Cost-Prediction Models for Managing Transmission Units of locally-Fabricated Palm Nut Digesters

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Abstract— *The cost components of the transmission unit of locally-fabricated oil palm fruit digester were studied for the economic management of our local small-scale oil mills. 5 major oil mills in Orumba South Local Government Area of Anambra State Nigeria were studied and a representative company whose operational activities and available records were most amenable to the analytical models selected. Descriptive survey was adopted for this research. The records were painstakingly collated and processed, and the costs modeled using regression methods. The purchase price, maintenance cost and scrap value were each predicted with time as exponential models with* R^2 *values of 0.9833, 0.9572 and 0.9641 respectively. The scrap value and maintenance cost were each predicted as a* 2^{nd} *order polynomial function of the new unit's purchase price; with* R^2 *values of 0.9719 and 0.9351 respectively. The accumulated annual maintenance cost was predicted as a* 2^{nd} *order polynomial function of the annual digested nut output with* R^2 *values of 0.8963. The annual depreciation increased with successive units change, reflecting the dependence of depreciation on purchase price. It also decreased for each successive year of use for any particular unit. The results of the study did not corroborate the general approach of estimating machinery salvage value as 10% of the purchase price, or the practice in some quarters of budgeting 10% of the machine price for its maintenance cost. Understanding these costs dynamics will facilitate our locally-fabricated oil palm fruit digester's competitiveness via economic management of the transmission units.*

Keywords*— *Oil-palm-nut digesters, Machinery costs, Cost prediction, Cost dynamics, Management.

I. INTRODUCTION

Nigeria today has enormous economic problems that require the diversification of her economy (Okafor *et al.*, 2010). Resuscitating her agricultural sector; the oil palm production sub-sector inclusive, is a welcome idea. Nigeria was the world's largest producer of palm oil in the 1950s and 1960s (Okafor, 2007). The production lines deployed during the era of palm oil production boom in Nigeria were mostly of the traditional technique, which incurred minimal breakdown and equipment cost. Advanced technologies are needed for palm oil production today due to its increased demand; occasioned by the growing world population and recent emphasis on renewable energy.

Modern oil milling today employs, among others, palm nut digesting and mashed nut oil- expressing machines which have high wear and breakdown in their material-processing screws and power transmission units. 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. Sound management of production machines are needed to realize the intended benefits of machinery deployment. All investments, agricultural machinery investments inclusive are engaged for profit and other attractive economic benefits (Amaefule *et al.*, 2018a and Takeshima *et al.*, 2020). Adequate information is required by a machinery manager to make cost-effective machinery management decisions.

Few studies on agricultural processing equipment costs and economics have been carried out in the country. Repair and maintenance costs of rice mills under different ownership systems in Southeast Nigeria were studied by Oluka and Nwani (2013). Nwajinka (2010) developed computer-assisted methods for predicting the optimal-cost size and replacement time for farm tractor in Nigeria. Amaefule *et al.* (2018a) developed a minimum-cost model for selecting heavy tillage machinery for combined use of farmers, and tested it with data from tillage operations in Anambra State Nigeria. A presentation of the maintenance and replacement scenario and costing encountered in the Nigerian manufacturing industry milieu was given by Bagshaw (2017).Deploying relevant cost and economic data for the management of oil palm fruit digester gear transmission units is needed for profitable oil palm milling. This study is therefore aimed at predicting the purchase, operation and maintenance costs, and the scrap values of the gear transmission units of the locally-fabricated small-scale oil palm nut digester.

II. MATERIALS AND METHODS

2.1 Theoretical Considerations

Machinery costing must be properly addressed for cost or profit control and optimization. Fixed costs and variable costs are the broad categories of machinery cost. While fixed costs are independent of machine use, variable machinery costs vary directly as the machinery use and can be expressed on hourly basis or cost per unit output or other appropriate measures (Field and Solie, 2007 and Amaefule *et al*, 2018b). Machinery depreciation, shelter cost, interest on investment, insurance costs and taxes and duties make up the fixed costs, while variable costs are made up of fuel, oil and lubricants, labour and repair and maintenance costs. Costs approximation is acceptable for future costs estimation since the future cannot be perfectly predicted (Hunt and Wilson, 2015). For ease of mathematical manipulation in cost modelling, machinery costs can be expressed as function of machine purchase price, (Field and Solie, 2007 and Amaefule *et al.*, 2018a). This makes the machinery purchase price an important predictor of machinery costs.

