An inflation-based maintenance profitability model

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Abstract: The maintenance profitability problem is an important but emerging concept of maintenance performance measurement that views the maintenance function as a value adding subsection of the organisation. The service provided by the maintenance system to production is charged as a price, which results in the monetary contribution of the maintenance department to the organisation. In the same way, as production would add financial benefits to the organisation the maintenance system is portrayed as adding profit to the organisation. In this work, we present a mathematical model that calculates the maintenance profitability of an organisation under the condition of inflation using a composite mathematical function. It is concluded that viewing maintenance from a profit-making orientation provides a challenge to the maintenance team, thus driving them towards improved performance.

Keywords: maintenance-profitability; maintenance-revenue; price; machinery and equipment; maintenance-team.

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1 Introduction

Today, organisations worldwide are experiencing globalisation, intense competition and organisational restructuring for improved performance in terms of productivity, profitability, quality, efficiency and effectiveness (Dessouky et al., 2007; Elangovan et al., 2007; Muthiah and Huang, 2006; Oke, 2005). This recent development has forced many organisations to rethink on how business is done (Hayshironohammadi and Wedley, 2004). The result is a close monitoring and scrutiny of the various sections of the organisation using various performance criteria. Profitability is an important performance criterion that has stood the tests of time for decades (Hilmola, 2006). Maintenance profitability, is another dimension of profitability that may attract the interest of both practitioners and researchers in view of the difficulty attached to quantity the efforts of maintenance (Fernandez et al., 2003; Liyanage and Kumar, 2003; Mjema and Mweta, 2003).

Traditionally, maintenance has been viewed from the perspective of a 'fund sinking function' or a 'bottomless pit of expenses' (Saranga, 2004). Fortunately, this viewpoint is gradually changing as the maintenance is now been considered as a value-adding unit of the organisation whose contribution in preventing machine failures, and inconsistent product quality is immense (Al-Ghanim, 2003; Bertolini et al., 2004; Cholasuke et al., 2004). If this perspective is correct, then the conflicts that usually arise between the maintenance department and production would be partially solved. This is because the effort of the maintenance function can be quantified in terms of selling services to production and other departments (Emblemsuag and Tonning, 2003). However, for the purpose of modelling simplicity, services offered by the maintenance department to other departments outside the production function would be assumed negligible since it may introduce some complexity the modelling if this assumption is not made. Primarily, the viewpoint springs up from the accounting literature that defines profitability as the ratio of revenue to cost.

Therefore, from the perspective of this paper, we defined maintenance profitability as the ratio of the revenue generated by the maintenance department through its services to the production system to the value of input resources utilised for the particular level of service rendered. An important question relates to the difference or relationship between the profitability of the organisation and the profitability of the maintenance department. The profitability of the organisation as a whole is made when products or services of the organisation are sold or rendered to the public. However, maintenance profitability relates to the activities within the organisation (Wang and Hwang, 2004).

Once the maintenance department provides the required services to the production function by the proper upkeep of equipment and machinery, the maintenance department is said to make its profit even though goods are not sold to the public. Once quality goods are produced by the production department for the finished goods inventory department, the maintenance department is credited for a job well done. Another assumption at this stage is that the services rendered by the maintenance department are wholly converted into useful products by the production department (Mirghani, 2003; Wang and Hwang, 2004).

The structure of this paper is sectioned into the following: Introduction, previous research, model development, case study and discussion of results and conclusion. The introduction motivates the readers in the subject of this paper. The previous research section discusses the literature and highlights the relevance of this paper and its justification. The model development deals with the profitability estimation methodology. The section on case study and discussion of results provides a detailed background on the case study and an in-depth discussion of the results obtained. The managerial implications of the application of the model are also discussed in this section. The concluding section provides remarks about the study.

2 Previous research

The maintenance literature contains several scientific studies related to performance evaluation (Elangovan et al., 2007; Karuppuswamy et al., 2007; Pramod et al., 2006; Zoeteman, 2006). Unfortunately, no assistance has been offered to solve the maintenance profitability problem considered in this work (Leung and Lai, 2003; Shankar and Sahani, 2003). The reason may be due to the fact that the perception given to maintenance has been different to what it is presently. As such, there are not many direct references on maintenance but across some other subject areas that have treated the subject of profitability. These ideas are borrowed and augmented to the current work in order to establish the concept of maintenance profitability (Kanne and Boukas, 2003). Furthermore, we argue that the profitability of the maintenance function needs to be optimised. Since optimisation deals with the minimisation and maximisation of cost due to revenue, respectively, we argue that the cost of maintenance activities must be minimised while the 'revenue generated' must be maximised (Sharma et al., 2007; Waeyenbergh et al., 2004).

