Cost-Effective Replacement Decision for the Transmission Unit of Locally Fabricated Palm NUT Digester

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Abstract— *This study sought to establish optimum techno-economic replacement policies for the transmission unit of locally-fabricated oil palm fruit digester for cost-effective operation over a planning horizon of sixteen years. Deterministic Dynamic programming models were used in the study. The companies whose records were most amenable to the model's application were used as as cases for the study. The records were painstakingly collated and processed for deployment in the models. The depreciation, cost of operation and maintenance, and the Equivalent Uniform Annual Cost (EUAC) of the unit were evaluated. The equipment EUAC is evaluated over all the periods of the planning horizon. The period with the lowest EUAC is recommended by the model as the most cost-effective replacement period. The companies' replacement practice was assessed for its conformity with the replacement policy predicted by the model in a kind auditing approach. The companies were shown to incur increased EUAC for retaining the transmission unit beyond the replacement age recommended by the models. Deployment of replacement models for machinery replacement decisions support can enhance an industry's economic advantage in today's competitive industrial environment.*

Keywords— Oil palm fruit digesters, Dynamic programming models, Equipment replacement age, Equipment economic life, Replacement practice audit and Equivalent uniform annual cost.

I. INTRODUCTION

Palm Oil is one of the commodities besides petroleum products that have contributed greatly to Nigerian economic survival, as Nigeria was the world's largest producer of palm oil then (Okafor, 2007). There is great economic problem in Nigeria today, and a dire need of diversifying the economy (Okafor *et al.*, 2010). Resuscitating the agricultural sector; the oil palm production sub-sector inclusive, is a welcome idea. During the era of palm oil production boom in Nigeria, crude technologies were deployed; with the traditional techniques dominating most of the production lines. Little maintenance cost was incurred with these technologies due to the associated minimal wear and breakdown. The growing world population and recent emphasis on renewable energy have led to increased demand on palm oil production and the need of advanced technologies for its production.

Modern oil milling today employs palm fruit digesting and mashed fruit oil-expressing machines, most of which have high wears and breakdown in their power transmission units and material-processing screws. While the digesting and oil pressing units of these machines are fabricated locally, their power transmission units which have gear transmission systems are imported. As a result, foreign exchange is incurred in the procurement of these gear transmission units. Studies on their maintenance and replacement costs dynamics will assist in profitable management of our local oil mills. Premature retirement of equipment results in underutilization and consequently waste of resources and poor productivity. On the other hand, retaining the equipment beyond the useful economic life leads to incurring the avoidable higher cost of running and maintaining the parts or machine. This has a negative effect on the overall productivity of the system. The optimum replacement plan or time of the palm fruit digesting and mashed fruit oil-expressing screw presses' gear transmission units depends on the economic life of the units.

Few studies on agricultural processing equipment's costs and economics have been carried out in the country. Oluka and Nwani (2013) studied the repair and maintenance costs of rice mills and developed a model for estimating the maintenance cost in Nigeria. Nwajinka (2010) developed computer-assisted methods for predicting the optimal-cost size and replacement time for farm tractor. Amaefule *et al.* (2018a) developed a minimum-cost model for selecting tillage machinery for combined use of farmers. Grano and Abensur (2017) reported that there are limited studies on the application of industrial assets replacement policies to farm equipment. Bagshaw (2017) presented maintenance and replacement scenario and costing encountered in manufacturing setups.Studies on the maintenance and replacement costs dynamics of the gear transmission units will assist in profitable management of our local oil mills. Deploying machinery replacement models in arriving at the most economic time for the replacement of oil palm fruit digester gear transmission units is needed for profitable oil palm milling. This work is aimed at establishing policies for the economic replacement of locally fabricated palm fruit digester transmission unit.

II. MATERIALS AND METHODS

2.1 Theoretical Considerations

In equipment replacement problems, the equipment in service that is considered for replacement (the defender) must have a better challenger (the considered alternative equipment) for the replacement to be worthwhile. The challenger and defender can equally be a unit of the equipment when what is considered for replacement is only the unit. Service life, accounting life and economic life are 3 concepts of machine life (Hunt and Wilson, 2015). Equipment economic life is the period of time the equipment can be retained in service without resulting in adverse equipment cost arising out of uneconomic repair cost or obsolescence. While the technical competence must necessarily be considered in machine replacement, the economics of the machine and in particular the involved costs and returns are easily employed in the machine replacement modeling (Zvipore *et al.*, 2015). The trade-in value of the defender is treated as a reduction in the initial cost of the challenger (Li, 2015).

