Project Subcontractors Selection in Fixed Price and Cost-plus Contracts

Paweł Błaszczyk, Tomasz Błaszczyk

Abstract — **Depending on your view of the allocation of risk between the project owner and contractor use are two main types of contracts. In this paper, we analyze the problem of optimal selection of sub-contractors in the case of the application of a fixed price and a cost-plus contracts. Models described in the article can be found applicable in the relations between the project owner and the contractor and between the contractor and sub-contractors.**

As a methodological basis we use the multi-criterial decision model assigning each task to specific contractors (or sub-contractors) in the project with the function of distribution of penalties arising from delayed completion and potential benefits in the event of early termination of the project.

Index Terms— **project procurement, subcontractors selection, fixed price contracts, cost-plus contracts**

I. Introduction

The issue of contract management and procurement management is one of the fundamental problems in the practice of project management. Its importance is highlighted in the one of the most common project management methodologies - PMBoK [8] of the Project Management Institute, which gives it one of the nine areas of knowledge. As the process of " Plan contracting" indicates selection of a sub-contractors cannot be planned without taking into account the relationship between the "project schedule", "activity cost estimations", " activity resource requirements", and “Project Management Plan” with its components focused on “risk register” and “risk-related contractual agreements”. Therefore, we believe that the process of selecting a contractor must include the methodology used to create the schedule in accordance to the policy of distribution of risks between the project owner and the contractor.

Classical scheduling methods of CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique) do not explicitly take into account the factors associated with the uncertainty that surrounds the choice of the contractor and his participation in the implementation of the project scope. Therefore, in the later part of the paper we use assumptions described by Błaszczyk et al. [3] in terms of the bi-criterial model of project with time and cost buffers designed based on the concept of CCPM (Critical Chain Project Management).

Concept of Critical Chain (Goldratt [4]) is one of the Newest project management methodologies. However, it is not impeccable (compare Herroelen and Leus [6], Rogalska *et al.* [9] Van de Vonder *et al.* [11]), is a balanced combination of CPM with the recognition of the overall uncertainty and the impact of the human factor in the planning and implementation of projects. Many later results (for example as described in review by Van de Vonder *et al.* [12], [13]) is based on the concepts set forth in the buffers.

In some industries (mainly IT) in later years has also found widespread the class of *agile* [1] methods like XP - eXtreme Programming, Scrum, Lean Software Development. These methods assume the collaboration between client and the contractor including, among others the dynamic adjustment of the schedule and budget for the project to imprecisely specified range, which can also evolve as the work progresses. This approach can be effective, but we must keep in mind that in many business environments, it is not acceptable because of the uncertainty of the final price of the contract for construction of the project. Therefore, we would not consider them later in this paper. Instead, we will focus on the method resulting the concept of CCPM. We will also present considerations for the two types of contract, without indicating which one is more appropriate for a particular project owner. The choice of the type of contract should be determined for a detailed analysis of the type of project, its associated risks and project owner’s risk management policies.

The chain and time buffers quantification methods were the results of successive authors. One of the detailed approaches was formally described by Tukel et al. [10]. The issues of buffering some project characteristics, other than duration, were considered by Leach [7], Gonzalez *et al.* [5], Błaszczyk and Nowak [2]. The model featured in the next part of this research takes into account the use of partition function the bonus fund for early implementation of the project.

The problem of cost and time overestimation occurs in the present case twice: firstly between the client and the general contractor of the project (related by the contract with the client) and after that between the subcontractors (performing partial ranges of the project) and a general contractor. Hence, if we assume that overestimations of cost and time act consistently in contracting relationships between client and contractor, and between contractor and sub-contractor, than estimations of cost and/or the schedule

