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COMPARATIVE COST ANALYSIS OF DIFFERENT THERMAL POWER PLANT PROJECTS

MUHAMMAD SAIFUL ISLAM[1] and LAITH A HADIDI[2]

[1]Project Management Discipline, School of Engineering and Technology, Central Queensland University, Melbourne, Australia
[2]Dept of Construction Engineering and Management, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

Realistic budgeting for complex power plant projects is important for informed investment decisions and avoiding frequent cost overruns. Comparative cost analysis thus provides significant insights for future projects' investment decisions. This study analyzed the project costs using a regression analysis and Monte Carlo Simulation (MCS) guided by the error analysis for Combined Cycle Power Plants (CCPP) and Natural Gas (NG)-based power plants. The regression analysis shows the cost trend lines with the prediction equation and its R^2 value against production capacity in Mega-Watts (MW) of power plant projects in Bangladesh. The MCS presents the cumulative probability function (CDF) and probability density function (PDF) of unit cost in Million U.S. Dollars (MUSD)/MW of both types of projects. The results show that the NG project costs are higher than CCPP power plant projects, where the most frequent project development cost is in a range of 1.01-1.25 MUSD/MW, comparing 0.95-1.15 MUSD/MW of CCPP projects. Among the models, the MCS performs better than the regression model predicting project costs. Finally, MCS is demonstrated in predicting the cost of both types of power plant projects. The study outcomes will assist decision-makers and policy planners in further investment decisions in the power plant and similar infrastructure projects in Bangladesh and economically similar countries.

Keywords: Investment decision, MCS, Realistic budgeting, Regression model.

1 INTRODUCTION

Bangladesh, a South Asian developing country, has invested huge capital for power generation projects towards uninterrupted electricity supply for its people. Almost 90% of its projects are based on natural gas (Shukla *et al.* 2017). The combined cycle power plant is also based on natural gas, where steam as a by-product is recycled for power generation. Some other power plants (completed or in progress) are supported by coal and heavy fuel, including nuclear plants and hydro and wind power plants (Guide 2017). The power plant project cost analysis is an essential step at the preliminary budgeting for a well-educated policy planning and budgeting towards investment decision considering available fuel supply, geological features, environmental conditions, and safety (Islam 2019). However, frequent cost overruns and comparatively a huge cost for power generation puzzles this vision (Sovacool *et al.* 2014).

Previous studies regarding Bangladesh power generation projects cover cost overrun risk studies, contingency prediction, cost modelling (Gazder *et al.* 2020, Islam *et al.* 2018, Islam *et al.* 2019). However, comparative cost scenario analysis is yet to discover for assisting further investment decisions. Thus, this study aims to analyze the cost profiles of different power plant projects in Bangladesh with regression analysis and MCS. The study scope is limited to CCPP and natural gas projects in Bangladesh as these projects are the most frequent in the race of fulfilling the country's energy demand. While this study focuses on Bangladesh power plant projects, the approach of developing MCS model can equally be applicable for other public funded infrastructure projects with similar characteristics. Besides, as some South Asian countries (India, Pakistan, Sri Lanka, etc.) are building similar thermal power plant projects (Shukla *et al.* 2017) and have similar project delivery methods and funding approaches (combination of external (Asian Development Bank (ADB), Islamic Development Bank, World Bank etc.) and internal sources) (Bank 2020, Nataraj 2007), they can be benefitted from this model. Additionally, many international contractors from China, India, and some parts of Europe are the construction partners of Bangladesh Power Development Board (BPDB), they can also be guided about the project costs from the study. The remainder of this paper consists of the literature review of relevant studies finding a research gap, methodology, result and discussion, and conclusion with recommendations to the field professionals and policy planners in Bangladesh.

2 LITERATURE REVIEW

Thermal power plants are the most common energy sources globally, primarily based on natural gas, oil, and coal (Hans-Wilhelm 2016). Also, the projected energy demand for the next twenty-five years shows the world's dependency on thermal plants instead of having serious concerns about shifting to renewable energy (Singer and Peterson 2017). Despite the commonness of thermal power plants, the successful provision of this infrastructure is affected by significant cost overruns (Sovacool *et al.* 2014). Therefore, cost estimation accuracy is the first step to reducing cost overruns. It enables better cost performance of thermal power plants, hence, lead to more thermal power projects procured at optimum budgets to increase energy access globally. The MCS simulation is a widely used and suggested tool for estimating project cost addressing uncertainties in its execution phases by both academic (Chang and Ko 2017) and professional organizations, including the USA (Nevada DOT 2012). Allahi *et al.* (2017) presented an MCS-based cost contingency prediction model considering risk probabilities and developed probability distribution for contingency costs encountered in railway projects. Chang and Ko (2017) also developed an MCS-based integrated risk assessment and cost prediction approach. They demonstrated for modeling net present value (NPV) and time-dependent revenue considering the cost impact of risks.

