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Akanbi O.P.

Stochastic Modelling of Linear Programming Application to Brewing Operational Systems

System where a large number of interrelated operations exist, technically-based operational mechanism is always required to achieve potential. An intuitive solution, which is common practice in most of the breweries, perhaps may not uncover the optimal solution, as there is hardly any guarantee to satisfy the best policy application. There is always high foreign exchange involved in procurement of imported raw materials and thus increases the cost of production, abandonment and poor utilization of available locally-sourced raw materials. This study focuses on the approaches which highlight the steps and mechanisms involved in optimizing the wort extract by the use of different types of adjuncts and formulating wort production models which are useful in proffering expected solutions. Optimization techniques, the generalized models and an overview of typical brewing processes were considered.

***Keywords**: wort, extracts, adjuncts, models optimization, brewing, techniques, raw, materials, production*

1. Introduction

Brewing is a very ancient process, there are nevertheless many practices brewing which are dependent on knowledge acquired empirically through generations. The making of beverages is a practice dated back as far as 300BC by the Egyptians (Kink-othmer, 1995). However, the scientific principles underlying the brewing processes have however been studied for more than 100 years and many problems associated with the brewing still awaits solution (Oyaniyi, 1997). Brewing technology is therefore based partly on well–established scientific facts and partly on empirical knowledge gained from years of practical experiences (Kent, 1983). Whenever any form cotton was discovered, type of fermented drink and earlier stages always from some naturally found sugar containing materials, such as the agaves juice of Mexico, the juice of the sugar maple, the juice of grapes of honey from wild bees.

The making of beer demanded a higher form of culture, because the people had to establish themselves as agriculturist and produce some sorts of grains and for this reason brewing is classed among the agricultural industries (Kent, 1983). It is also ranked as a fermenting industry because the chief stage in beer production still remains fermentation. In fact, brewing in Nigeria and Africa at large will have to cover the production of the alcoholic and non-alcoholic drinks. Barley was undoubtedly employed in the preparation of fermented liquors long before the dawn of recorded history, especially in places where it was the chief cereal used for food. Beer is known to have been widely uses a drink in ancient Egypt and has been traced back to the age of pyramids, some four or five millennia BC, but recent investigations suggest that the Egyptians learned the art of brewing from the peoples of the valleys of the Pignis and Euphrates, where beer played a large part in the domestic economy 5000 to 7000 years BC. Beers are made from cereal products. The cereal barley in Europe, and recently sorghum in African is malted in order to produce some necessary enzymes and to modify the major substrates–starch and protein (Brewers Guardian, 1986). Unmalted cereals such as maize and rice may be used as adjunct since they are cheaper sources of starch and protein. The cost of malt is roughly double that of the maize and rice (Akanya, 1995). The enzymatic part of these local cereals could be supplemented using artificial enzymes which economically is much cheaper.

With the advent of some indigenous breweries like Nigerian Breweries Plc, the use of 100% sorghum as the major raw material for brewing there has been a dramatic jump in the consumption and demand of beer and thus made this particular sector an important area of interest. One of the major problems has to do with the taste and colour of beers production with 100% sorghum. Beers of the early years were most likely brewed and consumed at the same establishment. In the early 50s, beers were generally consumed as it was done in the early years despite improvement in the number of brewing facilities with wood. Pewter or stone being among the most common drinking vessels. By the late 50s bottled beer was replacing some of the wooden kegs, thereby awakening the general public to the reality of importance of beers as a source of food (Kink-Othmer, 1995). In the past, these cereals were locally both in malted and unmalted forms for the production of some types of alcoholic beverages in the tropics. The uses of these cereals as adjuncts in brewing have both economic and technological merits. However, the addition of excessive quantities of these cereals could have some negative effects on beer quality. Based on the type of beer to be produce, the quality of malt used, enzyme application and different countries' brewing restrictions, the quantity of unmalted grains to be used must be predetermined(Ugboaja et al.,1991). It has been established by many researchers, that addition of adjunct in the right proportion to brewing raw material has no effect but has some added advantages.

