COMPUTER-AIDED SYSTEM FOR DETERMINING INDUSTRIAL MACHINERY OPTIMAL REPLACEMENT PERIOD

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ABSTRACT

This paper focuses on bridging the gap between age-dependent optimal replacement theory and its industrial applications by identifying and incorporating the criteria considered by field (maintenance) engineers before embarking on industrial machine replacement, into an existing model to make it appropriate industrial-wise. We aim to economically quantify the identified criteria and thereafter integrate them into the weighted average cost of running the machine from the time of its installation to the date of analysis to alleviate the drudgery in using this approach most especially when multiple machines are to be analyzed, the Machine Replacement Analysis Software (MRAS) was developed and its implementation was done using data obtained from a Grinder used for cocoa processing. A curve with polynomial function and coefficient of determination of 0.935 was obtained and this implies replacing the machine after the seventh year of usage.

Keywords: Industrial machine, maintenance, economic life, replacement model, criteria.

INTRODUCTION

The replacement of industrial machinery is a vital decision which has a sumptuous reward if timely and accurately carried out. Replacement projects are characteristically driven by technical obsolescence, requirements for performance improvements or requirements for functionality improvement since the functionality and performance of machines degrade as they approach

the end of design life. Economically, excessive operating and maintenance costs and higher reject/scrap rates are the factors often considered before performing an age-dependent machine replacement.

Industrial machines, just like any other machinery experiences failures at a rate which is generally observed to be increasing as the machinery ages. Machinery failure can be defined as any change in any of its parts or components which cause the entire system not to be able to perform its intended function effectively (Bloch, & Geitner, 1999). When the frequency of failure becomes high, its effects can be catastrophic: injury, loss of moral, annoyance and inconveniencies to the operators. These may cause delays and erratic supplies that can affect customer goodwill, products standard which can affect the company's image and lead to costly lawsuits in case of injury or loss of life. A machine due for replacement will generally lead to high loss of production as a result of scraps/wastages, downtimes and so on. These are capable of placing a company in a dangerous position of becoming uncompetitive.

The causes of failures can be due to faulty design, defects in its manufacturing material, processing and manufacturing deficiencies, assembly or installation defects, off-design or unintended service conditions, maintenance deficiencies (neglect, procedures) and improper or off-design operations (Bloch, & Geitner, 1999; Tadić, Vukelić & Jeremić, 2010). However, no matter how good a system design, installation, and maintenance are, its parts or components wears out with age.

considering the fact that machines can be classified as either a non-repairable or repairable system, an industrial machine was classified as repairable in this model which means that they can be restored to satisfactory operation by any action, including parts replacements or changes to adjustable settings (NIST/SEMATECH, 2006). In industrial settings, the repair rate of the machinery has to be kept as low as possible to prevent loss in production and ensure customer loyalty.

The complete life cycle of industrial machinery consists of its installation (after procurement), usage, the occurrence of failure at some time, the repair and restoration of the failed component, the occurrence of the second failure and its repair and restoration to service and so on. The failure and failure-free cycle repeats itself randomly (Tadić et al., 2010) until the machine is retired from service. Despite the machinery's life indicated by manufacturers, it is imperative for companies to determine the economic or optimal life of their machines which is principally influenced by the manner of usage and maintenance. The most fundamental idea of any economic analysis of

replacement is the difference between the physical and economic life of the equipment and there is a maintenance level for machines that either maximizes profit or minimizes cost (Collier, & Ledbetter, 1982). Replacement age for a machine that is placed on economic life arrives typically before fundamental breakdowns result into worn-out and technological disabling (Khoub-bakht, Ahmadi, Akram, & Karimi, 2008). Every industrial machine has an economic life that thereafter, using the machine is not economical.

Replacement decisions are critically important to a firm. The formulation of a replacement policy plays a major part in the determination of the basic technological and economical progress of a firm as undue or hasty replacement can be a serious drain on the operating capital that may be needed for other beneficial uses, while postponing it beyond reasonable time will lead to increasing production costs and less competitiveness on the part of the firm.

