ABSTRACT

Repair and maintenance cost is considered as one of important items for machinery management and selection especially agricultural tractors. The present study was carried out in Dongola area for tractor repair and maintenance costs estimation. The data was collected from records of Elshimalya Company for Agricultural services. Forty-four tractors representing two powers sizes, 75hp and 150hp used in the area were selected for this study. Based on the data collected, regression correlation analysis was carried out and mathematical models were derived to predict the accumulated repair and maintenance (R and M) costs as percent of purchase price in relation to accumulated hours of use and age (years) for each tractor size, and for the two sizes collectively. Five model forms (linear, logarithmic, polynomial, power and exponential) were derived and the power function was found the best fit to explain the relation. The accumulated Rand M costs as percent of purchase price (Y) was increased as the accumulated hours of use (x) and age (g) of the tractor in years were increased. A high correlation was found between the accumulated R and M cost and both accumulated hours of use and tractor age in years (Average $R^2 = 0.93$).
It was concluded that the power function was the best fit for repair and maintenance cost estimations and this relation may be used as an average of the two tractor powers, for estimation of the accumulated R and M costs as percent of purchase price (Y) with accumulated hours of use (x) and age (g): \[ Y=0.028x^{0.662} \text{ (mean)} \quad Y=12.294g^{1.276} \text{ (mean)}. \]

Keywords: Repair and maintenance; mathematical model; hours of use; power; Dongola.

1. INTRODUCTION

Agricultural tractor is one of the most important energy and power sources in agricultural mechanization [1]. It requires high initial capital investment. The introduction of modern technology during the last century resulted in rapid growth of farm production. Tractors and farm machinery are important samples of this modern technology [2]. 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 [3].

Costs of owning and operating farm machinery represent 35% to 50% of the costs of agricultural production when the land is excluded [4]. 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 [5]. 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 [6]. Agricultural engineers have carried out 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 [7,8,9]and [10]. Using of American and European mathematical relations to estimate R and M costs in under developed and developing countries produced unrealistic and misleading results and therefore, these countries developed their own mathematical models e.g., [11,12] and [13]. Poor and irregular maintenance reduce tractor reliability, increases fuel consumption, deuces engine power and life and increases exhaust emission [14]. In Sudan, agricultural tractors introduced in early 1990 and there are many tractor makes, models and sizes now distributed between irrigated and rain-fed agricultural farms. These tractors are owned by people from both the private and public sectors and even some are owned by individual farmers and they often work for more than 1200 hours per year [15]. Tractors have been used in Sudan, as a power source in agriculture for many years. The total number of tractors officially imported into the country between 1984 and 1994 increased from 23590 units to 32096 units [15]. In Sudan, machinery repair, maintenance, and fuel and lubricants consumption is not given enough attention. About 30- 40% of farm machinery could be out of work very quickly due to lack of proper maintenance and unavailability of genuine spare parts or using of spurious or second-hand spare parts of low prices. There are some prediction models for tractors repair and maintenance costs in the Sudan were developed [16,17] and [18]. They decided that the correlation between repair and maintenance costs as a percent of tractor initial purchase price and the tractor accumulated hours of use would be best described by a power function equation. There were variations between these models in the predictions for the different tractors. They were varied in structural components due to differences in tractors specifications and conditions and locations of work, therefore, the present study was carried to develop computer models for repair and maintenance costs estimation in relation to hours of use and age for two sizes of diesel engine agricultural tractors in Dongola area, northern of Sudan.

2. MATERIALS AND METHODS

The data of the study was collected from Dongola area-northern Sudan. The soil is sandy and clay particles, characterized by very low perm ability, deep cracking when dry, poor in nitrogen and organic matter. The climate of the area is classified as dry desert zone. There are many makes and sizes of tractors working in the area, but one of the most common make available is Massey Ferguson, and are chosen to carry out this study. Their sizes are mostly in the range of 75–150hp. The total number selected for this study was (44), from which twenty-two were
Table 1. Specifications of tractors used

| Item                  | Tractor (A)         | Tractor (B)          |
|-----------------------|---------------------|----------------------|
| Country of make       | UK                  | Brazil               |
| Engine rated power    | 75 hp               | 150 hp               |
| Engine speed rpm      | 2200                | 3600                |
| Drawbar power         | 63.2 hp             | 127.5 hp             |
| Engine type           | 4-cyl. Diesel       | 4-cyl. Diesel       |
| PTO (rpm)             | 540/1000            | 540/1000             |
| Fuel tank capacity    | 33.6 gal.           | 61 gal.             |
| Base weight           | 3265 kg             | 5670 kg             |
| Clutch                | Hydr. Wet multi-disc| Hydr. Wet multi-disc|
| Brakes                | independent hydraulic wet disc | independent hydraulic wet disc |
| Chassis               | 2WD                 | 4WD                 |
| Steering              | Electro-hydraulic,  | Electro-hydraulic,  |

(75hp), and the other twenty-two were (150hp). The tractor's technical specifications are shown in Table (1). Many sources were used to collect data concerning tractors repair and maintenance costs they included Elshamalia Company of Agricultural services, Mechanics, Engineers, Agricultural Engineers, individuals and operators.

