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Mathematical Modelling of Repair and Maintenance Cost for John Deer 5065e Tractor: A case study of Kaduna State, Nigeria

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Abstract: Mathematical model was developed to predict optimum repair and maintenance cost for John Deer 5056E model tractor, with a view to providing such decision making aids as machine's replacement and overall farm budgeting for machinery managers. Information on 75 John Deer 5065E tractors was obtained through a structured questionnaire. Data collected was sought on tractor characteristics and economic costs such as use of tractor each year, fuel consumption cost, lubrication oil cost, oil and fuel filters replacement cost and labour cost. Result showed that the cost of tractor spare parts replacement had the highest percentage share (54.2%) from the total percentage cost followed by cost of fuel (20.4%), labour cost (13.0%), and then cost of lubrication oil (10.3%) while cost of oil and fuel filter replacement had the least (2.1%) percentage share.

Keywords: Repair, maintenance, cost, tractor, john deer 5065E, Nigeria.

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1. Introduction

Tractors have traditionally been used on farms to mechanize several agricultural tasks. Modern tractors are used for ploughing, tilling and planting fields in addition to routine lawn care, landscape maintenance, moving or spreading fertilizer and clearing bushes (Bulgakov et al., 2018; Takeshima, 2017; Takeshima et al., 2018). Ever since there has been a significant improvement in the state of farming equipment in Nigeria, the role of modern tractors has become much more important with these being used on farms to automate quite a lot of agricultural responsibilities (Hatzenbuehler et al., 2018; Mottaleb et al., 2017; Ren et al., 2019; Takeshima et al., 2013). Modern tractors are helpful in a lot of ways be it ploughing the field, clearing bushes, tilling, spreading fertilizers or planting. Some farmers also use it as a tool to routinely care take care of their lawns and maintain their landscape areas (Emami et al., 2018; Paudel et al., 2019; Sims and Kienzle. 2016; Ren et al., 2019; Takeshima et al., 2018).

One of the difficulties in analyzing repair and maintenance costs is that they change over time. Depreciation tends to be great at first, especially for a machine purchased new, but declines over time. Likewise, interest expense is high initially but gradually diminishes (Theodorea et al., 2016).

This is true whether the interest cost is cash interest paid on a loan, or an opportunity cost based on revenue foregone by continuing to own a machine year after year. On the other hand, repair costs may amount to little or nothing when a machine is still under warranty, but eventually increase as parts wear out and maintenance requirements rise. Fuel and lubrication costs usually do not change much over time, although an older engine may eventually lose some degree of fuel efficiency (Theodorea et al., 2016; Zhang et al., 2017).

Tractor costs have great influence on farm business profit. Knowledge of tractor costs for farm operations has a prime importance in making management plans and decisions especially in

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comparing different tractor types and models thereby assisting in the selection of a more appropriate farm tractor (Chaya et al., 2019; Rosa-Schleich et al., 2019; Shockley et al., 2019). Costs of owning and operating farm machinery represent 35 to 50% of the costs of agricultural production when the land is excluded (Anderson, 1988). Making smart decisions about how to acquire machinery, when to trade, and how much capacity to invest in can reduce machinery costs as much as $50 per acre. All these decisions require accurate estimates of the costs of owning and operating farm machinery, Williams (2015). The repair and maintenance (R&M) cost is an important item in the costs of ownership and operation. R&M cost is a function of machine age and use (Hunt, 2001). In general, the costs other than those for R&M usually decrease with increasing usage, but the reverse is true with respect to R&M costs. The cost of R&M is usually about 10% of the total cost; as the machine age increases the cost increases until it becomes the largest cost item of owning and operating the farm machines (Rotz and Bowers, 1991).

