DSUB: A DECISION SUPPORT SYSTEM FOR SUBCONTRACTING CONSTRUCTION WORKS

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Abstract:

Letting work to subcontractors is a very common practice in construction industry. Subcontractors help contractors overcome problems including the need of special expertise, shortage in resources, and limitation in finances. The decision to subcontract involves determining work items to be subcontracted, and selecting subcontractors. Generally work assignments to subcontractors could be for the total quantity of a work item or a proportion thereof. This paper presents a decision support system that designates work items to be subcontracted and selects subcontractors to achieve them with the objective of minimizing the total cost of the project to the contractor. Moreover, the system calculates the cash flow profiles and profit based on the financial terms of the contract and project schedule. The system encompasses four basic components including project data, linear programming, sensitivity analysis module, and financial analysis module. The sensitivity analysis adds strength and flexibility to the system by allowing the user to experiment with different scenarios. Finally, the developed system which represents a structured method for making subcontracting decisions is demonstrated through an example project.

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Introduction

The general contractor always has the option to perform construction works using internal capacity when it is more economical and less risky. However, most general contractors sublet a large percentage of their work to subcontractors. Subletting work to subcontractors could be for reasons including the need for specialized equipment and expertise; shortage in resources; and limitation in finances. Between the two extremes of clear-cut subcontracting and self-achievement exists some combination that reaps the benefits subcontracting and yet represents an economical policy. Thus, the problem is always to find the practical policy that fulfils contractor's desire to sublet work to subcontractors but at the lowest cost. The formulation of these policies is very crucial to the competitiveness of the contractor and involves making assignments of work items or proportions thereof to subcontractors.

The existing practice (Shash 1998b) in subcontracting is such that the contractor prepares a detailed cost estimate for the work to be performed by in-house capacity. For a designated sublet work, the contractor does not prepare a cost estimate but rather invites subcontractors to submit price quotations before a given deadline. Interested subcontractors adhere to certain rules and submit their quotations for the sublet work. The general contractor then evaluates the submitted quotations and selects one quotation to be used for bidding. Following the award of the contract, the general contractor awards the sublet work to either the subcontractor whose quotation was used in the bid or to another subcontractor.

In construction industry, little is known about subcontractor practicing. Runeson and Uher (1984), Hinze and Tracey (1994), Al-Roumi (1994) and Shash (1998a,1998b) studied the bidding practices of subcontractors in Australia, Puget Sound Area, Saudi Arabia, and Colorado state respectively. In addition, Hsieh (1998) studied the contractor-subcontractor relationship in Taiwan and provided some explanation of the effects of subcontracting on site productivity.

A recent study (Tommelein and chua 1998) focused on an important task a specialty-contractor performs upon contract award, and prior to mobilizing on site namely creating detailed design drawings. The study elaborates on the detailing process and illustrates its effect on the efficiency of the specialty-contractor production process as a whole. A discrete-event simulation model was presented to model this design detailing process. This model captures the flow of resources through the production tasks of the specialty-contractor. With this model, queue levels and production capacity can be determined, and bottlenecks identified.

In the areas of providing maintenance and services, previous studies regarding subcontracting include; a discussion of the advantages and disadvantages of subcontracting versus executing with in-house resources (Conner 1943; Baker 1984); cost comparison between achieving work using the two policies (Farrel and Kilpatrick 1956; Jarrell and Skibniewski 1988); federal government guidelines to convert industrial or commercial activities ("Enhancing Governmental Productivity through competition", 1984); some individual agency's efforts to develop criteria to make decisions regarding contracting highway-related maintenance activities (Newman et.al.1991), a synthesis of knowledge documented on the practice of subcontracting maintenance work of highways (McMullen1986); and a knowledge-based approach for decisions regarding maintenance contracting (Elazouni 1996).