Investment receipts and disbursements are regarded as cash inflows and cash outflows respectively. By convention, financial transactions made during a period are assumed to occur at the end of the period, for ease of investment problems articulation. The replacement planning horizon covers the period from the point of replacement decision to the end of the service life of the challenger. Abensur (2010) stated that an equipment trade-in value should include its cash flow beyond the planning horizon if its working life is greater than the service life. Variable machinery costs vary directly as the machinery use and can be expressed on hourly basis, or as cost per unit output or other appropriate measures (Field and Solie, 2007 and Amaefule *et al.*, 2018b). Energy, oil, lubricants, labour and repair and maintenance costs are classed as variable costs.

In replacement analysis the average annual cost (*AC)* of the defender is compared with that of the challenger in evaluating the replacement period. For each decision period *i* of the *n* years of the equipment life, the *AC* of owning the equipment up to period *i* is obtained for the challenger and defender. The *AC* of purchase cost (*P*) for the period *i*, is added to the operating cost (C(i)) in the same period, while the resale value (*S)* at the periodis subtracted from the sum for the equipment. The replacement period which gives the minimum total *AC* of the challenger is its economic replacement age, *i.e.* the challenger's optimum economic life (Bagshaw, 2017). The equivalent annual cost (*EAC*) is evaluated by reckoning the time value of the involved cash flows using the appropriate interest rate (*r*) and discounting period (i), as shown in equation 1 and 2.

$$EAC = P(A/P_{r,i}) + C(i)(A/P_{r,i}) - S(A/F_{r,i}) \quad (1)$$

$$EAC = (P + C(i))(A/P_{r,i}) - S(A/P_{r,i})(P/F_{r,i}) \quad (2)$$

2.2 Equipment Replacement Modelling

The average annual cost (*AC*) of the machine is obtained by dividing the total concerned cost with the estimated machine life. The model employs the operation, maintenance and equipment ownership costs, and the equipment economic life in estimating the annual cost (Sharma*et al.*, 2006 and Tayari, 2018). In evaluating their Equivalent Uniform Annual Cost (*EUAC*) the time values of the involved costs are incorporated into the replacement model (Grano and Abensur, 2017). Machinery costs that remains unchanged for both the defender and challenger; such as is more likely in like-for-like replacement, are overlooked (Sharma and Sharma, 2007 and Hunt, 1999). Only the costs that vary are considered in the operating cost.

A Dynamic Programming (DP) replacement decision support procedure for a machine that deteriorates with age following total cost minimization approach was developed by Li (2015). Based on it the following assumptions applicable to the case under review were made:

a) Machine will be owned during each of the *n* year periods.

b) The age of the (defender) machine when we start the process (replacement decision) process is known and denoted as ***y***.

c) Known annual operating cost of machine aged *i* yrs (which) at the start of the year is and is given as *C*(*i*).

d) Price of the new machine (the challenger at age 0) is known and denoted as $\boldsymbol{P}$.

e) Known trade-in value $t(i)$for a machine aged i years at the start of the year.

f) Known salvage value*s* (i) for the i years aged machine at the end of year $\boldsymbol{n}$.

The objective of the DP problem was the minimization of $[S(x;k)]$; the cost of owning a machine for the years k to n; which is the planning horizon.

The age of the challenger is x years at the start of year $x{:}\,k$;

$k = 1, 2, \dots, n$

$x = 1, 2, \dots, k-1, y+k-1$ when $k > 1$

and

$x = y$ when $k = 1$

The generalized form of the DP model was as shown in Equation 3

$$S(x{:}\,k) = min\{ \begin{matrix} \xrightarrow{REPLACE} p - t(x) + c(0) + S(1{:}k+1) \\ \xrightarrow[KEEP]{} c(x) + S(x+1{:}k+1) \end{matrix} \tag{3}$$

DP Interpretation

The optimal value of the objective was to minimize $S(x;k)$the cost of owning a machine from year ***k*** through ***n*;** starting the year ***k*** with a machine that just turned age ***x***, for $k = 1,2, \dots., n$ (Zvipore *et al.*, 2015).

