ANALYSIS OF PRODUCTION CAPACITY OF A YAM FLOUR PRODUCING FIRM USING A MATHEMATICAL MODEL

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ABSTRACT

Yam flour is usually required for the preparation of pounded yam which is a daily nutritional food requirement for most Africans. It facilitates the preparation of pounded yam for both domestic and commercial consumption. The production process and the basic operations involved in the production of pounded yam flour have been investigated in other to estimate the production capacity of the company studied. A time study model was developed and applied to analyze the various basic operations involved in the production of pounded yam flour. These basic operations include; the selection of yam, weighing of yam**,** washing of yam, peeling of yam, slicing of yam with a slicing machine, parboiling of sliced yam with a parboiler, drying of parboiled yam with a dryer, milling of dried yam into yam flour with a hammer mill, packaging of the yam flour and sealing of the packages with a sealing machine. In this paper therefore, a mathematical model was developed with the application of different techniques of differential calculus to the component elements of the production process of yam flour. The study reveals that the time it takes to produce some kilogram unit of pounded yam flour is directly proportional to the number of production stages involved and the time spent at each of these production stages. This time is being represented by some structural equations which are characteristics of the system studied.

Keywords: mathematical model, yam flour, time study model, production capacity, production stages.

1. INTRODUCTION

Time study which is a branch of work study, incorporates a range of concerns, including its definition and management. It involves a technique of work measurement which is aimed at assessing human effectiveness thereby making possible improved planning and control manning and as basis for sound incentive schemes, for higher productivity. It is a scientific technique which is used by most manufacturing organizations to aid dispute settlement between the employees' association of the company and management regarding issues of productivity (Oke, 2006). Time study is a technique of work measurement designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance. The research on time study incorporates a range of concerns, including its definition and management (Edo *et al.*, 2001; Worrall and Smith, 1985; Watson, 1988; Aft, 2000).

The word "yam" comes from Portuguese name or Spanish name, which both ultimately derive from the Wolof word nyam, meaning "to sample" or "taste", in other African languages it can also mean "to eat" e.g. yamyam and nyama in Hausa (Mignouna, *et al*., 2003). Also yam is the common name for some species in the genus and they are perennial herbaceous vines cultivated for the consumption of their starchy tubers in Africa, Asia, Latin America and Oceania. They are used in a fashion similar to potatoes and sweet potatoes, (Brand - Miller, *et al*., 2003). Yam products generally have a lower glycemic index than potato products (Kay, 1987), which means that they will provide a more sustained form of energy, and give better protection against obesity and diabetes (Walsh, 2003).

Yam which is one of the oldest known recipes to man is a tuber crop which belongs to the class of carbohydrate and has been a part of the African meal for centuries. Its starchy nature allows yam to form a bond when it is been beaten in a mortar which is then consumed as meal with a good choice of soup. Pounded yam is a staple food, which is consumed by almost every tribe in Nigeria. The indigenous process of production is very laborious. It requires physical pounding by two or more men or women, depending on the quantity, in mortars with pistols. The world production of yam was estimated at 28.1 million tonnes in 1993. Out of this production, 96% came from West Africa, the main producers being Nigeria with 71% of world production; Côte d'Ivoire 8.1%; Benin 4.3% and Ghana 3.5% In the humid tropical countries of West Africa, yams are one of the most highly regarded food products and are closely integrated into the social, cultural, economic and religious aspects of life. Traditional ceremonies still accompany yam production, indicating the high status given to the plant. (Food Information Net, 2008).

This paper is an attempt to present the methodology used in the production of pounded yam flour by the company which involves the basic operations of yam selection, weighing of yam**,** washing of yam, peeling of yam, slicing of yam with a slicing machine, parboiling of sliced yam with a parboiler, drying of parboiled yam with a dryer, milling of dried yam into yam flour with a hammer mill, packaging of the yam flour and sealing of the packages with a sealing machine. The time study technique was used to develop a model which was used to estimate the production capacity of each of these operational stages and the total productivity of the company.