Komonen (2002) presents a cost model of industrial maintenance for profitability analysis and bench marking. The work presents a hierarchical system of maintenance performance indicators using an empirically tested cost model of industrial maintenance with data collection from more than 400 companies operating in various industries (Agiomirgianakis et al., 2006). Credit could be given to Komonen (2002) due to a new perspective of measuring profitability in terms of cost. Unfortunately the important item of revenue generation is missing. Maintenance must be viewed as a revenue generating function so that it could earn more recognition with the accompanied funds availability for running the maintenance function, this is an important gap that the current work aims to fill. Quite clearly there is much support for our viewpoint that maintenance must be viewed as a profit generation function.

Two profitability studies were championed by Heras et al. (2002a,b). The first study focuses on ISO 9000 registration's impact on sales and profitability and suggests the possible linkage between maintenance profitability and ISO implementation programmes. The second study compares the profitability of Basque region companies over a period of five years. Unfortunately, no attempt made at modelling the problem in a way that would be beneficial to the practitioners and researchers in maintenance profitability. In particular, revenue and costs are not compared. This is an important gap in the literature that this present work addresses.

In a study by Saranga (2004) the issue of opportunistic maintenance was treated. This paper addresses the questions of how to decide whether a particular item needs opportunistic maintenance, and if so how cost effective the opportunistic maintenance is in comparison to a later grounding. A hypothetical example is used to describe the methodology for genetic algorithms. Despite the attempt by this author to improve on the performance of the maintenance function through the model presented, no efforts were made to discuss a quantitative way of addressing the maintenance profitability problem. The issue is addressed in this present work.

Another paper relates to the optimisation of maintenance performance through a reconception of the centralisation and decentralisation systems (Hajshrmonhamadi and Wedley, 2004). This paper proposes a systematic model for evaluating different maintenance organisational structures with respect to the objectives of a maintenance department. A close scrutiny of this paper reveals that no attempt has been made to address the problem at hand.

The concept of value-based views of operations and maintenance was addressed by Liyanage and Kumar (2003) using oil and gas organisations in the Norwegian continental shelf. This study developed architecture for effective management of operations and maintenance performance linking results to performance drivers. This has further been extended to applying the balanced scorecard concept. This paper emphasises on the value rather than the cost of operations and maintenance in the emerging business environment, and stresses that there is a need to move from a plant-based policy to a more or less long-term business-oriented approach. Again, the work by these authors did not relate to the balance-scorecard method with the quantitative measurement of maintenance performance. Thus, the authors have left this gap opened.

Another interesting study is due to Mirghani (2003). This paper develops a case study on the application and implementation issues of a framework for costing planned maintenance. It outlines the methodology for the development of the case study and presents the major findings of the existing maintenance-costing system of the organisation under study. It presents the results of a pilot study of the application of the proposed costing framework to a sample of planned maintenance jobs. It provides recommendations and identifies critical issues for a successful implementation. Also, this paper did not address the maintenance profitability problem that is the key interest on the current work.

Yet in another work, the development and implementation of a decision support maintenance management system was of primary concerned to Fernandez et al. (2003). The work discusses the CMMS as a powerful tool necessary for obtaining information from raw data and support the decision-making process. Furthermore, a CMMS has been designed, developed, customised and implemented for a disc brake pad manufacturing company-based in England. In addition, a maintenance maturity grid has been proposed to support the CMMS implementation. The grid shows that the complexity of the CMMS will increase as the maintenance function moves from a reactive to a proactive culture. The implemented CMMS aims to reduce total downtime and frequency of failures of the machines by improving the efficiency and effectiveness of the maintenance force. The computer program simplifies and reduces the time of data capture compared to the currently used paper-based reporting system. It also provides the maintenance planners with a platform for decision analysis and support, which is often ignored in the commercial CMMS available in the market. By scrutinising this reviewed paper, it is obvious that the authors have not examined the concept of maintenance profitability which is considered for organisational survival. This is addressed in the current work.