The policy from this optimal function will translate to:

$P(x;k) =$ "$REPLACE$" if replace is cheaper than "$KEEP$" in the recursive relation, and

$P(x;k) =$ "$KEEP$" if otherwise.

The boundary condition being

$S(x;n+1) = -s(x)$ For $x = 1, 2, \dots.., n$ and $y + n$

2.3 Study Area

Orumba South Local Government Area located within latitude 5.96778N – 6.0163N and longitude 7.14758E – 7.3166E, is one of the twenty-one (21) local governments in Anambra State, Nigeria. It lies within the oil palm belt of the rain forest zone of Nigeria. Major small-scale palm oil mills in the area were studied. The oil palm digesters studied were locally fabricated and are of the vertical type. They operated on rotary mechanism and were each powered by an 8 HP stationary diesel engine. The digesters had gear transmission systems made from rear wheel axles of Toyota Dyna trucks. Though the use period before importation could not be ascertained, the transmission units were regarded as good-as-new for replacement purposes in this study.

1 batch of the digester's process vessel (drum) held as much as 540 kg of palm nut. Breakdown maintenance of the transmission unit was practiced in the companies; and was done only when the unit failed. Operator's wages was a fixed

amount per drum plus 0.72 litres of palm oil per batch of the processed product. This could not amount to differences in labour costs in the defenders and challengers. The oil mills were visited to obtain the general information on the maintenance and replacement practices they carried out on their digesters power transmission units. The data from a representative was used, for analysis and modelling.

III. METHODOLOGY

Data used for this study were obtained from both primary and secondary sources. Primary field data were obtained from the oil mills visited. Secondary data were obtained from manufacturers' manuals, relevant handbooks on machine maintenance and published journals papers. Descriptive survey was adopted for this study research design. Diesel consumption was obtained from the company's record, while the unit cost was obtained from national statistical data. The purchase cost and the salvage values of the transmission unit were obtained from the company's records. Prices for the intermediate years when purchase of new unit or sale of the scrap unit did not occur were obtained by regression models. A kind of auditing approach was deployed in assessing the economic effectiveness of the companies' replacement practice vis a vis the recommendations of the replacement model for the unit.

IV. RESULT AND DISCUSSION

The replacement decisions given by the DP model for the transmission unit of the studied company for the years 1999 to 2006 is shown in Table 1. The replacement decision for each stage of the planning horizon is also shown. The *EUAC* and annual transmission unit cost are also shown. For year k=1, being 1999, the first year of installation and market value of the unit was ₦3,000.00. The unit was just installed and was not considered for replacement yet. In the year 2000, the market value was ₦2,120.00, the actual depreciation was ₦880.00, cost of capital value at 10% for beginning of the year (BoY) of market value was ₦300.00. Annual expenditure was ₦350.00, total (marginal) cost per year was ₦ 530.00, while *EUAC* was ₦1,530.00.

In this period under review; 2000, it was not due for replacement because the *EUAC* of the unit was less than that for the next year, but higher than that of previous year. Based on the model, replacement should be done when the *EUAC* is minimum. From Table 1, the unit was due for replacement at the end of 2003, but was not replaced by the company. It was rather repaired in 2004 and replaced in 2006.