Although, development of the theories of replacement analysis had been carried out over the past decades, their practical application is often neglected by industrialists because of its inability to reflect some criteria fundamentally considered by maintenance personnel (Tai, & Ching, 2005). In most theoretical analyses, the optimal replacement moment is expressed in relation to the capital equipment's age, whereas in empirical applications other factors also play a part in timing replacements, as the output produced seems to be of high importance (Bethuyne, 1998). It was observed through industrial visitations embarked upon during the preliminary stage of this research that many industries in Nigeria depends on the personal judgment of their maintenance engineers in making replacement decisions. This either connotes the problem of ineffective modeling of the industrial situation, or complexity during application. this research work identifies the replacement criteria used by these field engineers, incorporates them into an existing model, and develop A user-friendly software for easy application of the model.

METHODOLOGY

Combination of facts from industrial visitations and literatures reviewed were used to identify the criteria which often triggers industrial machinery replacement decision model building (which includes identification of the input and output variables determination of the parameters and status variable and the logic of the model) design of documents for effective data collection and the development of software to facilitate the easy execution of the model in industries and the application of the model for generation.

MODEL DEVELOPMENT

To determine the economical status of a machine for the purpose of replacement decision, the time value of money must be considered by computing the weighted average of all the costs of running the machine from its year of installation till date as given by Sharma (2007):

$$R_n < \frac{A+R_1+DR_2+D^2R_3+\cdots+D^{n-1}R_n}{1+D+D^2+\cdots+D^{n-1}} < R_{n+1} \qquad (1)$$

Where *A* is the acquisition cost of the machine, $R_1, R_2, R_3 \dots R_T$ represents the running cost of the machine at the end of the first, second, till the *T* year; *D* represents the discounting factor; and denotes the running cost at year and respectively and the expression between and in equation (1) represents the weighted average [which is denoted as in this paper] of all costs up to the period with weights 1,,,… respectively. The given weights are actually the discounted factors of the costs in the previous years.

Model assumptions

In this research work, it was assumed that a machine for replacement is always available and during replacement, the machine is replaced with a functionally comparable machine (that is, a machine which processes the same raw materials and outputs the same products as the machine in use, but may produce better quantity and quality). It was also assumed that equipment utilization has a direct relationship with output unit.

Modifications to the selected model

The integration of the criteria considered by industrialists is necessary to ensure that the replacement decision encapsulates the vital industrial parameters for optimal decision. Sharma (2007) only considered acquisition costs of machine (A), running cost of machine (R) and discounting factor (D) for his model development but failed to take into account the yearly salvage value. This model of Sharma can be defined as the weighted average K(T), of all costs up to the period (T-1) with weights 1, D, D^2---- D^{T-1} respectively. Therefore, to take account of the yearly resale (or salvage) value of the machine, it is customary to deduct the discounted salvage value of the machine from its acquisition cost. In addition to this, the operating cost needs to be adjusted in Sharma's model because operating cost is expected to increase gradually as the machine ages. Although Sharma considered the value with reference to the running cost of the preceding and subsequent year, it was observed that

a curve with a minimum point at the replacement year can be established when values are plotted against its respective year and the curve has A high correlation with the general polynomial model which has been used by other authors (Khoub-bakht et al, 2008; Khoub-bakht, Ahmadi & Akram, 2010; Offiong, 2001; Ogunlade & Akinbinu, 2004).

Therefore, THE equation (1) can be expressed as:

$$K(T) = \frac{A + \sum_{n=1}^{T} R_n D^{n-1}}{\sum_{n=1}^{T} D^{n-1}} \qquad (2)$$

To take account of the yearly resale (or salvage) value of the machine with the assumption that it is ripe for replacement, it is customary to deduct the discounted salvage value of the machine from its acquisition cost. The Equation (2) can then be written as:

$$K(T) = \frac{A - S(T)D^T + \sum_{n=1}^{T} R_n D^{n-1}}{\sum_{n=1}^{T} D^{n-1}} \qquad (3)$$

The salvage value is the estimated value that an asset will realise upon its sale at the end of its useful life and in situations where the machine's parts are dissembled as spare parts; the salvage value is the summation of the worth of the various parts of the machine when sold.

