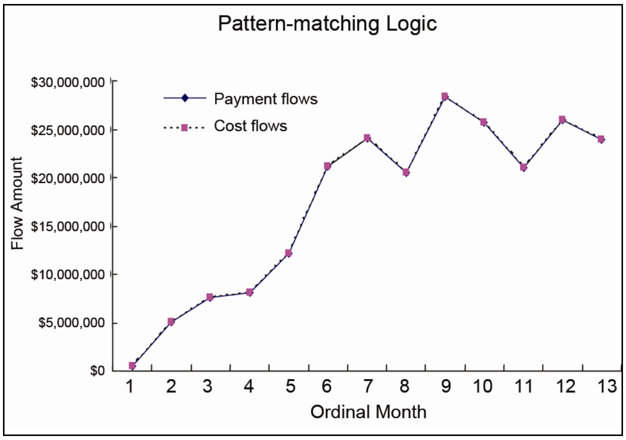

Fig. 8. Comparison between Payment Flows and Cost Flows Created with (T, F, C, SC, PI) for the Yangkong Project

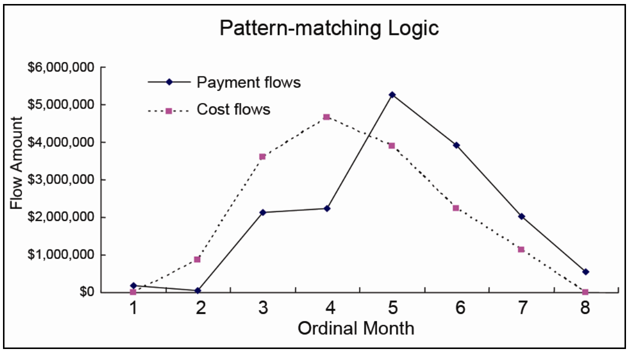

Fig. 9. Comparison between Payment Flows and Cost Flows Created with (NT, NF, NC, NSC, NPI) for the Cambridge Project

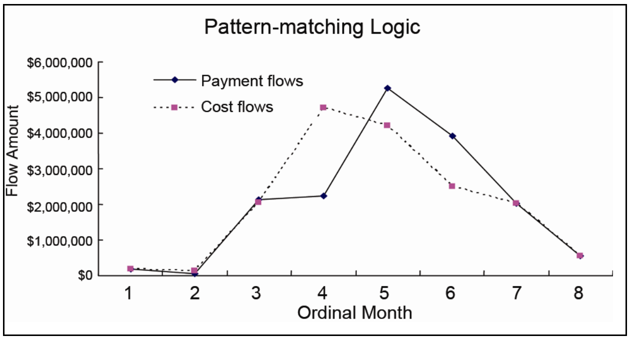

Fig. 10. Comparison between Payment Flows and Cost Flows Created with (T, F, C, NSC, NPI) for the Cambridge Project

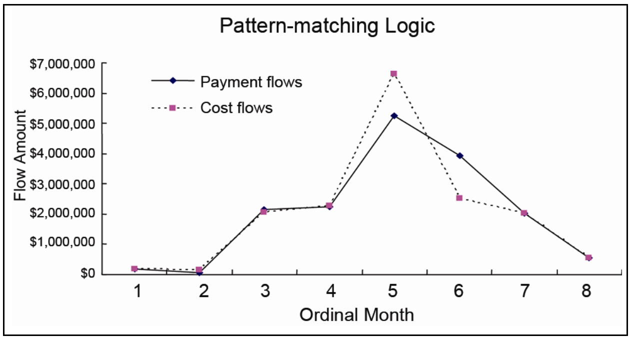

Fig. 11. Comparison between Payment Flows and Cost Flows Created with (T, F, C, SC, NPI) for the Cambridge Project

