Application of Mathematical Model to Optimization of the Production Capacity of Paint Manufacturing Company.

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ABSTRACT

This paper presents a case study in the development and application of a mathematical model to optimize the production capacity of a paint manufacturing company. The organization specializes in the production of different grades of paint and paint containers. The paint production activities include; weighing of raw materials, drying of raw materials, dissolving of raw materials, material filtering, material stirring, product inspection, and quality control and product packaging. The processes in paint container production comprise of cutting of sheet metal, sheet metal rolling, sheet metal pressing for overlapping hook, cutting of top cover, cutting of bottom cover, coiling of sheet metal to shape, and pressing bottom cover to position.

The study reveals that the time it takes to produce a unit product 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 being studied.

(Keywords: paint production, time study model, mathematical model, product inspection)

INTRODUCTION

There are numerous types of paints available on the market many of which incorporate special additives to provide decoration or protection for specific applications. The two basic paint types available are either water-thinned or turpentine-thinned. Water-thinned paints for example are usually used on interior walls and ceilings, primarily because they dry quickly, brushes or rollers clean up easily in water, the paint is less smelly, and doesn't yellow with age. Furthermore, they are available in a range of gloss levels to suit specific room requirements and are resistant to the alkaline present in masonry. Turpentine-thinned paints on the other hand provide a hard durable surface, are easily cleaned, and seal in tanning stains from timber. They also can give a very high gloss.

Most manufacturing organizations such as paint manufacturers have realized that scientific approaches could be developed to aid dispute settlement between employees' associations and management regarding issues of productivity.

Time study is one of the techniques used in solving productivity problems in such manufacturing companies. 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 and 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).

Although research on work measurement has evolved in a scientific and rigorous fashion, based on early work of Gilbert and others, the quantitative mathematical modeling of production activities in terms of time study has not evolved in a similarly rigorous fashion (Barnes, 1980; Oke, 2006; Karger and Bayha; 2003).

Paint is defined as a fluid or semi–fluid material which may be applied to a surface in relative thin layers and which changes to a solid, may or may not be reversible, and may occur by evaporation of solvent or by chemical reaction or by a combination of the two. It usually consists of a binder or a pigment which contributes opacity, color, and hardness, and a solvent or thinner which controls the consistency. In 1500 BC, the Egyptians developed the art of painting using a wide number and variety of colors. They also discovered the present day vanishes using naturally occurring resins as their film forming ingredient (Yugbovwre, 1995).

Clover Paint Company (name changed) is located in Nigeria and it specializes in the production of different grades of paint and paint containers. An important problem faced in the paint production system is that of determining the time it takes to produce a unit product. In order to thoroughly analyze the problem, the production processes for each of the products produced by the company were examined. Paint production activities could be broken down into seven activities; weighing, drying, dissolving of raw materials, material filtering, material stirring, product inspection, and quality control and product packaging. In the production of paint container, six steps are involved; cutting of sheet metal, sheet metal rolling, sheet metal pressing for overlapping hook, cutting of top and bottom cover, coiling of sheet metal to shape, and pressing bottom cover into position.

PAINT PRODUCTION PROCESS

There are four major groups of raw materials which are compounded together to form paint and they include; pigments, binder, solvent, and additives.

Pigments

Pigments are naturally occurring or synthetically produced fine powders which are dispersed or ground into a binding medium to provide the color and covering power as their major function in paints. Most natural pigments are inorganic in nature while others pigments are synthesized.

The organic pigments which make up the wide spectrum of bright colors available to the paint manufacturers are all synthetically produced. Prime pigments are basically concerned with the main function of providing color and opacity and they are either inorganic or organic in chemical structure.

Binder

The binder is a resin or polymer which is usually organic compound of high molecular weight, and each large molecule can contain many repeating parts in its chemical structure. The binder or resin binds the component pigments together into a cohesive, continuous film and provides the adhesive power for the paint to stick to a substrate. There are natural and synthetic resins, A synthetic resin based on vegetable oils is the alkyd resin. This is a polymer condensed from vegetable oil with a polyacid and a polyalcohol. The oil component provides the gloss, drying ability, flexibility and exterior durability while the other ingredients give the hardness, resistance properties and speed of dry potential.

Solvent

This is the third major component of paint and has the major purpose of reducing or thinning paints to a suitable handling consistency or "viscosity" for ease of manufacture and application. After the paint has been applied, the solvent evaporates and leaves the dry paint film on the substrate. Solvents used are either organic compounds or water. The major sources of organic solvents are petroleum refining, fermentation of vegetable matter, and chemical synthesis. They are generally divided into two groups, hydrocarbon solvents made up of carbon and hydrogen atoms, and oxygenated solvents which also contain oxygen atoms. Water is another important solvent used in paints. This provides obvious advantages in cost, availability, flammability and toxicity. The widespread use of water in the majority of today's house paints is one of the major reasons for the overwhelming popularity of vinyl and acrylic latex paints.