In a recent study, Islam *et al.* (2021) predicted contingency costs of TPPPs considering associated risk toward cost overruns introducing a fuzzy-Bayesian approach. However, cost simulation considering real-life projects' cost data for TPPPs in Bangladesh is yet to be discovered supporting budget approval for future power plant projects. This particular research gap motivates the author to discover unit cost per MW of power plant projects through linear regression model and MCS for a better comparison and informed decision making in further investment.

3 METHODOLOGY

3.1 Data Collection

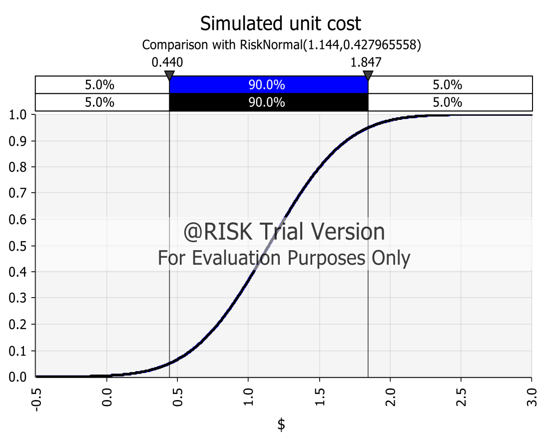
This study collected data from 37 CCPP projects ranging from 100 to 680 megawatts (MW) and 25 NG projects ranging from 50 to 660 MW from the Bangladesh power generation industry (BPDB 2020). Since the study used MCS for cost modeling, the minimum sample size should be 25 to 30 suggested in the previous similar studies (Chou 2011, Allahi *et al.* 2017). Some specialized project-based studies used close to 30 data sets for MCS-based cost modeling. For instance, Chang and Ko (2017) used cost data of 34 sewerage projects, and Maronati and Petrovic (2019) used cost data of 32 nuclear power plant projects for MCS-based cost simulation. Thus, the sample sizes for this study (37 CCPP and 25 NG projects) are justified. The cost data with corresponding project features were collected by project documents study available in the Bangladesh Power Development Board (BPDB)'s official website and also interviewing project personnel.

3.2 Modelling Techniques

Two types of cost prediction models, regression and MCS, were used to model power plant project costs. The regression models were developed by excel, and the MCS was done by adding Palisade's @Risk Software (free trial) in excel. The X-Y graph was plotted towards developing the regression model where the x-axis (independent variable) stands for power generation capacity and the y-axis (dependent variable) for corresponding project cost. The regression model shows a first-order equation for predicting project cost where the variable is designed to power generation capacity. For MCS, the unit costs of CCPP and NG projects were calculated by dividing the estimated project cost by the designed power generation capacity of a project. Afterward, the unit costs are simulated, assuming that the cost data are normally distributed. The MCS was also used to predict the estimated cost of two power plant projects taken from each type based on power generation capacity. The selected projects are the most frequent sized (MW) power plant projects among their domain.

4 RESULT AND DISCUSSIONS

The data of both project types were separately analyzed. The MCS was run for 5000 iterations to reach consistent outcomes. Figure 1 shows the cumulative distribution faction (CDF) of NG projects, and Figure 2 shows the CDF of CCPP projects. It is observed that if the cost per MW of an NG project is MUSD1.847, then 90% of projects will be completed with this cost rate. On the other hand, if the cost per MW of the CCPP project is MUSD1.573, 90% of projects will be completed with this cost rate. Figure 3 shows the unit cost probability density function (PDF) of NG projects, where the most frequent cost ranges from MUSD 1.05 to 1.23, and 90% cost probability is in the range of MUSD0.44 to 1.847. Figure 4 shows the unit cost PDF of CCPP projects, where the most frequent cost ranges from MUSD 0.95 to 1.15, and 90% cost probability is in the range of MUSD0.616 to 1.573.



