A Case Study Application of Time Study Model in an Aluminum Company

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ABSTRACT

This paper presents a case study in the development and application of a time study model in a hollowware aluminium manufacturing plant. The organization engages in the production of three product lines: kettles, frying pans, and cooking pots of diverse categories. The motivation for this study was the need to intervene in frequent crises that normally arose between the employee-association and the management of the company regarding questions of productivity. The three products have similar production processes. Hence, the method of breaking down the processes into jobs and tasks was adopted and analyzed through the use of differential calculus.

This method was applied to the manufacturing processes with the kettle production system drawn as an example. The kettle production process consists of several major activities including stamping and oiling, press forming, trimming, spinning, degreasing, polishing, labelling, wiping and wrapping, spout holing and bumping, inspection, riveting, and packing. By understanding and applying the model, managers can logically trace the effects of time wastages on the production output of systems and their effects.

The study’s most important finding is that the time of producing a unit of product is directly proportional to the number of production stages involved and the time spent at each stage. This can be represented by some structural equations, which are characteristics of the system being studied. The limitations of the study lie in the variability of the major components of the system. The model does not incorporate some variables which may influence decisions made based on the computation of time for which the model may be used.

(Keywords: manufacturing, process analysis, efficiency study, time study, management analysis, differential calculus, mathematical modelling)

INTRODUCTION

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 works of Gilbert and others, the quantitative mathematical modelling of production activities in terms of time study has not evolved in a similarly rigorous fashion (Barnes, 1980; Zandin, 2003; Doty, 1989; Karger and Bayha, 2003). In recent years, the manufacturing organization used as the case example in this work has realized that scientific approaches could be developed to aid dispute settlement between the employees’ association of the company and management regarding issues of productivity. In order to achieve this, the company was motivated to approach a management consultant.

This paper is an attempt to present the methodology used in solving productivity issues at this company. The aluminium company of concern has a manufacturing unit in Lagos, Nigeria. The company stocks various products and distributes them to consumers on order. The company representatives are engaged in the sales of the products. The company concentrates on the manufacture of three fast-moving items – kettles, pots, and frying pans. The operations are housed in a large factory floor consisting of several manufacturing machines, each of which costs an equivalent of several thousand Euros/Dollars. The products are produced in categories. For example, kettles could be of the general form (i.e. 4, 6, 8, 12 pint), tea pot kettle (i.e. 2.5 pint), globe kettle (4 or 6 pint), folding hand kettle (i.e. 4 or 6 pint), Bakelite handle kettle (6 pint), or electric kettle (6 or 8 pint). Cooking pots (usually referred to as casseroles) are of different groupings. This includes sets of 4 or 5 or larger sets of 2. There are also round bottom pots as well as stew pans (6" diameter). In addition, the company sells...
quality ware or special quality ware. Frying pans are specified by handle type. They could be fry pans with steel handles, Bakelite, quality ware, or deep quality ware (painted or plain).

An important problem faced in the hollowware production system is that of determining the time it takes to produce a unit of product. In order to thoroughly analyze the problem, the production processes for each of kettle, pots, and frying pans were examined (Figure 1). Kettle production activities could be broken down into 14 steps: stamping and oiling, press forming, trimming, spinning, degreasing, post degreasing, polishing, labelling, wiping and wrapping, spout bumping (manual and hydraulic), inspection, riveting, and packing. In the production of kettles, two processes are involved. The above process is the first stage that relates to the production of the body, while the second stage relates to the production of the kettle lid. In particular, six activities are involved in the manufacture of the kettle lid: press forming, swaging and perforating, polishing, knobbing, inside wiping, surface wiping and packaging.

THE TIME STUDY MODEL

Several types of information need to be declared in order to have a background understanding into the problem, its formulation, and solution. This would also guide practicing managers who may be in the same and similar systems, and who are willing to apply the model. From the information obtained at the factory floor, the production system is effective. It infers that no losses or leakages are in the production system. Thus, all the efforts put into the production system would yield the desired results. A second information type obtained from the production system is that the right calibre of production personnel is involved. For example, if a worker is of lower skill than required and is engaged in production activities, low or sub-optimal results may be obtained. The right skill, knowledge, and technical know-how of workers is therefore required. A third information category is that there is a defined responsibility for an individual production worker. Hence, a production target is in place, and could be monitored. An added information set is that machines are always in a heavy state. This means that the time study model proposed applies only to a full operational season for the system. Hence, in a real calculation of units produced, the equivalent units lost due to down time many have to be subtracted from the total possible units to be produced. It is noted that when a machine breaks down it can always be repaired and restored in a negligible true frame. There is a clear definition and measurement of output, hence the unit of measurement of production output is known and specified. It is assumed that no significant product damage is allowed during the production process.