A closely related work to the above is due to Mjema and Mweta (2003). The main objective of this study was to analyse the economics of introducing IT in the maintenance department. The economics in this case was determined by conducting a quantitative analysis in the reduction of operational costs, an increase in productivity and on quality improvement. A comparison was made to analyse company performance in the maintenance before and after the introduction of IT in the maintenance department. The analysis shows that there were reductions of operational and inventory holding costs. Likewise, it was shown that there was also improvement in product quality and productivity. Again, the work did not examine the issue of maintenance profitability, which is of core interest to the current authors.

3 Model development

In formulating the model, the idea is based on the principle of profitability as defined in the accounting literature. Traditionally, profitability is defined as the ratio of revenue to cost. Unfortunately, no related work to maintenance profitability is observed in the literature. Viewing from the new perspective of measuring maintenance performance, we argue that maintenance is a value-adding function of the organisation. The viewpoint proposed here states that maintenance should not be viewed as a 'bottomless pit of expenses' but as one that contributes to the revenue of the organisation. The contribution of maintenance comes from the upkeep services of plant, machinery and equipment that it provides to the organisation. We argue that it is only when maintenance performs its duty that the machinery and equipment could produce from where goods are sold to the customer at a price and revenue is generated. Thus, mathematically, Equation (1) can be presented as:

$$\text{Maintenance Profitability} = \frac{\text{Revenue generated by the maintenance department}}{\text{The cost incurred for the upkeep of the machines and running expenses}} \tag{1}$$

For the purpose of the model development, we define the following terms:

P = Maintenance profitability.

Q = Quantity of services sold to the production department.

U = Unit price of services sold to the production department.

I = Quantity of resources utilised by the maintenance department.

C_o = Unit cost of resources utilised by the maintenance department.

t = The period of assessment of maintenance department.

n = The inflation factor in the economy.

Thus, Equation (1) could be redefined in terms of the notations given above. Mathematically,

$$P = \frac{QU}{IC_o(1-n)^t} \tag{2}$$

For modelling simplicity, Equation (2) is considered as a composite function that could be separated into three distinct variables; $Y(Q)$, $X(I)$ and $T(t)$. Now, if the inflation factor is assumed to be constant, we can then proceed to formulate the model and then apply partial differential equations principles to further the work.

Thus, let us suppose that

$$Y = \frac{Q}{C_o}, X = \frac{U}{I} \text{ and } T = \frac{1}{(1-n)^t} \text{ and } P = Y(Q)X(I)T(t) \tag{3}$$

We could then apply the partial differential of the second order to obtain:

$$\frac{\partial^2 P}{\partial Q^2} + \frac{\partial^2 P}{\partial I^2} = \frac{1}{C_o^2 T}\frac{\partial^2 P}{\partial t^2} \tag{4}$$

If C_o is assumed to be a constant, then the second order differential in Equation (4) becomes:

$$\frac{1}{Y}\frac{d^2 Y}{dQ^2} + \frac{1}{X}\frac{d^2 X}{dI^2} = \frac{1}{C_o^2 T}\frac{d^2 T}{dt^2} \tag{5}$$

For simplicity of modelling, if we assumed that m is a constant and that:

$$\frac{1}{Y}\frac{d^2 Y}{dQ^2} = -m^2 \tag{6}$$

Then by transferring the value of $-m^2$ to the left hand side of Equation (6), then we have a new Equation (labelled as (7)). This gives:

$$\frac{1}{Y}\frac{d^2 Y}{dQ^2} + m^2 = 0 \tag{7}$$

Equation (7) takes the form of a standard solution for differential equations as expressed in Equation (8) below:

$$A\sin(mQ) + B\cos(mQ) = Y \tag{8}$$

For Equation (8), the values of A and B are constants. Similarly, following the standard solution form of differential equations, we can express X in terms of K in Equations (9) and (10) below to give Equation (11). Note that E and D are assumed to be constants. Thus, we have Equation (9)–(11) as follows:

$$\frac{1}{X}\frac{d^2 X}{dI^2} = -k^2 \tag{9}$$

$$\frac{1}{X}\frac{d^2 X}{dI^2} + k^2 = 0 \tag{10}$$

$$D\sin(kI) + E\cos(kI) = X \tag{11}$$

Now, transforming the right hand side of Equation (5) to the same form as in Equations (9)–(11), we obtain Equations (12)–(14) as follows:

$$\frac{1}{C_o^2 T}\frac{d^2T}{dt^2} = -a^2 \tag{12}$$

$$\frac{1}{C_o^2 T}\frac{d^2T}{dt^2} + a^2 = 0 \tag{13}$$

$$F\sin(aC_o t) + G\cos(aC_o t) = T \tag{14}$$

Note also that F and G are constants.