2.2 Machinery Cost Evaluation

Machinery cost analysis provides a framework for combining net cash flows for several machine operations, or machinery services, into a single annual value. Some of the studied cost items are discussed below.

2.2.1 Depreciation of machinery

Depreciation accounts for the reduction in machine value with the passage of time because every substance experiences a continual decay (Bagshaw, 2017 and Amaefule, 2018). The accumulated depreciation along with the salvage value should be able to replace the machine at the end of the useful life. Hunt and Wilson (2015) gave the following reasons for machine depreciation.

i) The need to change the existing capacity owing to changed operational scale,
ii) Failure of irreplaceable or economically irreparable parts,
iii) Increase in the expense of operation and
iv) Obsolescence arising from availability of better machines.

Methods used in evaluating equipment depreciation include: Estimated value method, Straight line method, Declining balance method, Sum-of-the-year' digits (SYD) method and the sinking fund method. The straight line method is the simplest but does not reflect the actual trend of the equipment value over the years. SYD method is among the more realistic methods as it attributes higher depreciation values to the earlier years of the machine life. In this method, the ratio of the remaining years of the machine life to the sum of the machine years digits is obtained. The depreciation (D) charged each year is evaluated as a product of the difference of purchase price and the salvage value and this ratio (Hunt and Wilson, 2015) as seen in Equation 1.

$$D = \frac{L-n}{YD}(P-S) \tag{1}$$

where:

D = depreciation charged for the the year in question, monetary value

L = machine life, yr

n = age of the machine, yr

YD = sum – of – the years' digits, yr

P = price of the machine, monetary value

S = salvage value of the machine, monetary value.

For unknown salvage value of the machine, 10 percent of the machine price is used.

2.2.2 Energy and lubricant costs

Energy is generated in prime movers to power the unit operations for transforming raw materials. Industrial outfits in the urban areas can run on the cheaper electric power from the public electricity supply grid. Inadequate public power supply leads to the need for the costlier standby generator power alternative. Outfits located in the rural areas where most oil palm mills are found in Nigeria, use mostly stationary engine power. Fuel and oil consumption is measured or estimated and multiplied by their respective prices to determine their cost (Field and Solie, 2007). Older machines tend to consume more fuel and oil.

2.2.3 Labour costs

Manpower involvement in utilizing agricultural machinery includes the machine work scheduling, maintenance, attendance and operation. Kepner *et al.* (2003) stated that labour charge should be based upon prevailing wage rate. Oluka and Nwani (2013) agreed with this opinion, stating that prevailing circumstances and local variations make it difficult to predict operator's wages in especially private and co-operative enterprises. Labour cost for the owner-operator should be determined from the alternative use of the owner time, while for the hired operator, a constant hourly rate is appropriate. Increased labour cost ensues with machine deterioration, as more human attention and longer batch production time are required.

2.2.4 Repair and maintenance costs

Maintenance enables an equipment to perform its proper function (Bagshaw and George, 2015), while inadequate maintenance shortens equipment service life (Oluka and Nwani, 2013). Hunt (1999) stated that deterioration of equipment results mostly from use, and that maintenance corrects or retards deterioration in equipment. He further added that the labour and parts costs for changing replacement parts and reconditioning renewable parts constitute repair cost. The relatively minor maintenance cost is usually lumped with the much larger repair cost under repair and maintenance costs. The various components of a machine incur more repair and maintenance cost as the machine ages. Because repair and maintenance cost tends to increase with machine age (Oluka, 2000), it should be an important factor in determining the optimal age for machinery replacement.