Any damage is assumed to be either during the parking period or time of logistics. An added information set is that the allowance periods (break, idle time, recess, etc.) for all of the departments for production are the same. In the modelling process, the starting point is to identify the various units of production. As a research strategy and for the ease of computation, only analyses relevant to kettle production are presented here. The process of producing a
kettle is clearly divided into sixteen steps; stamping and oiling, press forming, trimming, spinning, degreasing, post degreasing, polishing, labelling, wiping and wrapping, spout hole piercing, spout bumping (manual), spout bumping (hydraulic), inspection 1, riveting, inspection 2, and packing. The first mathematical expression for the model framework is as follows:

\[ t = \sum_{i=1}^{n} t_i \]  (1)

In this expression (t) represents the total time used in producing a unit of product. The interpretation of this is that for the kettle process, once an ‘aluminium circle’ which is the basic input into the production of aluminium pot, enters the process the times spent through the system by that single unit is observed. It is the sum of the time spent at the various work stations such as stamping and oiling, press forming, trimming, spinning, etc. up to the stage of packaging.

From Equation (1), the variable (i) represents the various workstations of interests, (i.e. stamping and oiling, press forming, etc.). The total number of workstations is represented by (n). In this case n = 16 since there is a total of sixteen workstations for the kettle process. However, it is more useful to express this formula in a general sense than in specifics. This is what is done in Equation (1).

From a 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. Thus, 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 the oiling and stamping station, (m_i) is the machine that does the work at the press forming stations, etc.). The assumption here is that a workstation is either human controlled or machine controlled. For human control systems, the human being does the work. However, for a machine control system, the machine does the operation.

Still on the discussion on rate, if the time taken by the ‘in-process’ product is termed (t), then we can form a rate expression that would show the rate of work of any machine at any workstation for the kettle production.

This may be expressed mathematically as:

\[ \frac{dm_i}{dt} \]

In the same way, if (w_i) represents the human worker at workstation (i), and this worker works for a period of ‘t’ time units, then we can express the rate working of this worker as: \[ \frac{dw_i}{dt} \]

Since in time study activities a provision of allowances is necessary, we incorporate a parameter ‘to’ into the model. The allowance time may include changing over allowances for the machine operator, periodic breaks for rest periods, tea breaks, breaks for visiting toilets, and observing all conveniences while working. Therefore, in Equation (2) we may need to multiply the unit produced for each workstation by a normalizing function x which converts the expression into time units.

Thus, the multiplication of \[ \frac{dt}{dm_i} \] and \[ \frac{dt}{dw_i} \] is incorporated into equation (2) below. The intent is to explore the reciprocal property of the expression in order to eventually integrate it so as to obtain a general formula that could be adjusted to our particular needs. Thus, equation (2) is expressed as follows:

\[ t_i = \frac{dt}{dm_i} x \frac{dt}{dw_i} f(x_i) + t_o \]  (2)

Now if we substitute the expression for (t) as derived for Equation (2) in Equation (1) stated earlier, we have a new Equation (3) which consists of the two rates of change involving machines and workers, summed up for all of the various workstations considered. Thus, we have:
\[
t = \sum_{i=1}^{n} \left( \frac{dt}{dm_i} x \frac{dt}{dw_i} f(x_i) + t_o \right) \quad (3)
\]

The inner part of Equation (3), (i.e. the portion contained in the bracket) could be further broken down so that we have the summation signs in parts. This is expressed below:

\[
t = \sum_{i=1}^{n} \frac{dt}{dm_i} x \frac{dt}{dw_i} f(x_i) + \sum_{i=1}^{n} t_o \quad (4)
\]

By taking note that \( \sum_{i=1}^{n} \) gives a value of \( n \), then equation (4) could be rewritten as:

\[
t = \sum_{i=1}^{n} \frac{dt}{dm_i} x \frac{dt}{dw_i} f(x_i) + nt_o \quad (5)
\]

In the practical sense, the rate at which machines are producing the units of products may not be the same as the rate at which the workers are producing the same unit of product. This brings complications into the modelling and the practitioner may not be comfortable with the resulting model. However, future work could attempt to address this when the simplified notion introduced here is substituted with this complication and the differences in the model result are observed.