2.1. Materials and methods

Optimization techniques are very important scientific approaches to optimal decision making in modelling of deterministic and probabilistic systems that originate from real life. In general, optimization has to do with selecting from among a set of feasible alternatives, one which is optimal according to a given criterion of optimality. Economic problems are typically of this nature since economics- theory as well as practical applications e.g. to industrial planning problems – is largely about optimal allocation of given or scarce resources.

2.1.1. Model formulation

The formulation mechanism involves;

i. A maximum of bi units of resources i. i=1,2…m is available.
ii. It is desired to produce Xj units of products j,j = 1,2…n.
iii. Aij units of resources I are assumed used in the production of each unit of the j-type product is cj.

The Linear Programming model is set up as follows:

a. as no more than available resources of any type may be used in the total production, the material balance equation for each resources I can derived as follows:

$$\sum^{n} aijXj \leq bi = 1.2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots m \qquad (1)$$

b. the non-negativity of the number of each product Xj made, leads to the relation

$$Xj \geq 0 \qquad (2)$$

c. the total cost reduction from all products sum up as

$$Z = \sum_{j=i}^{n} CjXj \qquad (3)$$

Where:

Z= the total reduced cost

This function is the objective function. The problem of Linear Programming is the choice of Xj – set that maximizes Z as defined in (3) above, the variables Xj being simultaneously, subject to the constraint (1) and (2) above.

Explicitly, the problem is stated as maximize $Z + C_1X_1 + C_2X_2 + \ldots\ldots\ldots + C_nX_n$

Subject to

$$a_{11}X_1 + a11\,X_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots + a1_n\,X_n \leq b_1 \qquad (4)$$

$$a_{21}X_1 + a_{21}\,X_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots a_{2n}\,X_n \leq b_2 \qquad (5)$$

$$am_1X_1 + am_2\,X_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + a_{mn}\,X_n \leq b_m \qquad (6)$$

$$X_2, X_2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots X_n \geq 0 \qquad (7)$$

2.1.2. Model development and validation

In this model, five main sources of starch are being considered in producing the required wort. The raw materials (i.e cereals) are;

i. malted barley
ii. Unmalted sorghum
iii. Unmalted maize
iv. Unmalted rice and
v. unmalted millet

Availability of these grains is represented by:

A_1kg/brew - malted barley
A_2kg/brew - unmalted sorghum
A_3kg/brew - unmalted maize
A_4kg/brew - unmalted rice
A_5kg/brew - unmalted millet

The simulation approach for using all the five starchy sources is to maximize the wort extract using maize, rice, millet and sorghum adjunct without altering the required wort gravity for fermentation of the wort thus accomplished by minimizing the cost of production of the required wort.

Notation:

Denoting the mash components used the wort production by Xj
Where
j = 1, 2, 3 ....n
1 = malted barley
2 = sorghum adjunct
3 = maize adjunct
4 = rice adjunct
5 = millet adjunct
Cj = cost of 1kg (1000g) of input j (₦/gravity)
Aij = the amount of components type i in kg of input type j.
Where, i = 1 = m simple sugar (fermentable and non-fermentable)
i = 2 = ash content
i = 3 = protein content
i = 4 = fat and oil
i = 5 = material balance
i = 6 = adjunct
bi = minimum industry specification for components i (g/hl)

In situation where each component contributes to the wort gravity of the mixing, an amount equal to the product of its gravity and its fraction of the total gravity of the mixing is required. This is taken care of in the model by considering percentage composition of each component of grains in a particular cereal. On substituting the stated notations in the model below.