Hunt and Wilson (2015) stated that maintenance cost per hour of use tends to remain constant as a machine becomes older, and depends on machine type. Deterioration through normal wear is directly related to use, whereas component failures are more random with respect to time and become more predictable only as accumulated value over the service life of the machine. The accumulated repair and maintenance cost (RM) for use hours was given by Hunt and Wilson (2015) as a 3rd order polynomial function. Kastens (1997) reported it as a logarithmic function. Calcante *et al.* (2013) used the power model for predicting maintenance cost in the study of self-propelled combines in Italy and Nigeria respectively. Oluka and Nwani (2013) developed power models for estimating the maintenance cost of rice mills under different ownership systems in Nigeria based on their accumulated use hours. Kastens (1997) argued that machinery management styles affect the annual repair and maintenance cost and suggested that the simulated cost should be multiplied by a factor between 0.75 and 1.25 to reflect this.

2.3 The Case Study

5 major palm oil mills in Orumba South Local Government Area; lying within latitudes 5.96778N – 6.0163N and longitudes 7.14758E – 7.3166E, were visited in Anambra state, Nigeria. Their mode of operations with regards to the material processing, and equipment maintenance and replacement activities was observed to be same. The oil mill complexes have locally-fabricated palm fruit digesters and other equipment that performed various functions. The oil palm digesters studied are of the vertical type. They operated on rotary mechanism and are each powered by an 8 HP stationary diesel engine. A batch of the digester, (referred to as 1 drum in this study), held 540 kg of oil palm nut.

Because of capital paucity, local oil palm digesters fabricators deploy used rear axle of trucks for the power transmission unit, since the cost is more affordable than standard gearboxes. Particularly foreign-used Toyota Dyna model truck axles were procured and reconstructed for this purpose. Breakdown maintenance of the transmission unit was practiced in the company, and was only done when the unit failed. A representative company whose operational activities and available records were most amenable to the analytical model was chosen as a case study.

2.4 Methodology

Descriptive survey was adopted for this research. Questionnaire was used to conduct reliable interview with the operators and maintenance technicians. Primary data was obtained from the field, while data from machine manufacturers' manuals, relevant handbooks on machine maintenance and scientific journals formed the secondary data. The transmission unit's initial cost, salvage value, service life and average maintenance cost were obtained from the collected data. The annual quantity of the oil palm nut digested was also obtained. The fuel consumed for the digester operation was also obtained from the company's record, while its cost was evaluated by multiplying it with the unit price obtained from national statistical data. The obtained data was regressed so that the corresponding ones for the other unavailable years covered in the study could be estimated. The salvage value and maintenance cost of the unit was also presented as a function of the machine price. Whereas it was difficult to obtain the machine use hours and its accumulated value, the quantity of palm nuts processed were extracted from the company's records.

III. RESULT AND DISCUSSION

3.1 Transmission Unit Purchase Price, Scrap value and Maintenance Costs

Table 1 shows the transmission units' cost components at each change period. The unit's purchase price, scrap value price and maintenance cost are comparatively presented. The transmission unit was procured for ₦3,000.00 in 1999, ₦5,000.00 in 2002, ₦8,000.00 in 2006, ₦12,000.00 in 2011, ₦14,000.00 in 2014, ₦20,000.00 in 2018 and ₦30,000.00 in 2020. The price (P) was increasing with increasing replacement year (x). The price was modelled as an exponential function (Equation 2), with an R^2 value of 0.9833.

$$P = 2379e^{0.3657x} \quad (2)$$

The increasing price could be due to market forces, tax changes, and inflation. Adverse prices are expected for increased foreign exchange regime. Nigeria has an import-dependent economy. Riggs (1977) and Kasten (1999) reported that inflation affects cost of material and production. Custom duties are paid on imported items and Value-Added Tax (VAT) is practiced in Nigeria as in many parts of the globe. However certain incentives; including a 5-years tax-free operation are part of government's effort to encourage establishment of agricultural enterprises, (Fonteh, 2013 and Amaefule, 2018). The price of the unit may also be related to how close-to-new status ("grade") of the unit. Ongkunaruk and Janssens (2018) stated that the value of a piece of equipment retrogrades with age and the extent of use.