Identification of criteria that triggers machinery replacement decision

Through industrial visitations carried out at different manufacturing companies in Nigeria, industrial machinery replacement criteria used in these industries were identified. From the results of the feedback received from interviews conducted with maintenance engineers in the selected industries which were visited, the following were identified as the critical factors that influenced industrial machinery replacement decision:

a) Excessive operating and maintenance cost – this leads to increase in the production cost which will eventually reduce the expected profit margin or even lead to running the machine at a loss. To prevent this unpleasant incident, the machine is usually considered due for replacement (Akinnuli, 2009).

b) Reduction in output capacity of the machine – this can make it difficult for the company to meet market demand, thereby denying the company the benefit of enjoying a larger market share. It can be caused by the need for frequent readjustment, defective outputs and so on. Bethuyne (1998) also identified this factor as one of the most important replacement criteria.

c) High frequency of failure – high failure rate has diverse negative impact on industries. For machine operators, it could cause loss of morale, injuries and even loss of life. It could also lead to loss of customer goodwill. When maintenance level is not adequate to prevent accumulation of tear and wear, frequency of failure will definitely increase rapidly (Gupta & Hira, 2012).

d) High cost of penalties incurred as a result of material wastage, clean-ups, reprocessing and huge loss in production especially in processing plants where the failure of a single machine can affect the whole production line and other unquantifiable penalties such as loss of customer loyalty.

e) Increase in downtime of the machine caused by longer repair time could trigger the decision to replace such machine. A prolonged downtime could also be due to absence of specialists who can repair such A machine (Akinnuli, 2011).

f) Scarcity of spare parts which can make the machine irreparable (Akinnuli, 2009; Sharma, 2007).

Five cocoa processing industries were visited:

A- Coop- cocoa processing industry, Akure, Ondo State Nigeria
B- Cocoa products Industry, Ede Osun State, Nigeria
C- Stanmark cocoa company Ondo, Ondo State, Nigeria
D- Tulib cocoa products, Sagamu, Ogun State, Nigeria
E- Ile- Oluji cocoa products limited, Ile-Oluji Ondo State, Nigeria

The criteria which affected these companies are shown in Table 1 the information to justify this claims were collated from the machines job cards as they affect excessive operating and maintenance cost, high frequency of failure and increase in downtime of machine caused by job cards. for reduction in output capacity of the machines, high cost of penalties incurred from material waste materials processing monitoring cards were used while for the scarcity of spare parts, spare parts inventory cards were used.

In the above generated table, it is deduced that scarcity of spare parts leads to reduction in output and capacity of machine increase in downtime of machine, while high frequency of failure leads to excessive operating and maintenance cost, reduction in output and capacity of the machine, increase in downtime of machine and high cost of penalties incurred from material waste (which results from unload and reload of a machine, decoupling and coupling material flow lines as well as leakages on the processing line).

Table 1

Effect Criteria and Affected Company or Companies

S/No	Criteria	Affected industries					
		A	B	C	D	E	F
1	Excessive operating and maintenance cost			×			×
2	Reduction in output and capacity of the machine						
3	High frequency of failure due to machine age			×			×
4	High cost of penalties incurred from material waste			×			×
5	Increase in downtime of machine						
6	Scarcity of spare parts	×	×		×	×	

Computation for the running cost

Since it is desirable that industrial machinery replacement period be elongated, a good maintenance policy must be adopted. Separating the cost of scheduled and corrective (unplanned) maintenance will give the maintenance personnel the opportunity to observe the effect of the present maintenance policy. The rate of occurrence of failure can also be monitored and this will give the opportunity to know when to increase the frequency or the time spent on scheduled maintenance per month so as to regulate the rate of occurrence of failure. The total running cost is a summation of the operating and maintenance cost of the machine.

$$R(T) = M(T) + F(T) \qquad (4)$$

Where is the running cost function of the machine at year , is the maintenance cost of the machine at year T, and is the adjusted operating cost at year *T*.

