# Studies of tractor maintenance and replacement strategies of Wonji Shoa Factory, Ethiopia

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## Abstract

This study mainly focuses on tractor maintenance and replacement strategies to assess the impact of various parameters on the economic life of tractors in order to improve the value of a profitable management choice on selected tractor samples. Considering the preventive replacement policy, the total annual costs were estimated taking into account the repair and depreciation costs. At a 95% level of confidence for each approach, the statistical analysis program "IBM SPSS Statistics 26" was used. An empirical relation based on multiple regression analysis has been generated to predict the economic operational life of a tractor using per-unit repair cost and annual usage (hours). From the analysis, John Dear 333, SAME 130, New Holland 80, and Massy Ferguson 150 are not supposed to be used economically in the field after the fifth, seventh, sixth, and eighth years respectively at Wonji Shoa Sugar Factory due to increasing maintenance cost in present condition.

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## Introduction

### Machinery maintenance strategies

The term "maintenance" refers to all planned and unplanned actions taken to maintain constant accessibility of operational equipment in the firms. "Technical skills, procedures, and methods to properly utilize the assets like factories, power plants, vehicles, equipment, and machines" are needed for proper maintenance. Maintenance is a crucial component of effective production. The significant contribution of maintenance expenses to the total expenditure of the manufacturing plant serves as a primary indicator of the need for an effective maintenance policy. A maintenance strategy is a predetermined approach to maintain equipment that includes steps like "identifying, researching, and implementing various repairs, replace, and inspect decisions." Executable tactical plans are required for strategy implementation (Velmurugan and Dhingra, 2015). A maintenance strategy comprises a set of policies and procedures that are utilized to "retain" or "restore" equipment as well as the decision support system in which maintenance operations are scheduled." A maintenance strategy is described as "an integrated system that is needed by corporate management to highlight the significance of a certain piece of equipment that affects particular sorts of maintenance work" in another description (Shafiee and Sorensen, 2019, Abd Rani *et al,* 2015). The corporate strategy will determine the best maintenance method to use.

Numerous authors have categorized maintenance strategies in various ways (Figure 1). Three generations of maintenance are identified during the relevant period, which presents the development of maintenance. First, was maintenance, during which time all efforts were focused on fixing, primarily up until the Second World War. Second, up until the 1970s, preventative maintenance was created as chores based on planning and scheduling. Both generations are related to the equipment life cycle dependent on the "bathtub" failure profile that describes the frequency of breakdowns. The third generation, or "the reliability-centered maintenance culture", refers to present-day operations that encompass forecasting and preventing problems as well as eradicating their harmful effects (Mikler, 2011). Since both preventative maintenance and condition-based policies work to stop problems before they happen, they are similar. Prognostic, predictive maintenance, health management, and on-condition maintenance are all phrases that are frequently used in conjunction with CBM. The observation of the state of the system and all of its components, as well as the evaluation of the items' conditions and the projection of damage risk using the information acquired, are crucial in this method (Kolhe and Datta, 2007).

## Machinery replacement strategies

One of the most crucial strategic decisions that manufacturing and service companies must make is whether to replace productive equipment. This is due to the fact that purchasing new equipment can be expensive and might have long-term effects on the company's productivity and competitiveness. The physical deterioration of the current equipment is highlighted in the conventional approach to the problem of equipment replacement. The primary concept is to replace the equipment when its operating and maintenance costs reach a level that, in terms of net anticipated present value, justifies a replacement (Nair and Hopp, 1992). There are at least five replacement strategies that businesses might use for their agricultural equipment. The optimum course of action from a profitability standpoint is to replace equipment when the yearly cost of the equipment in a given year starts to surpass the equipment cost from replacement (Perrin, 1972).

Businesses maximize long-term revenues by reducing equipment costs. However, from a cash flow standpoint, this approach might not be the best, since certain equipment might need to be replaced in years of low profitability, which would cause farmers to have cash flow issues. Edwards (2019) stated the four other approaches to replace things frequently, annually, when money is available, or keep the equipment forever.

Changing out machinery every few years or less is a tactic for reducing malfunctions, repairs, and maintenance. If repairs were required, they would probably be free for the farmer because they were covered by the warranty. The second strategy is to replace the item each year in order to keep spending roughly constant. With this approach, farmers can avoid needing to make significant financial investments every year. The drawback of this approach is that machinery may be replaced before it reaches the point of cost reduction, which could result in less-than-ideal long-term profitability. The third strategy is to replace when cash is available. This strategy has the benefit of flattening cash flow since farm equipment is purchased when there is more money available, and not purchased when there is less money available. This strategy may level out cash flow from year to year, but it won't be as profitable in the long run because certain equipment may need to be replaced before or beyond the ideal time (*i.e.*, when the cost per year is lowest).

Keeping machinery forever is the final and worst option. In other words, farmers would use the equipment until it broke down and couldn't be fixed. This strategy may optimize cash flow, but if machinery is kept past the point at which it should be replaced, long-term profitability is likely to be inferior. Wonji Shoa Sugar Factory (WSSF) uses this strategy.