Agricultural engineers have carried many studies regarding R&M of farm machines. Several studies were conducted in both developed and developing countries either to develop models to determine the cost during a certain period or to get absolute numbers to represent owning and operating certain equipment (Abdallah et al., 2014; Al-Suhaibani and Wahby, 2017; Farrow et al., 1980; Lorencowicz and Uziak, 2015; Rohani et al., 2011; Rotz, 1987; Ward et al., 1985). Some studies conducted in developed countries regarding R&M of farm machines have been reported in the literature. Bowers and Hunt (1970) collected information from several farms in Illinois and Indiana in the United States. Also Fairbanks et al., (1971) made an extensive survey on 114 farms in Kansas and they developed two models from their study. One model was to calculate the cost of repair for diesel tractors and the other one was to calculate the cost of repair for combine harvesters. The operating costs of the farm machines in developing countries were estimated using the models of developed countries (Inns, 1978). Henderson and Fanasb (1984) conducted a study in Jordan on the cost of tractor use. This study showed that there was a proportional increase of repair costs with tractor use. Farrow et al., (1980) tested the performance of prediction equations and estimated the required changes needed for seven farm machines including trucks. A standard model was established for the prediction of repair and maintenance costs of medium-size, two-wheel drive, diesel engine tractor in Sudan. The model was derived based on data collected over a 10-year period, from several locations in Sudan, and it predicts repair and maintenance costs as a power function of tractor cumulative use in hours. The model showed that the tractor cumulative use in hours was the major determinant factor of the tractor repair and maintenance costs. The study concluded with emphasis to improve the existing models for obtaining better accuracy. Ward et al., (1985) made an extensive study of 10 years of government records for repair costs of 4-wheel and 2-wheel drive tractors and developed a cost model for each type of tractor. This study agreed with other studies regarding the difference existing between the two types of tractors. Rotz (1987) developed a model based on equipment price and operating hours. Testing the model showed that the costs were more realistic when the area worked was considered instead of the operating hours.

Abuabkar et al. (2013) stated that “the agricultural tractor is at the centre point of agricultural mechanization. Tractor costs have great influence on farm business profit. Knowledge of tractor costs for farm operations has a prime importance in making management plans and decisions especially in comparing different tractor types and models thereby assisting in the selection of a more appropriate farm tractor”. Tchotang et al. (2016) presented an approach for deriving a mathematical model that predict R&M cost of farm tractors in the Gambia. As John Deere (JD) tractors are widely used by Gambian farmers, a study was conducted to predict accumulated repair & maintenance costs (Y) of the two-wheel drive (2WD) JD-5403 tractor based on accumulated working hours (X). In order to determine the mathematical model for the studied tractor, regression analysis using knowledge based analytical software (SPSS STATISTICS 21 and Excel 2016 version) was performed on the calculated data generating five regression models: linear, logarithmic, polynomial, power and exponential.

Fuel costs can be estimated by using average fuel consumption for field operations in litres per hour (Grisso et al., 2004; Marx et al., 2015). Those figures can be multiplied by the fuel cost per liter to calculate the average fuel cost per hour/hectare. Lubrication Surveys indicate that total lubrication costs on most farms average about 15 percent of fuel costs. Therefore, once the fuel cost per hour has been estimated, it can be multiplied by 0.15 to estimate total lubrication costs.

Labour cost also is an important consideration in comparing ownership to custom hiring. Actual hours of labour usually exceed field machine time by 10 to 20 percent, because of travel time and the time required to lubricate and service machines. Consequently, labour costs can be estimated by multiplying the labour wage rate times 1.1 or 1.2. Using a labour value of Rs 50 per hour for our tractor. Different wage rates can be used for operations requiring different levels of operator skill. Total Operating Cost Repair, fuel, lubrication, and labour costs are added to calculate total operating cost.

It is not always clear as to which category some of the specific costs belong. Estimations of yearly costs are adequate for determining crop production costs and for deciding if machine ownership is profitable; but the time of replacement decision depends on the accumulated costs over a period of years. Repair and maintenance (R&M) costs of farm machinery are difficult to estimate because of variability among machines and operating conditions from one farm to another and also due to unavailability of good records keeping (Lazarus and Selley, 2005). Therefore, the aim of this study is to provide a mathematical model for the repair and maintenance costs for John Deer 5065E tractor for Kaduna State of Nigeria. The results of the study could serve as benchmark information to tractor owners in the study area regarding optimum use of tractors for minimizing repair and maintenance cost per operating hour and for making replacement policy. Thus, it could be used by policy makers, farm managers and other agencies for future planning in the provision of tractor services to the farmers at relatively lower repair and maintenance cost.

2. Materials and Methods

2.1. Data Collection

The study was conducted in Zaria town of Kaduna State, Nigeria. Data were collected from randomly selected 50 JOHN DEER 5065E tractor operators using structured questionnaire. Information was sought on tractor characteristics and economic costs such as use of tractor each year, fuel consumption cost, lubrication oil cost, oil and fuel filters replacement cost and labour cost. The John Deere 5065E. 2018 John Deere 5065E cab tractor WITH 520M front end loader.

Fig. 1. The John Deer 5065E.