2.1.3. Model using malt, sorghum and maize

Minimize $c = 100x_1 + 21x_2 + 23x$

Subject to:

Ash content: $0.758\,x_1 + 0.732x_2 + 0.77x_3 \geq 706.8$

Ash content: $0.025\,x_1 + 0.022x_2 + 0.027x_3 \geq 21.5$

Protein: $0.12x_1 + 0.118x_2 + 0.116x_3 \geq 10.5$

Fat and oil: $0.17\,x_1 + 0.03x_2 + 0.027x_3 \geq 17.5$

Material balance

i. $x_1 + x_2 + x_3 = 1000$

ii. $x_2 + x_3 \geq 0$

Non- negativity constraint:

$X_1 \geq 0,\ X_2 \geq 0,\ X_3 \geq 0$

3.1. Results and discussion

The results of tested and validated models were explicitly explained. Also, due to existence of various breeds of the grains used which means different chemical composition, with very little variations, the values used in this work are the average values used by Consolidated Breweries for grains like malted barley, Sorghum and maize while the results collected from IITA were used for rice and millet.

3.1.1. Interpretation for sorghum and Malted Barley Model

The optimum solutions were as follows:

i. 96.15% of malted barley should be used in forming the mash;
ii. 3.85% of sorghum should be used in forming the mash;
iii. The combination above gives a maximum production cost of ₦96.961k/kg of grains; and
iv. There is a cost reduction of about ₦3.039k/kg of grain.

3.1.2. Maximum Change in Marginal Cost

This is to determine the range of variation for the objective coefficients (one at a time) for which the optimum remains unchanged;

i. the contribution coefficient of malt for wort production could vary from a value of 21.0 to a very large value positive infinity without affecting the present optimal solution; and
ii. the contribution coefficient of sorghum for wort production could vary from a very low number without affecting the present optimal solution.

3.1.3. Maximum Changes in Resources Availability

The maximum changes in resources availability determine the range of variation in the availability of a resource that would yield the unit worth encountered in the solution.

i. increasing the availability of carbohydrate over 0.757kg/hl and decreasing it to a very low value negative infinity if possible will lead to infeasibility of the present optimum situation;
ii. increasing the availability of ash above a very high value, positive infinity, and decreasing it to a very low value 0.025kh/hl if possible would lead to infeasibility of the present optimum situation;
iii. increasing the availability of protein over 0.112kg/hl and decreasing it to a very low value negative infinity if possible will lead to infeasibility;
iv. increasing the availability of fat and oil above 0.0215kg/hl and decreasing it to a value of 0.0175kg/hl if possible would lead to infeasibility;
v. increasing the raw materials used to a valued above 102.9% and decreasing it to a value below 93.36% will lead to infeasibility;
vi. increasing the adjunct used to a very large value positive infinity and decreasing it to a value less than 3.03% would lead to infeasibility of the model.

Table 1. Production models simulation output

Grain mix	Reduced cost (₦)	Adjunct used (%)	% of Malt used	% maize used	% of sorghum used	% of Rice used	% of Millet used
1	6.42	8.34	91.66	8.34	-	-	-
2	26.25	35	65	-	-	-	35
3	19.31	8.34	91.66	8.33	-	-	-
4	26.98	35	65	-	18.3	-	16.7
5	3.04	3.85	96.15	-	3.85	-	-
6	26.72	35	65	23.57	-	-	11.4
7	19.61	35	65	-	-	21.4	13.6
8	21.67	35	65	19	-	16	-
9	15.40	35	65	-	-	35	-
10	19.31	35	65	-	11.18	23.82	-
11	26.25	35	65	-	-	-	35
12	26.72	35	65	23.6	-	-	11.43

Sources: Simulation output

4. Conclusion

The basic idea of linearising of a brewing model is with view to maximizing profits from the proceed or minimizing cost of production using other cereals. Both functions centre on optimization of the availability resources. In the case of mashing, it would be appropriate to determine how best the raw grains could be mashed to form wort, in addition to how much of the wort formed should be made to maximize profits. The importance of brewing industry, demand and growth of brewing products has been highlighted. The concepts of linear programming have been reviewed, by discussing in brief the assumption of linear programming, problem formulation and solution technique. Optimal solutions were obtained as a result of sensitivity analysis performed on the coefficient objectives. This in thus shows that brewery units could be optimized irrespective of various constraints parameters.

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Address:

- Akanbi O.P., Department of Chemical Engineering, Auchi Polytechnic, Auchi, Nigeria.

Corresponding Author:engrakanbiolusola@yahoo.fr