Computation for the adjusted operating cost

The monthly operating cost of the machine includes the cost of power or fuel, expendable accessories, lubricants and oil used in the month. The monthly operating cost is adjusted by multiplying it with the "Performance Ratio" of the machine to account for variability in the utilization intensity of the machine. The adjusted monthly operating cost is given by:

$$F(t) = (\text{monthly operating cost}) \times \frac{C_e}{C_a} \qquad (5)$$

Where is the time in months, is the effective capacity of the machine, is the actual capacity of the machine and the ratio is termed the performance ratio of the machine. This ensures that the effect of the reduction in output capacity of

the machine is factored into the model. The effective capacity of the machine means the rate of output of the machine given the product mix, scheduling difficulties and machine maintenance schedules while the actual capacity is the rate of output actually achieved after using the machine for a period. Since the maintenance cost accounts for cost of lost times and penalties for the downtimes, the performance ratio was used to adjust only the operating cost of the machine to cater for situations which include, but not limited to, increase in setup time, need for more frequent lubrication, readjustments and realignments, all of which affect the actual capacity of the machine.

The operating cost function is expected to increase gradually as the machine ages. The adjusted yearly operating cost can be expressed as:

$$F(T) = \sum_{T=1}^{12} F(t) \tag{6}$$

Computation for maintenance cost

It is imperative to know that the replacement policy will only be optimal when all efforts had been taken to reduce the machinery running cost, especially the maintenance cost which in most cases increases greatly when machinery failure occurs during production run. The monthly maintenance cost is computed as the summation of the planned or scheduled maintenance cost and the unplanned (corrective) maintenance cost. The scheduled (or planned) maintenance cost is to cover the cost of materials, labor and cost per hour of planned downtime as a result of planned maintenance. Similarly, the unplanned maintenance cost is to cover the cost of materials and labor, cost per hour of unplanned downtime (which caters for the loss in production) and wastages as a result of the unplanned maintenance.

Hence, the maintenance cost per month:

$$M(t) = (m_p) + (m_f) \tag{7}$$

$$M(t) = (C_p + a_p t_p) + (C_f + a_f t_f) \tag{8}$$

Where = planned maintenance cost per month, = corrective maintenance cost per month; = time of machine usage in months, = cost of materials and labor of a planned maintenance, = Cost of + extra materials, labor and penalties due to failure, = cost per hour of planned downtime, = cost per hour of unplanned downtime; = downtime as a result of planned maintenance, = downtime as a result of maintenance forced by a failure.

These monthly data are summed yearly to give the yearly maintenance cost data as follows:

$$M(T) = M_p + M_f \tag{9}$$

Where: $M_p = \sum_1^{12} m_p$, and $M_f = \sum_1^{12} m_p$

Computations for the discounting factor

According to Offiong (2001), the discounting factor is a function of two variables – interest rate and the inflation rate. Hence, the discounting factor can be expressed as:

$$D = \frac{1}{(1+i)(1+s)} \tag{10}$$

Integration of the identified criteria into the replacement model

The identified criteria have been expressed mathematically as shown in equations (4) to (9) and they can be easily integrated into equation (3) which can be rewritten as:

$$K(T) = \frac{A - S(T)D^T + \sum_{n=1}^{T}[M(T) + F(T)]_n D^{n-1}}{\sum_{n=1}^{T} D^{n-1}} \tag{11}$$

Table 2

Summary of Model Modification

Initial Model	Final Model
$k(\tau) = \dfrac{A + (R_1 + DR_2 + D^2 R_3 \pm - - - D^{T-1} R_T}{1 + D + D^2 \pm - - - - D^{T-1}} \dots \dots eqn(1)$	$KK(\tau) =$ $\dfrac{A - S(T)D^T + \sum_{n=1}^{T}\{[M(T) + f(T)_n D^{n-1}]\}}{\sum_{n=1}^{T} D^{n-1}}$ Eqn (11)

The objective is to find the year that will be minimal as this will give the optimal replacement period for the machine. Computing this value for a single machine will require lots of data storage since a machine can be operational for many years. This necessitates computer application, both in the data management and mathematical analysis to make the model useful for industrialists who need to concurrently manage much machinery.