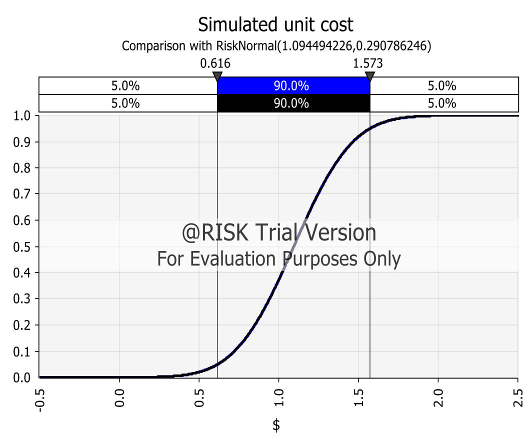


Figure 1. NG projects' CDF for the unit cost (MUSD). Figure 2. CCPP's CDF for the unit cost (MUSD).

The most frequent project size among NG projects was 100 MW projects. Thus, the cost of 100 MW was predicted using MCS (the figures are not shown due to space limitation). Towards cost prediction of 100MW NG project, the input was 100*(lower least unit cost within 90% limit+4*mean unit cost+Upper least unit cost within 90% limit)/6. The concept was taken from the Program Evaluation and Review Technique (PERT) method. Then, the project cost was simulated by 10,000 iterations. It is observed that in 90% of cases, the project cost ranges from USD72.2 to 128.3. The real-life cost data shows that the 100PW project's cost ranges from MUSD 93 to 142.7, with a standard deviation of MUSD17.04. The simulated result is almost equal to the mean ±first standard deviation. Thus, the MCS provides excellent cost prediction outcomes for 100MW NG projects. The most frequent project size among CCPP projects was 225 MW projects. Thus, the cost of 225 MW was predicted (the figures are not shown due to space limitation). In 90% of cases, the project cost ranges from USD131 to 439. The actual costs of the 225MW projects were ranged from USD 200 to 450, and the average cost was MSUD 285.25. Our simulated cost shows that the peak cost for this size project is MSUD 290. Thus, the MCS result for CCPP 225PM projects is also very close to the real cost of 225MW projects.

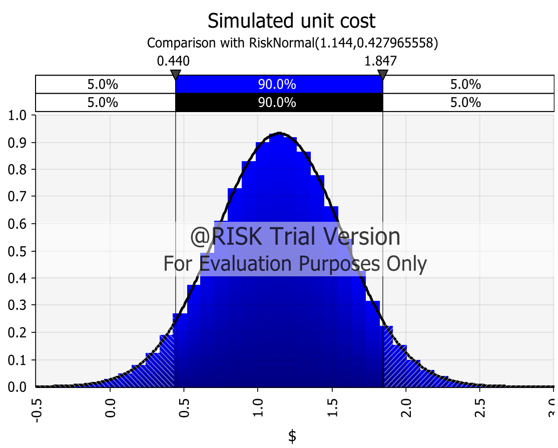


Figure 3. PDF for Unit cost of NG projects.

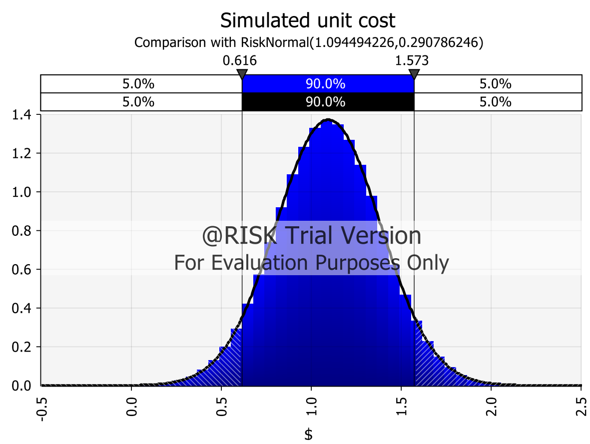


Figure 4. PDF for Unit cost of CCPP projects.

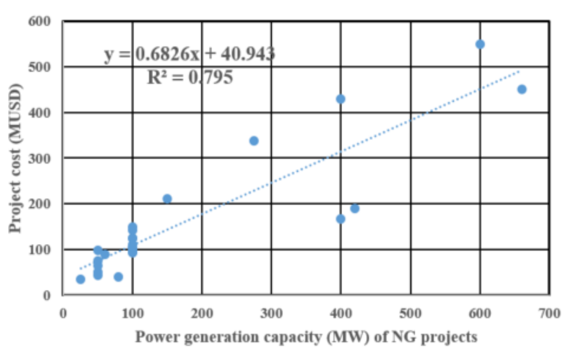


Figure 5. Regression model for the NG projects.

