Review of EPC Projects Cost Estimation and Minimum Error Technique Introduction

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Abstract— One of the most influential factors of why a project becomes successful is estimating the cost. Though there are bidding and auctions held in my country, Iran, based on the cost estimation, they end costing an arm and a leg because of inappropriate cost estimations. To avoid cost overrun, there should be a cost estimation approach to minimize the risk, errors associated with techniques and to provide the most appropriate usages to be applied in all EPC projects. Here, the techniques measuring these standards and goals are applied and studied based on the scope of PMBOK and PRINCE 2 standards. Analogous, bottom-up and parametric approaches were used to stochastic and deterministic modeling. Stochastic models were simulated with Monte Carlo process. The results helped to comparisons of three approaches with utilizing the qualitative and quantitative criteria and MCDM and finally best cost estimation approach is selected.

Keywords— Project Management, Cost Estimation, MCDM, Minimum Error Approach

II. REVIEW OF THE PREVIOUSLY CONDUCTED RESEARCHES INTO THIS FIELDS

A. The applied approaches for practicing the cost estimation

Though there were some interests in measuring the cost prior to the project before, our main focus is on today, especially after 2000, when two researchers in England, Fitzgerald and Akintoye, named the main reasons of being careless in cost estimations[2]. Wallace and Jogensen proposed an algorithm for simulating the overall cost (2000)[3]. Wang proposed a model to identify the rational sale of a project using the SIM-UTILITY method for simulating cost estimation [4]. M. Elkjaer also proposed a stochastic budget simulation approach [5]. In the U.S., Flybjerg and others understood the costs in transportation project are estimated considerably low because of political and psychological aspects (2002)[6]. Nassar and others used Statistical process control (SPC) (2005)[7]. In Australia, Pasco and Aibinu found the manufacturing is mainly influenced by project size in Australia (2008)[8]. Later in 2010, Hemanta Kumar Doloi devised a meaningful model SSM to create a standard for comparing the realistic situations (2010)[9]. In 2011, Xiangbai Gu in ‘Hierarchy probability cost analysis model incorporate MAIMS principle for EPC’ introduced HICP model, regarding to MAIMS principle[10]. Meanwhile, since the deterministic value method does not compute the risks in a project efficiently, analyzing the risks has gained a remarkable amount of interest. In 2011, Juisheng Chou applied Monte Carlo simulation to estimate the costs[11].

American National Standards Institute(ANSI), as an international and remarkable standard, propose impeccable hints to calculate the cost during running a project, which deals with the project like a live entity.

B. Practice standard for project estimating

Principles underlying the life cycle stages of project estimating include prepare to estimate, create estimates,
manage estimates and improving estimating process[12]. Baseline is an approved plan for a project, plus or minus approved changes. It is compared to the actual performance to determine if performance is within acceptable variance thresholds[13].

The stages of project estimating can be seen in the context of the project life cycle structure. Figure 1 shows that there is some overlap of project estimating stages within the project life cycle[14]. The process considered in this research specified separately by blue color.

While the estimating life cycle stages are the same for all types of projects, there are some differences in estimation metrics and models that are employed across industries. These variations are primarily related to the nature of the project's product[16].

C. PRINCE2 INTRODUCTION

PRINCE2 focuses on the products to be produced by a project, not the processes to produce them[17]. PRINCE2 gives a pragmatic tool through which one can put the flesh onto the introduction of PRINCE2. The perspectives PRINCE2 deal with are the PRINCE2 process model, the PRINCE2 components, the PRINCE2 principles and the PRINCE2 documents[18].PRINCE2 offers only a few techniques. You may already gave a technique that is satisfactorily covering that need. The exception is the product-based planning technique[19]. Because of this attitude of PRINCE2, the techniques introduced in it are not considered in this paper.