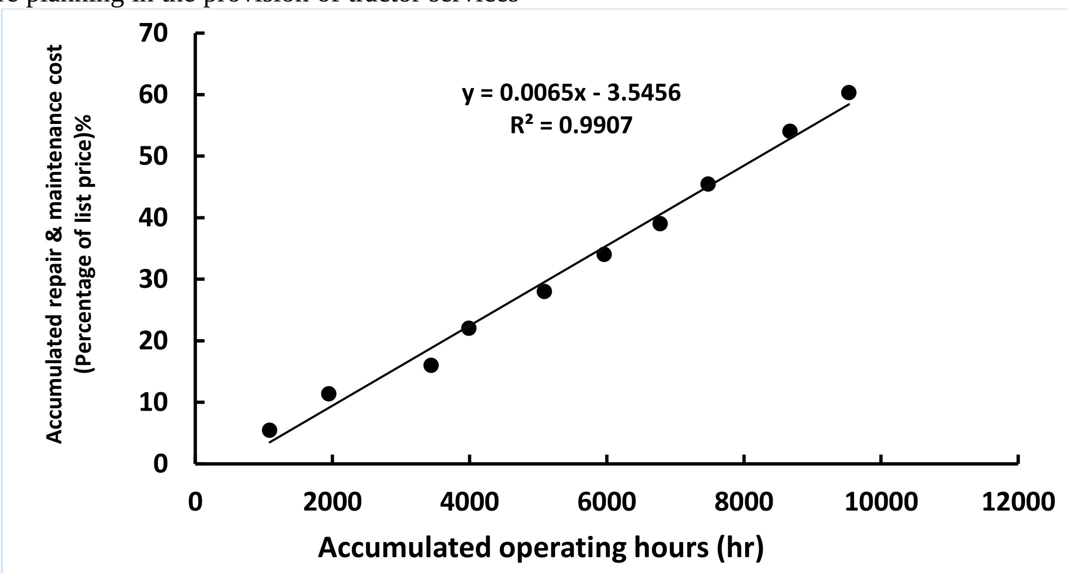

Fig. 2. Graph of linear relationship between the accumulated repair and maintenance cost and the accumulated operating hours

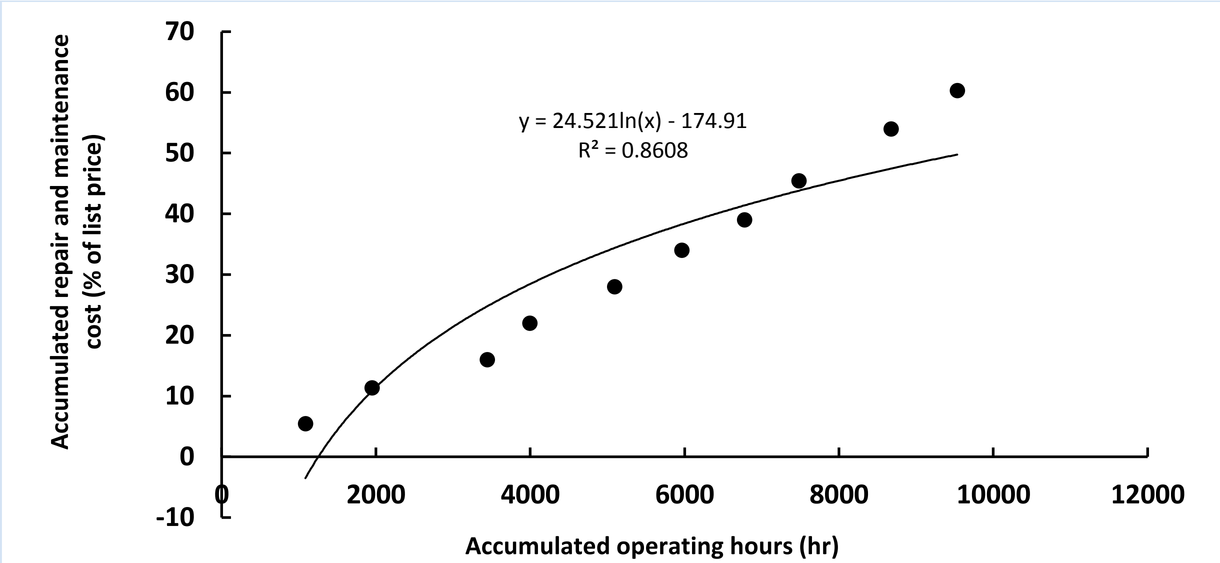

Fig. 3. Graph of logarithmic relationship between the accumulated repair and maintenance cost and the accumulated operating hours

Tractor has 67 engine HP and 49 PTO HP. Tractor is 4×4 and features a category 2 three-point hitch that can be converted to a category. The transmission is designed to match the excellent power and torque characteristics of the John Deere PowerTech™ engines. Transmission durability is enhanced with the pressure-lubricated top shaft, allowing an operator to achieve performance from one working season to the next. The picture of the tractor 5065e is presented in Fig. 1.