Now substituting for Y, X and T from Equations (8), (11) and (14) in Equation (3), we then have a new equation as:

$$P = (AX\sin(mQ) + B\cos(mQ))(D\sin(KI) + E\cos(KI))\left(F\sin(aC_o t) + G\cos(aC_o t)\right) \tag{15}$$

If we let $C_o m = \lambda$ and $C_o k = \phi$ where λ and ϕ are constants, then

$$m = \frac{\lambda}{C_o} \text{ and } k = \frac{\phi}{C_o} \tag{15a}$$

New revisiting Equation (5), we can substitute the values of m^2, k^2 and a^2 obtained from Equations (6), (9) and (12) in Equation (5). The new equation obtained is:

$$a^2 = m_2 + k^2 \tag{16}$$

From here, we obtain

$$a = \sqrt{m^2 + k^2} \tag{17}$$

New, substituting Equation (15(a)) *I* Equation (17) we have

$$a = \sqrt{\frac{\lambda^2 + \phi^2}{C_o}} \tag{18}$$

The next step is to substitute for m, k and a in Equation (15) to give a new Equation (19)

$$P = \left(A\sin\frac{\lambda}{C_o}Q + B\cos\frac{\lambda}{C_o}Q\right)\left(D\sin\frac{\phi}{C_o}I + E\cos\frac{\phi}{C_o}I\right)\left(F\sin\left(\sqrt{\lambda^2+\phi^2}\right)^t + G\cos\left(\sqrt{\lambda^2+\phi^2}\right)^t\right) \tag{19}$$

In the practical sense, if no services are provided by the maintenance department to production, then we may also assume that no resources are utilised by the maintenance department for the job. Therefore, for all periods of assessment the maintenance profitability would be nil. Thus, mathematically, when $Q = 0$, $I = 0$, for all values of t, $P = 0$. Now substituting these values in Equation (19), the expression then reduces to:

$$0 = \left(F\sin\left(\sqrt{\lambda^2+\phi^2}\right)t + G\cos\left(\sqrt{\lambda^2+\phi^2}\right)t\right) \tag{20}$$

The explanation supporting the expression in Equation (20) from Equation (19) is as follows. From the left hand side, $P = 0$ so zero is substituted for P. By substituting $Q = 0$ in the first term, the first term expression reduces to B. When $I = 0$ is substituted in the second term, the expression for the second term reduces to E. The last term is not affected by Q or I, hence it retains its initial form.

From Equation (19), let us consider both B and E to be zero, then we have a new Equation (21):

$$P(Q,I,t) = A\sin\left(\frac{\lambda Q}{C_o}\right) D\sin\left(\frac{\phi}{C_o}I\right)\left(F\sin\left(\sqrt{\lambda^2+\phi^2}\right)t + G\cos\left(\sqrt{\lambda^2+\phi^2}\right)t\right) \quad (21)$$

If A and D which are considered to be constants are inserted into the bracket such that they are multiplied with the third terms of the expression in Equation (21), then we have a new Equation (22).

$$P(Q,I,t) = A\sin\left(\frac{\lambda Q}{C_o}\right) D\sin\left(\frac{\phi I}{C_o}\right)\left(ADF\sin\left(\sqrt{\lambda^2+\phi^2}\right)t + ADG\cos\left(\sqrt{\lambda^2+\phi^2}\right)t\right) \quad (22)$$

If we let ADF be represented as C_n and ADG as B_n while $\sqrt{\lambda^2+\phi^2} = \alpha$, then Equation (22) could be reexpressed as Equation (23) below

$$P(Q,I,t) = A\sin\left(\frac{\lambda}{C_o}Q\right)\sin\left(\frac{\phi}{C_o}I\right)\left(C_n \sin\alpha t + B_n \cos\alpha t\right) \quad (23)$$

Now, let us consider a practical situation where input resources are utilised for the maintenance function and no maintenance output is achieved, then we assume that $Q = 0$, $I = q$ and $P = 0$. This situation may arise when the wrong skilled staff is used for maintenance activities or when funds are not available to execute maintenance plans. The situation may also arise in cases where machine components for replacement or input resources are pilfered or wasted, respectively. Mathematically, this situation is expressed as:

$$0 = \left(\frac{\phi}{C_o}\right) q\left(C_n \sin\alpha t + B_n \cos\alpha t\right) \quad (24)$$

