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Repair and Maintenance Cost Analysis of John Deere 5403 Tractor in the Gambia

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Abstract

The paper presents an approach for deriving a mathematical model that predict repair and maintenance (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. The statistical results showed that the polynomial model gave better cost prediction with higher confidence and less variation than other models. Finally, it was established that repair and maintenance cost increased with an increase in working hours of JD-5403 tractor.

Keywords: Statistical analysis; R&M cost; 2WD-Tractor; JD-5403; The Gambia.

1. Introduction

Machinery and equipment are major cost items in farm businesses. Larger machines, new technology, higher prices for parts and new machinery, and higher energy prices have all caused machinery and power costs to rise in recent years. However, good machinery managers can control machinery and power costs per acre.

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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 [1]. Gambia's agricultural mechanization technology has continued to be import-oriented. Over the years, the government in response to the national plight of farmers to alleviate their labor shortage, has brought into the country agricultural machines and equipment. The maintenance of these machines is paramount in order to get the expected results of increasing the productivity of the Gambian farmer leading to increase in food production. Accurate prediction of repair & maintenance cost trends is critical in determining the optimum economical life of agricultural machines as well as making appropriate decisions for machinery replacements and general farm management purposes [2].

One of the difficulties in analyzing R&M 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. 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 [3].

In order to specify the repair and maintenance factor, a regression analysis explaining the accumulated repair and maintenance costs as a function of accumulated work units is typically performed. Introducing the estimated service life as accumulated work units in the estimated function yields the repair and maintenance factor. Although widely applied, this approach suffers from two limitations. Firstly, only one independent variable is used, which reduces the explanatory power. As an important reason for this, a couple of analyses compare several functional forms, including quadratic form. Secondly, data requirements are substantial, with accumulated repair and maintenance costs as well as accumulated work units being necessary for each machine. To follow the trend of costs for each machine, the accumulated repair and maintenance costs for each service interval, say every 1,000 hours for tractors, is required. Bearing in mind that agricultural machinery can easily be used for 10 years or more, detailed records kept by the farm manager over decades are essential [1].

Limitations: This study will not address every aspect of the repair and maintenance cost analysis problem. It will only investigate the relationship between accumulated repair and maintenance costs (ARM) and accumulated working hours (AWH) of the machine. As such only two variables will be part of the regression equations: machine age in hours and R&M costs expressed as percentage of the initial cost price.

2. Material and Methods

The study was conducted in Yundum agricultural station, The Gambia. Data on twenty active 2WD tractors were collected using structured questionnaires, direct survey and oral interview during the nationwide maintenance activities carried by the Agricultural Engineering Service (AES) .The AES is the service unit of the Department of Agriculture (DOA), responsible for designing and introducing to farmers appropriate and low-cost machinery for crop production and processing. For each tractor, information was sought on, tractor model, age initial purchase price, annual hours of use, annual repairs and maintenance of costs (fuel consumption cost, lubrication cost, oil and filter cost, spare parts costs and workmanship cost). After stratifying samples, the tractors were then classified according to their age (years) into 10 groups (i.e. 1 to 10).

2.1. Characterization of the JD-5403 model

The JD-5403 model selected for this study is 65 hp, 2-wheel drive (2-WD) tractor (figure 1). They are mainly used for yard work on livestock farms, orchards, vineyards and specialist production of some field-scale vegetable and salad crops. One advantage of two-wheel drive is better maneuverability and cheaper purchase price as compare to a 4-WD tractor.

Figure 1: The John Deere JD-5403 model tractor

2.2. Determination of mathematical model to predict R&M costs of the JD-5403 tractor

To determine regression model(s) for predicting R&M costs of these tractors at any point of service life, accumulated working hours for each year were added up to previous usage hours and the sum was considered to be independent variable (X) of the model (s) as shown in equation (1) and reported by [4].

$$X_n = \sum_{i=1}^{n} x_i \tag{1}$$

where X_n is the accumulated working hours for the 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.