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given to the project owner will be based on data twice overestimated. On the other hand, there are also lots of cases of under-estimations that are evaluated by the project owner in order to select contractors. The reason for this phenomenon is to seek bidders to obtain the best evaluation in the selection phase at the expense of an increased risk of non-compliance with contractual provisions. In order to increase project owner's safety in similar to the consequences of actions that may result in extending the time for implementation the mechanism of contractual penalties applies. Such a mechanism causing that the bi-criterial time-cost trade-off can be represented as a single-criterial problem and can be applied in both considered contract types. Any exceeding the agreed deadline for completion of the project or any part of it results in measurable, and the financial consequences set before. When this decision problem is analyzed by the general contractor, it is necessary to take into account both the cost of penalties that the general contractor will be forced to pay for the customer, as well as any income from fines paid by its subcontractors. Also the type of the contract has influence how to select the subcontractors. Therefore, it appears appropriate to use for the design of the model of sub-contractors selection both the information about contract type and the concept of time and the cost of buffers. In this case such models can be used as a tool to compensate for liabilities and cash flows.

II. Methodology

We consider a project which consist $x_1,\dots,x_n$ tasks characterized by cost and time criteria. As the consequence of the contract between the project owner and the contractor there are contracted budget $K_{\max}$ and contracted duration $T_{\max}$ of the project. Moreover there are defined price I_p, success fee S_p and penalty fee P_p. For example the success fee and the contract penalty fee can be defined as follow:

$$\begin{aligned} S_p &= r_s \cdot I_p / day \\ P_p &= r_p \cdot I_p / day \end{aligned} \tag{1}$$

where r_s and r_p are success rate and penalty rate respectively. We assume that we have q potential subcontractors for n tasks in the project. Let us consider the following matrix X :

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1q} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nq} \end{bmatrix} \tag{2}$$

Elements of the matrix X equal 0 or 1. If x_{ij} equals 1 it means that subcontractor j submit a bid for task x_i. In the other case there is no such bid for task x_i. The matrix X we will call the subcontractor's matrix.

A. The fixed price contract

In our first model we assume that between project owner and the contractor there is contract with the fixed price. Let

$$K = \left[k_{ij}\right]_{i=1,\dots,n;\, j=1,\dots,q} \tag{3}$$

to be the matrix of cost's of all subcontractors for all tasks and let

$$T = \left[t_{ij}\right]_{i=1,\dots,n;\, j=1,\dots,q} \tag{4}$$

be the matrix of amounts of work for each subcontractors in each task. Denote by k_i the cost of the task x_i and by t_i duration of the activity x_i. Thus the total cost and the total duration of the project are given by

$$K_c = \sum_{i=1}^{n} k_i \tag{5}$$

and

$$T_c = \max_{i=1,\dots,n}\left(ES_i + t_i\right) \tag{6}$$

where ES_i is the earliest start of task x_i. Contracts with all subcontractors can also include success fee s_i and penalty fee p_i. Also let

$$A = \left[a_{ij}\right]_{i=1,\dots,n;\, j=1,\dots,q} \tag{7}$$

to be the subcontractors assign matrix. Elements of the matrix A equal 0 or 1. If a_{ij} equals 1 it means that subcontractor j will be perform task x_i. Moreover, let

$$M = \left[m_{ij}\right]_{i=1,\dots,n;\, j=1,\dots,\mathrm{n}} \tag{8}$$

denote the preference matrix. Elements of the matrix M equal 0 or 1. If m_{ij} equals 1 it means that the task i should be realized together with task j by the same subcontractors. Of course there are ones on the main diagonal. On the other hand let matrix

$$D = \left[d_{ij}\right]_{i=1,\dots,n;\, j=1,\dots,\mathrm{n}} \tag{9}$$

denote the restriction for tasks in project. Elements of the matrix D equal 0 or 1. If d_{ij} equals 1 it means that the task i could not be realized together with task j by the same subcontractors. In our case we have the following optimization problem. In order to simplified the calculation let us also introduce the following vectors

$$m = MI \tag{10}$$

and

$$d = DI \tag{11}$$

where $I = \left[i_{ij} \right]_{i=1,\ldots,n;\, j=1,\ldots,n}$ is an identity matrix. Under the following assumptions we maximize the total benefits of the project. In our case we have the following optimization problem