For Equation (24) to be valid, it means that either the first term or the second term must be zero. However, the second term is not zero. Therefore, the first term must be zero. Thus,

$$\sin\left(\frac{\phi}{C_o}q\right) = 0 \quad (25)$$

From Equation (25), the term $((\phi / C_o)q)$ is obtained thus,

$$\frac{\phi}{C_o}q = \sin^{-1}(0) \quad (26)$$

But $\sin^{-1}(0)$ could take the values 0, π, 2π,..., $h\pi$ where $h = 0, 1, 2, 3,\ldots$. Therefore,

$$\frac{\phi}{C_o} q = h\pi \tag{27}$$

From here,

$$\phi = \frac{C_o h\pi}{q} \tag{28}$$

If the quantity of services sold by the maintenance department to the production department diminishes, by implication the quantity of resources utilised by the maintenance department should also diminish. Therefore, the maintenance profitability tends to zero. We then have a new expression for Equation (24). Mathematically, we state that: $P \to 0$, when $Q \to \delta$, $I \to \varepsilon$. Thus,

$$0 = \sin\left(\frac{\lambda}{C}\delta\right)\sin\left(\frac{\phi}{C}\varepsilon\right)\left(C_n \sin\alpha t + B_n \cos\alpha tt\right) \tag{29}$$

The same argument for transforming Equation (24) holds here. Thus, we say either $\sin((\lambda/C)\delta) = 0$ or $\sin((\phi/C)\varepsilon) = 0$. Then $(\lambda/C_o)\delta = h\pi$ $(h = 0, 1, 2, 3,\ldots)$

$$\lambda = \frac{C_o h\pi}{\delta} \tag{30}$$

and $(\phi/C_o)\varepsilon = h\pi$ $(h = 0, 1, 2, 3,\ldots)$

$$\phi = \frac{C_o h\pi}{\varepsilon} \tag{31}$$

Now substituting for λ and ϕ which are obtained from Equations (30) and (31) in Equation (23), we have:

$$P = \sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)\left(C_n \sin\alpha t + B_n \cos\alpha t\right) \tag{32}$$

In order to get the total maintenance profitability over time, we sum-up the values of P from period $h = I$ to $h = \infty$ to obtain a new Equation (33)

$$P(Q,I,t) = \sum_{h=1}^{\infty} p = \sum_{h=1}^{\infty} \sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)\left(C_n \sin\alpha t + B_n \cos\alpha t\right) \tag{33}$$

At a point when $t = 0$,

$$F(Q,I) = \sum_{h=1}^{\infty} B_n \sin\left(\frac{h\pi}{\delta}\right)\sin\left(\frac{h\pi}{\varepsilon}\right) \tag{34}$$

Now expressing the periodic function as an infinite trigonometrical series in sine and cosine terms, the application of sourier series gives us:

$$B_n = 2 \times F(Q,I)\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right) \tag{35}$$

Considering Q to be from 0 to e and I from 0 to b

$$B_n = \left(\frac{1}{b-0}\right)\left(\frac{1}{e-0}\right)\int_0^e\int_0^b 2f(Q,I)\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)dQdI \tag{36}$$

$$B_n = \left(\frac{2}{be}\right)\int_0^e\int_0^b f(Q,I)\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)dQdI \tag{37}$$

From Equation (33)

$$\left(\frac{\partial p}{\partial t}\right)_{t=0} = \sum_{h=1}^{\infty}\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)\alpha\left(C_n\sin 0 + B_n\cos 0\right) \tag{38}$$

$$g(Q,I) = \sum_{h=1}^{\infty}\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)\alpha C_n \tag{39}$$

For Fourier Series, $\alpha C_n = 2X$ mean value of

$$g(Q,I)\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right) \tag{40}$$

Let Q be from 0 to e and I from 0 to b. This implies that:

$$\alpha C_n = \frac{2}{be}\int_0^e\int_0^b g(Q,I)\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)dQdI \tag{41}$$

Hence,

$$C_n \frac{2}{\alpha be}\int_0^e\int_0^b g(Q,I)\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)dQdI \tag{42}$$