The tractors were then classified according to their age (years) into 20 groups that is 1 to 20. Thereafter the mean operating hours per year was calculated separately then the mean annual repair and maintenance costs were also calculated separately for each group. The accumulated operating hours per group was calculated using equation given by as reported by Khoubbakht (2008):

$$X_n = \sum_{i=1}^{n} x_i \quad [1]$$

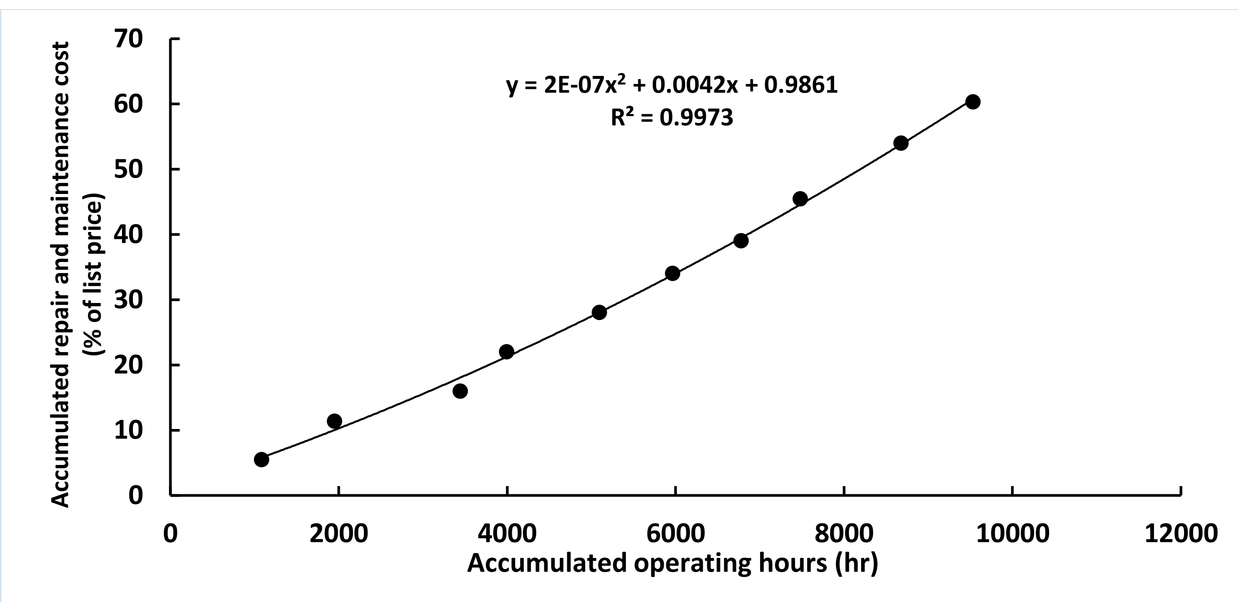

Fig. 4. Graph of Polynomial relationship between the accumulated repair and maintenance cost and the accumulated operating hours

Where X is the accumulated operating hours for the 'n' group in hour (h), n is the tractor age group in year (y), x is the mean annual operating hours per group in hour per year (h/y) for the group I. Also accumulated repair and maintenance cost was calculated using equation 2 below as reported by Ward et al., (1985):

$$Y_n = \sum_{i=1}^{n} y_i \qquad [2]$$

Where Y is the accumulated repair and maintenance cost based on percentage of list price for the 'n' group and y is the mean annual repair and maintenance cost based on percentage of list price for the group I.

Based on the above relationships, the ratio of the cumulative repair and maintenance costs per group based on the list price was estimated as the dependent variable and the cumulative operating hours were computed as independent variable. In order to determine mathematical model for the study, regression analysis was performed on the data using the Statistical Analysis Software (SAS, 2009). Five models were used to perform regression analysis, linear (equation 3), polynomial (equation 4), exponential (equation 5); logarithmic (equation 6); and power (equation 7), models.

$$Y = a + bx \qquad [3]$$

$$Y = a + bx + cx^2 \qquad [4]$$

$$A = ae^{bx} \qquad [5]$$

$$Y = a + b \text{ In x} \qquad [6]$$

$$A = ax^b \qquad [7]$$

Both the dependent and independent variables were used to obtain the best equations to estimate repair and maintenance costs from the five models above.