$$\begin{gathered} I_p + S_p - P_p - \sum_{i=1}^{n} a_{ij} x_{ij} \left(k_{ij} + s_{ij} - p_{ij} \right) \to \max \\ a_{ij} \in \{0,1\} \\ \forall_{i=1,\ldots,n} \sum_{j=1}^{n} a_{ij} = 1 \\ \forall_{i=1,\ldots,n} \sum_{j=1}^{n} a_{ij} x_{ij} = 1 \\ T_c = \max_{i=1,\ldots,n} \{ ES_i + t_i \} < T_{\max} \\ K_c = \sum_{i=1}^{n} \sum_{j=1}^{q} a_{ij} k_{ij} < K_{\max} \\ \forall_{j=1,\ldots,q} \sum_{i=1}^{n} \sum_{k=1}^{n} a_{ij} x_{ij} m_{ik} \in \{0, m_i\} \\ \forall_{j=1,\ldots,q} \sum_{i=1}^{n} \sum_{k=1}^{n} a_{ij} x_{ij} d_{ik} \in \{0, d_i\} \end{gathered} \tag{12}$$

where ES_i is the earliest start of task x_i, T_C denotes total duration of the project, and K_C denotes the total cost of the project $T_{\max}$, $K_{\max}$ denotes maximum duration and cost for the project respectively. The $T_{\max}$, $K_{\max}$ are results of the project requirements. It leads to find the optimal work assignments for every factor in each activity. From the set of alternate optimal solutions we choose this one, for which the total duration of project is minimal.

B. The cost-plus contract

In our second model we assume that the project will be settled by the cost-plus formula on the basis of the quantity survey.

Like in previous model let cost and duration matrices be given by formulas (3) and (4) respectively. In this model we treat cost from matrix (4) as the cost of actual implementation of each task for each subcontractors. Moreover let

$$G = \left[g_j \right]_{j=1,\ldots,n} \tag{13}$$

be the vector of profit margins for all subcontractors. The values g_j belongs to the interval $[0,1]$. To protect against the uncontrolled growth of the cost of the task x_i in such type of contracts the so-called ceiling price is used. So let

$$C = \left[c_i \right]_{i=1,\ldots,n} \tag{13}$$

Be the vector of ceiling price for each tasks. Like in previous case denote by k_i the cost of the task x_i and by t_i duration of the activity x_i. Thus the total cost of the project is given by

$$K_c = \sum_{i=1}^{n} k_i g_i \tag{14}$$

where g_i is the profit margin of that subcontractor who will perform the task x_i. The total duration of project is given by formula (6). Like in previous model let subcontractor assign matrix, preference matrix and restriction matrix be given by formulas (7)-(11) respectively. Under the following assumptions we maximize the total benefits of the project. In our case we have the following optimization problem

$$\begin{gathered} I_p + S_p - P_p - \sum_{i=1}^{n} a_{ij} x_{ij} \left(k_{ij} \left(1 + g_j\right) + s_{ij} - p_{ij} \right) \to \max \\ a_{ij} \in \{0,1\} \\ \forall_{i=1,\ldots,n} \sum_{j=1}^{n} a_{ij} = 1 \\ \forall_{i=1,\ldots,n} \sum_{j=1}^{n} a_{ij} x_{ij} = 1 \\ T_c = \max_{i=1,\ldots,n} \{ ES_i + t_i \} < T_{\max} \\ K_c = \sum_{i=1}^{n} \sum_{j=1}^{q} a_{ij} k_{ij} < K_{\max} \\ \forall_{j=1,\ldots,q} \sum_{i=1}^{n} \sum_{k=1}^{n} a_{ij} x_{ij} m_{ik} \in \{0, m_i\} \\ \forall_{j=1,\ldots,q} \sum_{i=1}^{n} \sum_{k=1}^{n} a_{ij} x_{ij} d_{ik} \in \{0, d_i\} \\ \forall_{i=1,\ldots,n} \sum_{j=1}^{n} a_{ij} x_{ij} k_{ij} \left(1 + g_j\right) < c_i \end{gathered} \tag{15}$$

III. Example

Let us consider the simplified example of typical software development project. In the following project we want to design and implement a software with three functionalities. The whole project was divided into 22 tasks A_1, A_2, ..., A_{22}. At the beginning we should define the problem (task A_1), describe the requirements (task A_2) and action plan (task

