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PREDICTION OF REPAIR AND MAINTENANCE COSTS OF TWO-WHEEL DRIVE TRACTORS IN IRAN

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ABSTRACT Predicting of repair and maintenance (R&M) costs of tractors in any mechanized farm is necessary for owners and managers to obtain information on overall maintenance costs in order to control production cost. In this context a study was conducted to predict accumulated R&M costs (Y) of two-wheel drive (2WD) tractors based on total usage hours (X) in Misagh-e-Sabz Agribusiness Company in Iran. Recorded data from the company was used to determine regression models for predicting total R&M costs (as percentage of initial purchase price) based on total usage hours. The statistical results of the study indicated that in order to predict total R&M costs of 2WD tractors with based on usage hours of 2260 h or less the power regression model $Y = 0.013\ (X/100)^{1.677}$ with $R^2 = 0.976$, and to predict total R&M costs of 2WD tractors with based on usage hours of 2260 hours or more the polynomial regression model $Y = 0.004\ (X/100)^2 - 0.181\ (X/100) + 4.373$ with $R^2 = 0.998$ is strongly suggested. Results of the study also indicated that total R&M costs predicted in this study were lower than those predicted in the previous studies. Cumulative life of 12000 hours, for instance, indicated an total R&M costs equivalent to 40.3% of initial purchase price. The most likely reasons that explain these differences between the predicted results in this study and those predicted in the previous studies probably can be attributed to new tractor technology for production during the last two decades and lower labor wages in Iran.

Keywords: Repair and maintenance costs, Two-wheel drive tractor, Prediction, Modeling, Iran.

INTRODUCTION Machinery ownership (fixed) and operating (variable) costs represent substantial portion of total production expenses. Machinery ownership costs usually include charges for depreciation, interest of investment (opportunity cost), taxes, insurance and housing facilities. Operating costs include repair and maintenance, i.e. spare-parts, wages and lubricants (Bowers, 1981; Morris, 1987). Repair and maintenance (R&M) costs of farm machinery are those expenditures necessary to restore or maintain technical soundness and reliability of the machine (Srivastava et al., 2006). Accurate prediction of R&M costs trends is critical to determine optimum economical life of

machine and to make appropriate decisions for machinery replacements, and also for general farm management purposes (Hunt, 2001). Since variation in R&M costs depends on site and time specifications, a general relationship can not be suggested. But prediction of these costs at an acceptable level can be made by fitting a regression model based on the previous data (Rotz, 1987).

Larson & Bowers (1965) collected R&M costs data as part of a large survey which covered about 1100 tractors in Mid-West in USA. They obtained models for predicting R&M costs of different tractor types (Bowers, 1981). Bower & Hunt (1970) surveyed around 1800 farmers in Illinois and Indiana and used R&M costs data to develop models for predicting R&M costs. Fairbanks et al. (1971) working in Kansas collected R&M costs data through investigation from 114 farm managers. At the end, accumulated R&M costs were predicted using a power regression model based on cumulative usage hours of tractors. Ward et al. (1985) obtained a power regression model for predicting accumulated R&M costs based on accumulated usage hours for 63 forestry tractors in Ireland which gave very high cost estimates compared to other references. They concluded that the observed R&M costs variation on tractors was so high as to preclude the use of an obtained model for predicting R&M costs for a single tractor. They suggested this variation was most likely attributable to differences in tractor operation, maintenance services, operating practices and inherent tractor qualities, but they were not in a position to substantiate this claim. Morris (1988) collected R&M costs data of 50 tractors in Weasenham Farm Company in Norfolk and used them to obtain R&M costs prediction model. His study showed that hours of use he could account for, shared no more than 16% of the observed variations in R&M costs. Skill of operator, working conditions and maintenance standards were reported as important determinants of machinery R&M costs. The models developed by Bower & Hunt (1970) were revised by Rotz & Bower (1991) based on expert opinion, but they did not do another survey. Obviously, machinery has changed a lot since the 1970 survey. The equations predict R&M costs as a percentage of the machine purchase price, so the equations should remain valid as long as the machine purchase price goes up at the same rate as the R&M costs. But, we do not know that for sure. Funding has just not been available to do much research in this area (Lazarus, 2008).

In Iran very limited studies have done on R&M costs of tractors and farm machinery too. Almassi & Yeganeh (2002) obtained an appropriate regression model for accurate prediction of accumulated R&M costs based on accumulated usage hours for 213 tractors in Karoon Agro-Industrial Company in north of Khuzestan province. Also, Ashtiani-Eraghi et al. (2006) conducted a study in order to derive a power regression model for predicting accumulated R&M costs based on cumulative usage hours for 27 active tractors of two different models in Dasht-e-Naz Agricultural Company in Mazandaran province. Moreover, Ajabshirchi et al. (2006) obtained a polynomial regression model for predicting accumulated R&M costs based on accumulated usage hours for 42 tractors working actively at Astan-e-Ghods-e-Razavi farms in Khorasan province.