Substituting C_n and B_n in Equation (33), we obtain a new Equation (43):

$$P(Q,I,t) = \sum_{h=1}^{\infty}\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)\times\left[\left(\frac{2}{\alpha be}\int_0^e\int_0^b g(Q,I)\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)dQdI\right)\right.$$
$$\left.\sin\alpha t\left(\frac{2}{be}\int_0^e\int_0^b f(Q,I)\sin\left(\frac{h\pi Q}{\delta}\right)\sin\left(\frac{h\pi I}{\varepsilon}\right)dQdI\right)\cos\alpha t\right] \tag{43}$$

But, $\alpha = \sqrt{\lambda^2 + \phi^2}$

$$\alpha = \sqrt{\left(\frac{6h\pi}{\delta}\right)^2 + \left(\frac{C_o h\pi}{\varepsilon}\right)^2} \tag{44}$$

$$\alpha = \sqrt{(C_o h\pi)^2\left(\frac{1}{\delta^2} + \frac{1}{\varepsilon^2}\right)} \tag{45}$$

$$\alpha = C_o h\pi\sqrt{\frac{\varepsilon^2 + \delta^2}{\delta^2\varepsilon^2}} \tag{46}$$

4 Case study and discussion of results

4.1 Case study analysis

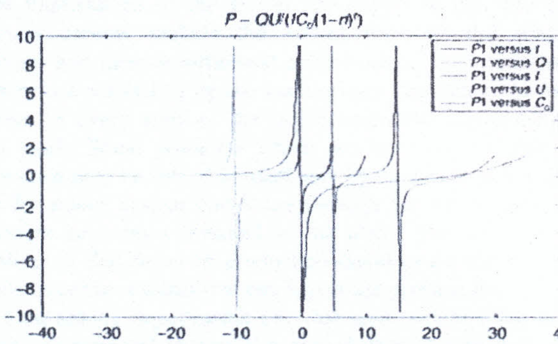
The case investigation relates to a company located in Lagos, Nigeria. This hypothetical company, christened Dynamics Limited (DL), manufactures various categories of roofing sheets. These vary in lengths (metres) and girths (i.e. 0.45 mm, 0.50 mm and 0.55 mm). Two main crew groups are available in the plant. The first relates to the production crew, who are responsible for roofing sheets manufacture. This group loads coils through the uncoiler to the rolling machine. These coils are then rolled to section of the machine where the cutting action is done. The finished products are then loaded into a stand-by forklift. Apart from the roofing sheets, attachments to roof angles are also bent on the bending machine. These processes are mainly managed by the production crew. However, due to the continuous utilisation of these machines, breakdowns do occur, which requires machines to be restored to their original functional stage. The team responsible for this is the maintenance crew. Unfortunately, conflicts do exist between the production crew and the maintenance team in relation to who should absorb the downtime, which may be excessive. This constant conflict brought about the concept of charging the services that maintenance provides to production. A consultant from the university has been invited by the joint cooperation of the management and the union of the company to investigate and solve this problem. This gives rise to the model proposed in this work.

In order to demonstrate the practical application of the maintenance profitability concept, the viewpoint of the consultant is that the internal maintenance service team would be treated as a hired company whose services must be paid for. Thus, the quantity of maintenance service offered to the production department, its frequency, as well as the period changes in price of input resources utilised by the maintenance department is taken into consideration in the computation of maintenance profitability. It is desired by the maintenance team leader to know what its team profitability is.

Computer programs were developed in Mathslab to generate values for the profitability and other variables. The results are shown in Figures 1–3. Figure 1 relates to Equation (2) with random values were used for U, t, Q, I and C_o. Plots were made between P and U, P and t, P and Q, P and I, P and C_o. In plotting P against and variable, other values were held constant. For example, in a plot between P and U, t, Q, I and C_o were held constant. In the plot between P and t, the variables U, Q, I and C_o were made constant. In plotting P against Q, U, t, I and C_o were held constant. Also, in plotting a graph between P and I, the values of U, Q, t and C_o were held constant. Again, in plotting a relationship between P and C_o, Q, t, I and U were held constant.