Therefore, we will assume that the rate at which machines are producing and the working rate of workers is constant. This gives us the opportunity of bringing the rate \( \frac{dt}{dm_i} \) and \( \frac{dt}{dw_i} \) outside the summation sign.

Thus, we form a generalization of the model by taking \( f(x_i) \) as \( f(x) \), \( \frac{dt}{dm_i} \) as \( \frac{dt}{dm} \).

It is important to note that the expression, which may result, is shown in equation (6):

\[
t = \frac{dt}{dm} x \frac{dt}{dw} \int_{1}^{n} f(x)dx + nt_o \quad (6)
\]

Equation (6) shows a change from sign \( \sum_{i=1}^{n} \) as evident in equation (5) to an integral sign \( \int_{1}^{n} \).

Now, if the total number of products produced is denoted by symbol \( y \), then we may introduce \( T \) as the total time spent for all the products. In this case \( T \) will be the product of \( y \) and \( t \). Therefore a new expression emerges as:

\[
T = yt = y \left( \frac{dt}{dm} x \frac{dt}{dw} \int_{1}^{n} f(x)dx + nt_o \right) \quad (7)
\]

Equation (7) is the general formula for the total time spent in producing \( y \) products. Experimentation could be performed on equation (7) in order to test the results generated.

In the equations that follow, we introduce some degrees of variations in the modelling. This is a relaxation of the earlier rule that we should avoid complexity in the model development. At this stage, we consider practical situations that may exist which would affect the model that we are generating. In practice, the number of units projected for a period may not be actualized due to certain factors beyond the immediate control of the manager at the production floor.

The issue of irregular electricity supply, unavailability of raw materials, and the skill levels of workers are important examples at this stage. We may also add the breakdown frequency of machines. In the last point for instance, the company may be constrained to the purchase an older machines due to financial limitations. This is very common for small and medium enterprises (SMEs) in developing countries that are always at the mercy of sponsoring agencies for financial assistance. No matter how much effort is put into the maintenance of machines, there is always a steady number of breakdowns experienced due to machine age. This is one parameter that may be incorporated into the model to increase its flexibility. Another important parameter is that of irregular electricity supply.
In developing countries, erratic power supply has devastating effects on businesses, particularly on manufacturing. If a business investor could not afford an alternative standby generator, then the number of units produced would be affected in the long run. This is an important factor to incorporate into the model.

A third factor is the unavailability of raw materials to be used in the manufacturing process. The case is common for developing countries where no organized supply systems could be guaranteed. The production crew may need materials for certain processes where the absence of materials would cause production stoppages. This is an important factor to incorporate into the model.

Now let us assume that there are some indices that could measure these factors. For example, the machine breakdown frequency index may represent a measure of breakdown of the machines below the average expected for a new machine. Also, electricity failure index may describe the erratic supply of electricity for production processes. For raw material unavailability, we define an index termed materials unavailability index, which would measure the rate at which materials are made unavailable when, needed for production processes. All these indices could be incorporated into the model. However, let us pick two of these which will be electricity failure index and materials unavailability index.