Additives

This group of chemicals is comprised of a vast multitude of proprietary and in-house compounds which are employed by paint makers at low levels (usually < 6.5%) in coatings to perform quite specific functions or to counter adverse side-effects of other components. For example, turps-thinned paints contain drying agents which speed up the drying process. They also contain anti-skinnning agents to prevent the paint forming into a tough skin-like covering in the can.

DEVELOPMENT OF THE TIME STUDY MODEL

Some information needs to be declared in order to have a thorough understanding of the problem in the paint manufacturing company, its formulation, and solution. This is very necessary for us to develop the model which is intended to serve as a guide to other practicing managers in manufacturing systems, who are willing to apply the model. The necessary information was obtained at the factory floor, and it was discovered that the production system is effective.

In the operation of the activities of the paint manufacturing company, the production manager interacts with the marketing department which in turn interacts with the finance department while the finance department then interacts with the purchasing department, who then interacts with the production manager. This is shown in Figure 1.

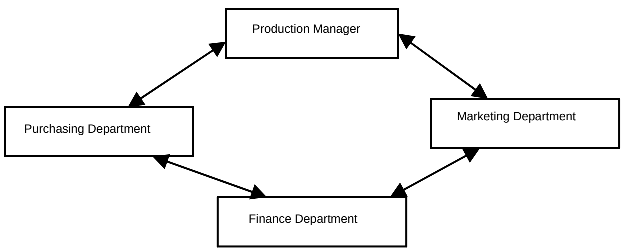

Figure1: The System Concept for the Manager.

The production of paint by Clover Paint Company involves two major stages: the first stage is the production of liquid paint while the second stage involves the production of paint containers. The basic stages in paint production by Clover Paint Company are shown in Figure 2.

THE TIME STUDY MODEL

The major activities in paint production were studied and from the information obtained at the company floor, the production system is effective. It infers that no major losses or leakages in the production system of the organization studied. Thus, all the effort put into the production system would yield the desired results. The second type of information obtained from the production system is that the right caliber of production personnel is involved. A third information category is that there is a defined responsibility for each production worker, thus, a production target is in place and could be monitored. The fourth class of information is that the machines are always available in a ready state. However, it is assumed that whenever a machine breaks down, it can always be repaired and restored in a negligible time frame.

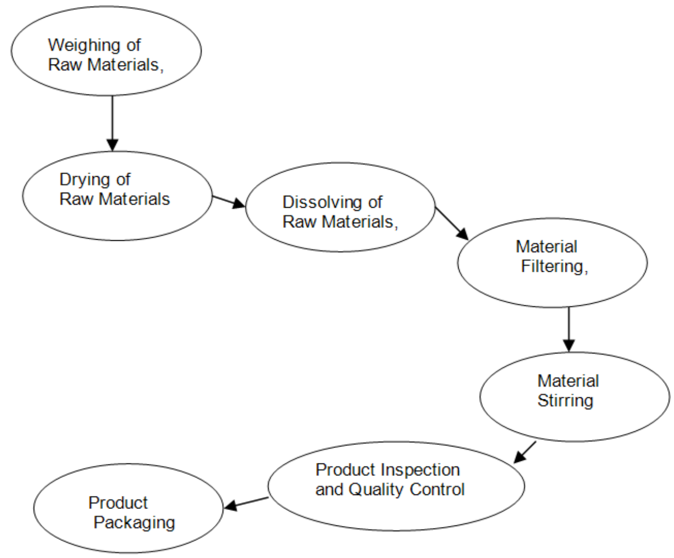

Figure 2: The Basic Activities in Paint Production Process.

The first mathematical expression for the model framework is as follows:

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

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

The variable (i) represents the various workstations of interests, (i.e. weighing and drying of raw materials, mixing of raw materials, dissolving of raw materials, material filtering, material stirring, inspection and quality control and product packaging). 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 weighing and drying of raw materials station, m_2 is the machine that does the work at mixing of raw materials 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 $\Delta = \frac{d}{dt}$

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 $\Delta = \frac{d}{dt}$.

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 t_i at each workstation is given as;

$$T_i = \frac{\Delta}{m_i} x \frac{\Delta}{w_i} \text{ x } f(y_i) + T_a \qquad \textbf{(2)}$$

where $f(y_i)$ is a normalizing function which converts the expression into time units.

Substituting Equation 2 into Equation 1 gives the following equation.