TABLE 1
DIGESTER TRANSMISSION UNIT'S COSTS COMPONENTS PER REPLACEMENT

Year of Replacement	Price of New Unit (₦)	Scrap Value (₦)	Maintenance Cost (₦)
1999	3,000	800	2,000
2002	5,000	1,500	2,200
2006	8,000	2,500	2,500
2011	12,000	5,000	3,500
2014	14,000	7,500	5,000
2018	20,000	9,500	7,000
2020	30,000	11,000	7,500

Scrap value of the transmission unit was ₦800.00 in the 1st year of the 1st unit's use; 1999. In the year of 1st replacement; 2002, it was ₦1,500.00. It was ₦2,500.00 in the 2nd; 2006, ₦5,000.00 in the 3rd; 2011, ₦7,500.00 in the 4th; 2014, ₦9,500.00 in the 5th; 2018 and ₦11,000.00 in 6th; 2020. The price of the scrapped unit was continually increasing as the years progressed, most probably due to inflation and market forces. The model describing the salvage values (S) with the corresponding years (x) is shown in Equation 3. The R^2 value was 0.9572.

$$S = 625.78e^{0.4519x} \quad (3)$$

Higher scrap values reduce the cost implication of bringing in a new unit. Scrap parts and metals are purchased by local foundries and recycling plants, and do not attract much price. The progression could be as the result of inflation and market forces.

For the first transmission unit in use, the maintenance cost for the 1st year used (1999) was ₦2,000.00. It was ₦2,200.00 for the 2nd unit's 1st year of use (2002), ₦2,500.00 for the 3rd unit; (2006), and ₦3,500.00 for the 4th; (2011). The cost was ₦5,000.00 for the 5th unit; (2014), ₦7,000.00 for the 6th unit; (2018) and ₦7,500.00 for the 7th unit; (2020), as shown in the figure. The change in the cost of maintenance increased with increasing years. The rapid increase could be as the result of adverse economy, taxation and change in the market price of commodities. The variation of the maintenance cost (RM) for the first year use with the successive units' replacement period (x) was described by the exponential model in Equation 4. It had an R^2 value of 0.9641.

$$RM = 1378.6e^{0.249x} \tag{4}$$

The unit's scrap value (S) and maintenance cost (RM) were predicted as 2nd order polynomial functions of the new unit's purchase price(P); with R^2 values of 0.9719 and 0.9351 respectively.

$$S = -0.00001P^2 + 0.7865P - 2096.2 \tag{5}$$

$$RM = -0.000004P^2 + 0.3673P - 429.15 \tag{6}$$

The prediction equations did not agree with the recommended estimation machinery salvage value as 10 % of the purchase price (Hunt, 1999). It was also at variance with the practice of allocating 10 % of the purchase price for maintenance budget in some industrial outfits (Amaefule, 2007).

3.2 Transmission Unit Throughput, Diesel Consumed and Depreciation

The annual cumulative quantity of the palm nut digested, the diesel used and diesel cost are shown in Table 2. The unit's ending years of service and their corresponding cumulative throughputs and fuel consumption. For the first unit that was installed in 1999 and replaced in 2002, a total of 1,600 drums of palm fruit; each holding 540 kg of fruit, were handled (digested) during its service life.

TABLE 2
CUMULATIVE DIGESTER THROUGHPUT, DIESEL USED AND COST

Year	Cumulative Throughput (Drums)	Cumulative Diesel Use (Litres)	Cumulative Diesel Cost (₦)
2001	1600	3340	76,060.00
2005	2178	4400	199,330.00
2010	2048	3998	265,050.00
2013	1148	2296	228,660.00
2017	1306	2510	390,650.00
2019	709	1262	315,500.00
2020	302	602	156,520.00

3,340 litres of diesel was consumed in the processing, which amounted to a diesel cost of ₦76,060.00. The second unit installed in 2002 and replaced in 2006 handled 2,178 drums of palm nut and consumed 4,400 litres of diesel; which cost ₦199,330.00. The third unit was in service from 2006 to 2010 and handled a total of 2,048 drums; for which 3,998 litres of diesel was consumed at a cost of ₦265,050.00. For the fourth unit that was in service from 2011 to 2017, within which a total of 1,310 drums was handled, consuming 2,510 litres of diesel at a cost of ₦390,650.00.