The Repair & Maintenance costs as percentage of initial purchase price which was considered to be dependent variable (Y) obtained through dividing the total accumulated R&M costs by initial purchase price of tractor using equation (2) below as reported by [5].

$$Y_n = \sum_{i=1}^{n} y_i \tag{2}$$

Where Y_n is the accumulated repair and maintenance costs based on percent of list price, y is the mean annual repair and maintenance costs each tractor in per class based on percent of list price. In order to determine mathematical model for the studied tractor, regression analysis using SPSS 21 was performed on the data. Five models as shown in equation (3-7) were used to carry out regression analysis, which included the following:

$Y = a + bx$ Linear mode (3)

$Y = a + bx$ Polynomial model (4)

$Y = ae^{bz}$ Exponential model (5)

$Y = a + ln\, bx$ Logarithmic model (6)

$Y = ax^{b}$ Power model (7)

Where Y and x are dependent and independent variables; a, b, c, z: are regression coefficients.

The regression model (s) having the highest coefficient of determination (R^2) was selected as the best model(s) for predicting actual R&M costs trend. In addition, in the most published studies 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 equation (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.

Average fuel consumption and cost

Average annual fuel consumption and fuel cost for the studied tractors were estimated using equation (8-9) and as reported by [6].

$$Q_{avg} = 0.060 \times P_{pto} \tag{8}$$

$$Fc = Q_{avg} \times fuel\, price \tag{9}$$

where:

Q_{avg} is average gasoline consumption (l/h)

P_{pto} is maximum PTO power (kW)

Fc is fuel cost

Lubrication cost

The lubricating cost was calculated using 15% of the fuel cost in line with the approach employed by [7] using equation (10).

$$Lc = 0.15Fc \quad (10)$$

Where,

Lc is the lubricating cost

Fc is the fuel cost

Workmanship cost

The labor costs were determined by multiplying the labor wage rate times by 1.1 or 1.2 as reported by [6] using equation (11).

$$Workmanship\ cost = wage\ rate\ \times 1.1\ or\ 1.2 \quad (11)$$

Other cost parameters such as the cost of spare parts and filters (oil and fuel) were determined from the records presented at the AES

3. Result and Discussions

3.1. Determination of mean annual R&M cost of the studied tractor

Repair and maintenance costs of the JD-5403 tractor were sought from the following: fuel consumption cost, lubrication oil cost, oil and filter replacement cost, spare parts cost and workmanship cost. Figure (2) presents the result of the calculated mean annual repair and maintenance costs of the studied tractor with the cost of each parameter and percentage share of the total using equations (8-11). It was observed that the cost of tractor spare parts replacement had the highest percentage share compared to other cost parameters. The resulted values of spare parts cost for JD-5403 was 52%. The large share of tractor spare parts cost can be due to numerous factors such as making use of substandard tractor spare parts and unsuitable use of tractor by inexperience operators.