3. Results and Discussion

3.1. Determination of repair and maintenance costs of the John Deer 5065E tractor

Repair and maintenance costs of the John Deer 5065E tractor were sought from the following: fuel consumption cost, lubrication oil cost, oil and filter replacement cost, spare parts cost and labour cost. Table 1, presents the result of the calculated mean annual repair and maintenance costs of the John Deer 5065E tractor with the cost of each variable and percentage share of the total.

It was observed that the cost of tractor spare parts replacement (54.2%) had the highest percentage share compared to another variable's cost. This could be due to the fact that majority of the spare parts used were substandard which led to continuous replacement of spare parts. The next single variable with high cost of the percentage total was the fuel consumption (20.4%). While the least cost was obtained from oil and fuel filters variable (2.1%). Also this may be attributed to the age of the tractors which could lead to consumption of more fuel. The result reported in this study was similar to the one obtained by Khoubbakht et al., (2008).

Table 1: Mean annual repair and maintenance costs of the JOHN DEER 5065E tractor Variable Cost N ($)* Percentage

Variable	Cost n	%
Fuel consumption	3,774,000 (24,192)	20.4
Lubrication oil	1,905,500 (12,215)	0.3
Oil and fuel filters	388,500 (2,490)	2.1
Spare parts	10,027,000 (64,276)	54.2
Labour	2,405,000 (15,417)	13.0
Total	18,500,000 (118,590)	100

* Exchange rate of N360.00 per 1.00$ as at 2018.

Table 3: Tabulation of comparison of Developed Models by Researchers

Models developed by different researchers	Accumulated repair and maintenance costs based on percentage of list price			Source(s)
	5000 hours	8000 hours	10000 hours	
$y = 0.042\left(\frac{x}{120}\right)1.895$	49	120	183	Ward et al., (1985)
$y = 0.072\left(\frac{x}{120}\right)1.6$	30	63	89	Bowers and Hunt, (1970)
$y = 0.005X^{1.2}$	36	62	85	Abubakar et al., (2013)
y = 0.0026x1.0901	29	57	80	Shani et al., (2018) Present model

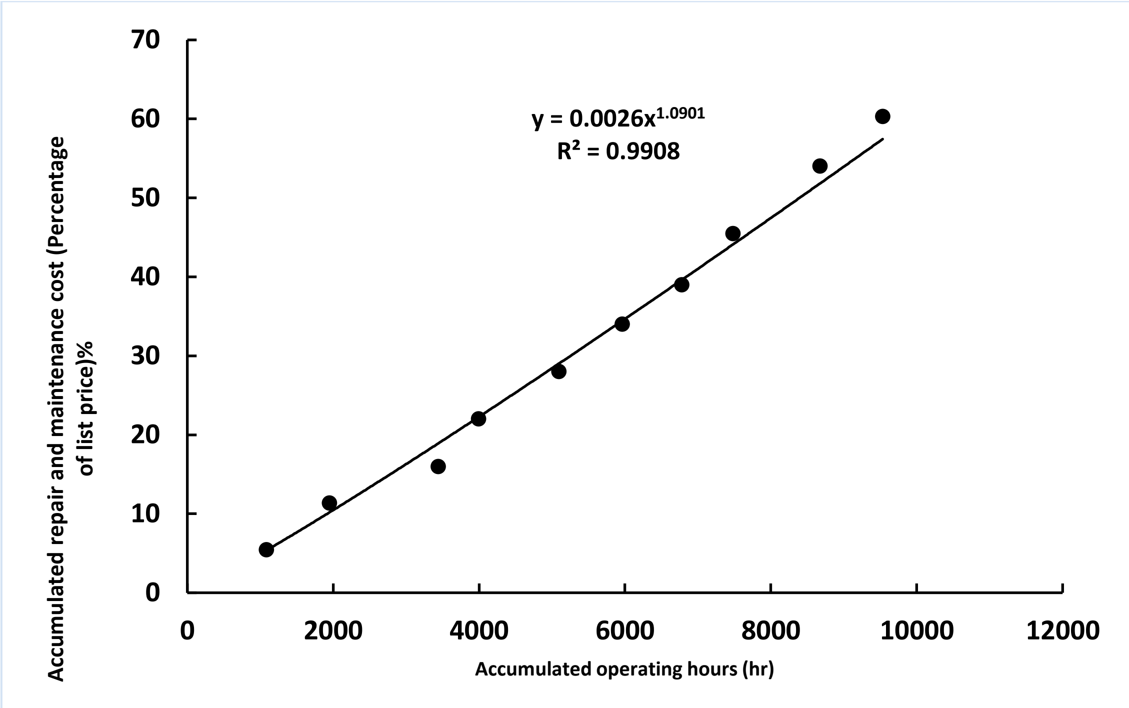

Fig. 5.Power relationship between the accumulated repair and maintenance cost and the accumulated operating hours.