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

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

but $\sum_i^n t_a = nt_a$

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

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 $\frac{1}{\Delta w}$.

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

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:

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

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

Raw Materials and Electricity Supply

Consider the issue of unavailability of raw materials, hich 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:

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

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

DISCUSSION

This study is a case study of Clover paint manufacturing company located in one of the states in Nigeria. The company specializes in the production of different grades of paint and paint containers with a capacity of 118 workers. The company has five different types of machines and other facilities for its production. The basic products of the company are emulsion paint, gloss paint and paint containers, and the company operates a ten hour daily production cycle.

For the application of the model to our study, the electricity unavailability index and the unavailability of raw materials are defined by functions f(y) and f(*z*). Then $f(y_i)$ is given as a function of:

(y) and (z). And so, $f(y_i) = f(y, z)$ **(9)**

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:

$$t = my^3 + m^2y^2 + y \qquad \textbf{(10)}$$

Differentiating Equation 10 gives:

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

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

$$\frac{1}{\Delta m} = y^3 + 2my^2 \qquad \textbf{(11)}$$

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

$$t = wy^3 + w^2y^2 + y \qquad \textbf{(12)}$$

Differentiating above gives:

$$\frac{1}{\Delta w} = y3 + 2wy2 \qquad \textbf{(13)}$$

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

If 2,800 products are produced by the company for 0.5 second per unit product, then:
t_a = 2,800 x 0.5 seconds.

Therefore t_a = 1,400 seconds.

Given that n = 7 and from Equation above, we have:

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

But $\frac{1}{\Delta m} = y^3 + 2my^2$ and $\frac{1}{\Delta w} = y^3 + 2wy^2$.

There are 7 workstations for the paint production processes, hence n = 7. From equation 6, we can now estimate the values of t.

We know that $t = t_j = \frac{1}{\Delta m} \times \frac{1}{\Delta w} \int_1^n f(y)dy + nt_a$

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 = 1,400 seconds.

The average period electricity fails in a day is 95 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, $x = \frac{95 \min utes}{9x60 \min utes} = \frac{95}{540} = 0.1759.$

This gives an index value of 0.1759. Note that the number of machines m = 5, number of workers w = 118. Then since f(x) = 2y + 5, we now evaluate the function by substituting into Equation 6 as follows:

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

so $t = \frac{1}{\Delta m} \times \frac{1}{\Delta w} (y^2 + 5y + c) + nt_a$, were c is the production constant.

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.

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

Now substituting the required values into the equation gives:

$$t = t_j = (y^3 + 2my^2)(y^3 + 2wy^2)(y^2 + 5y) + nt_a \qquad \textbf{(15)}$$

$\therefore t = \{(0.1759^3 + 2 \times 5 \times 0.1759^2)(0.1759^3 + 2 \times 118 \times 0.1759^2)(0.1759^2 + 5 \times 0.1759)\} + (7 \times 1400)$ seconds = 9802.094708 seconds.

$\therefore t$ = 2.722804086 hours = 2 hours 43 minutes.

Note that t_i = 0.5 second per unit product, therefore the total products produced in 2.7228

$$\text{hours} = \frac{2.7228 \text{ hours}}{0.5 \text{ second per unit product}}$$

$$= \frac{2.7228 \times 3600 \text{ seconds}}{0.5 \text{ second per unit product}}$$

= 19.604.16 units of product.

That is 19,604 units of product would be produced in 2 hours 43 minutes.

In conclusion, we have therefore be able to apply a time study mathematical model in calculating the time required for operational activities in the production processes for the manufacture of paint and it is seen that 19,604 units of paint would be produced in two hours forty three minutes.

Observations

The impact of setting standards in the achievement of production targets in paint production by the paint manufacturing company has not been given a thorough consideration until this current study. The company however realized that one of the approaches in achieving this aim is the application of time study models in the monitoring and control of employees on the production floor. It was observed that the current model is slightly different from previous models in the sense that it incorporates some uncontrollable factors such as irregular supply of electricity, unavailability of raw materials, excessive, frequent machine breakdown due to old age, and unavailability of adequate water supply. All of these factors have been considered to have a positive impact on the model.

CONCLUSION

The production of paint by the company studied has been thoroughly examined. The seven basic operational activities were thoroughly studied and these operational activities include**;** weighing of raw materials, drying of raw materials, dissolving of raw materials, material filtering, material stirring, product inspection, and quality control and product packaging.

Our studied 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 on the company production floor. The mathematical model was developed with the application of differential calculus to the elements of the production systems that have significant effect on the production output from the system studied. The study is however considered to be very beneficial to practicing managers in the industries and is therefore recommended for use.

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