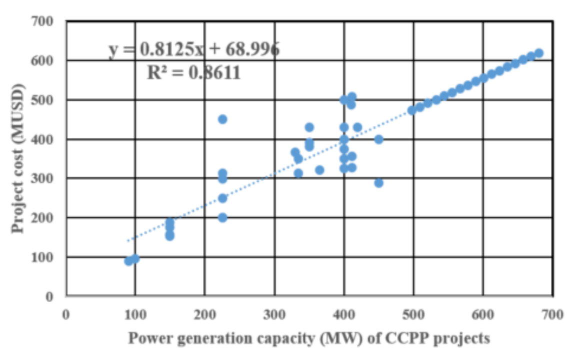


Figure 6. Regression model for the CCPP projects.

This study also develops the regression models of NG and CCPP projects, shown in Figure. 5 and 6 respectively. The comparative outcomes of regression models for both types of projects show that the model is best suited for CCPP projects with an R^2 value of 0.86. Alternatively, it can be explained that the regression model for the CCPP project will be successful 86% time to predict a CCPP project cost. On the other side, the R^2 value for the NG project is 0.795, which means the model can be successful for 79.5% of cases predicting an NG project cost. The lower performance of NG projects' regression model would be the reason for not having enough data from past similar projects.

For error analysis, this study considers regression outcome for cost prediction of all NG and CCPP projects and compared with the actual costs finding the mean square error (MSE), root MSE (RMSE), and mean absolute percentage error (MAPE). Further, the PERT concept was adopted to find the unit cost from the simulated results. It means the lower likely and upper likely unit costs of 90% confidence level for each project are considered lower least likely and upper least likely successively, and the mean unit cost is considered the most likely value. Then PERT is applied to find the unit cost per MW construction for both project types. That unit cost is multiplied by the designed power plant capacity to predict the project cost. Following that, the predicted costs of all projects are compared with the actual estimated cost to find the errors. The error analysis results are present in Table 1. Table 1 shows that the cost prediction performance of CCPP projects is better than NG projects for both models, and MCS performs better than the regression model for both project types.

Table. 1. Error analysis of Regression and MCS outcomes for both types of projects.

Project type	**Model**	**MSE**	**RMSE**	**MAPE (100%)**
NG	Regression	1687.237	41.076	61.478
NG	MCS	745	27.297	43.323
CCPP	Regression	4580.049	67.676	23.345
CCPP	MCS	5780	76.032	22.116

The MCS models are developed based on the cost data of real-life power plant projects funded by BPDB, Bangladesh government, and some international fund donors like Asian Development Bank, World Bank, and Islamic Development Bank. The fund sources and project development and management are almost similar for other infrastructure projects such as bridge, flyover, tunnel, metro rail projects etc. the Bangladesh government currently focuses on these projects for frequent and fast development. Since project development and management structure are similar to these projects (Islam *et al.* 2018), thus, this model development approach will assist practitioners in cost modeling of those infrastructure projects in Bangladesh. This study can also be useful for economically similar developing countries, in which multiple fund donors and public funds are the major sources of infrastructure development. Besides, mostly international contractors and consultants are involved in the design, procurement, and construction of complex infrastructure projects under Engineering, Procurement and Construction contract in Bangladesh and similar developing countries (Nataraj 2007). Therefore, this study will also assist them in realistic budgeting and bid price negotiation.

5 CONCLUSION

The regression analysis and MCS approaches are well-accepted tools for cost prediction under certain conditions. This study develops regression models for NG and CCPP projects by collecting cost data from Bangladesh power plant projects. Further, the unit costs of both types of power plant projects are modeled by the MCS approach, assuming that the cost data are normally distributed. Finally, the costs of two frequent sizes power plant projects taking one size from each type were predicted to demonstrate the performance of MCS for cost prediction. The result shows that MCS performs better than regression models. Besides, the unit cost of CCPP projects is found lower than the NG projects. This study is a first step towards modeling the costs of power plant projects in Bangladesh. The model can be applied to estimate other infrastructure projects in Bangladesh and economically similar countries. The international contractors working for power plant and other infrastructure projects in Bangladesh can also be benefitted from this study's outcomes. However, a more detailed analysis with quantitative data considering critical risks associated with projects is recommended for the model's broader applications. This is, in fact, the author's future research plan.

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