3.2 Mathematical model to predict the repair and maintenance costs of the John Deer 5065E tractor

The result of the calculated accumulated repair and maintenance cost and the operating hours of the John Deer 5065E tractor from the fifty number of tractors are presented in Table 2. The accumulated repair and maintenance and the operating hours values obtained were used to analysis and determine the mathematical model.

The relationship between the accumulated repair and maintenance cost and the accumulated operating hours were used to develop the mathematical models are shown in Fig. 2,3,4,5 and 6 respectively. It was observed that the highest value of coefficient of correlation (R^2) amongst the models was found on polynomial model (R^2 = 0.9973) then followed by the power, linear, exponential and logarithmic models with R^2 of 0.9908, 0.9907, 0.9332 and 0.8608 respectively. These findings are in agreement with results of earlier reports (Abubakar et al., 2013; Adekoya and Otono, 1990; Khoub bakht et al., 2008).

Comparison of models developed by different researchers in predicting the accumulated repair and maintenance costs (Table 3) showed overestimation of accumulated repair and maintenance costs (> 3 times) when compared with the model developed in the present study.

However, the comparison of Kaduna standard prediction model with similar models revealed that the estimates of repair and maintenance costs of the agricultural tractor in Sudan were not significantly higher but with that of industrialized countries, they were significantly higher. The regression model (s) having the highest coefficient of determination (R^2) was chosen as the best model(s) for the modelling of actual R&M costs evaluation. Further to it, in the most recent published researches in this field power and polynomial models gave better cost prediction with higher confidence and less variation than that of linear exponential and logarithmic models.

Because of, its easiness in calculations, high correlation coefficients and using of this model by many researchers, the polynomial model as given in eq [4] was suggested as final form of the repair and maintenance cost model in the present study. The following repair and maintenance cost components of the JD-5403 tractor were determined.

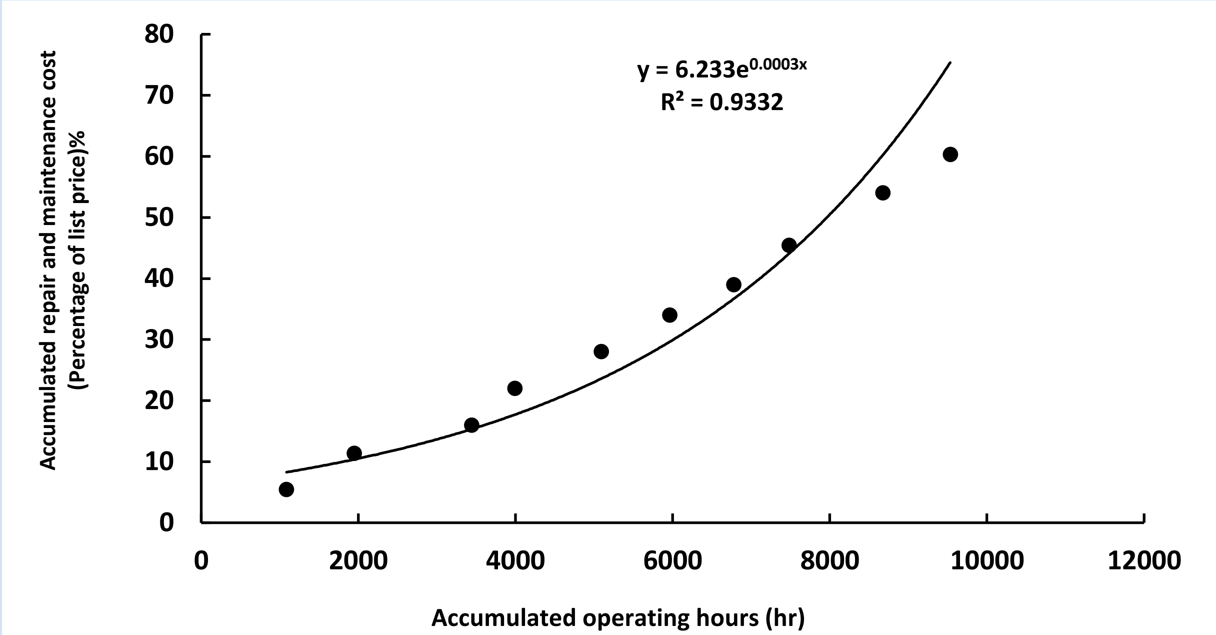

Fig. 6. Exponential relationship between the accumulated repair and maintenance cost and the accumulated operating hours

Table 2: Accumulated repair and maintenance cost and operating hours of John Deer 5065E tractor.

