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Modelling of total cost of process plants in ghana

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ABSTRACT

Cost estimation models are used to prepare initial estimates of the cost of new engineering projects or revamping of existing projects. In this study, cost estimating model for the installation of processing plants in Ghana is developed. Simplex algorithm method for linear programming is applied to obtain a model for the total cost of installing processing plants in Ghana. Using the purchased equipment cost as the main cost factor, it is shown that the total cost of process plants is related to the purchased equipment cost.

KEYWORDS

Cost factors;
Cost estimation models;
Decision variables;
Objective function;
constraints.

INTRODUCTION

At an early stage after the conception of a new process route or when a new or extended production facility is contemplated, the engineer will have to prepare a quick appraisal of costs. The first steps in the preparation of a preliminary cost estimate (both for new capital and for manufacturing cost) is to lay out a process flow sheet showing all the major items of equipment, including flow lines and instrumentation. The heat and material balance is computed to know temperature, pressure and stream composition.

The second step is to calculate the size and shape of the pieces of equipment and to specify the materials of construction. After the first two steps have been completed a good deal of technical information would have been gathered. A technical evaluation should always accompany the economic evaluation.

The last, but not the least, step is making a preliminary cost estimate and this consists of two parts:

i) Estimate the purchased costs of all the equipment shown on the flowsheet and the installed cost of the complete plant,
ii) Estimate the manufacturing cost of the product from the process heat and material balances and the cost of raw materials, utilities, labour and depreciation.

A lot of methods exist in literature for the estimation of such preliminary costs. Since cost trends in any two different countries are different and the fact that these methods have been developed with cost data from a particular country, their application in another country gives figures that are unrealistic. Thus an engineer, who uses such methods, has to go through the tedious work of adjusting the cost to make it meaningful to an investor.

The costs of process equipment normally change with time. Many attempts have been made to correlate equipment costs with some economic indices, which would reflect this change with time. The most widely known index in the process industry is the *chemical engineering plant cost (CEPC) index*, which is published regularly in the *chemical engineering magazine*.

Detailed estimates are usually required to enable contractors to make a firm commitment to their clients and therefore have to be estimated to a greater accuracy than for any other purpose. A considerable amount of engineering design work will be necessary to prepare this type of estimate and very significant costs can be incurred in the preparation of the required information.

Most of the costs estimating methods in literature depend on the fact that the total installed cost of any process plant is a function of the cost of several items. These items include:

Purchased equipment, b) Purchased equipment installation, c) Instrumentation and controls,

d) Piping, e) Electrical, f) Civil works, g) Construction, h) Engineering and supervision, i) Contingency

These methods start with a purchased equipment cost, apply various factors to that cost to estimate the costs of material and labour required to insert a particular piece of equipment into a functioning plant, and then add all the factors together to obtain a material and labour factor that will convert the purchased equipment cost into the installed equipment cost. These costs may then be added to obtain a total installed equipment cost. Thus the sum of process equipment costs, either purchased or installed, may be used to obtain a correlation of the various factors that make up the installed cost of process plants.

As a result of the problems associated with the use of existing cost models in Ghana, there is therefore the need to use local cost data for the development of a cost-estimating model that will reflect the situation in Ghana. The overall effect is to produce a good theoretical picture of the process and its economics that could be used to guide practical thinking about cost factors in Ghana. This can predict the total cost with some accuracy. This paper therefore seeks to develop a cost estimating method that is based on cost data from Ghana.

Collection of data

Fifteen companies were contacted for information on the cost of their assets.

The data is shown in the table below.

Where PE = Purchased equipment, PEI = Purchased equipment installation, IC = Instrumentation and control, P = Piping, E = Electrical, CW = Civil works, C = Construction, ES = Engineering and su-

TABLE 1

SIndustry	Costs in million Ghana cedi(Gh¢Sm)									Capital
	PE	PEI	IC	P	E	CW	C	ES	CF	Invested
1	0.37	0.04	0.03	0.06	0.02	0.02	0.02	0.03	0.03	1.29
2	0.52	0.06	0.04	0.14	0.03	0.04	0.03	0.04	0.05	1.80
3	0.84	0.11	0.12	0.14	0.30	0.15	0.14	0.14	0.20	2.92
4	1.23	0.12	0.20	0.13	0.34	0.15	0.17	0.19	0.21	4.12
5	1.75	0.44	0.21	0.37	0.34	0.19	0.10	0.14	0.23	5.70
6	2.00	0.44	0.31	0.15	0.33	0.24	0.17	0.22	0.41	6.94
7	2.5	0.58	0.35	0.24	0.56	0.25	0.30	0.23	0.46	7.98
8	3.63	0.67	0.41	0.5	0.29	0.41	0.17	0.29	0.44	12.49
9	4.74	0.99	0.93	0.24	0.64	0.34	0.32	0.43	0.53	16.61
10	6.86	1.25	1.18	0.41	0.74	0.64	0.47	0.48	2.52	24.41
11	7.81	2.34	1.01	1.07	0.57	0.61	0.42	0.65	2.41	26.98
12	8.83	3.11	1.68	1.64	0.82	0.60	0.66	0.81	2.66	27.84
13	12.75	4.86	2.68	2.58	0.99	0.68	0.91	0.84	3.72	40.87
14	16.72	6.53	4.97	3.91	1.77	1.27	1.33	0.94	4.31	56.98
15	25.18	8.62	6.23	4.17	4.67	3.39	3.67	3.84	6.55	78.67