A questionnaire was prepared to collect the required data then a survey was carried out in the area of the study to interview the targeted sources of data. The questionnaire included information about; tractor age, model and make, initial purchase price ($), annual hours of use (hr), annual area covered (fed), annual repairs costs ($), annual maintenance costs ($), annual number of repairs and labor cost per year ($).

2.1 Tractor Systems Failures and Repair and Maintenance Distribution Calculation

The total costs of repair and maintenance for the different tractor systems and types were carried out by summation of failures during the period of study and calculating the costs of repairing and maintenance for the systems and the two types of tractors.

2.2 Annual Hours of Use Calculation

The total accumulated hours of use was calculated by summation of the total mean annual hours of use which was calculated on the basis of effective working hours of the tractor up to the last year of the age for each of the selected tractor size [10].

2.3 Accumulated Repair and Maintenance Costs Computation

The annual repair and maintenance costs were calculated by adding the annual repair and maintenance costs together. The annual repair and maintenance costs were expressed as percentage of the initial purchase price of the tractor. The total accumulated repair and maintenance costs as a percentage of initial purchase prices were calculated by summation of mean annual repair and maintenance costs as a percentage of initial purchase prices for all years in the age of the selected tractors [10].

Using the SPSS computer program, the relationship between the accumulated annual repair and maintenance costs as a percentage of initial purchase price and accumulated annual hours of use was computed.

3. RESULTS AND DISCUSSION

3.1 Tractor Systems Failures and Repair and Maintenance Distribution

It was observed that the average repair and maintenance costs of different systems for the two tractor powers generally increased with size, but the rate of increase varies for the two tractor types. However, the mean R&M cost of the two tractor types generally showed relative increase with age except for the fuel system (Table 2). The engine and fuel systems accounted for more than 50% of the total accumulated R & M costs of the two tractor sizes when five years ownership was considered (Figs.1a and 1b).
distribution of the accumulated R & M cost of different tractor systems was almost similar for the two types, but the transmission system R & M cost was the highest for both types of tractors (Figs. 2a, 2b and 2c).

3.2 Development of Repair and Maintenance Costs Prediction Models

Regression analysis of the data was carried out to present the relation between the mean accumulated R&M cost as percent of purchase price and the mean accumulated hours of use of the two tractor types, on the models of linear, polynomial, logarithmic, power and exponential with correlation coefficient (Table 3). The lowest value of correlation coefficient among the presented models was related to exponential model with $R^2 = 0.62$ and the highest value of correlation was for power model with $R^2 = 0.93$ which is very close to the previous studies [12]. Therefore, in the present study, power model was suggested as suitable form for repair and maintenance cost estimation. The power relations of accumulated R and M costs with accumulated hours of use and tractor age in years of study for the two tractor types and the average of the two types are given in Table 4 and Table 5 respectively. The average correlation coefficient was very high ($R^2 = 0.93, 0.95$) indicating that the tractor accumulated hours of use and age could adequately explain variations in R&M costs.

Fig. 3a and 3b show low predicted accumulated R & M costs of the early-stage tractor life, and then costs increased gradually with increasing age and accumulated hours of use in 75hp and 150 hp tractor types. The rate of increase in the accumulated repair and maintenance cost of the two tractor types varied with accumulated hours of use and age.

Table 2. Repair and Maintenance costs distribution for different tractor systems

| Age | Engine | Transmission | Hydraulic | Fuel | Other |
|-----|--------|--------------|-----------|------|-------|
| **(A) 75 hp tractor** | | | | | |
| 1   | 39820  | 45465        | 34275     | 59706 | 17055 |
| 2   | 5465   | 64270        | 45710     | 46320 | 14983 |
| 3   | 78908  | 94745        | 53925     | 34270 | 18340 |
| 4   | 81825  | 100677       | 53890     | 25098 | 25636 |
| 5   | 75361  | 86410        | 48060     | 13755 | 17590 |
| Mean| 56275.8| 78313.4      | 47172     | 35829.8| 18720.8|
| **(B) 150 hp tractor** | | | | | |
| 1   | 66353  | 83532        | 49778     | 114960| 19120 |
| 2   | 109415 | 139647       | 83185     | 834564| 38220 |
| 3   | 138072 | 165570       | 102735    | 111855| 44140 |
| 4   | 165140 | 218955       | 120365    | 81675 | 34845 |
| 5   | 204415 | 250514       | 154290    | 75000 | 57175 |
| Mean| 136679 | 171471.6     | 102070.6  | 243610.8| 38700 |