This paper presents a decision support system DSS that helps practitioners make decisions regarding subletting construction works to subcontractors. A schematic diagram of the DSS is shown in Fig.1. The DSS employs a linear programming module with an objective function that minimizes the total contract cost to the contractor under constraints. The constraints express all the contractor's desires and policies regarding the distribution of work between subcontracted and self-achieved. The DSS simultaneously selects subcontractors and determines work assigned to each one. The DSS encompasses a financial analysis module to calculate the cash flow profile along the project duration, and the profit at the end of the project. The presented DSS is coded in a user-friendly software called DSUB, with the linear programming module, financial analysis module, and the necessary interfaces written in Visual Basic. The software provides the contractor with the utility to enter his or her own project data including work items, and their associated costs, resource limitation, the roster of subcontractors and their price quotations, and any desired constraints. The DSS provides flexibility to the decision-maker using sensitivity analysis. Sensitivity analysis assesses the effect of changing the optimum decision on the contractor's cost and profit. The capabilities of the presented DSS are demonstrated through an example project. The DSS represents a structured approach and rational bases to the decision-making without resorting to any unethical practices and unfair use of subcontractor's quotations.

COST MINIMIZATION MODEL

The first step in minimizing the total costs for the contractor involves identifying the cost elements in the cost model. The cost of each work item in the model is represented by a multitude of elements. The first element represents the contractor's cost for the self-performed proportion which is the unit cost multiplied by the number of work units assigned by the model. The other elements represent the contractor cost for subcontractors' performance which is the summation of each subcontractor's price quotation multiplied by the number of work units assigned by the model. Subcontractors' price quotations are elevated by a factor to express the contractor administrative costs. Thus, the decision variables in the model represent the number of work units of a work item assigned to either the contractor or the subcontractor. All subcontractors and work items are included in the model. The contractor's cost for his performance represents the direct and indirect costs per unit of the work item. The contractor's cost for subcontractors' performance includes the price of the unit of work item quotated by a subcontractor elevated by a factor to express administrative costs.

$C_c = DC + IC$

$C_s = P(1 + f)$

where; C_c = Cost of unit for contractor performance.

DC = Direct cost of unit for contractor performance .

IC = indirect cost of unit for contractor performance

C_s = Cost of unit paid by contractor for subcontractor performance .

P = Unit price for subcontractor performance .

f = factor for the contractor administrative costs

Thus ,the objective function of the model is as follows :

$$\text{Minimize} \quad Z = \sum_{i=1}^{K} C_{ci} x_i + \sum_{J=1}^{M} \sum_{i=1}^{K} C_{Sij} x_{ij}$$

where; K is the number of work items; M is the number of subcontractors; C_{ci} is the contractor's unit cost of the self-performance in work item i; C_{sij} is the contractor's unit cost for the subcontractor performance in work item i of subcontractor j; x_i is the number of work units of work item i assigned to the contractor; and x_{ij} is the number of work units of work items i assigned to subcontractor j.

Despite subletting work to subcontractors mainly relies on judgment concerning reliability and qualifications of the participants. In subletting work to either specialized subcontractors or to others who supplement the shortage in capacity, contractors find them selves deal with many subcontractors each with different quotations. Contractors usually distribute the total quantity of a work item on more than one subcontractor for reasons including diminishing the risk of dealing with only one subcontractor, and reducing the project duration. Therefore, contractors in order to manage the situation need a generic model that incorporates the various factors involved in the decision-making. The purpose of the model is not to present an optimum solution that might be practically meaningless but more important is to provide a sensitivity analysis tool. However, the output can be totally neglected without affecting the other functions of the system.

Since the problem is basically to distribute project work items among the contractor and subcontractors, any contractor's policy or reason for subcontracting can be directly fulfilled through putting constraints on work assignments. In other words, policies and reasons for subcontracting can be reflected as limitations on work assigned to either the contractor, all subcontractors, or a particular subcontractor. Thus, the constraints were formulated in the model as follows:

1- Quantity constraint

The number of work units of a work item assigned to subcontractors and the contractor must add up to the total quantity of the work item in the bid form.

$$x_i + \sum_{j=1}^{M} x_{ij} = Q \qquad \text{----------------------------------} \quad (1)$$

where Q is the total quantity of work item i in the bid form.