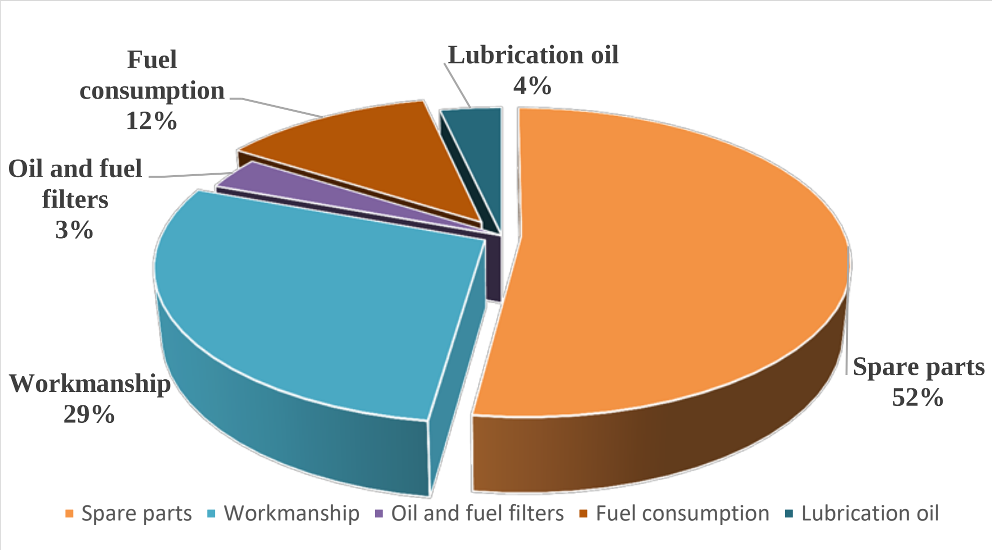

Figure 2: The mean annual R&M costs for JD-5403

The next R&M cost parameter with high cost of the percentage total was the workmanship cost with 29%. While the least cost was obtained from oil and fuel filters parameter valuing 3% for JD-5403. The large share of workmanship cost can be mainly due to high interest rate and subsequent rapid wage increase. The results reported in this study was similar to the one obtained by [4] and [8]. Table (1) presents the results of the calculated accumulated repair and maintenance cost (dependent variable) and accumulated working hours (independent variable), determined for the JD-5403 tractor using Eq (1-2) for their different ages. These results were used as data base for the trend function analysis, regression analysis and development of our mathematical model.

Table 1: Accumulated Working Hours and Accumulated Repair and Maintenance cost percentage for the studied tractor

Age (Years)	JD-5403	
	Accumulated working hours (h)	**Accumulated R&M cost as a Percentage of list purchase price (%)**
1	1020	0.38
2	2150	1.19
3	3380	2.45
4	4318	3.98
5	5461	6.65
6	6506	7.89
7	7381	11.03
8	8406	14.33
9	9318	18.86
10	10284	24.43

3.2. Results of the trend function analysis using Excel

In order to establish the equations for predicting future R&M cost of the studied tractors, a trend function analysis was carried out using Excel 2016. This permits us to create scatterplots and overlay trend line on the chart.

The results of the trend analysis outlining the equations and R^2 value of the five models (linear, logarithmic, polynomial, power and exponential) are presented in figure (3). These results allow us to select the relationship that seems to "fit" (best describe) our data base on the R^2 value. The closer to 1, the better the line fits the data. The R^2 also permits us to select the best model for our predictions. Notice the shape of the graphs. The slope of the curve increases as the number of hours of use increases. This indicates that repair costs are low early in the life of a machine, but increase rapidly as the machine accumulates more hours of operation.