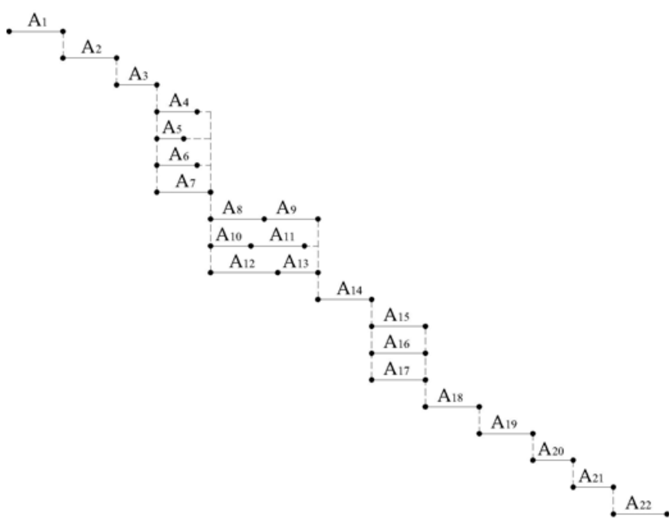

Fig. 1. Project Gantt chart

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A_3). After that each functionality should be designed (tasks A_4, A_5, A_6). Also some functionality integration should be done. After the phase of designing the functionality each of them should be implemented (tasks A_8, A_9, A_{10}) and tested (tasks A_{11}, A_{12}, A_{13}). Also all of the functionalities should be tested together (task A_{17}). Next necessary improvements in each functionality should be done (tasks A_{14}, A_{15}, A_{16}). After that all of the functionalities should be integrated together. After that the whole program should be implemented into our customer environment (task A_{19}). After that some improvements may be necessary (task A_{20}). At the end the customers employees should be learned how to use this program (task A_{21}) and some marketing should be done (task A_{22}).

Project Gantt chart network is represented on Figure 1. These tasks can be performed by subcontractors or by ourselves. In the first step of the procedure we collect bids from subcontractors and note their estimation of the time and costs required to complete this project. In this way we can construct the matrix of subcontractors X , time and cost matrices T and K respectively. Consider the first of the models. Let us assume that in our case we received bids from three potential subcontractors. Moreover part of the tasks we want to perform ourselves. The values of elements in matrix X are given in Table I:

TABLE I
THE SUBCONTRACTORS INFLUENCE MATRIX

activity	subcontractor 1	subcontractor 2	subcontractor 3	self
A_1	1	0	0	0
A_2	1	1	1	0
A_3	1	0	0	1
A_4	1	0	1	0
A_5	1	1	0	0
A_6	1	1	0	0
A_7	1	0	1	1
A_8	1	0	1	0
A_9	1	1	0	0
A_{10}	1	1	0	0
A_{11}	1	0	1	1
A_{12}	1	1	0	1
A_{13}	1	1	0	1
A_{14}	1	0	1	0
A_{15}	1	1	0	0
A_{16}	1	1	0	0
A_{17}	1	1	0	1
A_{18}	1	1	0	0
A_{19}	1	0	0	1
A_{20}	1	0	0	1
A_{21}	1	0	0	1
A_{22}	1	0	0	1

In our contract fixed price equals $I_p = 250000$ \$ and time of duration $T_p = 300$ days. The maximal cost of the project equals $K_{max} = 200000$ \$, the maximal time of duration for whole project was fixed at $T_{max} = 270$ days. The times of duration (matrix T) and cost (matrix K) for tasks in project for all subcontractors are given in Table II and Table III respectively. In both of these matrices we add our estimations of times and costs for tasks in project.