Consider Equation (2) which calculates profitability. For constant values of Q, U, I, C_o and n, periods 0, 1, 2, 3 and 4 resulted in a multiplying ratio of 1, 2, 1.92, 8 and 16, respectively for the reciprocal of $(1-n)^{-t}$ when n is held at 0.5. This means that productivity of the system improves greatly over time. This is the relationship between maintenance profitability and time. However, the relationship between quantity of service offered, units cost of service offered and maintenance profitability and quantity of inputs and its cost is indirect. All these relationships are shown in Figure 1. For Figure 2, the expression of maintenance profitability against Q, I, t, A, B, D, E, F and G is a sinusoidal. It fluctuates over time. Detailed graphs of these relationships are shown in Figure 2. Figure 3 also has a sinusoidal characteristic. However, it has a relatively different behaviour when compared with Figure 2.

Figure 1 A plot of the values of P against Q, U, I, t, n and C_o while some of the values were held constant



Note: That in all cases n was constant.

Figure 2 Plot of maintenance profitability against other variables in Equation (15)

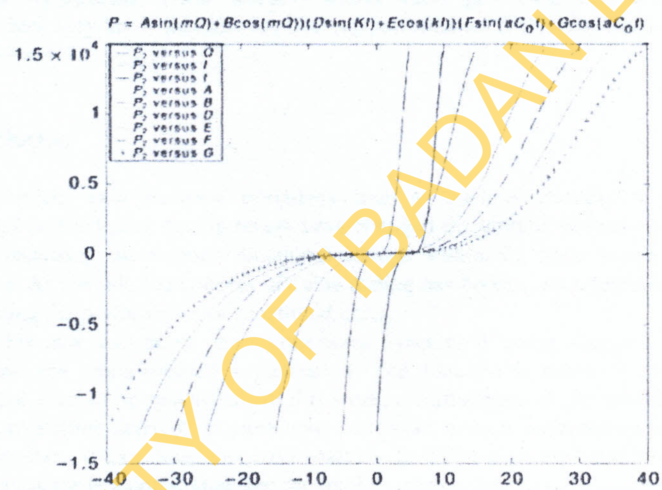
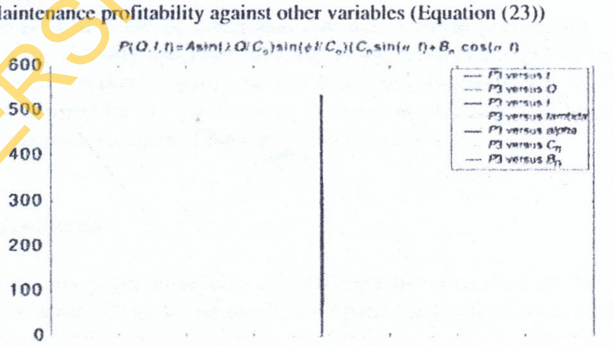


Figure 3 Maintenance profitability against other variables (Equation (23))



4.2 Managerial implications of the work

The managerial implications of the model application in real life environments are diverse. Important aspects include the contributions of the work to efficiency, effectiveness, intra- and inter-departmental effectiveness. The consciousness that prices are placed on services performed by the maintenance department to other units creates the consciousness in every staff of the organisation towards a culture of improved performance at work. Some problems which are too minor to call the attention of the maintenance crew may be solved immediately by the production staff since they have the knowledge for minor system correction through the total productive maintenance schemes that might have been installed in the plant. This motivation is a result of the negative influence that delay in production could cause the company, which may consequently influence the rewards that employees are given at the end of the year. There is also competition among departments on what team would incur the least cost, and subsequently be compensated during the annual reward schemes. Another possible consequence of the implementation of the proposed model in the organisation is the drive towards improved team performance by members of both the maintenance and production departments. These workers would likely give their best efforts to the company since they know that non-satisfactory performance could lead to termination of their employment.

5 Conclusion

For some years, new business initiatives such as business process reengineering, organisation restructuring among others have changed the attitude of business executive towards visualising the various functional set-ups within the organisation from new perspective. As a result, the concept of value adding has become an important parameter for evaluating the performance of functional units.

With this new viewpoint, the maintenance function is being accessed as a profit making unit the manufacturing organisation. The function is assumed to be selling services that need to be quantified. In this work, a furtherance of this effort is pursued through a modelling activity. In particular, the model presented visualises maintenance profitability from the revenue-cost ratio analysis. In addition to this traditional formula, an inflation factor is incorporated into the model structure due to the changes / the value of money overtime.

From the work it could be concluded that maintenance profitability is significantly influenced by the quantity and price attached to the services offered by the maintenance function to other function, in particular the production function. It is also influenced by the expenses incurred by the maintenance department. Another significant influence on the model is the price changes of the input qualities overtime.

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