Farm power in Ethiopia generally relies on animal traction and human power, especially among small-scale farmers who provide around 80% of the country's agricultural output. A farmer can likely prepare 0.5 hectares for planting each season using just hand equipment. Farmers cannot rely solely on hand-tool technology to support their livelihoods in agriculture because people are a rather inefficient source of power, producing just approximately 0.01 horsepower of continuous production (FAO, 2010). Tractors are the most significant and useful piece of agricultural technology employed by farmers looking to mechanize some or all of their farm operations. Tractors help couple various motorized and non-motorized equipment for the effective and timely field preparation needed for obtaining high yields and reducing postharvest losses. Tractors are also an important means of carrying heavy agricultural inputs and produce to and from farms. In 2010, there were reportedly 5,090 tractors in use in Ethiopia, a significant increase from the about 3,000 tractors there in 2004. When "walking" or pedestrian tractors are taken into account, the 2010 figure rises to roughly 6,000. This constant rise in the number of tractors is primarily due to the increasing number of foreign private investors, mostly from China, India, and Saudi Arabia, who are involved in large-scale commercial agriculture in Ethiopia (Mbata, 2012). Tractors

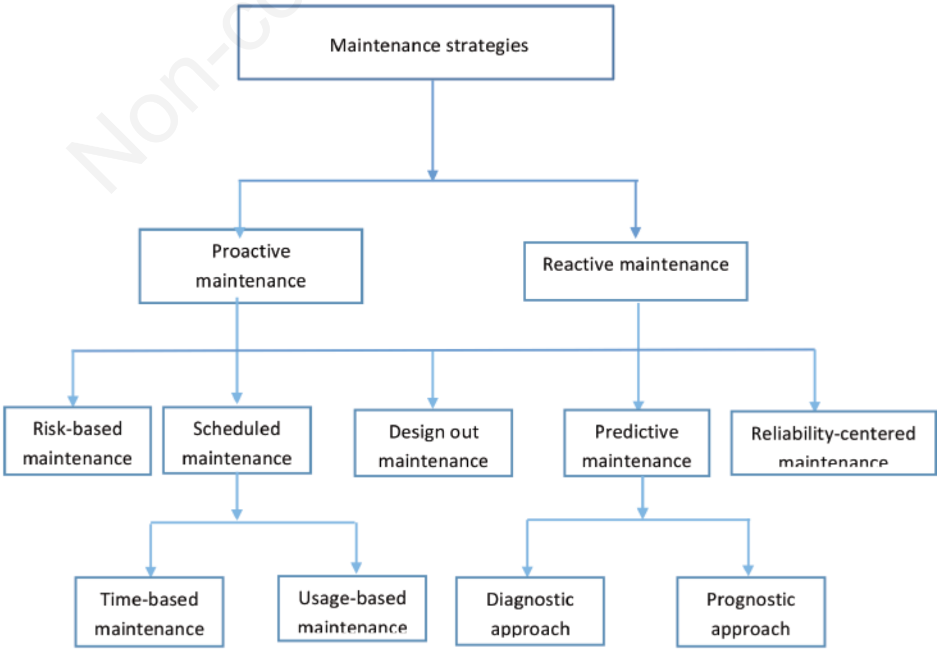

**Figure 1.** Classifications of maintenance strategies.

in Ethiopia have a relatively short economic life span compared to what is technically feasible. This is a result of the lack of maintenance facilities and replacement parts and the inadequate or nonexistent after-sale regular services provided by dealers. Some dealers don't have service facilities outside of Addis Ababa, the country's capital and the tractors received little to no after-sales care or regular maintenance. Since the majority of those purchasing tractors are first-time buyers with little to no experience in the usage and maintenance of the equipment, this is a significant problem for the tractor industry. Nowadays, for example, it is common to observe a pile of machinery scraps in the compounds of sugar industries in Ethiopia (Figure 2). These piles of scraps indicate a clear lack of farm machinery replacement strategies in the sugar industries of Ethiopia. With use and time, agricultural equipment mechanically degrades and loses functionality. There is a need to replace them because managing such equipment comes at a greater operating and maintenance expense. One of the crucial components of managing farm machinery is making decisions about replacing old, similar agricultural equipment with new ones. The replacement criteria, which determines the best time for a tractor or its components to operate, is based on economic considerations rather than just physical ones. Normally, a tractor is used until it is worn out or is unable to execute its duty adequately before being replaced. Replacement on failure and preventive replacement are the two primary replacement techniques in general (Eilon, 1966). The minimization of anticipated operational costs per time unit and the maximum operational profit per time unit can both be used to optimize the tractor's utilization period (Dohi *et al*., 2006).

### Types of costs

Costs are divided into two categories, fixed costs, and operational costs. While fixed expenses are unaffected by use, running costs always rise proportionately as operational use increases over time. Similar to how the price of fuel, lubrication, daily services, and labor wages are related to the use of machinery, the cost of interest on a machine investment, taxes, housing costs, and insurance are all time-dependent. Only two cost items – the cost of depreciation and the cost of repairs and maintenance – appear to be affected by usage and time. Instead of taking into account all the costs, these two costs are highlighted in this study.