Consider a situation where \( f(x_i) \) is a function of these two parameters of indices such that we have \( f(x) \) and \( f(x, z) \). Therefore Equation 7 can now be expressed as follows:

\[
T = yt = y \left( \frac{dt}{dm} x \frac{dt}{dw} \int f(x, z) dx dz + n t_o \right) \quad ------ (8)
\]

Equation (8) may be described as the general formula for the total time spent in producing \( y \) products. It should be noted that \( f(x) \) and \( f(x, z) \) could be any mathematical function that defines \( x \) and \( x \) and \( z \) respectively. If we assume the electricity supply index \( x \) is a linear function, the equation that describes it is displayed as:

\[
f(x) = 2x + 5, \text{ where } 2 \text{ and } 5 \text{ are constants.}
\]

Also, if the electricity supply index which has been taken as \( x \) is quadratic, the equation that describes its state is displayed as:

\[
f(x) = 3x^2 + 5x + 6.
\]

Electricity supply index \( x \) could also describe a state of exponential condition. Therefore, when exponential state is being described the equation that described it is displayed below:

\[
f(x) = e^{3x}.
\]

If we take the raw materials availability index as \( z \) (it should be noted that the electricity supply index is taken as \( x \)), then relating the two indices under one function, gives us \( f(x, z) \) which describes a state of linear function where the equation is displayed as:

\[
f(x, z) = 3xz + 7, \text{ where } 3 \text{ and } 7 \text{ are constants and } (x) \text{ and } (z) \text{ have been described earlier.}
\]

Taking into consideration, the case where \( f(x, z) \) describes the state of quadratic function, the equation would be quadratic. Therefore the equation described by \( f(x, z) \) when a quadratic function is obeyed by \( f(x, z) \) is displayed as:

\[
f(x, z) = 4(xz)^2 + 6xz + 8, \text{ where } 4, 6 \text{ and } 8 \text{ are constant values.}
\]

Now, it is possible for \( f(x, z) \) to describe a state of exponential function. When \( f(x, z) \) describes a state of exponential function, the equation that describes it is displayed as:

\[
f(x, z) = e^{3xz}, \text{ where } 3 \text{ is a constant in the equation above.}
\]

In an effort to modify the model, now let us consider a scenario where the rate at which the machines and workers are operating are the same.

Equation (2) could be revisited with some adjustments.

The differential \( \frac{dt}{dm_i} \) could be inversed and substituted in the original expression for equation (2) to obtain a new Equation (9). Thus,

\[
t_i = \left( \frac{dm}{dt} \right)^{-1} x \frac{dt}{dw_i} f(x_i) + t_o \quad ------ (9)
\]
Now, let \( \frac{dm}{dt} \) be represented by a function \( g(x) \), and \( \frac{dw_i}{dt} \) represents the function \( h(x) \). In addition let \( f(x_i) \) be represented by \( f(x) \) where \( (x) \) could be any particular parameter. Then by substituting these values in Equation (7), we have a new expression:

\[
t = \int g(x) h(x) dx + n t_o \quad \text{(10)}
\]

By adding the term \( y \), the expression for \( (T) \) is then defined as follows:

\[
T = y \left( \int g(x) h(x) dx \right) + n t_o \quad \text{(11)}
\]

However, for a situation where \( f(x_i) \) is defined by \( f(x, z) \), the equation becomes:

\[
T = y \left( \int_1^{n} \frac{f(x)}{h(x) g(x)} dx + n t_o \right) \quad \text{(12)}
\]

**MODEL APPLICATION AND DISCUSSION**

This case study represents a real life situation of an engineering company in Nigeria. However, the name has been changed to protect the identity of the company. The name used in this paper is Dynamics Limited (DL). The company specializes in producing different types of aluminium hollowware products. Dynamics Limited is a large engineering company with a capacity of 300 workers. It has a considerable manufacturing area. The company has different types of manufacturing machines and other facilities that aid the hollowware production processes. The products of the company are kettles, cooking pots, and frying pans, etc. The company is highly recognized for hollowware product sales in view of its long-term high-quality products to customers at affordable prices.

The business environment in which DL operates is highly commercial. There are many companies also located in this area with diverse products outside the range produced by DL. The company operates twenty-four hours everyday with three shifts periods of eight hours each among the workers. DL’s company structure may be sectioned into management, engineers, and craftsmen. The engineers in the company are well trained with major professional training experience obtained from overseas countries. The market size of DL’s products is further strengthened by a large number of customers in the environment that patronize the company’s products.

During festive periods (i.e. Christmas, etc.), a large number of customers usually patronize the company’s products, thus resulting in huge sales spikes. This has generated a great deal of controversy in the past among the trade union in the company. In a recent event, the trade union held a meeting concluding that workers are denied some bonuses based on elevated production spikes. The union made known their complaints to management; unfortunately, management ignored these complaints by the union. Consequently, the union threatened to go on strike and stop the production processes.