pervision, CF = Contingency funds.

The decision variable

The problem seeks to find the characteristic factors of the various cost items that will minimize the total plant installation cost. Thus the problem is modelled by defining the cost decision variable F_j to be the characteristic factor of item j such that:

F_1 = characteristic factor of Purchased equipment cost.

F_2 = characteristic factor of equipment installation cost.

F_3 = characteristic factor of Instrumentation cost.

F_4 = characteristic factor of Piping cost

F_5 = characteristic factor of Electrical cost.

F_6 = characteristic factor of Civil works cost.

F_7 = characteristic factor of Construction cost

F_8 = characteristic factor of Engineering and supervision cost.

F_9 = characteristic factor of Contingency

Total plant cost (T)

Suppose C_{ij} is the installed cost of item j in industry i and F_j is the characteristic factor of item j, then the objective is to determine the characteristic factor, F_j, so as to minimize the total plant cost (T).

$$T = \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij}F_j$$

Where; n = number of industries and m = number of cost items.

The constraints

If Aij is the amount spent on item j in industry i and Bi is the estimated cost of putting up industry i, then the total amount spent in putting up industry i is

$$\sum_{i=1}^{n}\sum_{j=1}^{m} A_{ij}F_j$$

Since Bi is the total amount invested in a given industry i and that we seek to minimize this cost, this amount is set so as to obtain the minimum possible. That is:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} A_{ij}F_j \geq B_i$$

The total plant cost model

Since fifteen (15) industries and nine (9) cost items are considered, the model, in the form of linear programming, becomes:

Minimize

$$T = \sum_{i=1}^{15}\sum_{j=1}^{9} C_{ij}F_j$$

Subject to:

$$\sum_{i=1}^{15}\sum_{j=1}^{9} A_{ij}F_j \geq B_i$$

In matrix form, this becomes

Minimize T=

$$\begin{bmatrix}95.667 & 30.160 & 20.560 & 16.149 & 12.877 & 9.349 & 9.168 & 9.331 & 26.070\end{bmatrix}\begin{bmatrix}F1\\F2\\F3\\F4\\F5\\F6\\F7\\F8\\F9\end{bmatrix}$$

Subject to:

$$\begin{bmatrix}
0.370 & 0.040 & 0.030 & 0.060 & 0.020 & 0.020 & 0.020 & 0.030 & 0.030\\
0.516 & 0.060 & 0.040 & 0.140 & 0.030 & 0.040 & 0.030 & 0.040 & 0.050\\
0.835 & 0.107 & 0.119 & 0.149 & 0.302 & 0.150 & 0.138 & 0.144 & 0.196\\
1.229 & 0.115 & 0.204 & 0.158 & 0.338 & 0.166 & 0.168 & 0.186 & 0.212\\
1.750 & 0.440 & 0.210 & 0.270 & 0.339 & 0.190 & 0.180 & 0.190 & 0.230\\
1.996 & 0.458 & 0.309 & 0.346 & 0.344 & 0.242 & 0.188 & 0.224 & 0.414\\
2.457 & 0.579 & 0.309 & 0.346 & 0.344 & 0.242 & 0.188 & 0.224 & 0.414\\
3.630 & 0.670 & 0.411 & 0.400 & 0.609 & 0.480 & 0.307 & 0.290 & 0.480\\
4.735 & 0.987 & 0.932 & 0.441 & 0.636 & 0.542 & 0.322 & 0.432 & 0.527\\
6.860 & 1.249 & 1.180 & 0.467 & 0.741 & 0.636 & 0.465 & 0.480 & 2.516\\
7.810 & 2.340 & 1.213 & 1.070 & 0.707 & 0.640 & 0.480 & 0.650 & 2.910\\
8.829 & 3.105 & 1.684 & 1.644 & 0.818 & 0.657 & 0.664 & 0.814 & 3.264\\
12.750 & 4.860 & 2.680 & 2.580 & 0.990 & 0.680 & 0.910 & 0.840 & 3.920\\
16.720 & 6.530 & 4.970 & 3.905 & 1.770 & 1.270 & 1.330 & 0.940 & 4.310\\
25.180 & 8.620 & 6.230 & 4.170 & 4.670 & 3.390 & 3.670 & 3.840 & 6.550
\end{bmatrix}
\begin{bmatrix}F1\\F2\\F3\\F4\\F5\\F6\\F7\\F8\\F9\end{bmatrix}
\geq
\begin{bmatrix}1.213\\1.539\\3.015\\4.119\\5.197\\5.936\\7.983\\12.286\\14.613\\20.408\\26.665\\27.639\\39.773\\52.483\\79.465\end{bmatrix}$$