Fig. 1. Distributions of accumulated repair and maintenance of agricultural tractor systems as percentage (a) 75hp tractor type (b) 150hp tractor type
Table 3. Regression analysis of the relation between the mean accumulated R&M cost as percent of purchase price and mean accumulated hours of use

| Model          | Equation                 | R square |
|----------------|--------------------------|----------|
| Linear         | $Y= 0.0003x+22.181$      | 0.73     |
| Logarithmic    | $Y=23.598\ln (x)- 209.025$ | 0.86     |
| Polynomial     | $Y=E^{-0.91.568x^2+0.001x+7.04}$ | 0.86     |
| Exponential    | $Y=20.017e^{0.461x-0.93x}$ | 0.62     |
| Power          | $Y=0.028x^{0.662}$       | 0.93     |

Table 4. The power relation of accumulated R&M cost with accumulated hours of use of the two tractors

| Tractor type  | Power model | R square | F     |
|---------------|-------------|----------|-------|
| Tractor 75Hp  | $Y= 0.011x^{0.763}$ | 0.99     | 501.813 |
| Tractor 150Hp | $Y= 0.019x^{0.677}$ | 0.99     | 466.297** |
| Mean          | $Y=0.028x^{0.662}$ | 0.93     | 101.534** |

Table 5. The power relation of accumulated R and M cost with accumulated age (years) of the two tractors

| Tractor type  | Power model | R square | F     |
|---------------|-------------|----------|-------|
| Tractor 75Hp  | $Y= 14.14g^{1.412}$ | 0.99     | 465.008 |
| Tractor 150Hp | $Y= 10.689g^{1.412}$ | 0.94     | 50.601** |
| Mean          | $Y=12.294g^{0.662}$ | 0.95     | 158.781** |

*significant difference at $P<0.01$
Fig 3a. Accumulated repair and maintenance costs as percent of purchase price as affected by hours of use and age (year) for the 75 Hp tractor

Fig 3b. Accumulated repair and maintenance costs as percent of purchase price as affected by hours of use and age (year) for the 150 Hp tractor

Fig. 4. Comparison of the present study prediction model with other models in Sudan
3.3 Comparison of the Present Predictions Model with Other Models Developed in Sudan

The predicted model in this study was compared to other models from Sudan as shown in Fig. 4. It can be observed that the present model accounted for lower values than [16] model for accumulated repair and maintenance costs, after 1000 accumulated hours of use and forward. This may be attributed to variations in tractors specifications, ages and makes, however when the prediction model of this study was also compared to [20] and [21], the estimates of the present model accounted for larger values until about 3000 accumulated hours of use, after which this model accounted for lower values. This may be attributed to variations in tractors specifications and makes, condition of work and skills of mechanics, operators and labor used. Generally, the present models’ predictions of accumulated repair and maintenance costs were lower than other compared models.

3.4 Comparison of the Present Study Prediction Models with Other Models in the World

The model of the average accumulated repair and maintenance costs predicted in this study was compared to other similar models from USA [10], UK [22] and Iran [12] as shown in Fig. 5. It was clear that the present derived average model accounted for relatively lower values of accumulated repair and maintenance costs compared to the world mentioned models. These variations may be attributed to the differences in spare parts prices between Sudan and the industrial countries, or may be due to variations in soil type, climate, preventive maintenance program applied and field operation conditions. This lower value of repair and maintenance costs may be also due to the procurement and usage of spurious and second-hand spare parts, variations in tractors technical specifications and lower labor charges for repairing and maintaining tractors in Sudan compared to the industrial world countries.

4. CONCLUSIONS

The following conclusion may be drawn from the present study:

1- The relationship between accumulated repair and maintenance costs as percentage of the initial purchase price of the tractor and accumulated hours of use and age in years for the two tractors in studied area could better be described by the power function equation.

2- The accumulated repair and maintenance costs were increased with tractor age and hours of use. The prediction models for repair and maintenance costs of tractors in Sudan were found lower than those of other countries; therefore, each area or country develops its own models of R&M costs to its operational and field conditions.
DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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