Numerous studies are being conducted from various perspectives to determine the best time to replace or use tractors. From the perspective of cost reduction (Ajibade *et al*., 2014; Amiens *et al*., 2015; Kolhe and Jadhev, 2011) researched equipment replacement; from the perspective of profit maximization (Offiong *et al*., 2013) evaluated vehicle replacement time. The two scenarios are nevertheless comparable to two sides of a coin because, while the profit maximization model illustrates how cost minimization strengthens profit maximization, the cost minimization perspective of equipment replacement explains how the optimal replacement time is critical to the cost minimization of a firm. According to the reviews, it is evident that a variety of factors affect a tractor's life expectancy, but reducing operating costs per hour is one of the most important for getting the most out of any size tractor. And ultimately, that will result in the owner's profit being maximized.

Here are a few restrictions that the researchers have put in place to evaluate the farm machinery maintenance and replacement strategies: i) when something is done incorrectly but the elements that led to it are not immediately apparent; this calls for investigating the root causes; ii) when it is necessary to determine whether the current situation is adequate or needs to be improve; iii) when a researcher aims to comprehend the details of tractor maintenance and replacement methods to derive broad conclusions regarding the effectiveness of farm machinery management systems. The performance assessment of the current tractor maintenance and replacement system is crucial in determining whether or not more system improvement is needed in light of the current performance. The characteristics of performance indicators should be based on a core model of that component of the maintenance and replacement systems that have been experimentally measured and statistically tested from a scientific perspective. Therefore, the objective of this study was to evaluate the current tractor maintenance and replacement practices of WSSF and develop alternatives for improvements to the tractor maintenance and replacement strategies of the company.

## Materials and Methods

### Description of the study area

WSSF is situated 110 kilometers from Ethiopia's capital city of Addis Ababa in the Southeast Shoa Zone of Oromia Regional State. It is located between 8° 21′ and 8° 29′ N and 39° 12′ and 39° 18′ E, at an altitude of 1223 to 1550 m above mean sea level (Figure 3) The average annual rainfall in the area is 831 millimeters, and the average annual maximum and minimum temperatures are 27 and 15°C,

**Figure 2.** Scraps of tractors observed in Wonji Shoa Sugar Factory's compound.

respectively. The Factory was built in 1951 at Wonji by the Ethiopian government, private investors, and the Dutch Hender Verneering Amsterdam Company. The factory's initial output was 140 tons annually when it began operations in 1954 (Bati Fedi *et al.*, 2022). Up until recently, the two facilities known as the Wonji and Shoa sugar factories had a combined ability to produce 75,000 tons of sugar annually (prior to the completion of the new WSSF at the Dodota site). Currently, there are 12,000 hectares of irrigated land under the WSSE sugarcane plantation, of which 12,000 ha are maintained by out-growers and 5,000 ha by the Estate itself.

## Experimental details

The details for this research embrace experimental and observational types of research to get the necessary data for the evaluation of the existing tractor maintenance and replacement strategies of WSSF. The study was carried out at the WSSF, Ethiopia. The factory's records of the tractors utilized for many years served as the source of the study's data. Additionally, only four tractor brands with a suitable amount of data were included in the data set: John Deer, Massey Ferguson, SAME, and New Holland. Because it was difficult to obtain data on purchase pricing and repair and maintenance costs, tractors bought before 2006 were omitted. Tractors under the age of five were also not considered since there was not enough information that would have helped to produce reliable and accurate results. Year of purchase, number of tractors of specific make, and capacity (hp) of tractors were collected for the specified duration as indicated in Table 1.

The status of the wheel tractor found at WSSF is shown below in Table 2. From this data, it is observed that only 58% of the tractors are in good condition for undertaking field activities. The experimental parameters identified for deciding the replacement age of various make tractors at WSSF are: i) dependent variable categorized as replacement age; ii) independent variables like annual usage (hrs), repair and maintenance, depreciation, *etc*.

## Determination of tractor costs

The two primary categories of machinery costs are fixed costs and operational costs. While fixed expenses are unaffected by use, operational costs always rise proportionately as use increases over time. Similar to how the price of fuel, lubrication, daily services, and labor wages are related to the use of machinery, the cost of interest on a machine investment, taxes, housing costs, and insur-