2- Contractor-limited-resource constraints

$$\sum_{J=1}^{M} x_{ij} \geq Q_{Ai} \qquad \text{---------------------} \quad (2)$$

This constraint limits the work assigned to the contractor to self-capacity. Thus, the total work units assigned to all subcontractors must be greater or equal to the quantity that the contractor can not afford to self-achieve with own resources (Q_{Ai}).

3- Subletting-to-subcontractors constraints.

This constraint limits the total work submitted for subcontracting to a specified limit. These limits express the contractor desirable policies.

$$\sum_{j=1}^{M} x_{ij} \leq Q_{Bi} \qquad \text{---------------------} \quad (3)$$

where Q_{Bi} is the desirable limit of subcontracting of work item i .

4-Assignment-to-a subcontractor constraints.

This constraint is basically when it is desired to put a limit on work assigned to a subcontractor so as not to exceed a specified limit.

$$x_{ij} \leq Qc_{ij} \qquad \text{----------------------------------} \quad (4)$$

where Qc_{ij} is the maximum work units of work item i that must be assigned to subcontractor j.

FINANCIAL ANALYSIS

Subcontracting is a common practice contractors rely on to partially finance projects. As contractors are interested in formulating subcontracting decisions to minimize their costs, they are equally interested in monitoring the effect of their determinations on their cash flow profile and profit at the end of project. The financial analysis module provides the facility to calculate the financial parameters and profit corresponding to the optimal policy presented by the linear programming module. In addition, it provides the same output for any other desired policy different from the optimal policy. Thus, this module provides a rational framework for analyzing the effects of various subcontracting decisions on the profit and other financial parameters of a construction project. The commercially available software provides only cash out forecasts, conversely, the financial module in this system provides forecasts for cash out, cash in, overdraft, and profit at the end of the project. The system plots figures for the output and also in tabular format.

This study follows the financial analysis framework, including parameters and method, presented by Au and Hendrickson (1986). This method considers the financing costs of overdraft and the effect of this cost item on profit since overdraft is the most common form of financing for small and medium size projects. The module calculates the income and expenditures for the contractor according to the work assignment outcome of the optimization module. The system depicts a bar chart for the project through allowing the user to enter the proportion of the work to be executed by the contractor and subcontractors at each month. The system performs financial analysis with two options. The first option represents the case when payment from the owner to the contractor for work completed is made at the end of the month. The second option represents the case when payment is made one month latter. The contractor pays the entitlements of subcontractors upon the receipt of the pay-request from the owner. The subcontractors' entitlements and expenditures are discarded in the cash in and cash out calculations to exclusively describe the financial situation of the contractor. The framework of financial analysis is outlined as follows :

- The net cash flow at the end of month t excluding interest expenses is A_t

$$A_t = P_t + E_t \qquad \text{------------------------------------} \quad (5)$$

where ; E_t = construction expenses in month t excluding interest payments, E_t is defined as negative for expenses

P_t = receipts from owner payment in month t, P_t is defined as positive for receipts

t = 0,1,2,.............., n periods in months

-The cumulative cash flow at the end of month t before receiving payment p_t is :

$$F_t = N_{t-1} + E_t \qquad \text{------------------------------------} \quad (6)$$

Where ; N_{t-1} = cumulative net cash flow till month (t-1).