Software development

A software application was developed to facilitate the implementation of the model in industries and to serve as a tool for the easy analysis of the machine data. The software, Machine Replacement Analysis software, is also known as MRAS 2011. It was developed using the Microsoft Visual Basic 2008 professional edition. The software basically consists of two parts – the database segment and the analysis segment as in Figure 1. The database segment allows the input of the data either from machine monthly or yearly utility cards. Every data that is input is stored in the database and the hard copy of the data can be printed out when necessary. The database also provides the data to be used in the analysis segment. The analysis segment utilizes the data stored in the database to compute the optimal replacement period using equation (11) and displays the optimum replacement period for the machine on a graph page.
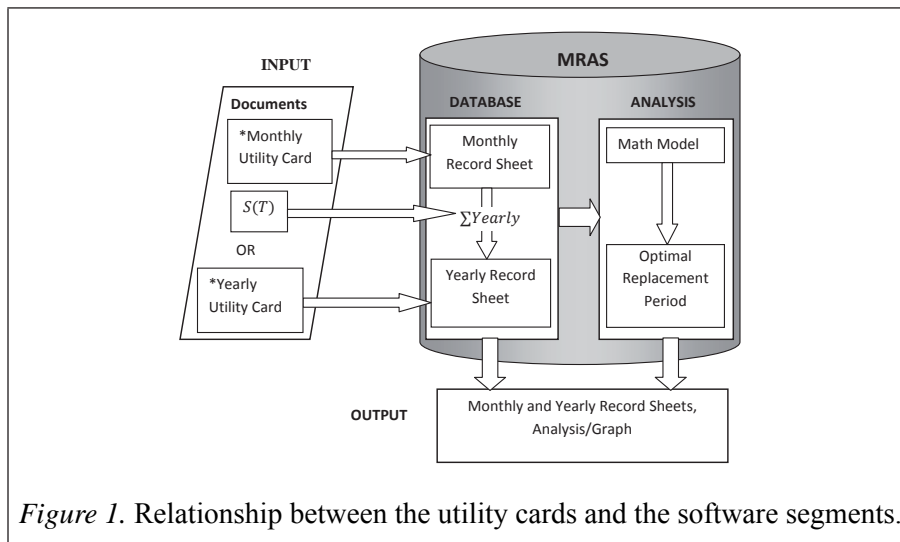
Figure 1. Relationship between the utility cards and the software segments.

The replacement analysis result and graph, machine information, monthly and the yearly report sheets are in printable formats. Figure 2 displays the menu of MRAS.
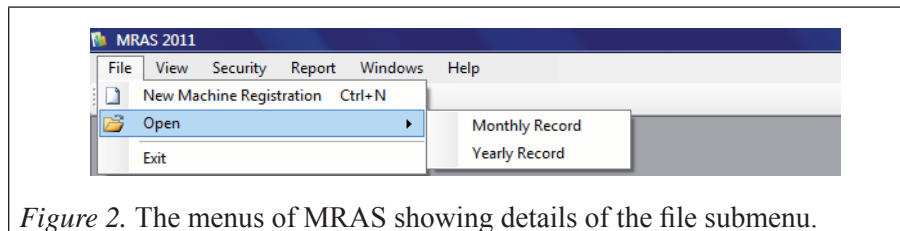
Figure 2. The menus of MRAS showing details of the file submenu.

CASE STUDY

To illustrate the application of the model and its software, the data of an industrial machine obtained at a cocoa processing company was used. The yearly data used for the analysis are as shown in Table 3.