TABLE 1
EUAC AND THE REPLACEMENT DECISIONS FOR 1999 TO 2006

End of Year (k)	Market Value @ End of yr k (₦)	Depreciation During yr k (₦)	*Cost of Capital (₦)	Annual Exp. (₦)	Total (Marginal) Cost per Year (₦)	EUAC for yr k (₦)	Replacement Decisions based on the model	Actual replacement decision
1999	3000						Starting point	
2000	2120	880	300	350	1530	1530	**Keep**	**Kept**
2001	1460	660	212	700	1572	1551	**Keep**	**Kept**
2002	1020	440	146	950	1536	1546	**Keep**	**Kept**
2003	800	220	102	1100	1422	1066	**Due For Replacement**	**Kept**
2004	2550	0	80	2600	2680	1388	**Overdue For Replacement**	**Repaired**
2005	1450	1100	255	1750	4555	1916	**Overdue For Replacement**	**Kept**
2006	600	850	145	1900	3495	2142	**Overdue For Replacement**	**Replaced**

cost of capital is 10% of Market Value @ BOY

The market value in the year 2004 was ₦2550.00, and the actual depreciation was ₦0.00; indicating that the unit have outlived its economic life. The cost of capital was ₦145.00, annual expenditure was ₦2,600.00, and total annual (marginal) cost was ₦2680.00. *EUAC* increased to ₦1,388.80. It is noteworthy that in the period under review, based on the model's decision criteria, the unit was long overdue for replacement, since its *EUAC* has begun to increase after arriving at its minimum value in the previous year. In 2006, the market value was ₦600.00, the actual depreciation was ₦850.00 and cost of capital ₦145.00. Annual expenditure was ₦1,900.00, and total annual (marginal) cost was ₦2,895.00. *EUAC* increased to ₦1,675.00 showing the unit as overdue for replacement based on the model's criteria. The company eventually replaced the unit in this period.

The replacement decision recommendations from the DP model for the unit in the studied company for the years 2006 to 2011 is shown in Table 2. In 2006; the second unit's year of installation, market value of the unit was ₦8,000.00, the unit was not considered for replacement yet. In the year 2007, the market value was ₦6,166.67, the actual depreciation was ₦1,833.33, and cost of capital was ₦800.00. Annual expenditure was ₦2,500.00, total (marginal) cost per year was ₦5,133.33, *EUAC* was ₦5,133.33, and indicating the unit was not due for replacement.

TABLE 2
EUAC AND THE REPLACEMENT DECISIONS FOR 2006 TO 2011.

End of Year (k)	Market Value @ End of yr k (₦)	Depreciation During yr k (₦)	*Cost of Capital (₦)	Annual Exp. (₦)	Total (Marginal) Cost per Year (₦)	EUAC for yr k (₦)	Replacement Decisions based on the model	Actual replacement decision
2006	8000						Starting point	
2007	6166	1833	800	2500	5133	5133	**Keep**	**Kept**
2008	4700	1467	617	3000	5083	5110	**Keep**	**Kept**
2009	3600	1100	470	3500	5070	5098	**Keep**	**Kept**
2010	2867	733	360	3800	4893	5054	**Due for replacement**	**Kept**
2011	2500	367	287	5600	6253	5250	**Overdue for replacement**	**Replaced**

cost of capital is 10% of Market Value @ BOY

In 2008, the market value was ₦4,700.00, the actual depreciation was ₦1,466.67, cost of capital ₦616.67, annual expenditure ₦3,000.00, total (marginal) cost per year was ₦5,083.33, *EUAC* was ₦5,109.52, and in the period under review, it was not due for replacement. In the year 2009, the market value was ₦3,600.00, the actual depreciation was ₦1,100.00, and cost of capital value ₦470.00. Annual expenditure on the unit was ₦3,500.00, annual (marginal) cost was ₦5,070.00, *EUAC* was ₦5,097.58 and in the period under review, it was not due for replacement.

In 2010, the market value was ₦2,866.67, the actual depreciation was ₦733.33, and cost of capital ₦360.00. Annual expenditure was ₦3,800.00, total (marginal) cost per year was ₦4,893.33, and *EUAC*₦5,053.57. In the period under review, it was due for replacement because the *EUAC* of the unit was lower than that for the previous year, and also lower than that of next year but the company did not replace. The unit should have been replaced as the model recommended. In the year 2011, market value was ₦2,500.00, the actual depreciation was ₦366.67, cost of capital was ₦286.66. Annual expenditure was ₦5,600.00, total (marginal) cost per year was ₦6,253.33, *EUAC* was ₦5,250.00. In the period under review, it was overdue for replacement because the *EUAC* has started increasing after reaching a minimum value in the previous year. The unit was eventually replaced in this period.

