Modelling of Operating Cost for a Pulp and Paper Plant

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Cost reduction is an important aspect for today's operating manager. Success in cost reduction program is possible only when the variables and factors affecting the cost function are understood properly.

In a manufacturing plant like an integrated pulp and paper plant cost reduction is possible at various levels and in individual sections and operations of the plant. These result from the operating experience of the plant personnel. Normally with this kind of approach even though cost may reduce in a particular area, but the effect of the changes made to achieve this, in other areas are known only later. At times the effect in other areas may not be of a positive nature.

Therefore to make the cost reduction program successful and free from anomalies, the cost function of the whole plant has to be understood. For this purpose a cost model is required for the operations of the plant. A cost model is a quantitative representation of the cost function of the plant. Here the operating cost is a mathematical function of certain key inputs which affect the cost of the opertaions.

This article discusses how an operating cost model was developed for an existing integrated pulp and paper plant and what are the skills and inputs required for doing this.

For developing a model it is essential that the operation of the plant be simulated with reasonable accuracy. For doing this there are two alternatives.

(a) simulation based on theoretical considerations and relationship, and

(b) simulation based on actual operation of the plant.

The first alternative may not be very helpful except for making predictions for a proposed plant. The second alternative is the one which is very useful for simulating the model for cost of actual operations This alternative was used for developing the model by the author.

As a first step the operations are broken into certain categories, e. g. power consumption, fuel consumption, raw material consumption and chemicals consumption etc. After this a mathematical expression is developed for each category which gives the consumption as a fuuction of production variables. This expression is developed from the actual performance data of the plant. Therefore it is essential that :

(a) operation of each section of the plant is understood well so that the relationship between the output and input is derived satisfactorily; and

(b) adequate knowledge of numerical analysis and regression methods is available.

After determining the expressions for each section/sub-section of the plant for various consumptions, categorywise consumption fanctions are generated, e. g for electrical energy consumption the total consumption function (or model) is developed from consumption expressions of all the sections. At this stage certain intermediate production variables are expressed in terms of basic ones so that the number of inputs required for the model does not become large.

The model under discussion was developed for a plant having three pulping streets i. e. wood, bagasse and waste paper, four paper machines with steam turbine drives (except one), recovery plant, co-generation

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system, water and effluent treatment plants and other utilities. The inputs required (termed as basic inputs) for the model to calculate operating cost for a certain pattern of operations (product mix, raw materials, total quantities to be produced, etc) are :

(1) production and substance of the qualities to be made on each machine,

(2) raw materials to be used,

(3) bleached pulp requirement,

(4) constraints set by the management or environment (power cut, etc.)

(5) unit cost of different inputs.

The accurancy of the model is good as it was developed by simulation from analysis of actual operating data. The model can be made better and better by fine tuning as it is used more and more. The model was developed with day as a unit of time. The modelling work was done on a Radio Shack Personal Computer (TRS-80 Model 4) with Basic language. Algorithm for generating the model is given in the Appendix alongwith a few simple demonstrative calculations.

The various benefits from having a computer model for operating cost may be listed below as :

(1) the overall effect of different changes made in various sections of the Plant is known.

(2) decision making is fast and at a higher confidence level.

(3) can be used for making profitability exercises once the production targets are specified

(4) The varying production level is incorporated for cost calculation.

(5) Helps to know where to attach for cost reduction or modify the operations for optimising cost.

Already the model developed has helped to highlight certain facts to the top management which were not easily discernible by subjective and piecewise analysis.

It is hoped that the utility of this kind of exercise will grow fast in the environment faced by the industry at present.

APPENDIX

ALGORITHM FOR GENERATING THE MODEL

1 **Specifying the inputs & constraints**

a) **Basic inputs**

i)	Total machine production	MT	Qi
ii)	Chemical pulp production	CP	
iii)	Wood pulp/Bagasse pulp	WP	
iv)	Bleached pulp	BP	
v)	Production & Substance on each machine	Mi, Gi	

b) **Constraints**

i) Power cut

ii) Priority of using Boilers

iii) Cost of various inputs

2 **Getting the total power consumption**

Power consumption in section i = Pi = fi (qi),

$$q_{min} \leq q_i \leq q_{max}$$

$$\text{Total Power consumption} = PT = \sum_{i=1}^{n} fi\ (qi)$$

Convert each qi in terms of Qi $\rightarrow$ qi = Fi (Qi)

$$\therefore \text{Total power consumption} = PT = \sum_{i=1}^{n} fi\ (Fi\ (Q))$$