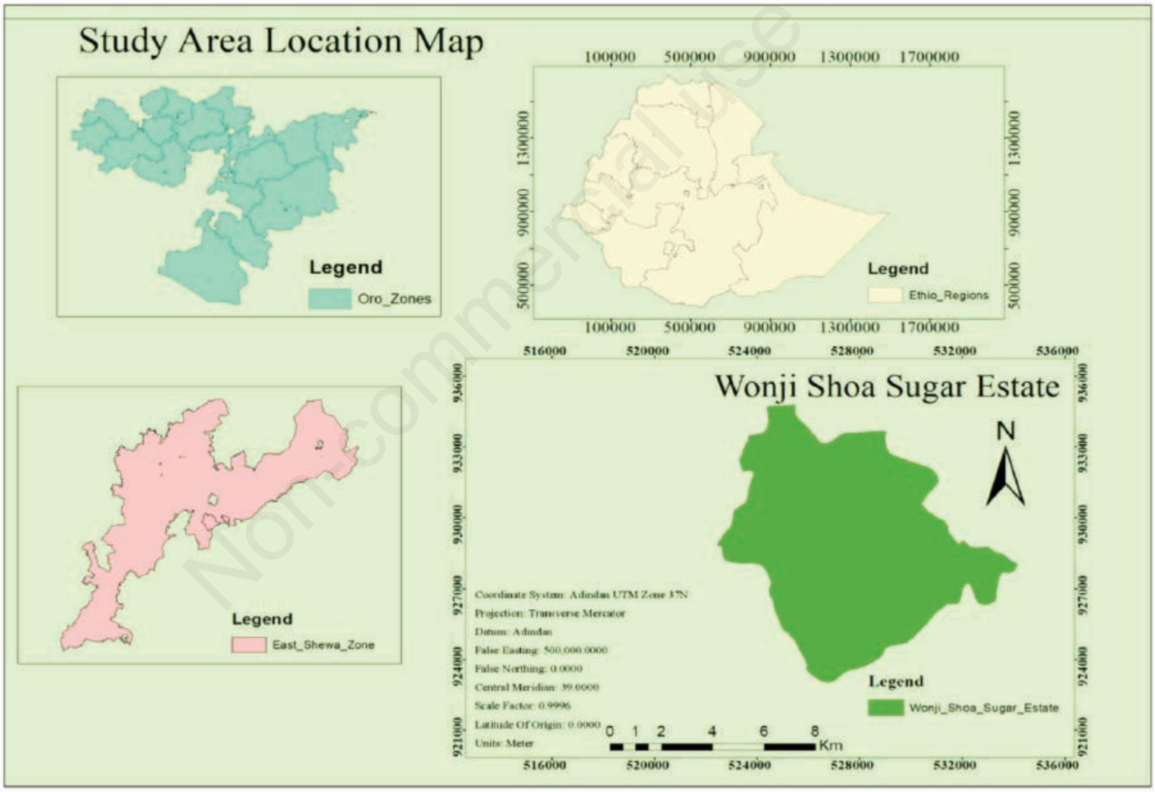

**Figure 3.** Map of the study area (Wonji Shoa Sugar Estate).

**Table 1.** The present randomly selected available tractors purchased after 2006 in Wonji Shoa Sugar Factory.

| Category | Make (HP) | Duration of data collection (years) | N. of tractors observed |
|---|---|---|---|
| A | John Deer (330) | 2011-2020 | 5 |
| B | SAME (130) | 2011-2020 | 8 |
| C | New Holland (80) | 2012-2021 | 12 |
| D | Massey Fergusson (150) | 2006-2015 | 4 |

ance are all time-dependent. Only two cost items – the cost of depreciation and the cost of repairs and maintenance – appear to be affected by usage and time. Instead of taking into account all the costs, these two costs are mainly focused on in this research (Pagare, 2019).

## Determination of depreciation

Depreciation is the phrase used to describe the decrease in a machine's commercial worth over the course of its useful life, and it is frequently used to refer to the cost of agricultural equipment (Calcante *et al*., 2013). The normal deterioration of its irreparable parts, its obsolescence owing to advancements that replace it, or the change in agricultural production that renders it insufficient are the three main causes of the machinery's declining worth over time (Robb *et al*., 1988). There are a number of techniques that can be used to forecast machinery depreciation, such as the sinking-fund method and decreasing balance (Kolhe, 2015). Depreciation was calculated using a linear method shown in Equation 1 (Cunha *et al*., 2019).

$$D = \frac{Vi - Vf}{L} \quad (1)$$

where:
D = the value of the depreciation per year;
Vi = is the purchase price;
Vf = refers to the value of the machine at the end of service life (L, years) or remaining value.

The remaining value of machinery is in most cases not available; a study has been conducted on the basis of equations to depend Vf on machinery list price. Using a constant rate of market value depreciation, it is frequently assumed that a machine's remaining value (Vf) is determined by its age rather than its rate of use. For this study, the following equation was used which is proposed by the ASAE D497 (ASAE, 2000),

$$Vf = Vi * D1 * D2^{Agen} \quad (2)$$

if Age is <1, $Vf = Vi*0.85$

where *Vf* is the machine's remaining value expressed in function of the purchase value (Vi) and D1 and D2 are depreciation factors (decimals with no unit).

## Determination of repair and maintenance costs

Any machine's expected yearly repair costs are quite speculative. It represents the total cost of the parts, fuel, oil, and labor. This cost is taken into account in two different situations when reconditioning worn-out parts and replacing defective parts entirely. In this instance, the annual repair and maintenance expenses were gathered from the sources for each tractor and amassed for a period of ten years. Several factors, including machine characteristics, purchase price, climate, soil, and maintenance strategy, affect typical of repairs and maintenance (Calcante, 2013).