- The cumulative net cash flow after receiving payment P_t at the end of month t is :

$$N_t = F_t + P_t = N_{t-1} + A_t \quad \text{-----------------------------------} \quad (7)$$

- The monthly interest paid for overdraft financing becomes

$$\hat{I} = I_t + \tilde{I}_t \quad \text{-----------------------------------} \quad (8)$$

where ; $I_t = iN_{t-1}$ (interest on the accumulated overdraft at borrowing rate i for month(t-1)) ----------------------------------- (9)

$$\tilde{I}_t \cong i\,\frac{E_t}{2} \qquad \text{(Approximate monthly interest on } E_t \text{)} \quad \text{-------------} \quad (10)$$

- If payment of monthly interest is deferred, then the monthly additional overdraft to finance the interest payments is added to F_t , and the cumulative cash flow at the end of month t including accumulated interest charges just before receiving P_t equals :

$$\hat{F}_t = F_t + \sum_{k=1}^{t} \hat{I}_k (1+i)^{t-k} \quad \text{-----------------------------------} \quad (11)$$

- Finally , the cumulative net cash flow including accumulated interest charges after receiving payment P_t at the end of month t ($t \geq 1$) is:

$$\hat{N}_t = \hat{F}_t + P_t \quad \text{-----------------------------------} \quad (12)$$

$$\text{for} \quad t = n \qquad \hat{N}_n = \hat{G} \quad \text{-----------------------------------} \quad (13)$$

where ; $\hat{G}$ = gross operating profit less financing cost for a project .

SENSITIVITY ANALYSIS

In making decisions regarding subcontracting construction works, the contractor may want to investigate the effect of changing the values of some of the variables in the linear programming module and financial analysis module. In the linear programming module, changing the prices of subcontractors, the unit costs of the contractor, or the right hand sides of the constraints affect the solution of the model. Sometimes, some values such as the right-hand values of the constraints are often approximations at best which makes it necessary to examine more than one set of circumstances. In the DSUB program, such exploration of the effect of changing in the linear programming module is accounted for by a sensitivity analysis conducted using the simplex method technique. The objective is to study the sensitivity of the model outputs to changes in the model inputs. Moreover, the contractor may want to discard the solution suggested by the DSS and make up his own solution, the DSS in this case presents the deviation in total cost between the suggested solution and the desired solution.

On the other hand, investigating the parameters of the financial analysis module is of great importance to the contractor. Financial analysis parameters include the interest rate, the advance payment, the time elapsed till the contractor is reimbursed for his work, and positioning of the different work assignments on the time scale of the project. As a matter of fact, changing any of these parameters inevitably change the financial profile of the project and the profit at the end of the project. In addition, contractors may want to adjust the value of their overdrafts to a certain limit to get benefits from bankers. This can be done through adjusting the pace of work to produce the required overdraft limit. The DSUB program enables contractors to plug changed values in the financial module and observe the corresponding consequences.

VERIFICATION OF THE DSS

One of the major objectives of the DSS was to design a user-friendly interface that facilitates the task of entering data and solving the optimization model especially for those who are not familiar with model formulation. This requirement entitled writing programs for executing the simplex method instead of using the available optimization softwares. In addition, another program was written to formulate the objective function and constraints of the model out of the entered project data. The simplex program was first tested using models of different sizes.

The results were compared against that obtained by QSB and LINDO optimization softwares which showed identical results. Moreover, the second program was tested to make sure that it formulates the model correctly and was a success. The optimization program points out special situations to the user as no feasible solution, and unbounded solution. On the other hand, the financial analysis module was verified by solving problems manually to make sure that the program gives identical results.