TABLE II
THE TIME MATRIX

activity	subcontractor 1	subcontractor 2	subcontractor 3	self
A_1	7	0	0	14
A_2	30	28	25	0
A_3	14	0	0	14
A_4	14	0	12	0
A_5	10	5	0	0
A_6	8	5	0	0
A_7	30	0	0	14
A_8	70	0	65	0
A_9	52	40	0	0
A_{10}	34	38	0	0
A_{11}	7	0	10	10
A_{12}	7	10	0	10
A_{13}	7	10	0	10
A_{14}	14	0	7	0
A_{15}	14	14	0	0
A_{16}	14	12	0	0
A_{17}	21	14	0	30
A_{18}	14	21	0	0
A_{19}	5	0	0	14
A_{20}	14	0	0	10
A_{21}	7	0	0	7
A_{22}	14	0	0	28

TABLE III
THE COST MATRIX

activity	subcontractor 1	subcontractor 2	subcontractor 3	Self
A_1	2000	0	0	1000
A_2	10000	8000	12500	0
A_3	3000	0	0	1500
A_4	10000	0	8000	0
A_5	8000	9000	0	0
A_6	5000	4000	0	0
A_7	1500	0	0	1500
A_8	25000	0	18000	0
A_9	15000	14500	0	0
A_{10}	12500	12000	0	0
A_{11}	5000	0	4000	2000
A_{12}	3000	2500	0	1500
A_{13}	2000	2000	0	1000
A_{14}	0	0	0	2000
A_{15}	0	0	0	2000
A_{16}	0	0	0	2000
A_{17}	8250	5000	0	4800
A_{18}	15000	17000	0	0
A_{19}	20000	0	0	25000
A_{20}	10000	0	0	12000
A_{21}	6000	0	0	5000
A_{22}	30000	0	0	25000

In this case we also have the following preferences. The functionality 1 should be designed (task A_4) and implemented (task A_5) by the same subcontractors. The same should be applied for functionality 2 and 3. Moreover the any two of functionalities should not to be designed or implemented by the same subcontractors. Also the tests for all functionalities (tasks A_{11}, A_{12}, A_{13}, A_{14}) should be done by another subcontractor. Moreover, the necessary corrections in each function should be performed by subcontractor, which implement that functionality. The values of assignment matrix A are given in Table IV.

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TABLE IV
ASSIGNMENT MATRIX

activity	subcontractor 1	subcontractor 2	subcontractor 3	Self
A_1	0	0	0	1
A_2	0	1	0	0
A_3	0	0	0	1
A_4	0	0	1	0
A_5	1	0	0	0
A_6	0	1	0	0
A_7	0	0	0	1
A_8	0	0	1	0
A_9	1	0	0	0
A_{10}	0	1	0	0
A_{11}	0	0	0	1
A_{12}	0	0	0	1
A_{13}	0	0	0	1
A_{14}	0	0	1	0
A_{15}	1	0	0	0
A_{16}	0	1	0	0
A_{17}	0	0	0	1
A_{18}	1	0	0	0
A_{19}	1	0	0	0
A_{20}	1	0	0	0
A_{21}	0	0	0	1
A_{22}	0	0	0	1

With such a task distribution we obtain the total cost of the project $K_C = 161300\$$ and the total duration $T_C = 257$ days. Finally, the total profits of the project equals 88700$.

Now let us consider the second of the models. In such case the values of elements in matrix X are given in Table I. Moreover in this model, we assume that each of the subcontractors reliably estimated the direct costs of the task. The times of duration (matrix T) and costs (matrix K) for tasks in project for all subcontractors are given in Table V and Table VI respectively. In both of these matrices we add our estimations of times and costs for tasks in project.

TABLE V
THE TIME MATRIX

activity	subcontractor 1	subcontractor 2	subcontractor 3	self
A_1	7	0	0	14
A_2	30	28	25	0
A_3	14	0	0	14
A_4	14	0	12	0
A_5	10	5	0	0
A_6	8	5	0	0
A_7	30	0	0	14
A_8	70	0	65	0
A_9	52	40	0	0
A_{10}	34	38	0	0
A_{11}	7	0	10	10
A_{12}	7	10	0	10
A_{13}	7	10	0	10
A_{14}	14	0	7	0
A_{15}	14	14	0	0
A_{16}	14	12	0	0
A_{17}	21	14	0	30
A_{18}	14	21	0	0
A_{19}	5	0	0	14
A_{20}	14	0	0	10
A_{21}	7	0	0	7
A_{22}	14	0	0	28