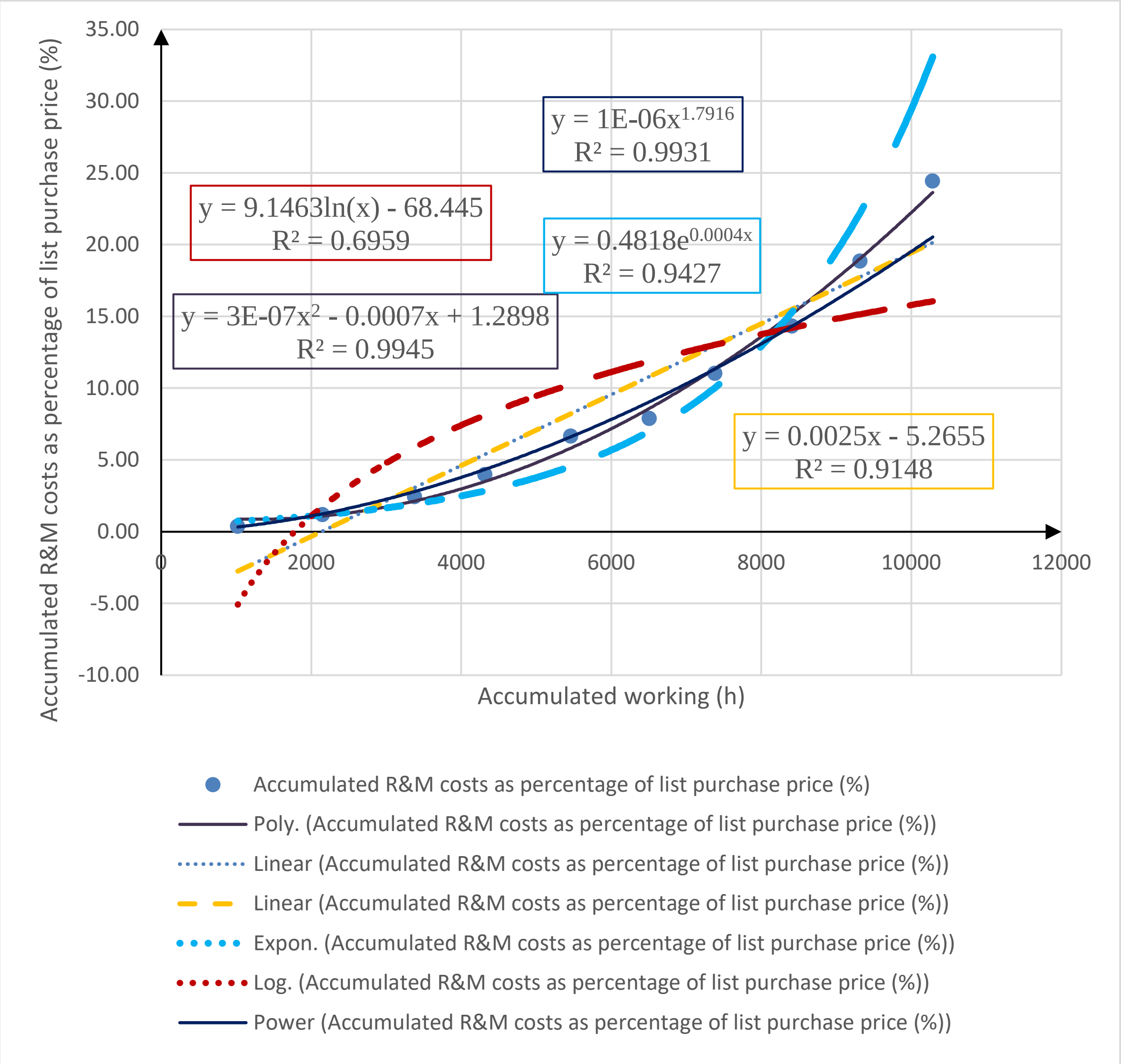

Figure 3: Comparison of accumulated R&M costs as percent of list price based on accumulated working hours of the JD-5503 tractor using Excel

3.3. Results of the regression analysis using SPSS

The relationship between the accumulated repair and maintenance cost and the accumulated working hours on the mathematical models is shown in Table (2). It illustrates the description, coefficient of determination (R^2) and Fisher (F) test results of the analysis obtained for the studied tractors. It was observed that the highest value of coefficient of correlation (R^2) amongst the models were found on polynomial model ($R^2 = 0.9945$), which indicate its higher conformity with the actual data trend in comparison with the other models (linear, polynomial logarithmic and exponential). These findings are in agreement with results obtain by [9] and [10] with R^2 values of (0.996) & (0.998) respectively.

Table 2: Model summary and parameter estimates for JD-5403

Model	**Model summary**		**Parameter estimate**		
	R^2	**F value**	**a**	**B**	**c**
Linear	0.9148	4346.622	-5.2655	0.0025	
Logarithmic	0.6959	45.646	-68.445	9.1463	
Polynomial	0.9945	3980.293	1.2898	-0.0007	3E-07
Power	0.9931	2100.673	1E-06	1.7916	
Exponential	0.9427	71.898	0.4818	0.0004	

3.4. Determination of the final model for prediction of R&M cost for JD-5403 tractor

For prediction of accumulated R&M costs in the present study, the polynomial model as in equation (12) was selected as the final model for tractor JD-5403 for having the highest correlation coefficients and conforming well to actual data trend particularly at later life time of tractor.

$$Y = 0.003\left(\frac{X}{100}\right)^2 - 0.07\left(\frac{X}{100}\right) + 1.2898 \tag{12}$$

3.5. Comparison of Actual data and Modelled data obtained by the predictive Model

Figure (4) illustrate the comparison between the actual and modelled data obtained by the final predictive model (Polynomial) for JD-5403 model tractor.