Tractor age (year)	Accumulated operating hours	Accumulated repair and maintenance cost (% of list price)
1	1085.19	5.45
2	1948.21	11.35
3	3441.64	15.97
4	3992.1	22.02
5	5092.76	28.01
6	5962.9	34
7	6778.32	39
8	7480.87	45.45
9	8675.05	54
10	9532.75	60.3

5. Conclusion

The conclusions drawn from this study was that the repair and maintenance cost increased with an increase in operating hours of John Deer 5065E tractor and the mathematical model developed has the tractor accumulated operating hours as the major determining factor of the repair and maintenance costs. It is therefore recommended that the mathematical models developed be use for tractor repair and maintenance and should be applied only to those conditions for which they were developed.

Competing Interest Statement: All the Authors declare that they have no competing interest.

Author's Contribution: B.B.S. conceived and designed of the study. B.B.S., A.M. and A.M.B,I. conducted the experiment and performed the data analysis. B.B.S. wrote the manuscript. Finally, all the authors read and approved the final manuscript.

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References

Abdallah, F.E., W. Ding, M.H. Dahab, A.E.I. dris and M. Alhadi. 2014. Estimation of repair and maintenance cost of a tractor base on HP and working hours: Case study of Sudan. J. Environ. Agric. Sci. 1(1): 1-6.

Abubakar, M.S., M.D. Zakari, S.K. Shittu and M.L. Attanda. 2013. Determination of repair and maintenance cost for MF375 tractor: a case study in Kano metropolis, Nigeria, arid zone. J. Eng. Tech. Environ. 9: 27- 35.

Adekoya, L.O. and P.A. Otono. 1990. Repair and maintenance costs of agricultural tractors in Nigeria. Trop. Agric. 67(2): 119-122.

Al-Suhaibani, S.A. and M.F. Wahby. 2017. Farm tractors breakdown classification. J. Saudi Soc. Agric. Sci. 16(3): 294-298.

Anderson, A.W. 1988. Factors affecting machinery costs in grain production. American Soc. Agric. Eng. 88-1057.

ASAE 1983. Agricultural machinery management data - Standards, EP496.1. ASAE Standards.

Bowers, W. and D.R. Hunt. 1970. Application of mathematical formulas to repair cost data. American Soc. Agric. Eng. 13(6): 806-809.

Bulgakov, V., S. Pascuzzi, V. Nadykto and S. Ivanovs. 2018. A mathematical model of the plane-parallel movement of an asymmetric machine-and-tractor aggregate. Agric. 8(10): 151-155.

Chaya, W., B. Bunnag and S.H. Gheewala. 2019. Adoption, cost and livelihood impact of machinery services used in small-scale sugarcane production in Thailand. Sugar Tech. 21(4): 543-556.

Emami, M., M. Almassi, H. Bakhoda and I. kalantari. 2018. Agricultural mechanization, a key to food security in developing countries: strategy formulating for Iran. Agric. Food Sec. 7(24): 1-12.

Fairbanks, G.E., G.H. Larson and D.S. Hung,. 1971. Cost of using farm machinery. Trans. American Soc. Agric. Eng . 14(1): 98-101.

Farrow, S., J.F. Shepherd, and H. Waelti. 1980. A regional test of machinery repair cost equations. American Soc. Agric. Eng . 80-1017.

Grisso, R.D., M. F. Kocher and D. H. Vaughan. 2004. Predicting tractor fuel consumption. Appl. Eng. Agric. 20(5): 553-561.

Hatzenbuehler, P.L., H. Takeshima, H. Edeh and A. Lawal. 2018. Cost and policy determinants of features of tractor markets in Nigeria: Case studies of tractor sellers in Kaduna state and tractor owners in Benue state. Intl Food Policy Res Inst. p: 1-31.

Henderson, H.D. and S. Fanasb. 1984. Tractor costs and use data in Jordan. Transactions American Soc. Agric. Eng. 27(4): 1003-1008.

Hunt, D.R. 2001. Farm Power and Machinery Management (2nd Edition). USA: Iowa State University Press. Ames.

Inns, F.M. 1978. Operational aspects of tractor use in developing countries – A case for the small tractor. Agric. Eng. Summer. 52-54.