RESULTS AND DISCUSSIONS

Using MapleSoft's Maple Simulation software, the optimum solution is:

F_1 =1.483 F_2=2.343 F_3=1.980 F_4=1.921 F_5=2.408 F_6=2.112 F_7=1.670 F_8=2.529 F_9=2.760

Analysis of optimal solution

The results show that the total cost of a proposed processing plant in Ghana can be extrapolated from a similar plant using the following correlation:

Total Plant Cost = $1.483C_{EQ} + 2.343C_I + 1.980C_{IC} + 1.921C_P + 2.408C_{EL} + 2.112C_{CW} + 1.670C_C + 2.529C_{ES} + 2.760C_{CO}$

Where

C_{EQ} = Cost of purchased equipment C_I = Cost of installation C_{IC} = Cost of instrumentation and control C_P = Cost of piping C_{EL} = Cost of electrical C_{CW} = Cost of civil works

C_C = Cost of construction C_{ES} = Cost of engineering and supervision

C_{CO} = Contingency funds

Since the correlation depends on the availability of cost data and that most process industries in Ghana do not have valid cost data, the purchased equipment is therefore used as basis for the correlation. Expressing the other cost items as fractions of the purchased equipment costs gives a constant factor of 3.261. Hence

Total plant cost = 3.261*(purchased equipment cost). The value, 3.261, is referred to, in literature, as the Lang factor. This value falls well in the range given in literature, where it is stated that Lang factors vary from about 2.0 to 10.0 depending on the process, scale, material of construction and location.

Accuracy of the model

The table below shows the error generated between the actual total capital and the total capital predicted by the model.

Stability of proposed model

To check the stability of the proposed models, consider the following plants in Ghana:

i) Bogoso Resources Ltd, a mining company at Bogoso, in the western region of Ghana, built in 1989 at a total cost of Gh⊄207.34million, with equipment component of Gh⊄65.26million. The proposed model gives a total cost of Gh⊄212.81million, which is 2.82% more than the actual cost.

ii) The Sansu biological oxidation plant built in 1994 at Obuasi, in the Ashanti region of Ghana, by AngloGold Ashanti Co. Ltd at a total cost of Gh⊄483.41million, with equipment component of Gh⊄151.90million. The proposed model gives a total cost of Gh⊄495.35 million, which is 2.53% more than the actual cost.

iii) An Afrikoko drink processing plant built in 1996 by Paramount Distilleries Limited in Kumasi, in the Ashanti region of Ghana. The total cost is Gh⊄2.26million, with an equipment component of Gh⊄0.68million. The proposed model gives a total cost of Gh⊄2.20million which is 2.65% less than the actual cost.

iv) Twifo Oil Palm Plantation at Twifo Praso in the central region of Ghana. The total cost is Gh⊄12.53 million with equipment component of Gh⊄3.95 million. The proposed correlation gives a total cost of GH⊄12.89 million, which is 2.87% more than the actual cost

TABLE 2

SIndustry	Actual Total Capital	Model Total Capital	%Error
1	1.293	1.207	6.651198763
2	1.799	1.683	6.448026681
3	2.915	2.723	6.586620926
4	4.319	4.008	7.200740912
5	5.697	5.707	-0.175530981
6	6.936	6.509	6.156286044
7	7.683	8.012	-4.28218144
8	12.486	11.837	5.19782156
9	16.613	15.441	7.054716186
10	24.408	22.37	8.349721403
11	26.975	25.468	5.58665431
12	27.839	28.791	-3.419663063
13	40.873	41.578	-1.724855039
14	56.983	54.524	4.315322114
15	78.665	82.112	-4.381872497
Average			3.304200392

Thus the average margin of error is ±3.304

All these give a very good indication of the stability of the proposed model

CONCLUSIONS

The total cost of installing process plant in Ghana can be estimated from the purchased equipment cost using the following correlation: Total plant cost = 3.261*(purchased equipment cost). This has ±3.30 margin of error. It may therefore be concluded that the sum of the process equipment costs, either purchased or installed, may be used as a basis for rapid preliminary estimate of the final erected plant cost.

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