The figures show that the actual data and modelled data have very little differences in their curve. It can be seen that the rate of accumulated R&M costs for the tractors at earlier life time of them was low and fairly similar. However, trend of R&M costs was rapidly increasing thereafter. Differences in increasing rate of R&M costs may be attributed to the facts like quality in design and manufacturing, inherent deficiencies, and also incompatible field operations to their power and efficiencies.

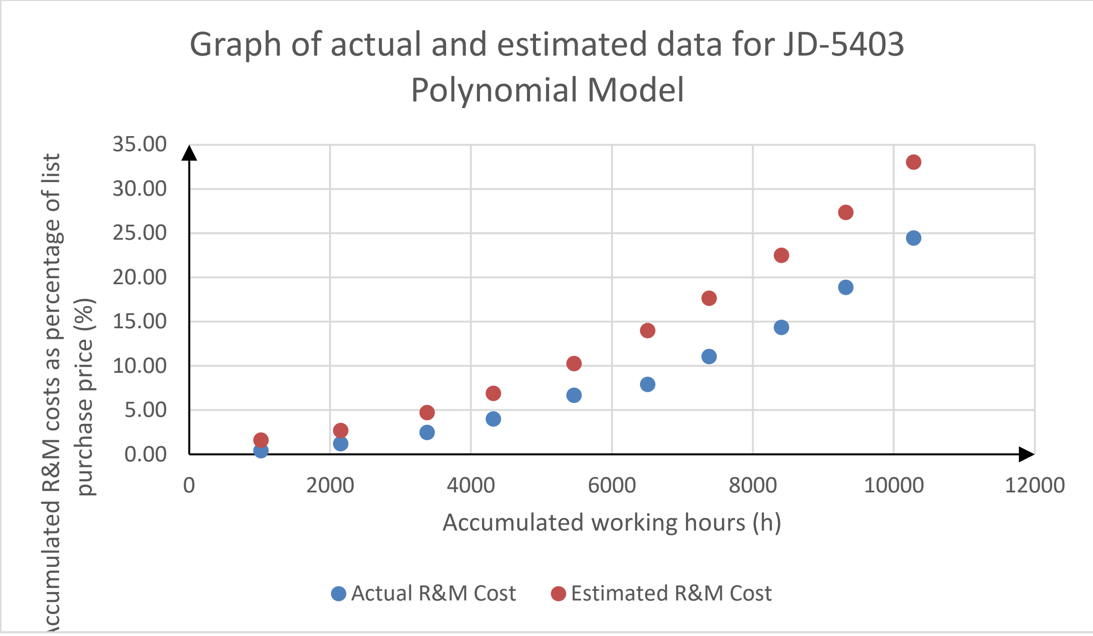

Figure 4: Comparison of Actual Data and Modelled Data using polynomial model

3.6. Percentage error determination

The magnitude of the errors in terms of percentage was determined as the difference between the actual and modelled data as shown in figure (5). It's worthy of note that graphs produced from these developed models, are seen as depicting the more accurate accumulated repair and maintenance cost (ARM) and accumulated working hours (AWH) for the tractor models studied, when compared with that obtained from the data collected. The little difference as noticed among the two is likely to be as a result of errors inherent in the documentation of the data ranging from input error, biased information, etc.