The fifth unit was used from 2018 to 2019, and handled a total of 709 drums, consuming 1,262 litres of diesel at a cost of ₦315,500.00. The sixth unit came into service in 2020; the last year covered in the study. A total of 302 drums was processed during this 1 year captured by the study, and consumed 602 litres of diesel at a cost of ₦156,520.00. There was no trend in the quantity of palm nuts processed. The amount was based rather on the customers patronage. The diesel cost however maintained an increasingly upward trend, but for the temporal ditch in the 2011 to 2013 value; that has equally low diesel consumption. The continual increase in diesel price increase could be responsible for this. Government policies; like partial removal of petroleum products subsidy, and inflation could have affected the price of diesel.

The depreciation of the unit for the various years of operation is shown in Figure 1. For each span of the service years, the depreciation decreased for the successive years. Higher values of depreciation are shown for the earlier years of the units use and for high new unit prices. Units with longer span of service have more gradual decrease in their annual depreciation, while those with higher new unit prices had less gradual decrease. The corresponding years' depreciation increased with successive units use, reflecting the previously discussed purchase price increases, and the dependence of depreciation on purchase price.

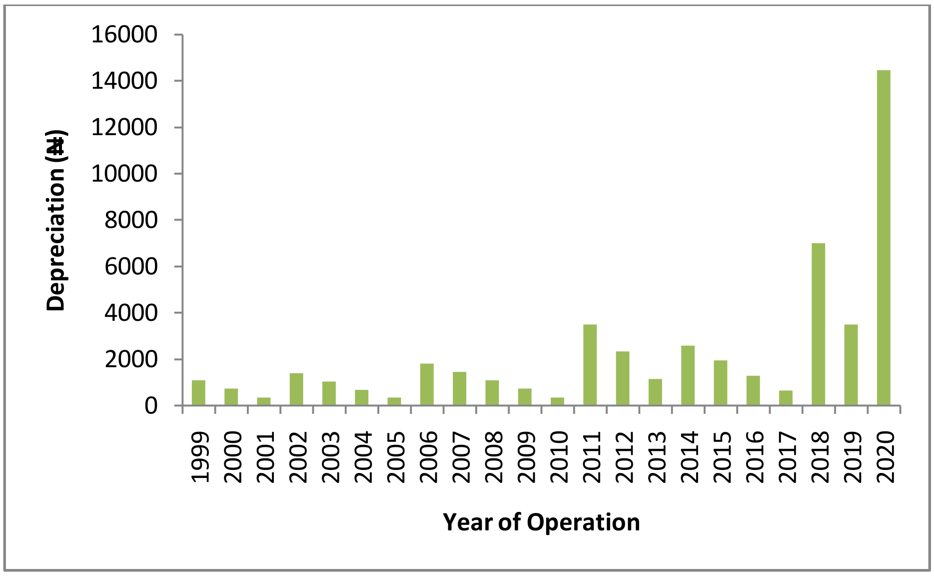

FIGURE 1: Annual Depreciation of Digester Transmission Unit

Figure 2 shows the variation of the various units first year's maintenance cost with the corresponding digested nut output. The highest maintenance cost, ₦7,500.00 was incurred for the 7th unit in 2020 (see Figure 1) with only 302 drums production. The lowest, ₦2,000.00 was obtained for the 1st unit in 1999 with 537 drums production. A maintenance cost of ₦7,000.00 was obtained for a production of 307 drums during the 6th unit's first year 2018 and cost of ₦2,200.00 with 602 drums production in 2002.