EXAMPLE APPLICATION

To demonstrate the operation of program DSUB as a decision-support system, an example applications are presented. The first project is a big housing project composed of ten multistory buildings consisting of 23 work items. A list of the work items and the project bar chart is shown in Fig. 5.1. The reinforced concrete items, items 7 through 13 of the project need formwork quantities more than the capacity of the contractor, for this reason the contractor resorted to subcontract these items to supplement the lack in resources. The second project represents a specialty work of manufacturing and erecting doors and windows. The work package includes four work items, three for doors and the last for windows. The main contractor decided to sublet the whole package to subcontractors. First, the contractor has to input the project data, as shown in Fig. 2. The user plug in his input data in a tabular format as shown in the middle box of the screen shown in Fig. 2 . The table size is provided for the user according to the number of work items and number of subcontractors the user enters at the top box of the screen, the example-project data are shown in Table 1. The program provides vertical and horizontal scroll bars, when necessary, to enable filling in the whole table. Once data are entered, the contractor may print or preview the entered data to check for accuracy, save the data, and then select the solve option. The program formulates the model objective function and constraints, solves using simplex method and accordingly prompts the user with the optimum solution screen (Fig. 3) showing the assignments to the contractor and subcontractors of each work item and the minimum cost. Table 2 shows the values of the optimum assignments which partially appears in the screen of Fig. 3. At this point, the contractor may want to partially or totally change the outcome of the model and see how that can affect the cost of the project, the program offers this facility to the user.

To investigate the effect of changes, or variation, in the initial setting of the model on the optimum solution, a sensitivity analysis is conducted via the optimum solution screen. Using the sensitivity analysis module of the software, the user is prompted with four different options of sensitivity analysis. The sensitivity analysis of the objective function coefficients which represent the price quotations of subcontractors and unit costs of the contractor is presented in Table 3 and shown in Fig.4. In addition, the sensitivity analysis and shadow prices for the different right-hand sides of the constraints are given in tables 4, 5, and 6. After investigating the effect of changes on the optimum solution, the program returns the user to the optimum solution screen. In an effort to verify the optimization program, its results were compared with the results of the optimization software of QSB. The example-project data were entered to QSB and the model was solved. The output of QSB model, which is presented in Appendix III, showed identical results. However, it was noted that the values of sensitivity analysis of objective function coefficients obtained by the model sometimes differs from that of QSB, which is shown in Table 7, by not more than unity. The accuracy of the optimization program was verified when its values were entered in the objective function of QSB and no change was noticed in the solution. Therefore, these negligible differences can be attributed to rounding off figures.

The second major feature of DSUB program represents the financial analysis. From the screen of the optimum solution the user is prompted with the financial analysis screen shown in Fig. 5. This screen prompts the user to enter the data required for the financial analysis. These data include the financial terms of the project, as shown in the top box of Fig. 5, and the positioning of the work items that are assigned by the model with respect to time as shown in the middle box. Financial terms are entered as percentage of the project total cost such as the mobilization cost, overhead, bond, tax, and retainage. The positioning of work assignments with respect to time is entered to the program through specifying the percentage planned for achievement by the contractor and each subcontractor every calendar month. This percentages are presented in Table 8 for the example project. Using the financial module outlined before, the cash flow profiles are calculated and accordingly, the user is prompted with the table of financial parameters along the project duration, which is presented in Table 9 and the screen in Fig. 6. The expected gross profit at the end of the project equals 57,858 and is given at the bottom of the last column of Table 9. Fig. 7 shows the overdraft required for the contractor along the project duration.

SUMMARY AND REMARKS

A decision-support system (DSUB) for subcontracting construction works was developed using linear programming technique. The objective function of the linear programming minimizes the total cost of the contractor including the cost of the self-achieved and sublet work. The minimization is done subjected to constraints. The constraints express the different reasons the contractor may consider in his decision-making regarding the distribution of work items between self-achieved and subcontracted. Thus, the area of feasible subcontracting alternative determinations is intercepted by constraints that limit work assigned to contractor, subcontractors, or an individual subcontractor. The objective function finds the determination that corresponds to the minimum project cost. The model not only produces an optimum solution regarding the distribution of the project work items to contractor and subcontractors but also provides the decision maker with indication about the cash flow profiles along the project, the amount of the overdraft required to finance the project, and the profit at the end of the project. The decision-support system developed has several interesting characteristics, including the following:

It incorporates a deterministic model that provide a structured approach for making decisions regarding the most common and frequent practice of subcontracting.