2. PRODUCTION PROCESS OF POUNDED YAM

The production process of pounded yam flour consists of some operations, which have been mechanized. The basic operations include the selection and weighing of yam, washing of yam, peeling of yam, slicing of yam, parboiling of sliced yam, drying of parboiled yam, milling of dried yam into yam flour, packaging of yam flour and sealing of the packages The general operation therefore involve the selection of tubers of yam which are weighed and properly washed to remove adhering sand. The washed tubers are carefully peeled and the peeled tubers of yam are then mechanically sliced to desirable thickness in a slicing machine made of stainless steel blades. The yam slices are then blanched in boiling water (parboiled) for some minutes, depending on the thickness of the slices and after which the blanched yam slices are dried in a dryer at specified drying temperature for few hours. The dried yam chips are pulverized directly into flour of uniform particle size distribution while the remaining dried yam chips are stored in airtight containers. The produced yam flour is packed into airtight, moisture-proof packaging containers which are tightly sealed by a sealing machine. The operational processes are shown in Figure-1.

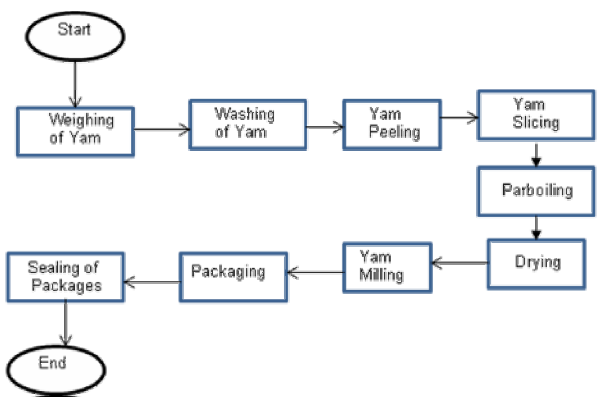

Figure-1. Production process of yam flour.

3. THE MATHEMATICAL MODEL

The basic activities in yam flour production were studied in order to be able to develop mathematical model for the problem. The first mathematical expression for the time study model framework is as follows:

$$t = \sum_{i=1}^{n} t_i \qquad (1)$$

where (t) represents the total time used in producing a unit of product.

The variable (i) represents the various workstations of interests, (i.e., selection and weighing of yam**,** washing of yam, peeling of yam, slicing of yam with a slicing machine, parboiling of sliced yam, drying of parboiled yam, milling of dried yam into yam flour, packaging of the yam flour and sealing of the packages with a sealing machine) With close observation of the various workstations, there are variations in the rate of working for both the individuals at the workstations and the machines doing the actual operation. Therefore, we introduce the rate of working for both the machines at the various workstations and the workers as differentials that are expressed mathematically. For instance, if machine i is represented as m_i, where m_i may be m_1 for the machine that does the work such as selection and weighing yam station, m_2 is the machine that does the work at washing of yam station, while m_3 is the machine that does the work at peeling of yam station, etc.).

If the time taken by the 'in-process' product is time t, then mathematical expression becomes;

$$\frac{dm_i}{dt} = \Delta m_i$$

where $\Delta = \dfrac{d}{dt}$

Also, if (w_i) represents the human worker at workstation (i), and this worker works for a period of time t units, then we can express the rate of working of this worker as:

$$\frac{dw_i}{dt} = \Delta w_i$$

where $\Delta = \dfrac{d}{dt}$.

Since in time study activities a provision of allowance is always very necessary, we now introduce a parameter 'T_a' into the model.

Therefore, the general mathematical expression for the production time $g(t)_i$ at each workstation is given as:

$$T_i = \frac{\Delta}{m_i} \times \frac{\Delta}{w_i} \times f(y_i) + T_s \qquad (2)$$

where $g(t)_i$ is a normalizing function which converts the expression into time units.