## Economic life of tractors

The main decision is typically whether to replace an old machine with a new one or keep it in place for at least another year. To make this choice, it is first required to ascertain the ideal replacement time in the context of cost minimization. The (anticipated) long-term unit of time is a more inclusive optimization criterion that has been taken into account here. The price involved in replacing a machine is known as the holding cost or total cost of the machine, which is made up of the depreciation (fixed cost) and

**Table 2.** The current status of tractors available at Wonji Shoa Sugar Factory.

| Sr. no | Make/model | Purchase year | Age (years) | Subtotal | Status | |
|---|---|---|---|---|---|---|
| | | | | | Active | Obsolete/waiting for spare parts |
| 1 | MF/178 | 1970/71 | 52 | 2 | 0 | 2 |
| 2 | STYRE/8100A | 1981 | 42 | 4 | 2 | 2 |
| 3 | MF/3982 | 1993/94 | 30 | 3 | 0 | 3 |
| 4 | MF/4260 | 2002/03 | 21 | 2 | 0 | 2 |
| 5 | NH/80-66S | 2003/04 | 20 | 7 | 0 | 7 |
| 6 | MF/5365 | 2003/04 | 20 | 3 | 0 | 3 |
| 7 | MF/660 | 2006/07 | 17 | 2 | 0 | 2 |
| 8 | MF/465 | 2006/07 | 17 | 2 | 0 | 2 |
| 9 | MF/440 | 2006/07 | 17 | 12 | 0 | 12 |
| 10 | BELARUS/920 | 2008/09 | 15 | 1 | 0 | 1 |
| 11 | JD/375 | 2011/12 | 12 | 3 | 0 | 3 |
| 12 | NH/TD80 | 2012/13 | 11 | 13 | 13 | 0 |
| 13 | SAME 130 | 2011/12 | 12 | 12 | 8 | 4 |
| 14 | MF/5475 | 2013/04 | 10 | 5 | 0 | 5 |
| 15 | BELL/1716AF | 2013/14 | 10 | 4 | 4 | 0 |
| 16 | KAT/1804 | 2014/15 | 9 | 9 | 9 | 0 |
| 17 | URUS/20014A | 2015/16 | 8 | 10 | 10 | 0 |
| 18 | URUS/25014A | 2016/17 | 7 | 5 | 5 | 0 |
| 19 | KAT/1804 | 2020/2021 | 3 | 12 | 13 | 0 |
| Total | | | | 111 | 64 | 47 |

MF, Massey Fergusson; NH, New Holland; JD, John Deer.

cumulative repair and maintenance costs (variable cost). The costs associated with this ideal replacement cycle are then converted into an equivalent stream of costs that are equal every year at the proper rate of time preference. The existing machine should be replaced with a new one in order to maximize profit if the current cost of maintenance is equal to or close to the equivalent annuity, cost (avg. annual cost) or when the machine's annuity cost is at its lowest value. We can write the optimization criterion in the following form:

$$B^T = M^T/S^T \tag{3}$$

where $B^T$ is the optimum cost,
$M^T$ is the expected total cost associated with a replacement cycle;
$S^T$ is the expected length of a year of a replacement cycle. $T$ denotes the time (Kolhe, 2014)

### Data analysis

At a 95% level of confidence for each approach, the statistical analysis program "IBM SPSS Statistics 26" was used to assess the ANOVA, correlation, and multiple linear regressions of the obtained data.

## Results

The results obtained from this study are presented in Tables 3-6.

**Table 3.** Depreciation factors for calculating remaining value percentages by machinery group.

| Depreciation factor | Machinery residual groups (RG)<br>Tractors (RG1) | Combines (RG4) | Windrowers/Mowers (RG3) | Forage/Harvesters (RG2) | Balers (RG3) | Planters/Tillage (RG4) |
|---|---|---|---|---|---|---|
| D1 | 0.67 | 0.65 | 0.67 | 0.56 | 0.66 | 0.66 |
| D2 | 0.94 | 0.93 | 0.9 | 0.9 | 0.92 | 0.96 |

**Table 4.** Annual repair and maintenance costs and estimated average annual total costs in United States dollars for different makes of tractors.