The strike thus started. On the third day of the strike, the management called the union’s president for negotiations. This led to inviting a university professor who is a consultant and specialist on “Work Study” matters. After many deliberations, the professor agreed to assist the company in solving the problem through a scientific approach as proposed in this paper.

In implementing the mathematical model, the consultant considered some factors that would militate against hitting the production targets. The factors considered are electricity supply fluctuation, unavailability of raw materials, and frequent breakdown of machines as a result of old age. The factors are measured by some indices: electricity failure index represents the measure in the irregular supply of electricity, materials unavailability index represents the unavailability of raw materials, and machine breakdown frequency index represents the average breakdown of the machines used in production processes.

For the purpose of model illustration, we include only two factors in our application. The model
aspects that concern this are treated as follows. Suppose the two factors picked are electricity supply and unavailability of raw materials: if the electricity unavailability index and the unavailability of raw materials are defined by functions \((x)\) and \((z)\), \(f(x)\) is given as a function \((x)\) and \((z)\). Also, \(f(x_i) = f(x, z)\).

We will consider the electricity supply index which is given as \((x)\). If \(x\) obeys a linear function, then the expression is \(f(x) = 2x + 5\). From the above equations, we know that \((n)\) is the number of workstations while \((t_o)\) is the time allowance. From the actual production observation, the mathematical model that fit the time problem in terms of number of machines is:

\[
    t = mx^3 + m^2x^2 + x. \quad \text{(13)}
\]

It should be noted that \((m)\) is the number of machines.

We could differentiate this expression. This could be stated mathematically as:

\[
\frac{dt}{dm} = x^3 + 2mx^2 \quad \text{(14)}
\]

In the same way, the mathematical expression that represents the time problem with respect to the number of workers is:

\[
    t = wx^3 + w^2x^2 + x \quad \text{(15)}
\]

It should be noted that \((w)\) represents the number of workers. Thus, the differential of this expression could be expressed as:

\[
\frac{dt}{dw} = x + 2wx^2 \quad \text{(16)}
\]

Note that \((n)\) has been stated earlier to be the number of workstations, and \((t_o)\), the time allowance. If 280,000 products are produced by the company for 0.01 seconds per unit product, then \(t_o = 280,000 \times 0.01\) seconds. Therefore, \(t_o = 2,800\) seconds.

Since the company specializes in different types of aluminium products, by taking the kettle production process into the analysis, there are sixteen workstations for the kettle production processes. Hence, \(n = 16\). Now, if we recall equation (6), we have all the values to substitute in this expression but are left with \(f(x)dx\). That is, from the expression:

\[
    t = t_i = \frac{dt}{dm} x \frac{dt}{dx} \int f(x)dx + nt_o, \quad \text{we know the}
\]

values of \(\frac{dt}{dm}\) as \(x^3 + 2mx^2\), \(\frac{dt}{dw}\) as \(x^3 + 2wx^2\), \(n = 16\), and \(t_o = 2800\) seconds. In order to calculate the value of \(f(x)dx\), we need to introduce the actual meaning of \((x)\). Thus, \((x)\) means the ratio of the period when electricity fails in a day to that of the working hours for that same day.

Now, the average period that the electricity fails in a day is 30 minutes, while the average working time is 8 hours.

So, \(x = \frac{30 \text{ minutes}}{8 \times 60 \text{ minutes}} = \frac{30}{480} = 0.0625\).

This gives an index of 0.0625. Note that other values are number of machines = 9, \(w = \) number of workers = 300. Then since \(f(x) = 2x + 5\) is the mathematical function that represents this situation, \((x)\) obeys a linear functional behaviour.