D. Getting to know Pertmaster[20]

Pertmaster allows definition of both a riskless program and a program with different aspects of risks. Moreover, it can be applied different tools, like Monte Carlo simulation. Using the project risk analysis allows the possibility of accomplishing a project in a certain time and with a certain budget to be measured. A program only shows one plausible way for accomplishing the project without risk analysis; however, using the risk analysis allows us to evaluate different outputs and ways of accomplishing a project. It should also be noted the most practical distribution for simulating time and cost of an activity is the triangle distribution.

E. Mean Squared Error, the least flawed approach[21]

MSE is a risk function and measures the mean square of errors. The mean squared error (MSE) of an estimator is one of many ways to quantify the difference between values implied by an estimator and the true values of the quantity being estimated. MSE is the second moment of error and both estimated variance and diagonal variance surround it. The lowest square root or root-mean-square deviation is the typically used amount for measuring the defined deviations above.

MSE and RMSE for the estimator \( \hat{\theta} \) which estimated the parameter \( \theta \) are defined as follow:

\[
MSE (\hat{\theta}) = E[(\hat{\theta} - \theta)^2]
\]

\[
RMSE (\hat{\theta}) = \sqrt{MSE (\hat{\theta})} = \sqrt{E[(\hat{\theta} - \theta)^2]}
\]

III. EXPLAINING THE STUDIED PROJECT AND SIMULATION ANALYSIS

EPC project of an electrical substation in different voltages of 400KV, 360KV, 230KV and 132KV and extension of 66KV is created. Electrical substations are created to transform the high voltage flowing through the lines into low voltage used in the industries. The finally transformed voltage cannot be used for domestic consumers and another transformation is required to make it useable for them. These substations are divided into outdoors and indoors.

Here in this paper, 20 electrical substations were studied under the same circumstances. By 'under the same circumstances', we mean the designs, equipment supplies, buildings and installing the equipment were same with the same time intervals, resulting in planning and doing the projects with the same costs. In the implementation phase, the actual costs of doing a project differs because of the different reasons and situations which are not under control of the organization. Here, we applied the mean distribution of the actual costs in measuring the MSE.

A. The primary data of the project for preparing the estimation

At first, the primary data of the project should be obtained to use the aforementioned techniques. The entries for practicing the estimations win this project were gathered from the experts and project managers. It should firmly be noted that all the following data, assumptions and stated points were entered into the software the same, because the primary data should be the same for all points to compare the data (because of having more homogeneous and valid outcomes of comparing different techniques). Moreover, the WBS level was chosen to highlight the limits of estimation, regarding to Xiangbai Gu research in 2011.

1. The scheduling of activities were considered as same as the similarly conducted project.
2. the links between activities considering predecessors and successors are demonstrated via FS (Finish to Start) - SS(Start to Start ) - FF (Finish to Finish).Then, press short F 9 key to create the primary schedule structure.
3. The required sources of the projects in the engineering sector (E) include the expert work force and the designing work force were predicted similar

Figure 1. Relationship of the Estimating Life Cycle[15]
to the previously conducted projects. In the procurement sector (P), expert human resource and the budget resource were predicted. In the construction sector (C), since this sector is done outsource, the mateDollars and machines were considered as limitless.

4. The risks in this project was considered as follow:
   - the time risk for all activities was considered.
   - the resource risk for the activities in the procurement and construction sectors was considered, because there is need to use a resource except the expert human resource. Therefore, this risk is not considered for the engineering sector, as there are sufficient numbers of human resource.
   - The contingencies relevant to the physical situation and local conditions of the project are influential; thus, a coefficient in the costs as contingency reserve was considered.

5. In this project, it was assumed that the resource calendar was definite and limitless, and all the resources were available due to the working calendar.

6. It was assumed that there are all the quality documents, like ISO1000, ISO9001and HSE, and organization properties, such as processes, instructions and procedures which have to be done so that the organization process becomes assuring, regarding to this organization work.

7. The correlation between the activities (risks) can be an amount from -100% to +100%. When the prolonging of one activity affects the other one and makes the activity longer, the correlation between them is considered as positive. By adding the correlation to the project avoids planning in an unrealistic condition significantly. The correlation can be computed by estimation. At any situation, this amount has been measured between correlated activities in a team consisting of professional experts. When the correlation coefficient is identified in the software, it calculates the correlation amount relying on Pearson and Spearman correlation.