Substituting Equation (2) into Equation (1) gives the following equation.

$$t = \sum_{i}^{n} \left(\frac{1}{\Delta m_i} x \frac{1}{\Delta w_i} x\ f(y_i) + t_a \right) \qquad (3)$$

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$$= \sum_i^n \left(\frac{1}{\Delta m_i} x \frac{1}{\Delta w_i} \text{ x f } (y_i) + \sum_i^n t_a \right) \quad (4)$$

but $\sum_i^n t_a = nt_a$

$$\therefore \quad t = \sum_i^n \left(\frac{1}{\Delta m_i} x \frac{1}{\Delta w_i} \text{ x f } (y_i) + nt_a \right. \quad (5)$$

It is assumed that the rate at which machines are producing and the working rate of workers is constant. Thus Equation (5) becomes:

$$t = \left(\frac{1}{\Delta m_i} x \frac{1}{\Delta w_i} \right) \sum_i^n f(y_t) + nt_a$$

We generalize the model by taking f (y_i) as f(y), $\frac{1}{\Delta m_i}$ as: $\frac{1}{\Delta m}$ and $\frac{1}{\Delta w_i}$ as $\frac{1}{\Delta w}$.

$$\text{Thus } t = \frac{1}{\Delta m} \text{ x } \frac{1}{\Delta w} \int_1^n f(y)dy + nt_a \quad (6)$$

Assuming that the total number of products produced is denoted by symbol (X), while T is the total time spent for all the products, Equation (6) above becomes,

$$T = Xt = X\left(\frac{1}{\Delta m} \text{ x } \frac{1}{\Delta w} \int_1^n f(y)dy + nt_a \right) \quad (7)$$

Equation (7) is the general formula for the total time spent in producing x products.

3.1 Raw materials and electricity supply

Consider the issue of unavailability of raw materials which are the fresh palm fruit bunches and irregular electricity supply and assuming that $f(y_j)$ is a function of these two parameters of indices such that we have $f(y_j)$ and f(y, z). Therefore Equation 7 can now be expressed as follows:

$$T = Xt = X\left(\frac{1}{\Delta m} \text{ x } \frac{1}{\Delta w} \int_1^n f(y,z)dydz + nt_a \right) \quad (8)$$

This equation gives the real general formula for the total time spent in producing y products.

4. APPLICATION OF THE TIME STUDY MODEL AND DISCUSSION

This study which is a case study of a pounded yam flour processing company is a real life situation of a production company in Edo state of Nigeria. The company specializes in the production of pounded yam flour with 18 workers. It has different types of machines and other facilities for its production. The company operates a nine hours daily production cycle. However, during festive periods such as Christmas, a large number of customers usually patronize the company's products resulting in huge spike sales. This sometimes, usually leads to increase in the daily working hours of the workers.

This general formula for the total time spent in producing y products is given in the equation below (Oke, 2006).

$$T = Xt = X\left(\frac{1}{\Delta m} \text{ x } \frac{1}{\Delta w} \int_1^n f(y)dy + nt_a \right) \quad (9)$$

where T is the total time spent for all the products,
X = number of products produced
n = number of workstations
and t_a = the time allowance

Assuming that the electricity supply index (y) obeys a linear function such as 2y + 5, then the expression is now f(y) = 2y + 5. From the above equations, we know that (n) is the number of workstations while (t_a) is the time allowance. From the actual production observation, the mathematical model that fit the time problem in terms of number of machines is:

$$t = my^3 + m^2y^2 + y \quad (10)$$

Differentiating Equation (10) gives:

$$\frac{dt}{dm} = y^3 + 2my^2 \quad (11)$$

Also, the mathematical expression that represents time with respect to the number of workers is:

$$t = wy^3 + w^2y^2 + y \quad (12)$$

Differentiating above gives:

$$\frac{dt}{dw} = y^3 + 2wy^2. \quad (13)$$

Note that (n) has been stated earlier as the number of workstations, and (t_a) is the time allowance.

If 87 gm of yam flour are produced by the company for 0.056 second per unit product, then we have allowance.