Get the power to be generated by using power cut constraint

3. GETTING THE PROCESS STEAM CONSUMPTION.

Steam consumption in section i

$= S_i = g(q_i) q_{mn} \leq q_{min} \leq q_{max}$

$\therefore$ Total steam consumption

$$= SP = \sum_{i=1}^{n} gi(qi)$$

In terms of basic inputs, $SP = \sum_{i=1}^{n} gi(Fi(Qi))$

4. GETTING THE STEAM BALANCE AND FUEL USED.

Get steam consumption at different pressures, SP_j

Get flow through Paper Machine Turbines.
$fli=Fi\ (Mi, Gi)$

Get total flows in different pressures.
$fl_j=F_j(fli, SP_j)$

Get extraction flows for TG Set from above and determine power generated by extraction. Remaining power to be generated by condensation. Get steam production in soda recovery boilers as a junction of CP & WP. After this get the steam production from power boilers. Get fuels used by applying the various constraints.

i. e. $L_j=f_j\ (SP, \overset{n}{Mi}, \overset{n}{Gi}, PT, PS)$ for $j=10$ ton

(different fuels)

5. GETTING THE RAW MATERIAL USED.

$r_j=f_j\ (MT, CP, WP, BP)$ for $j=1$ to n
(differnt raw materials)

6. GETTING THE CHEMICALS CONSUMPTION

Here each section may use more than one chemicals.

∴ Consumption of j^{th} chemical in section is given by :

$hi_j=fi_j\ (qi_j)$
Next express in terms of Qi (Basic input)
$hi_j=fi_j\ (Fi_j\ (Qi_j))$

7. GETTING THE TOTAL OPERATING COST (CT).

Multiply the various consumption of power, steam, raw materials and chemicals with their respective input costs and sum.

$$CT=Cp\times PS+\sum_{i=1}^{n} Cli\times Li+\sum_{i=1}^{n} Cri\times ri+\sum_{i=1}^{n}\left(\sum_{j=1}^{m} Chi_j\times hij\right)$$

(alln's are not same)

In addition to getting the operating cost, the various consumptions can also be provided by the model.

NOTE :

The functions denoted by F, f & g have to be derived from analysis of operating data by applying principles of numerical analysis and regression.

NOMENCLATURE OF VARIABLES:

S. No.
1. Csub = Unit cost of input denoted by subscript.
2. CT = Total operating cost.
3. F.f.g = Mathematical functions relating the output to input derived from analysis of operating data.
4. fli = Steam flow through paper machine turbine.
5. hij = Chemical consumption in section 'i' for 'j' °chemical.
6. Li = Fuels used.
7. Pi = Sectional power consumption.
8. PS = Power from grid supply.
9. qi = Sectional production input/variable.
10. Qi = Basic inputs i. e. MT, CP, WP, BP, M1, M2, M3, M4. G1, G2, G3, G4.
11. ri = Raw Material consumption.
12 Si = Sectional steam consumption.

EXAMPLES ON THE WORKING OF MODEL

Some examples are given below which indicate how the Model takes care of changes in certain variables :

1 Fuel and Power Cost

Take case (a) where MT=165, CP=116, WP=76, BP=70, M1=40, M2=60, M3=0, M4=65 (all in tons), G1=60, G2=240, G4=150
Grid power 91800 kwh/day

We get the following costs for fuel and power
Fuel cost=Rs 1274/t & Power cost=Rs 596/t,
take case (b) where, MT, CP, WP remain same, but BP=45, M1=45, M2=50, M3=0, M4=70, G1=60, G2=100, G4=150, grid power 91800 kwh/day.

We get the following costs for fuel and power
Fuel cost=Rs 1237/t and Power cost=Rs 587/t
It can be seen that fuel and power cost for (a) & (b) are different eventhough the total paper production remains the same, thus, the effect of changing the production on m/c no. 2 from 60 to(D. Board) to 50 t (Kraft Paper) and increasing the production on m/c no. 4 to 70 t and reducing the bleached pulp to 45 t is clearly reflected on the operating cost. In addition, there will be change in the chemical cost as bleached pulp production changes.

2 Chemical Cost

Take case (a) where MT=165, CP=116, BP=100 and case (b) where MT=165, CP=116, BP=40

Case (a) Cost of alum used for water treatment
=Rs 110/t of paper

Case (b) Cost of alum used for water treatment
=Rs 99/t of paper

The difference arising because of more fresh water consumption in case (a) because of higher bleached pulp production.

3 **Effect of change in furnish**

Case (a) MT=165 t, CP=116, WP=100 t

Case (b) MT=165 t, CP=116, WP=50 t

Case (a) make up chemicals cost=Rs 350/t of paper

Case (b) make up chemicals cost=Rs 445/t of paper

The difference arising because of lower recovery of chemicals in case (b) where bagasse pulp is higher in the chemical pulp furnish when compared to case (a), also steam used for black liquor evaporation for

Case (a) =1.4 t/t of paper

and

Case (b) =1.7 t/t of paper because the weak black liquor produced from washing of bagasse pulp is dilute when compared to that produced from washing of wood pulp.

Thus the Model brings out the changes in operating cost because of changes in certain input variables.

It may be noted that it is important to define the maximum and minimum limits for each variable as the Model cannot be valid for an infinite range of input variable.