8. The assumptions in this project are as followed:
   - The activities are definite and probabilistic or risky activities are not considered.
   - The links (the predecessors and successors) are not probabilistic, but definite.
   - The calendars are definite and there is no probable calendar.

To create the model of the estimation, it is decided to make the introduced work breakdown structure thresholds, in which the estimation is calculated via its thresholds transparently. Considering all the aforementioned principles and assumptions, the models were created in Pertmaster software. After receiving the entry data for practicing the cost estimation, it is necessary to clarify the estimation approach relying on the available information. Since it is possible that different data is required to use different approaches, which may not be available in this phase, clarifying the estimation approach limits the approaches which can be chosen.

Here, we tried to use all the mentioned approaches in PRINCE2 standard and Practice standard for project estimating in PMI, elaborated sufficiently in the theatrical principles. And among them, the one which shows the most appropriate and accurate results for estimation was chosen and we hope it will be applied in the future estimations.

B. Practicing estimation approach

In this process, the following steps should be done relying on accessing to the previously identified entries
   - Define the estimation threshold for the project.
   - Consider the points which should be updated during accomplishing the project.
   - Plan the contingency reserves.

Based on the following proposed theoretical principles, different models for practicing the estimation in different projects were defined. Some models are only effective in one project, as any project cannot be modeled via them. Some models are not general enough to cover all the considered points in the cost estimation. Some models are merely used for the definite estimation practice, while others are not accurate enough to be applied in indefinite estimation practice. In this paper, we tried that the chosen model to be a general approach as much as possible; meaning, it can be modeled in all projects. Moreover, the chosen approach was tried to be accurate and in the estimation management process can be controlled after running the project. Hence, the three common approaches for estimating including all standards were used, after we had studied and evaluated different models. They are Analogous, bottom-up and parametric cost estimating approaches. To practice the estimation via applying each approach, the practice confine is different.

C. Contingency Reserve analysis

Contingency reserves are estimated costs to be used at the discretion of the project manager to deal with anticipated, but not certain, events. These events are "known unknowns" and are part of the project scope and cost baselines. This type of contingency reserve is defined based on the chosen approach.22

In the analogous and bottom-up approaches, all the known unknowns are defined in the Pertmaster as risks. But in the parametric approach, the contingency reserve is considered as 3% of the total estimated cost of the project due to its definite estimation. This number was defined in PMO.

There is another type of contingency reserve, called as 'management contingency reserves'. They are budgeted reserved for unplanned, but potentially required, changes to project scope and cost. These are "unknown unknowns" and the project manager must obtain approval before obligating or spending this reserve. Management contingency reserves are not part of the project cost baseline, but included in the budget for the project[23]. Here, the management contingency reserve for all techniques was defined.
D. Analogous approach

In this method, a combination of three points estimation and coefficient estimation was used. In this technique, for all activities of third level of WBS, the costs, taken from the similar project, were considered as most likely costs of the project with consideration of 30% inflation ratio. Then, professional experts were asked to estimate the lower and higher costs than the most likely ones as 'optimistic costs' and 'pessimistic costs'. Moreover, the most likely costs were balanced by these experts.

In this project, some activities did not have the previous documentations; therefore, coefficient was applied to estimate them. In the coefficient estimation different coefficients, like local coefficients, and other coefficients in the price list were used[24]. When analogous approach was applied, because of the estimation practice of likelihood, the contingency reserve for all of them was considered.

To practice the estimation using the analogous technique, the third level of WBS in the Pertmaster was defined. This is because the ability of Pertmaster to analyze the time and cost risk simultaneously. Using the project risk analysis, the possibility of finishing project is defined at the determined time and cost. To apply analogous, at first, we entered the most likely cost into the software and applied all the available risks, based on what defined in 3-1-4. The triangle distribution was used for entering the time and cost risk in the Pertmaster, which is recommended as the most applicable distribution for all stochastic simulations.