It provides a decision aid in terms of assigning work to subcontractors. In addition it provides some indication about the implications of these assignments on financial aspects including the required amount of overdraft, cash flows along the project duration, and profit at the end of the project.

It has a user-friendly interface that facilitates entering project data in table format, checking the entered data, and storing project data. The model formulates the objective function and constraints out of the data entered to the model.

It incorporates sensitivity analysis to enable investigating the impact of changes in the objective function coefficients, and right-hand values of the constraints on the optimum solution.

It provides a measure of the profit at the end of the project, and a tool that plans the project activities so as to attain a certain overdraft.

It provides flexibility to the contractor to make changes or even discard the optimum solution and instantaneously see the deviation from the minimum cost.

It represents a decision tool that enables contractors make subcontracting optimum decisions without resorting to unfair and unethical practices that impairs the contractors and subcontractors.

Appendix I : References

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$$C_{ci} = D_i + I_i$$

Appendix II : Notations

A_t = The net cash flow at end of month t excluding interest expenses.

C_{ci} = The contractor unit cost of the self-performance in work item i.

C_{sij} = Contractor unit cost for the subcontractor J performance in work item i.

D_i = Direct cost of unit for contractor performance in work item i.

E_t = construction expenses in month t excluding interest payments (-ve).

F_t = cumulative cash flow for operation at end of month t just before receiving payment P_t.

$\hat{F}_t$ = cumulative cash flow for operation and financial charges at end of month t just before receiving payment P_t.

f = factor for the contractor administrative costs.

$\hat{G}$ = gross operating profit less financing cost for a project.

I_t = interest on the accumulated overdraft at borrowing rate i for month (t-1).

I_i = Indirect cost of unit for contractor performance in work item i.

$\tilde{I}_t$ = interest in month t on construction expenses E_t.

$\hat{I}_t$ = total interest in month t for overdraft financing.

i = interest rate per month.

k = a dummy variable for summation.

K = the number of work items.

M = the number of subcontractors.

N_{t-1} = cumulative net cash flow till month (t-1).

$\hat{N}_t$ = combined cumulative net cash flow resulting from operation and financing from month 0 to month t.

p_{ij} = Unit price quoted by the subcontractor J in work item i.

P_t = receipts from owner payment in month t (+ve).

Q = the total quantity of work item i in the bid form.

Q_{Ai} = the number of work units of work item i the contractor can not afford to achieve with his own resources.

Q_{Bi} = the desirable limit of subcontracting work item i.

Qc_{ij} = the maximum work units of work item i that must be assigned to subcontractor j.

t = 0,1,2,..............,n periods in months.

x_i = is the number of work units of work item i assigned to the.

x_{ij} = is the number of work units of work items i assigned to subcontractor j.

Appendix III : The QSB model

Min 255 X1 + 206 X2 + 182 X3 + 300 X4 + 285.6 X5 + 234.6 X6 + 234.6 X7 + 234.6 X8 + 387.6 X9 + 316.2 X10 + 316.2 X11 + 489.6 X12 + 185.64 X13 + 135.66 X14 + 142.8 X15 + 418.2 X16

subject to

(1) X1 + X5 + X9 + X13 = 210

(2) X2 + X6 + X10 + X14 = 420

(3) X3 + X7 + X11 + X15 = 210

(4) X4 + X8 + X12 + X16 = 105

(5) X5 + X9 + X13 < 210

(6) X6 + X10 + X14 < 420

(7) X7 + X11 + X15 <210

(8) X8 + X12 + X16 < 105

(9) X5 + X9 + X13 > 210

(10) X6 + X10 + X14 > 420

(11) X7 + X11 + X15 > 210

(12) X8 + X12 + X16 > 105

(13) X5 < 80

(14) X6 < 160

(15) X7 < 80

(16) X8 < 40

(17) X9 < 90

(18) X10 < 160

(19) X11 < 90

(20) X12 < 40

(21) X13 < 80

(22) X14 < 160

(23) X15 < 8

(24) X16 < 40