| Age (years) | JD 330 | | SAME 130 | | NH 80 | | MF 150 | |
|---|---|---|---|---|---|---|---|---|
| | R&M Cost/hr | Total Cost/hr | R&M Cost/hr | Total Cost/hr | R&M Cost/hr | Total Cost/hr | R&M Cost/hr | Total Cost/hr |
| 1 | 12106 | 34710 | 1234 | 19256 | 1782 | 7174 | 1826 | 7825 |
| 2 | 13399 | 28269 | 1370 | 18432 | 2713 | 6932 | 2051 | 7194 |
| 3 | 16187 | 22960 | 2592 | 15985 | 3111 | 6421 | 2332 | 6142 |
| 4 | 17029 | 17204 | 5500 | 15163 | 3644 | 5630 | 3086 | 5789 |
| 5 | 17826 | 17773 | 7123 | 14781 | 3923 | 4946 | 3644 | 5117 |
| 6 | 18186 | 17863 | 9675 | 14157 | 4574 | 4481 | 4194 | 4675 |
| 7 | 18514 | 18328 | 11193 | 10678 | 4932 | 4627 | 4746 | 4764 |
| 8 | 20746 | 18555 | 12380 | 11270 | 5160 | 4724 | 4956 | 4560 |
| 9 | 22886 | 18676 | 13044 | 12005 | 5337 | 4920 | 5254 | 4704 |
| 10 | 26513 | 24615 | 14056 | 12738 | 6490 | 5634 | 5375 | 5123 |

JD, John Deer; NH, New Holland; MF, Massey Fergusson; R&M, repair and maintenance.

**Table 5.** Observed parameters and model predicted economic life of farm tractors.

| Make | HP | Annual usage (hrs) | R&M Cost/hr | Observed replacement year | Model predicted replacement year | Error (+/-) |
|---|---|---|---|---|---|---|
| John Deer | 330 | 1753 | 785 | 5 | 5.12 | -0.12 |
| Massey Fergusson | 150 | 625 | 322 | 8 | 7.82 | 0.18 |
| SAME | 130 | 667 | 360 | 7 | 7.01 | -0.01 |
| New Holland | 80 | 846 | 450 | 6 | 5.88 | 0.12 |

HP, capacity; R&M, repair and maintenance.

**Table 6.** Coefficients of the dependent variable (replacement age) of tractor from the linear regression.

| Model | | Unstandardized coefficients<br>B | Standard error | Standardized coefficients<br>Beta | t | Sig. | 95.0% confidence interval for B<br>Lower bound | Upper bound |
|---|---|---|---|---|---|---|---|---|
| 1 | Constant | 12.105 | .278 | | 43.574 | .015 | 8.575 | 15.635 |
| | Birr | -.038 | .003 | -6.228 | -13.566 | .047 | -.074 | -.002 |
| | Hours | .013 | .001 | 5.339 | 11.629 | .045 | -.001 | .027 |

# Discussion

## Estimated optimum replacement years

According to the number of years of operation, Table 4 shows the total annual cost and annual maintenance cost for various sizes of tractors. As parts deteriorate and maintenance needs increase, it demonstrates an annual pattern of rising repair and maintenance (R&M) costs. The average yearly costs were high in the early years, fell to their lowest level in a given year, and then started to grow because of the rising maintenance costs with advancing age. The total annual cost is determined to be lowest in the fifth year (17773 USD), seventh year (10678 USD), sixth year (4481 USD), and eighth year (4560 USD), for JD 333, SAME, 130, NH 80 and MF 150, tractors respectively.

The association between repair and maintenance expenses and the total annual cost with tractors ages (years) is depicted in Figure 4. The total annual cost is the sum of R&M cost and annual depreciation cost. From these figures, it was observed that the repair and maintenance costs are less at the earlier ages of tractors but increase with years of service as parts become worn. Whereas the total annual costs are higher in the early years due to higher depreciation and decrease to the lowest point as the service years of tractors increase and then start to rise as a result of increasing repair and maintenance costs with increasing tractors age. The lowest values of the total annual cost were considered to be economically the optimum time for the replacement of the tractors. Accordingly, it is fifth year, seventh year, sixth year and eighth year for John Deer 330, SAME 130, New Holland 80 and Massey Fergusson150, tractors respectively.

## An empirical model to predict the optimum replacement age of tractors under investigation

The observed values of several factors, including replacement year, annual uses, tractor size (measured in horsepower), and R&M cost are shown in Table 5. Based on these findings, a multiple regression analysis was performed to forecast a tractor's ideal life and verify that the relationships between the variables were linear. The approach produces an empirical equation with just two independent variables: annual use and R&M expense. Despite being one of its independent variables, the tractor's size did not have any