If we now substitute the values that we obtain in equation (6), we obtain:

\[
    t = \frac{dt}{dm} x \frac{dt}{dx} \int (2x + 5)dx + nt_o = \\
    \frac{dt}{dm} x \frac{dt}{dx} (x^2 + 5x + c) + nt_o \quad \text{(17)}
\]

Note that \((c)\) is the constant of integration. Now, at the start of the production process, all the factors are assumed to be zero. That is \((t)\), \((x)\), \((n)\), and \((c) = 0\). This is the initial boundary condition.
Now substituting the required values into the equation immediately preceding the text in the immediate paragraph above:
\[
t = t_i = (x^3 + 2mx^2) (x^3 + 2wx^2) (x^2 + 5x) + nt_o \quad (18)
\]
\[
t = (0.0625^3 + 2 \times 9 \times 0.0625^2) x
\]
\[
(0.0625^3 + 2 \times 300 \times 0.0625^2) x
\]
\[
(0.0625^3 + 5 \times 0.0625) + (16 \times 2800 \text{ sec}) = 12.44 \text{ hrs.}
\]

Now, it has been stated in the earlier computation that \( t_i = 0.01 \) second per unit product. Therefore, the total products produced in 12hrs. = \( \frac{12.44 \text{ hrs.}}{0.01 \text{ second per unit product}} \).

Converting 12 hours into seconds gives 12.44 x 3600 seconds = 44784 seconds. This means that \( \frac{44784}{0.01} \) per unit product would be produced in 12 hours. That is 4,478,400 units of product would be produced in 12 hours. The above analysis is for the kettle system.

However, the same systematic approach adopted for kettle production is suitable for pot production. We therefore analyze the pot production systems as follows. The number of workstations for the pot production process is twelve. Therefore \( n = 12 \). The number of workers required for pots production is 26 workers and the number of machines required = \( m = 6 \). Using the mathematical modelling presented in this paper the following holds true:

\[
t = \sum_{i=1}^{n} t_i = \frac{dt}{dm} x \frac{dt}{dw} \int f(x)dx + nt_o \quad - - - - (19)
\]

where \( f(x) \) obeys a linear function \( ax + b \) but \( z = 2, b = 5 \).

Therefore, \( ax + b \) becomes \( 2x + 5 \). For the machine requirement: \( t = mx^3 + m^2x^2 + x \), for the manpower requirement, \( t = wx^3 + w^2x^2 + x \). The electricity index \( (x) \) has been defined in this paper.

For kettle production, if the electricity supply fails for 25 minutes per 8 working hours per that day.

\[
x = \frac{25 \text{ minutes}}{8 \times 60 \text{ minutes}} = \frac{25 \text{ minutes}}{480 \text{ minutes}}, x = 0.0521.
\]

Now, \( \frac{dt}{dm} = x^3 + 2mx^2 \), \( \frac{dt}{dw} = x^3 + 2wx^2 \), since \( x = 0.0521, m = 6, w = 26 \) workers.

\[
\frac{dt}{dm} = x^3 + 2mx^2 = 0.0521^3 + 2 \times 6 \times 0.0521^2 = 0.00014142 + 0.03257 = 0.0327
\]

\[
\frac{dt}{dw} = x^3 + 2wx^2 = 0.0521^3 + 2 \times 26 \times 0.0521^2 = 0.00014142 + 52 \times 0.002714 = 0.1413
\]

\[
\int f(x)dx = \int 2x + 5 dx = \frac{2x^2}{2} + 5x + c = x^2 + 5x + c
\]

If 280,000 products are produced by the company for 0.01 second per unit product then, \( t_o = 2800 \) seconds as explained earlier on in the paper. Therefore \( nt_o = 12 \times 2800 = 33,600 \). It has also been stated and explained earlier in the paper that assuming an initial condition when no production processes are taking place, \( c = 0 \). Therefore, \( x^2 + 5x + c = x^2 + 5x \).

Substituting the necessary parameters into the equation:

\[t = \frac{dt}{dm} x \frac{dt}{dw} \int f(x)dx + nt_o\]

we have:

\[t = (0.0327) (0.1413) (x^2 + 5x) + 33600, \text{ but } x = 0.0521, \text{ therefore:} \]

\[t = (0.0327) (0.1413) (0.0521^2 + 5(0.0521)) + 33,600 = 33,600 \text{ seconds} = 9.33 \text{ hours.} \]

But \( t_i = 0.01 \) second per unit product, therefore, the total products produced in 9.33 hours = \( \frac{9.33 \times 3600 \text{ second}}{0.01} \) per unit product = 

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3360000 = 3,360,000 units of products in 9.33 hours.