TABLE VI
THE COST MATRIX

activity	subcontractor 1	subcontractor 2	subcontractor 3	self
A_1	2000	2000	2000	2000
A_2	10000	10000	10000	10000
A_3	3000	3000	3000	3000
A_4	8000	8000	8000	8000
A_5	8000	8000	8000	8000
A_6	5000	5000	5000	5000
A_7	1500	1500	1500	1500
A_8	18000	18000	18000	18000
A_9	15000	15000	15000	15000
A_{10}	12500	12500	12500	12500
A_{11}	4000	4000	4000	4000
A_{12}	2500	2500	2500	2500
A_{13}	2000	2000	2000	2000
A_{14}	2000	2000	2000	2000
A_{15}	2000	2000	2000	2000
A_{16}	2000	2000	2000	2000
A_{17}	5000	5000	5000	5000
A_{18}	15000	15000	15000	15000
A_{19}	20000	20000	20000	20000
A_{20}	10000	10000	10000	10000
A_{21}	5000	5000	5000	5000
A_{22}	25000	25000	25000	25000

In this case also the preferences are exactly the same like in previous model. Moreover in this case we the vector of the profit margins and vector of ceiling prices for all task in the project. This information are given in Table VII and Table VIII respectively.

TABLE VII
PROFIT MARGINS

subcontractor 1	subcontractor 2	subcontractor 3	self
30%	35%	40%	20%

TABLE VIII
CEILING PRICES

activity	ceiling price
A_1	3200
A_2	16000
A_3	4800
A_4	12800
A_5	12800
A_6	8000
A_7	2400
A_8	28800
A_9	24000
A_{10}	20000
A_{11}	6400
A_{12}	4000
A_{13}	3200
A_{14}	3200
A_{15}	3200
A_{16}	3200
A_{17}	8000
A_{18}	24000
A_{19}	32000
A_{20}	16000
A_{21}	8000
A_{22}	40000

The values of assignment matrix A are given in Table IV.

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TABLE IV
ASSIGNMENT MATRIX

activity	subcontractor 1	subcontractor 2	subcontractor 3	self
A_1	0	0	0	1
A_2	0	0	1	0
A_3	0	0	0	1
A_4	0	0	1	0
A_5	0	1	0	0
A_6	1	0	0	0
A_7	0	0	0	1
A_8	0	0	1	0
A_9	0	1	0	0
A_{10}	1	0	1	0
A_{11}	0	1	0	1
A_{12}	1	0	0	1
A_{13}	0	0	0	1
A_{14}	0	0	1	0
A_{15}	0	1	0	0
A_{16}	1	0	0	0
A_{17}	0	0	0	1
A_{18}	1	0	0	0
A_{19}	0	0	0	1
A_{20}	0	0	0	1
A_{21}	0	0	0	1
A_{22}	0	0	0	1

With such a task distribution we obtain the total cost of the project $K_C = 231050\$$ and the total duration $T_C = 259$ days. Finally, the total profits of the project equals 1850$.

IV. CONCLUSION

In this paper we consider two different contract types: the fixed price contract and the cost-plus contract. For both of this contract types we have presented a theoretical approaches for selecting subcontractors to develop selected tasks in the project. Even though the fact that each of the models relates to a completely different type of contact they are similar to each other. In the presented models, it is possible that such a division of labor is part of the job was done by the contractor itself and part by the subcontractor. Moreover, the presented models takes into account both preferences and constraints contracting authority in relation to the number and type of tasks that should be or cannot be done by one subcontractor. The usefulness of both of these models has been presented with an embodiment of the software development project. For this simple example we present the principle of each of the models and the differences between them. However, the exploration of the possibility of applying both of this models in real-life conditions requires further studies, both theoretical and practical on the basis of the real-life decision-making problems. The problem of optimal choice of the contract type (the fixed price contract or the cost-plus contract), according to the project environment and risk transfer policy, will be the subject of the future research.

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