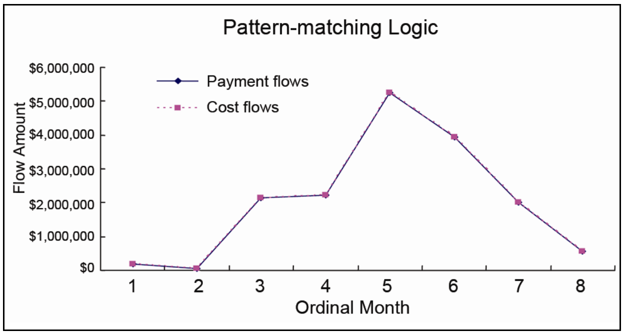

Fig. 12. Comparison between Payment Flows and Cost Flows Created with (T, F, C, SC, PI) for the Cambridge Project

5. Conclusions

This study presents a model of mechanisms for resolving the limitations of CSI models. These mechanisms include problems in the logic of the schedule between construction and cost activities, detailed payment conditions, and the combined effect of payment irregularity and uniform distribution of cost over time. The developed coordination mechanisms provide a method of accounting for differential payment lags, materials and labor components, and payment frequency, as well as absorbing the combined effect of payment irregularity and uniform distribution of cost over time.

The model is shown to be effective using a set of case examples. Analysis of pattern-matching logic using simulated cost flow data indicates that while the simulation input parameters are based on the actual cost and schedule for the work performed, the model is capable of eliminating the deviations between cost flows and historical payment flows. While substantial efforts remain for obtaining the mechanisms suitable for industrial use, the growing computerization of schedule and cost data make the implementation of such mechanisms feasible.

Both researchers and practitioners can directly apply the mechanisms developed in this study. Accordingly, the specific extensions of CSI models are a direct benefit to researchers and practitioners, providing more accurate and reliable means of forecasting cost flow for projects. More broadly, the research and methods of this study contribute to a larger discussion of project cash flow models. A more subtle benefit to practitioners associated with this study is the reminder that project cash flow forecasts require a multi-disciplinary effort. Even with sophisticated models and detailed data, project cash flow predictions are unlikely to be accurate unless they account for cost and schedule uncertainty. Consequently, assessments of the required degree of accuracy remain important components for management decision-making. Furthermore, extending the research in this study to project sales flow forecasts with project-specific data can provide management with a complete vision of project cash flow forecasting techniques.

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SĄNAUDŲ IR MOKĖJIMO KOORDINAVIMO MODELIO, SKIRTO PROJEKTŲ SĄNAUDŲ SRAUTŲ PROGNOZĖMS, KŪRIMAS

H. L. Chen, W. T. Chen, N.-C. Wei

Santrauka

Su projektų veikla susijusių pinigų srautų prognozavimo metodai atsirado siekiant sudaryti detalias prognozes atskiriems projektams. Šiuose metoduose, o dažniausia sąnaudų ir darbų grafiko integracijos (angl. *Cost-schedule integration*, CSI) modelyje dažnai naudojamos projektų sąmatos ir duomenys apie darbų grafiką. Nors apskritai sąnaudų ir darbų grafiko integracijos modeliai pripažinti tinkamais, jie buvo kritikuoti, nes kyla problemų dėl skirtingų tinklinių ir su sąnaudomis susijusios veiklos grafikų, taip pat ignoruojama svarbi informacija apie mokėjimo sąlygas, kurias sudaro mokėjimų vėlavimas, komponentai bei dažnis, ir bendrą neigiamą nereguliaraus mokėjimo bei vienodo sąnaudų pasiskirstymo laikui bėgant poveikį. Siekiant šias problemas sumažinti ir išspręsti, šiame tyrime sukuriama sąnaudų ir mokėjimo koordinavimo mechanizmų grupė, sukurianti sąveiką tarp veiklos, susijusios su sąnaudomis ir mokėjimu. Tuomet iš šių mechanizmų sudaromas modelis. Modelio tikslumas įvertinamas lyginant dviejų atvejui tirti pasirinktų projektų srautų istoriją. Rezultatas rodo, kad su modeliu sudarytose sąnaudų srautų prognozėse tendencijos labai artimos realių sąnaudų srautų istorijos tendencijoms.

Reikšminiai žodžiai: projektų valdymas, sąnaudų kontrolė, sąnaudų analizė, prognozavimas.

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