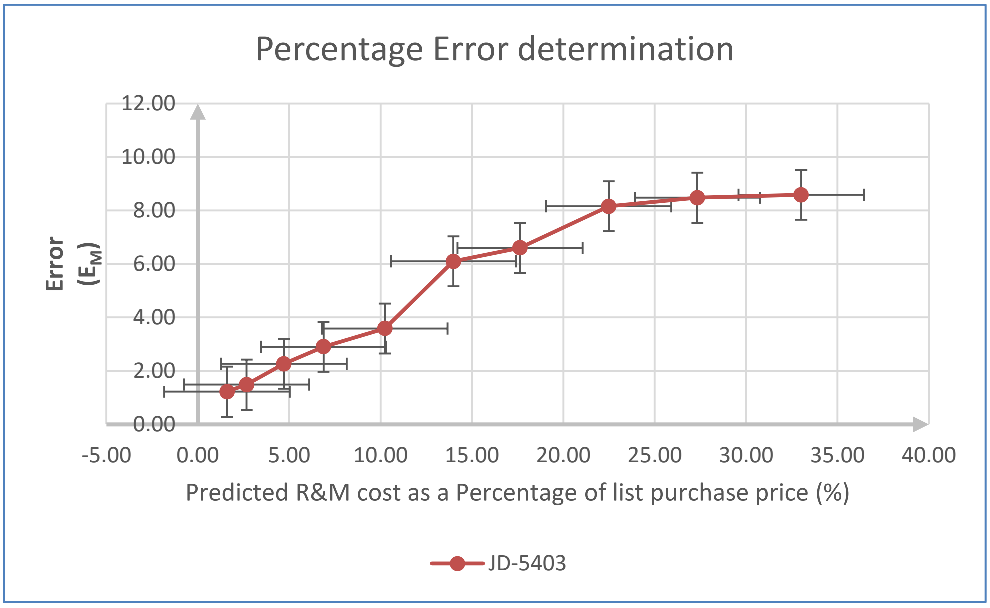

Figure 5: Percentage error determination of the actual and modelled data

3.7. Comparison of models developed by different researchers in predicting R&M costs

The comparison of models developed by different researchers in predicting the accumulated repair and maintenance costs are presented in table (3). It was observed that most of these models developed gave a similar R^2 values when compared with the model developed in the present study. And in terms of the model developed, it was observed that the model developed in this study has similar structure and characteristics as the model obtained by [9].

Table 3: Models developed by different researchers and for present study

Models developed by different researchers	R2	Source
$Y = 1.2\left(\frac{X}{1000}\right)^2$	0.890	ASAE (1983)
$Y = 0.042\left(\frac{X}{100}\right)^{1.796}$	0.986	R. Majid (2010)
$Y = 0.002\,(\frac{X}{100})^2 - 0.109\left(\frac{X}{100}\right) + 2.877$	0.996	
$Y = 0.072\left(\frac{X}{120}\right)^{1.6}$	0.920	Bowers and Hunt (1970)
$Y = 0.005X^{1.2}$	0.977	Abubakar and his colleagues (2013) [11]
$Y = 0.003\,\left(\frac{X}{100}\right)^2 - 0.07\left(\frac{X}{100}\right) + 1.2898$	0.995	For the present work (JD-5403 Tractor)

3.8. Discussion

The R&M costs prediction models and agricultural machinery repair coefficients values are generally dependent on factors such as research method performance and time spans, number and type of samples under study, type of operation and working conditions, repair and maintenance management, quality of materials used, weather conditions and skill of operator. Results of this study indicated that average R&M costs per hour increased with machine age. This resulted in a marginally increased total repair cost curve.

These results also confirmed that the model developed for the studied tractors (JD-5403) has the tractor accumulated operating hours as the major determining factor of the repair and maintenance costs. In summary, the results of this finding will be very useful in farm machinery management with regards to prediction of R&M costs of agricultural tractors in The Gambia. It would provide 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.

4. Conclusions

The following conclusions were drawn from this study:

It was established that repair and maintenance cost increased with an increase in working hours of JD-5403 tractor.

The model developed has the tractor accumulated operating hours as the major determining factor of the repair and maintenance costs.

Repair and maintenance cost of the JD-5403 tractor as a percentage of initial purchase price (%) in The Gambia can be accurately predicted using the following mathematical model:

$$Y = 0.003\left(\frac{X}{100}\right)^2 - 0.07\left(\frac{X}{100}\right) + 1.2898$$

5. Recommendations

It is recommended to carry out a comparative study of the John Deere tractor and other models of tractors (Massey Ferguson, New Holland, Mahindra) present in The Gambia in order to develop a standard cost model to predict the repair & maintenance cost.

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