The replacement decisions given by the DP model for the transmission unit of the studied company for the years 2011 to 2015 is shown in Table 3. In the year 2011, when another new transmission unit was installed, the market value was ₦12,000.00. The unit was just installed and not considered for replacement yet. In the year 2012, the market value was ₦9,200.00, the actual depreciation was ₦2,800.00, and the cost of capital (10% of market value @ BoY) ₦1,200.00. Annual expenditure of ₦3,500.00 was incurred, total annual (marginal) cost was ₦7,500.00, and *EUAC* was ₦7,500.00. In the reviewed period, the unit was not due for replacement because the *EUAC* of the unit was greater than that for the next year. The company also did not replace unit.

TABLE 3
EUAC AND THE REPLACEMENT DECISIONS FOR 2011 TO 2015

End of Year (k)	Market Value @ End of yr k (₦)	Depreciation During yr k (₦)	*Cost of Capital (₦)	Annual Exp. (₦)	Total (Marginal) Cost per Year (₦)	EUAC for yr k (₦)	Replacement Decisions based on the model	Actual replacement decision
2011	12000						Starting point	
2012	9200	2800	1200	3500	7500	7500	**Keep**	**Kept**
2013	7100	2100	920	4300	7320	7410	**Keep**	**Kept**
2014	5700	1400	710	5200	7310	7376	**Due for replacement**	**Kept**
2015	5000	700	570	6800	8070	7550	**Overdue for replacement**	**Kept**

cost of capital is 10% of Market Value @ BOY

For the year 2013 the market value was ₦7,100.00, the actual depreciation was ₦2,100.00 and their costs of capital was ₦920.00. Annual expenditure was ₦4,300.00, total annual (marginal) cost was ₦7,320.00, EUAC was ₦7,410.00, and for this period, the *EUAC* of the unit was higher than that for the previous year, though less than that of next year. The unit was therefore not due for replacement. In the year 2014, the market value was ₦5,700.00, there was an actual depreciation of ₦1,400.00, and cost of capital of ₦710.00. Annual expenditure was ₦5,200.00, total (marginal) cost per year was ₦7,310.00, and *EUAC*₦7,376.67. In the period under review, the unit was due for replacement because the *EUAC* was lower than that for both the previous and next years. The company did not however replace it. In the year 2015, the unit had a market value of ₦5,000.00, the actual depreciation was ₦700.00, and cost of capital value ₦570.000. There was an annual expenditure of ₦6,800.00. Total (marginal) cost for the year was ₦8,070.00, and *EUAC* was ₦7,500.00. The unit was already overdue for replacement during the period under review and was eventually replaced.

V. CONCLUSION

The company's replacement activity was in tandem with the recommendations of the replacement policy given by the model for some of the years studied. Thus the keeping of the unit in the years 2000, 2001 and 2002 during the first transmission unit use period tallied with the models recommendations. However the failure to replace the unit in 2003, up till 2005 was contrary to the models recommendation of "Due for replacement". If the company had replaced the unit in 2003, there would have been a savings of ₦322.00 *EUAC* in 2004, an additional savings of ₦528.00 in 2005 and an extra savings of ₦226.00 *EUAC* in 2006. Also during the second transmission unit use period the non-replacement of the unit in the years 2007, 2008 and 2009 was in tandem with the model's recommendation of "Keep". But in 2010 the continued retention of the unit in service when the model recommended "Due for replacement" led to the *EUAC* gaining an increase after reaching a minimum value. If the company had replaced the unit in 2010, it would have reaped a *EUAC* savings of ₦196.00 in 2011. Similarly the keeping of the unit in the years 2012 and 2013 during the third transmission unit use period was in tune with the model's recommendations of "Keep". The continued retention of the unit in 2014 and 2015, however was contrary to the models recommendation "due for replacement". The company would have gained a *EUAC* saving of ₦173.33 in 2011, if the unit was replaced in 2010. Zvipore *et al.* (2015) reported revenue increase from DP-based replacement analysis of a gold mine conveyor belt via replacement age determination. In conclusion, the use of engineering economic models, including replacement models for machinery management decisions support can enhance an industry's economic advantage in today's competitive industrial environment.

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