Table 3
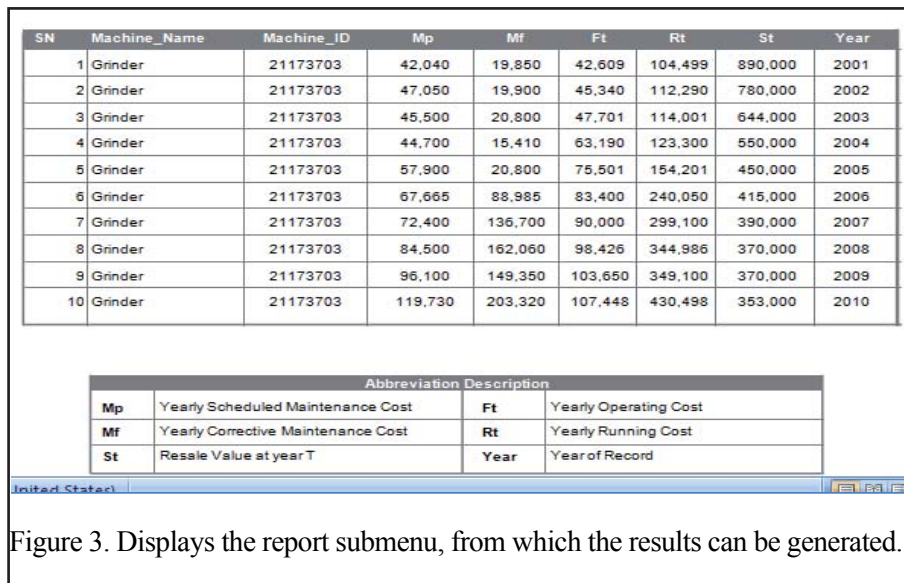
MRAS Display of Yearly Data Used for the Analysis

SN	Machine_Name	Machine_ID	Mp	Mf	Ft	Rt	St	Year
1	Grinder	21173703	42,040	19,850	42,609	104,499	890,000	2001
2	Grinder	21173703	47,050	19,900	45,340	112,290	780,000	2002
3	Grinder	21173703	45,500	20,800	47,701	114,001	644,000	2003
4	Grinder	21173703	44,700	15,410	63,190	123,300	550,000	2004
5	Grinder	21173703	57,900	20,800	75,501	154,201	450,000	2005
6	Grinder	21173703	67,665	88,985	83,400	240,050	415,000	2006
7	Grinder	21173703	72,400	136,700	90,000	299,100	390,000	2007
8	Grinder	21173703	84,500	162,060	98,426	344,986	370,000	2008
9	Grinder	21173703	96,100	149,350	103,650	349,100	370,000	2009
10	Grinder	21173703	119,730	203,320	107,448	430,498	353,000	2010

	Abbreviation Description			
Mp	Yearly Scheduled Maintenance Cost	Ft	Yearly Operating Cost
Mf	Yearly Corrective Maintenance Cost	Rt	Yearly Running Cost
St	Resale Value at year T	Year	Year of Record

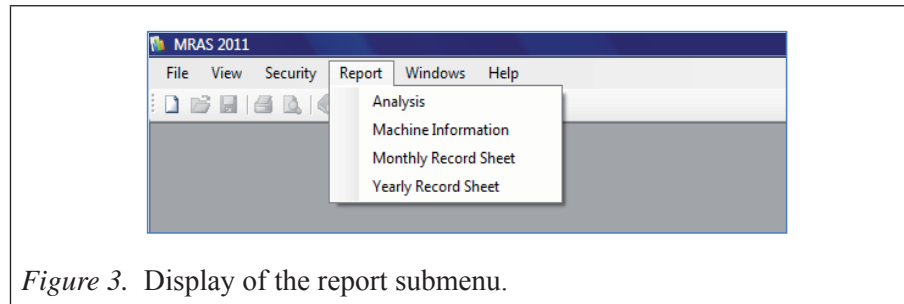Figure 3. Displays the report submenu, from which the results can be generated.

Figure 3. Display of the report submenu.

Analysis of results

Populating MRAS with the yearly data in Table 3, the replacement analysis resultS graph as processed and presented in the report menu of MRAS was printed out as shown in Figure 4 and this was validated using the MS Access