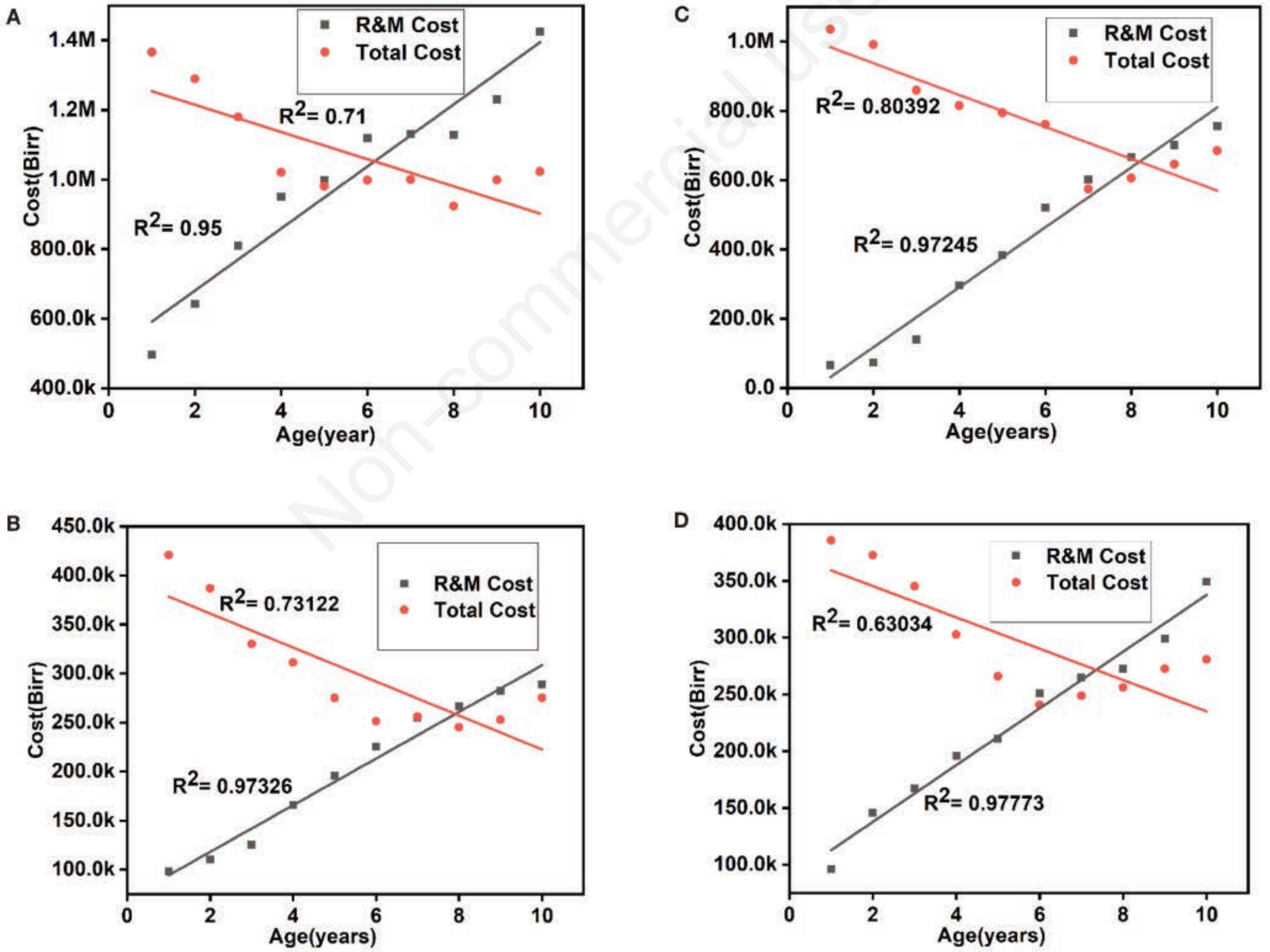

**Figure 4.** Influence of repair and maintenance cost and total cost on tractor on replacement age. **A**) John Deer 330; **B**) Massey F 150; **C**) SAME 130; D) New Holland80.

bearing on the model. According to the empirical model shown below by equation 5, it was taken to estimate the optimum tractors' life under consideration:

$$Y = C - ax_1 - bx_2 \qquad (4)$$

where:
Y: replacement year (dependent variable);
C: constant;
$x_1$: annual usage, hours;
$x_2$: R&M cost per hour;
a, b: coefficients.

The proposed equation (Eq. 4) was shown to have the best fit by regression analysis of the observed data, with the coefficient of determination $R^2$ being 0.999. We may infer that there is a linear relationship between the variables based on the ANOVA findings, which demonstrate that the p-value of this model, which is 0.03, is significant and rejects the null hypothesis. The estimate coefficients found from the analysis are listed in Table 6, and the significance level of those coefficients denotes the influence of those factors on the forecast value.

## Conclusions

1. Contrary to what is technically feasible, tractors used in WSSF have a short economic life because of the lack of replacement strategy, and poor maintenance facilities.
2. Although partially implementing both planned and unplanned machinery maintenance strategies, WSSF has no clear policy and strategy for machinery replacement. The absence of this replacement policy is clearly manifested by a large number of used machinery and scraps piled inside and outside of the factory's compound.
3. In an ideal scenario, the rise in overall cost can provide a broad indication of when to replace a specific tractor, but it cannot provide a specific response. It is important to keep in mind that while repair and maintenance costs are projected to rise gradually over time, this is not always the case as they significantly vary from year to year. So, one of the most important factors in choosing when to replace it is the ability to decide when a significantly high expense is required.
4. Additionally, it has been discovered that annual usage and repair maintenance costs per hour play a considerable role in determining a tractor's economic life. Based on that, an empirical model is developed to precisely predict the tractor's ideal lifespan when annual consumption and maintenance cost per hour are known.
5. For the tractors taken into the investigation, the observed and predicted optimal replacement years are within tolerable and acceptable bounds in terms of the machines' useful lives. Another sign of the model's dependability is the agreement between the measured and predicted optimal replacement years. A correlation coefficient of 0.99 shows that the study's observed and predicted outcomes compare favorably in terms of dependability and usability.