Now using the same analysis for frying pan,

\[ t = \sum_{i=1}^{n} t_i = \int_0^t \left( f(2x + 5)dx + nt_0 \right) \]

When \( n = 9 \),

\[ \frac{dt}{dm} = x^3 + 2mx^2, \quad \frac{dt}{dw} = x^3 + 2wx^2 \]

\[ 2wx^2, \ t_0 = 2800 \text{ seconds}, \ x = \frac{18 \text{ minutes}}{8 \times 60 \text{ minutes}}. \]

The value of \( (x) \) has been explained earlier in the paper. If there was a period of 18 minutes of power failure out of the 8 hours of operation per day when frying pans are being produced:

\[ x = \frac{18}{480} = 0.0375, \ m = 5, \ w = 14 \]

\[ t = (0.0375)^3 + 2 \times 5 \times 0.0375^2 \times 0.0375^3 + 2 \times 14 \times 0.0375^2 \int (2x + 5) dx + 9 \times 2800 \]

\[ t = (0.000052734 + 0.014063) x (0.000052734 + 0.039375) x^2 + 5x + c + 25200 \]

At the initial stage when production process is not taking place, \( c = 0 \).

Therefore \( t = (0.01412) (0.03943) (x^2 + 5x) + 25200 \)

\[ t = (0.0005568) (0.0375^2 + 5 \times 0.0375) + 25200 \]

\[ = \frac{25200}{3600} \text{ hours} = 7 \text{ hours} \]

But \( t_i = 0.01 \text{ second per unit product for the frying pan process, therefore the total products} \)

produced in 7 hours = \( \frac{25200}{0.01} = 2520000 \text{ units.} \)

To conclude this section, it is important to state that we have succeeded in applying a time study mathematical model in calculating the time required for operational activities in the production processes for kettles, cooking pots, and frying pans. For the kettle production system 4,478,400 units of kettles could be produced in 12 hours. Also, 3,360,000 units of pots could be produced in 9.33 hours and 2,520,000 units of frying pans could be produced in 7 hours.

In the following section, we give some conclusions on the work done and propose some future directions for exploration by the members of the performance management community.

**CONCLUSION**

The impact of setting standards in the achievement of production targets is well documented in the management literature. 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. In this paper, the time study concept in a production process is modelled mathematically. An application is made in a hollowware manufacturing company that engages in the production of kettles, frying pans, and cooking pots of diverse categories. The modelling was developed with the application of differential calculus to the elements of the production systems that have significant effect on the output production from the system.

This paper has argued for a need by current production managers or work-study engineers to embrace more quantitative approaches in the determination of time standards. Bearing in mind this article may have addressed key issues of concern to managers; we therefore strongly believe that the work would readily have values to practicing engineers. Some of the key questions that people may ask about this paper are: (i) What research has been conducted in the current paper? (ii) What approaches or methods have been adopted in disseminating the information to the readers? (iii) What are the main findings from the study? (iv) Of what benefit is the work to me as a manager in the industry that wants more efficiency and profit? (v) In considering research on this topic, what are the areas that I may need to look into so as to complement the current study?

We have addressed issues raised in points (i) an (ii) above in the early part of the conclusion. However, we need to address the third issue...
about these findings. 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 machine breakdown due to old age, etc. All of these factors have been considered to have a positive impact on the model. Unfortunately, there seems to be no documentation that has incorporated this into a model. This is an important gap closed by the current study. We have found that it is feasible to apply the model in a real life situation. This then suggests the possibility of applying the model in other situations with some adjustments in the data collection instrument. The study may be very beneficial to practicing managers in the industry since it has captured some aspects that have been ignored till date in the management literature. This therefore, gives more reliable information about the system being studied when compared with previously obtainable information.

There are several analytical tools that may be augmented to the current work in order to add more value (Hartley et al., 1998). An immediate extension of the work is the application of soft computing tools such as neuro-fuzzy, fuzzy logic, artificial neural networks, etc. to the current framework. Some optimization techniques could be applied so as to determine optimal point for some key decision variables in the model. Applications of a Lagrangian multiplier may add much value to the current work.

REFERENCES


ABOUT THE AUTHOR

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