(See Figure 5). Performing regression analysis on the values of K(T) obtained using the MS Excel packages gave a polynomial trend with the equation and coefficient of determination of 0.935 as shown in Figure 5.
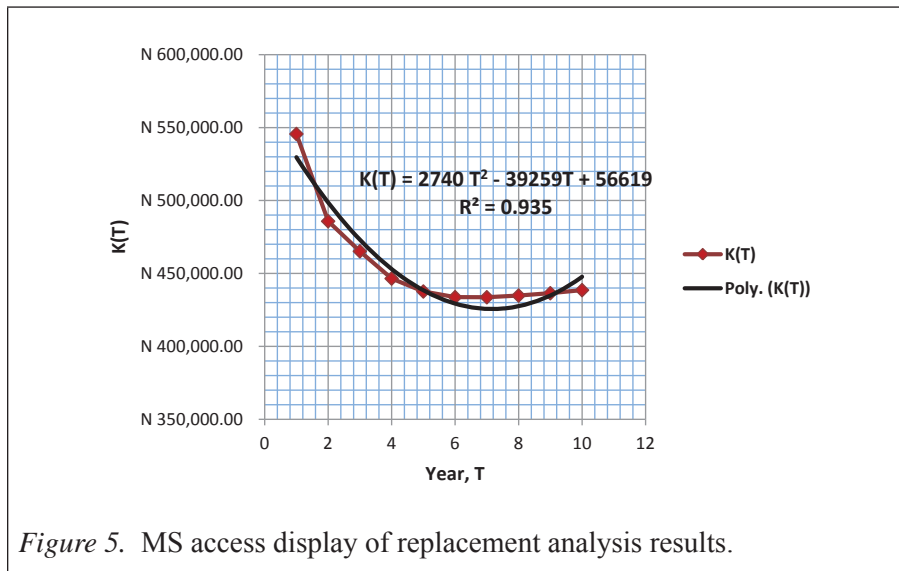

Figure 5. MS access display of replacement analysis results.

From the results obtained, it can be seen that it is economical to replace the machine once it is in the 7th year of usage because it gave the lowest weighted average cost []. After the 7th year of running the machine, the production cost of using the machine starts increasing which indicates that the machine is no more economical to use.
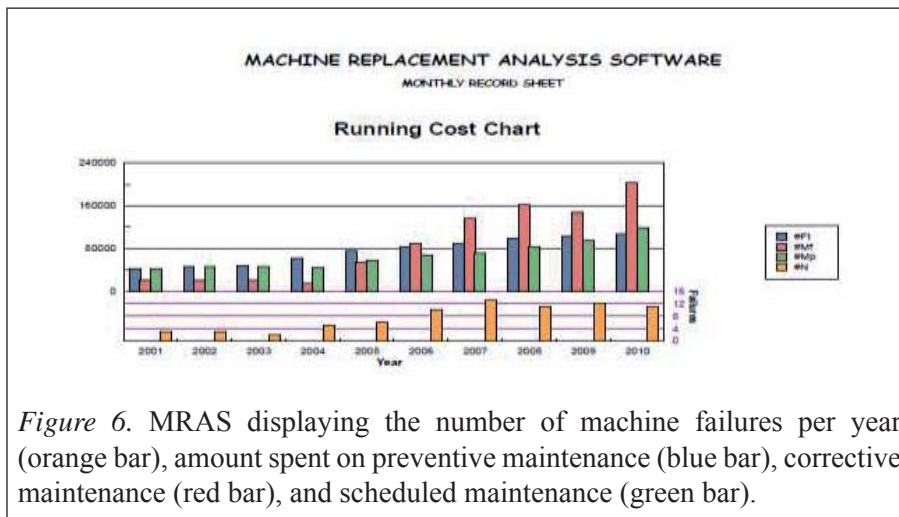

Figure 6. MRAS displaying the number of machine failures per year (orange bar), amount spent on preventive maintenance (blue bar), corrective maintenance (red bar), and scheduled maintenance (green bar).

For the cocoa grinder investigated in this case study, Figure 6 shows the bar chart on maintenance costs, operating costs and the number of machine failures experienced per year.

CONCLUSION

It is worth stating that when industrial machinery has never required expensive running cost, the replacement decision based on the age of the machine never arises. Other circumstances such as a need for change in product design and specifications can also prompt a replacement decision. With a view to assist industrial engineers in identifying the optimal replacement period for industrial machineries, this research work itemizes the basic criteria often considered in industries, and a software package (known as MRAS – *Machinery Replacement Analysis Software*) was developed for the easy execution of the model in industries. The software developed was capable of producing the replacement analysis table, annual running cost chart, as well as the replacement analysis graph in printable formats.

In summary, this research work has shown how management science can be employed in the analysis of machine replacement decision in industries. The impact of computer software in successfully managing and identifying the optimal replacement period of industrial machinery cannot be overemphasized.

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