Khoub, B.G.M., H. Ahmadi, A. Akram and M. Karimi. 2009. Repair and maintenance cost models for MF285 tractor: A case study in central region of Iran. American Eurasian J. Agric. Environ. Sci. 3(1-2): 19-23.

Konda, I. and D.L. Larson. 1990. Tractor repair and maintenance costs and management policies in Burkina Faso. American Soc. Agric. Eng. 90-8503.

Lazarus, W. and R. Selley. 2005. Farm machinery economic cost estimates for late 2005. University of Minnesota Extension Services, St. Paul, Minnesota. 1-12.

Lorencowicz, E. and J. Uziak. 2015. Repair cost of tractors and agricultural machines in family farms. Agric. Agric. Sci. Proc. 7: 152-157.

Marx, S.E., J.D. Luck, R.M. Hoy, S.K. Pitla, E.E. Blankenship and M.J. Darr. 2015. Validation of machine CAN bus J1939 fuel rate accuracy using Nebraska Tractor Test Laboratory fuel rate data. Comput. Electron. Agric. 118: 179-185.

Mottaleb, K.A., D.B. Rahut, A. Ali, B. Gérard and O. Erenstein. 2017. Enhancing smallholder access to agricultural machinery services: Lessons from Bangladesh. J. Devel. Stud. 53(9): 1502-1517.

Paudel, G.P., D.B. Kc, D.B. Rahut, N.P. Khanal, S.E. Justice and A.J. McDonald. 2019. Smallholder farmers' willingness to pay for scale-appropriate farm mechanization: Evidence from the mid-hills of Nepal. Technol. Soc.. 59: 101196.

Ren, C., S. Liu, H. van Grinsven, S. Reis, S. Jin, H. Liu and B. Gu. 2019. The impact of farm size on agricultural sustainability. J. Clean. Prod. 220: 357-367.

Rohani, A., M.H. Abbaspour-Fard and S. Abdolahpour. 2011. Prediction of tractor repair and maintenance costs using Artificial Neural Network. Expert Sys. App. 38(7): 8999-9007.

Rosa-Schleich, J., J. Loos, O. Mußhoff and T. Tscharntke. 2019. Ecological-economic trade-offs of diversified farming systems – A review. Ecol. Econ. 160: 251-263.

Rotz, C.A. 1987. A standard model for repair costs of agricultural machinery. App. Eng. Agric. 3(1): 3-9.

Rotz, C.A. and W. Bowers. 1991. Repair and maintenance cost data for agricultural equipment. American Soc. Agric. Eng. 91-1531.

Shockley, J.M., C.R. Dillon and S.A. Shearer. 2019. An economic feasibility assessment of autonomous field machinery in grain crop production. Prec. Agric. 20(5): 1068-1085.

Sims, B. and J. Kienzle. 2016. Making Mechanization Accessible to Smallholder Farmers in Sub-Saharan Africa. Environ. 3(2): 11.

Singh, G. 2000a. Modernization of Agriculture in India (part I)-Farm Mechanization. New Delhi: Ministry of Agriculture.

Singh, G. 2006. Estimation of a mechanization index and its impact on production and economic factors—a case study in India. Bio. Sys. Eng. 93(1): 99–106.

Singh, R.B. 2000b. Environmental consequences of agricultural development: a case study from the

Green Revolution state of Haryana. India. Agric. Ecosys. Environ. 82(1-3): 97-103.

Takeshima, H. 2017. Custom-hired tractor services and returns to scale in smallholder agriculture: a production function approach. Agric. Economics. 48(3): 363-372.

Takeshima, H., A. Nin-Pratt and X. Diao. 2013. Mechanization and agricultural technology evolution, agricultural intensification in Sub-Saharan Africa: Typology of agricultural mechanization in Nigeria. American. J. Agric. Econ. 95(5): 1230-1236.

Takeshima, H., N. Houssou and X. Diao. 2018. Effects of tractor ownership on returns-to-scale in agriculture: Evidence from maize in Ghana. Food Policy. 77: 33-49.

Ward, S.M., P.B. McNulty and M.B. Cunney. 1985. Repair costs of 2 and 4 WD tractors. Trans. American Soc. Agric. Eng. 28(4): 1074-1076.

William "Estimating Farm Machinery Costs," Iowa State University Extension and Outreach, Iowa, 2015.

Zhang, X., J. Yang and R. Thomas. 2017. Mechanization outsourcing clusters and division of labor in Chinese agriculture. China Econ. Rev. 43: 184-195.