### Recommendations

The following recommendations are given for improving tractor maintenance and replacement strategy at WSSF based on the present findings:

1. Improvement of records' documentation of all types of costs for all tractors is required as it will be used as an important input for the next researchers;
2. Maintenance facilities, especially those that are required for preventive maintenance, should be fulfilled to utilize all the designed economic life of farm tractors;
3. Using the empirical model developed by this study to estimate the ideal economic life by simply using annual usage hours and maintenance costs per hour.

## References

1. Abd Rani N.A., Baharum M.R., Akbar A.R.N., Nawawi A.H. 2015. Perception of Maintenance Management Strategy on Healthcare Facilities. Soc. Behav. Sci. 170:272-81.
2. Ajibade A.D., Odusina M.T., Rafiu A.A., Ayarinde A.W., Adeleke B.S., Babarinde S.N. 2014. The use of replacement model to determine the appropriate time to replace a deteriorating industrial equipment. IOSR J. Math. 10:9-13.
3. Amiens E.O., Oisamoje M.D., Inegbenebor A.U. 2015. A Dynamic Programming Approach to Replacement of Transport Vehicles in Benin City, Nigeria. Br. J. Math. Comput. Sci. 6:204-14.
4. ASAE D497. 2000. Agricultural Machinery Management Data. Science. 85:350-7.
5. Bati Fedi G., Dereje Asefa F., Tafa Waktole A. 2022. Farm households' perception about sugarcane out-growers scheme: Empirical evidence around Wonji/Shoa Sugar Factory. Cogent. Econ. Financ. Taylors Fransis J. 10:200.
6. Calcante A., Fontanini L., Mazzetto F. 2013. Repair and maintenance costs of 4WD tractors and self-propelled combine harvesters in Italy. J. Agric. Eng. 4:10-5.
7. Cunha M, Gonçalves S.G. MACHoice: 2019. A decision support system for agricultural machinery management. Open Agric. 4:305-21.
8. Dohi T., Ashioka A., Kaio N., Osaki S. 2006 Statistical estimation algorithms for repairs-time limit replacement scheduling under-earning rate criteria. Comput. Math. Appl. 51:345-56.
9. Edwards W. 2019. Replacement strategies for farm machinery. Iowa State Uni. Ext. Outreach. pp 1-7.
10. Eilon S., King J.R., Hutchinson D.E. 1966. A Study in Equipment Replacement. J. Oper. Res. Soc. 17:59-71.
11. FAO. 2010. Agricultural mechanization in Mali and Ghana: strategies, experiences, and lessons for sustained impacts. Available from: https://www.fao.org/sustainable-agricultural-mechanization/resources/publications/details/fr/c/456121/
12. Kolhe K.P., Datta C.K. 2007. Prediction of Microstructure and Mechanical Properties of Multipass SAW. J. Mater. Process Tech. 197:241-9.
13. Kolhe K.P., Jadhav B.B. 2011. Testing and Performance Evaluation of Tractor Mounted Hydraulic Elevator for Mango Orchard. Am. J. Eng. Appl. Sci. 4:179-86.
14. Kolhe K.P. 2014. Testing and ergonomically evaluation of tractor mounted. and self propelled coconut climber. Int. J. Eng. Technol. 3:357-62.
15. Kolhe K.P. 2015. Stability analysis of tractor mounted hydraulic elevator for horticultural orchards. World J. Eng. 12:479-88.
16. Mbata J. 2012. Agribusiness indicators: Ethiopia. Tech. Rep. Agric. Rural Dev. RN:68237-E.
17. Mikler J. 2011. Life cycle costing used for justifying transition to predictive maintenance strategies. J. Mach. Eng. 11:49-58.

18. Nair S.K, Hopp W.J. 1992. A model for equipment replacement due to technological obsolescence. Eur. J. Oper. Res. 63:207-21.
19. Offiong A. 2013. Development of Vehicle Replacement Programme for a Road Transport Company. Int. J. Appl. Sci. Tech. 3:31-5.
20. Pagare V. 2019. Appraisal of Optimum Economic Life for Farm Tractor: A Case Study. Econ. Aff. 64:111-8.
21. Perrin R.K. 1972. Asset Replacement Principles. Am. J. Agr. Econ. 54:60-7.
22. Robb J.G., Smith J.A., Ellis D.E. 1998. Estimating Field Machinery Cost: A Whole Farm Approach. J. Nat. Resour. Life Sci. Educ. 27:25-9.
23. Shafiee M., Sørensen J.D. 2019. Maintenance optimization and inspection planning of wind energy assets: Models, methods and strategies. J. Reliab. Eng. Syst. Safe. 192.
24. Velmurugan R.S., Dhingra T. 2015. Maintenance strategy selection and its impact in maintenance function: A conceptual framework. Int. J. Oper Prod. Man. 35:1622-61.