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t_a = 87 x 0.056 seconds = 4.872 seconds

Therefore, t_a = 4.872 seconds

While nt_a = 7 x 4.872 = 34.104 seconds

$$t = tj = \frac{1}{\Delta m} \text{ x } \frac{1}{\Delta w} \int_1^n f(y)dy + nt_a$$

But $\frac{1}{\Delta m}$ = $x^3 + 2mx^2$ and $\frac{1}{\Delta w}$ = $x3 + 2wx^2$. There are 7 workstations for the yam flour production processes, hence n = 7. From equation (6), we can now estimate the values of t.

We know that $t = t_j = \frac{1}{\Delta m} \text{ x } \frac{1}{\Delta w} \int_1^n f(y)dy + nt_a$ and the values of $\frac{1}{\Delta m}$ as $x^3 + 2mx^2$ and $\frac{1}{\Delta w}$ as $x^3 + 2wx^2$, n = 7 and t_a = 4.872 seconds.

The average period electricity fails in a day is 65 minutes, while the average daily working time is 9 hours.

Note that "x" is the ratio of the period when electricity fails in a day to that of the working hours for that same day.

Thus, $x = \frac{65 \text{ minutes}}{9 * 60 \text{ minutes}} = \frac{65}{540} = 0 \cdot 1204$

This gives an index value of 0.1204.

Note that the number of machines m = 5, number of workers w = 18. Then since f(y) = 2y + 5, we now evaluate the function by substituting into Equation 6 as follows;

$$t = \frac{1}{\Delta m} \text{ x } \frac{1}{\Delta w} \int_1^n f(2y+5)dy + nt_a$$

$$\text{so } t = \frac{1}{\Delta m} \text{ x } \frac{1}{\Delta w} (y^2 + 5y + c) + nt_a$$

Note that at the start of production process, all the factors are zero since no product has been produced. This gives the production constant c to be zero.

$$\therefore t = \frac{1}{\Delta m} \text{ x } \frac{1}{\Delta w} (y^2 + 5y) + nt_a \quad (14)$$

Now substituting the required values into the equation gives:

$$t = t_j = (y^3 + 2my^2)(y3 + 2wy^2)(y^2 + 5y) + nt_a \quad (15)$$

$\therefore$ t = (0.1204^3 + 2 x 5 x 0.1204^2) (0.12043 + 2 x 18 x 0.1204^2) (0.12042 + 5 x 0.1204) + (7 x 4.872) seconds

$\therefore$ t = (0.146706937) (0.523607097) (0.61649616) + 34.104 = 34.151357 seconds

$\therefore$ t = 34.151357 seconds

or t = 34.2 seconds

Note that t_i = 0.075 second per unit product, therefore the total products produced in 34.2 seconds;

$$= \frac{34.2 \text{ seconds}}{0.075 \text{ second per unit product}}$$

$$= \frac{34.2}{0.075} \text{ unit product}$$

= 456 units of product in 34.2 seconds.

Therefore, the total units of product produce in average daily working period of 9 hours is:

$$\frac{456 \times 9 \times 360 \text{ seconds}}{34.2 \text{ seconds}} \text{ grams of yam flour}$$

= 432, 000 grams of yam flour

= 432 kilograms of yam flour

That is 432 kilogram units of yam flour would be produced in an average daily working period of 9 hours.

In conclusion, we have therefore be able to apply a time study mathematical model in computing the time required for operational activities in the production processes for yam flour which is used for making pounded yam and it is seen that 432 kilogram units of yam flour could be produced in nine hours.

5. CONCLUSIONS

The production of yam flour by the company studied has been thoroughly examined. The nine basic operational activities were thoroughly studied and these operational activities include; the selection of yam, weighing of yam**,** washing of yam, peeling of yam, slicing of yam with a slicing machine, parboiling of sliced yam, drying of parboiled yam, milling of dried yam into yam flour, packaging of the yam flour and sealing of the packages with a sealing machine.

Our studies reviewed that the setting of standards for achieving production targets for the yam flour company is very important and one of the techniques for achieving this aim is the application of a mathematically developed time study models in the monitoring and control of employees at the company production floor. In this paper therefore, a time study mathematical model was developed with the application of different techniques of differential calculus to the component elements of the production process of yam flour in other to analyze the various production activities of the company.

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