The analysis iterations must be at least 76,833, regarding to an article Jui-Sheng Chou by (2011). Hence, the iterations in this project were set at 80,000 and then the simulation was run. The data provided by the software in terms of cost project simulation based on the analogous technique are shown in table 1.

<table>
<thead>
<tr>
<th>Cost of Entire Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis</td>
</tr>
<tr>
<td>Iterations:</td>
</tr>
<tr>
<td>Statistics</td>
</tr>
<tr>
<td>Minimum:</td>
</tr>
<tr>
<td>Maximum:</td>
</tr>
<tr>
<td>Mean:</td>
</tr>
<tr>
<td>Bar Width:</td>
</tr>
<tr>
<td>Highlighters</td>
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<tr>
<td>Deterministic</td>
</tr>
<tr>
<td>(44,700,000,000)</td>
</tr>
<tr>
<td>50%</td>
</tr>
<tr>
<td>80%</td>
</tr>
</tbody>
</table>

Table 1: Total cost using analogous estimation

The average costs required for finishing the project, or the cost which all activities with all of their probabilities are done, is 45,448,725,024 Dollars. The followings are two possibilities which are the most important ones in statistics analysis, regarding to the software suggestion:

- What is the total cost of finishing a project at the probability of 50%? 45,448,725,024 Dollars
- What is the total cost of finishing a project at the probability of 80%? 46,723,737,699 Dollars

Figure 2: Cost distribution using analogous estimation

Now, by looking at the graph, we can identify the probability in which the project with the primary estimated cost was finished without considering the cost risk. This cost in the second figure is 44,700,000,000 Dollars. It can be implied the project will finish with the probability of 32%, a low probability, and the primary definite estimation, without considering the contingencies, if we look at the yellow line. The other conclusion reached by the carried out analysis is the project with the probability of 0% is the project cannot be ended at any cost lower than 40,975,600,326 Dollars.

E. Bottom-up approach

It allows to estimate the consumption amount of each source in the project details, and then these estimations are added together to measure the middle levels and all levels of the project, which produces a clear and structure-based estimation. The requirements of this approach are list of the works in which activities are defined and detailed specifications of the project.

In the bottom-up approach, the three points estimation or PERT can be used instead of single point estimation at both levels of activity and work package. Consequently, after adding the estimations at project level, a more accurate and clear picture of all the required works and costs for the project is computed, helping to have a more accurate control[25].

To apply this method, at first, WBS of the project was entered in the Pertmaster to the level 4. The times and links based on the project management team's view and experience are defined and entered in the software. Then, the identified sources based on 3-1-3 are coordinated with the activities and the intended risks at different sectors are entered. Finally, the identified sources are added at project level, a more accurate and clear picture of all the required works and costs for the project is computed, helping to have a more accurate control[25].
products made from subproducts are correlated with the time risk of producing them

- The time risk of construction engineering is correlated with its performance time risk.
- The time risk of fundamental executive constructing activities is correlated with the time risk of installing equipment.

When the bottom-up approach was applied, due to the practicing statistical estimation, the contingency reserve for all contingencies was considered and there is no need to recalculate it. The results of simulation are shown in the table 2. In terms of risk analysis, the cost distribution was shown as follow:

<table>
<thead>
<tr>
<th>Cost of Entire Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis</td>
</tr>
<tr>
<td>Iterations: 80000</td>
</tr>
<tr>
<td>Statistics</td>
</tr>
<tr>
<td>Minimum: 44,018,311,081</td>
</tr>
<tr>
<td>Maximum: 47,868,584,497</td>
</tr>
<tr>
<td>Mean: 45,910,291,597</td>
</tr>
<tr>
<td>Bar Width: 250,000,000</td>
</tr>
<tr>
<td>Highlighters</td>
</tr>
<tr>
<td>Deterministic (45,889,126,218) 49%</td>
</tr>
<tr>
<td>50% 45,909,345,686</td>
</tr>
<tr>
<td>80% 46,378,649,779</td>
</tr>
</tbody>
</table>