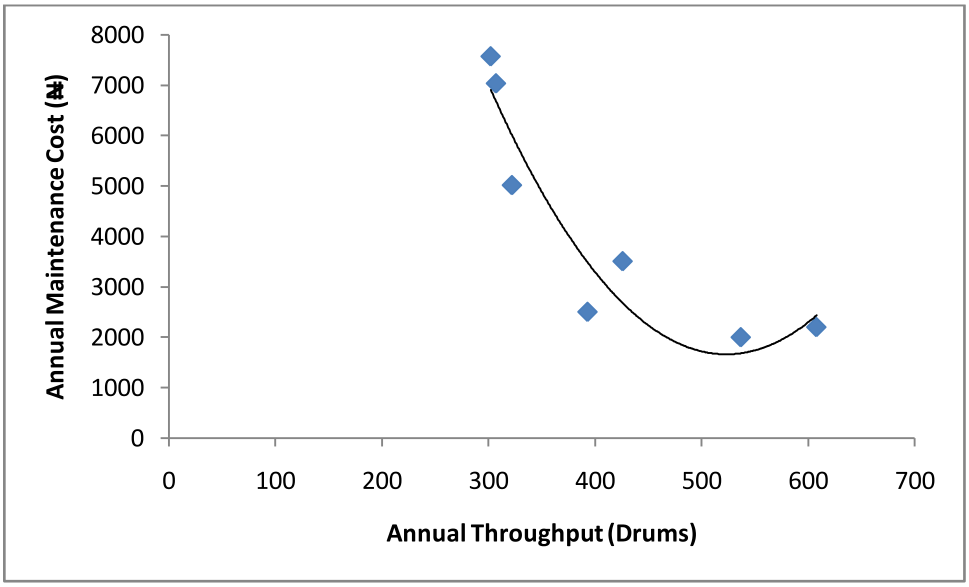

FIGURE 2: Transmission Unit Maintenance Costs versus Machine Throughput

Higher values of the maintenance cost coincided with lower annual output. The variation of the cost (RM) of the units for their first year use with the annual output (u) was described by the second order polynomial model in Equation 7. The R^2 value was 0.8963. The seeming higher maintenance costs with even low production values could be attributed to inflation.

$$RM=0.107u2-112.16u+30999 \quad (7)$$

The (close-to-new) state of the transmission units will also affect maintenance cost. According to Hartman and Rogers (2006) increases in equipment age correlates with decreased equipment utilization, and increases in total operation and maintenance costs. This they attributed to reduced equipment availability as a result of increased equipment down time. Hunt and Wilson (2015) and Oluka and Nwani (2013) reported power models for evaluating accumulated repair and maintenance cost from accumulated use hours.

IV. CONCLUSION

The digester's transmission unit was found to be in upward purchase price, energy and maintenance costs, scrap value and annual depreciation increases for successive units changes. This was considered to result from inflation and market forces. The new units price could be predicted as a function of the replacement period (x). The scrap value and maintenance cost were also predictable as functions of the new units price. Equally, the annual maintenance cost was predictable as functions of change period and price of new unit. The findings of the study could not support the evaluation of the scrap value as 10% of the machine price; suggested commonly for unknown salvage values by some researchers (Field and Solie, 2007 and Hunt and Wilson, 2015). Since the overall goal of machinery management should be profit optimization rather than mere cost minimization (Schueller, undated), the mills competitiveness will be enhanced with the proper application of these costs' knowledge. A good understanding of these transmission unit's costs dynamics can therefore assist in sound management of our local oil palm digesters and oil milling

NOTATIONS

D = depreciation charged for the the year in question,	monetary value
L = machine life,	yr
n = age of the machine,	yr
YD = sum – of – the years digits,	yr
P = price of the machine,	monetary value
S = salvage value of the machine,	monetary value
Y = New transmission unit purchase price,	monetary value
RM = transmission unit repair and maintenance cost,	monetary value
u = annual output,	drums (equivalent to 540 kg)
x = transmission unit change period,	years

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