The average costs required for finishing the project, or the cost which all activities with all of their probabilities are done, is 45,910,291,597 Dollars. The followings are two possibilities which are the most important ones in statistics analysis, regarding to the software suggestion:

- What is the total cost of finishing a project at the probability of 50%? 45,909,345,686 Dollars
- What is the total cost of finishing a project at the probability of 80%? 46,378,649,779 Dollars

Now, by looking at the graph, we can identify the probability in which the project with the primary estimated cost was finished without considering the cost risk (figure 3). This cost in this graph is 45,889,126,218 Dollars. In this graph, the probability is precisely shown 48% in the left side, which implies the project will finish with the probability of 48% and the primary definite estimation, without considering the contingencies, if we look at the yellow line.

The another conclusion reached by the carried out analysis is the project with the probability of 0% is the project cannot be ended at any cost lower than 44,018,311,081 Dollars.

In parametric approach, a definite model is devised by using the links between previous data and other variables for estimating the cost of an activity. The cost of activities can be computed either by multiplying the required work amount by the time length or by its cost in the previous projects. The required work amount in this project is defined as follow:

- The previous data used in the prepared model are accurate.
- The applied parameters in the model have the ability of being quantitative.
- The prepared model is capable of being measured in order to be applied for project with lower scale, as it can be applied for projects with larger scale.

F. Parametric approach

Using this approach allows to estimate the details of fourth and fifth level of WBS.

The accuracy of this approach is highly valid and reliable, when the following criteria are met:

- The average costs required for finishing the project, or the cost which all activities with all of their probabilities are done, is 45,910,291,597 Dollars.

G. Identifying the best approach for estimating the project cost (EPC)

Three processes, create schedule model, prepare to estimate and create estimates were applied so far. In three approaches, analogous, bottom-up and parametric, were applied for practicing the EPC of electrical substations. To find out all results of each approach, we should know which one had the lowest error. As mentioned previously, mean squared error (MSE) is the best approach to do so; therefore, by applying this in the research, the following RMSD(θ) for all estimators are shown in the table 3.

Table 2: mean squared error

| RMSD(Analogous) | 942,681,976$ |
| RMSD(Parametric) | 637,430,353$ |
| RMSD(bottom-up) | 481,115,408$ |

According to the comparison between the estimated costs amounts via different approaches and the actual cost of the 20 previous projects, it can be concluded that which approach was the most accurate one. Moreover, other factors for an appropriate estimator can be defined except the deviation, which are as follow:

1. the Root-Mean-Square Deviation
2. Being user friendly
   2.1 the approach should not be sophisticated.
   2.2 the size of entries should be appropriate or not too much.
In this article, the possible approaches were simulated using the bottom-up and analogous approaches. They were simulated for 80,000 times in the Monte Carlo simulator inside the Pertmaster software, and their probable results were achieved. In addition, the definite estimation using parametric approach was carried out and the definite estimation of that was computed. In another step, the deviation of all estimators from the realistic project information using the root-mean-square deviation was computed. The results show the bottom-up cost estimation approach had lowest deviation comparing to the actual data. Moreover, by considering the other factors besides RMSD in the AHP group decision making approach, the most appropriate approach for estimating the costs in EPC project was bottom-up cost estimation approach. This approach in the weighted deviation was also the best. It should also be taken into account that parametric approach in comparison with others was the best approach for managing the earned value in terms of controllability. However, it was weaker in terms of risk coverage standard and MSE than the bottom-up.

B. Suggestions

First, it is worthy to find out the most appropriate approach for managing estimation, because being unsure means a limit for the baseline of project budget. Hence, estimation management is obscure in terms of the probable estimations.

Next, as one of the major problems of project-oriented organizations is measuring the being thrifty in spending, the actual cost of each sector and the baseline can be computed by estimating the costs in each sector of the project by the expert team of the same sector. Finally, measuring the deviation by the expert in each sector allows the calculation of the expenditure and the cost conservation in each sector.

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REFERENCES


[22] Project management institute, PMBOK, 166
[23] Project management institute, PMBOK, 169