In summary, researchers state that in general there is a little reliable recorded R&M costs data, especially for older machines, and great variations in R&M costs between tractors and their operating conditions, make it difficult to obtain meaningful generalized models. In this perspective the purpose of this study was to predict accumulated R&M costs based on accumulated usage hours using farm records to obtain R&M costs model(s) for 60

active two-wheel drive (2WD) tractors of different models in Misagh-e-Sabz Agribusiness Company in Ilam and Kermanshah province in the west of Iran, and to examine the extent to which the hours of use explain variations in R&M costs, and also to compare the obtained R&M costs model(s) with previous models.

MATERIALS AND METHODS Required data were obtained from the Misagh-e-Sabz Agribusiness Company in Ilam and Kermanshah provinces which keep machinery records as part of a large management accounting system. For each tractor, separate records are kept as monthly hours of tractor's counter readings, and R&M costs including spare-parts, lubricants and labor costs. Labor charged at hourly rates includes all workshop related wages and overheads. Sixty active 2WD tractors on four different models including Universal 650 (U-650), Massey Ferguson 285 (MF-285), John Deere 3140 (JD-3140) and John Deere 4955 (JD-4955) with complete records were selected for analysis. Data over 15 years time period from 1991 to 2005 were collected. In order to adjust for inflation effect, all of the cost elements were adjusted to a common base year, i.e. 2005. The average annual operation hours for each tractor was about 1212 h. Majority of the tractors had worked much more than 12000 h, which is the normal service life of tractor as suggested by the American Society of Agricultural and Biological Engineers (ASABE). Some variations were apparent between individual tractors for the service hours. Hours of annual usage for each tractor were needed for the purpose of data analysis study. For the tractors which had no intact hour-meter, the engine oil change intervals were considered as 120 hours of service. To determine regression model(s) for predicting R&M costs of these tractors at any point of service life, accumulated hours of use for each year were added up to previous usage hours and the sum was considered to be independent variable (X) of the model(s). Then, R&M 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. To acquire information (i.e. R&M costs, hours of service and also initial purchase price) for all tractors, weighted average of data was employed for analysis. Regression analysis of data for each individual type of tractor and, also as well on all tractors as whole was done using SPSS 12.0 (Version, 2003). Linear, exponential, power and polynomial regression types were tried. Accuracy of different regression models and significance of their coefficients were examined using analysis of variance and F statistical test. 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.

RESULTS AND DISCUSSION Table 1 shows mean annual values and mean annual percent of R&M costs, i.e. spare-parts, wages and lubricants per unit of all tractors for different ages of them. This table also indicates average of whole annual R&M costs, average of annual usage hours and average of R&M costs per hour per unit of all tractors for different ages of them. Figure 1 shows mean R&M costs fractions, i.e. spare-parts, wages and lubricants to be 69.54%, 24.15% and 6.31%, respectively, among which spare-parts costs are the highest. Table 2 provides information on mean accumulated usage hours and mean accumulated R&M costs as percentage of initial purchase price per unit of all tractors for different ages of them which were used as base data for regression analysis. In this study, tractors' initial purchase prices declared by the Misagh-e-Sabz Agribusiness Company were adjusted for mean annual inflation rate for a period of 15 years.

Table 1. Mean annual values and mean annual percent of R&M costs (spare-parts, wages and lubricants), average of whole annual R&M costs, average of annual usage hours and average of R&M costs per hour per unit of all tractors for different ages of them.

Age (years)	Spare-parts		Wages		Lubricants		Average of whole annual R&M costs (Rials)	Average of annual usage hours (h)	Average of R&M costs per hour (Rials)
	Value (Rials)	%*	Value (Rials)	%	Value (Rials)	%			
1	626572	59.85	258117	24.66	162138	15.49	1046827	987.50	1060
2	723558	61.75	278724	23.79	169447	14.46	1171729	1090.0	1075
3	1469455	68.38	479445	22.31	199940	9.30	2148840	1289.6	1666
4	1914256	69.89	591663	21.60	233138	8.51	2739057	1382.5	1981
5	2601489	69.45	881354	23.53	263247	7.03	3746090	1472.4	2730
6	3114299	69.80	1040751	23.33	306891	6.88	4461942	1404.4	3177
7	4223267	69.60	1502648	24.76	342248	5.64	6068163	1435.2	4228
8	4975056	67.66	1973164	26.84	404681	5.50	7352902	1408.7	5220
9	6377547	67.03	2655577	27.91	480783	5.05	9513907	1358.7	7002
10	8746043	71.68	2871566	23.54	583577	5.78	12201187	1241.3	9829
11	9586391	73.23	2806774	21.44	697104	5.33	13090269	1085.5	12060
12	7334245	69.18	2596409	24.49	670979	6.33	10601633	959.60	11048
13	7804522	68.64	2814729	24.76	751039	6.61	11370290	1011.7	11239
14	7636723	68.95	2639510	23.83	799355	7.22	11075589	1052.0	10528
15	9507604	69.77	3227558	23.69	891671	6.54	13626833	1002.6	13592
Average	5109402	69.54	1774533	24.15	462749	6.31	7347684	1212.0	6429

* = As percentage of average of whole annual R&M costs

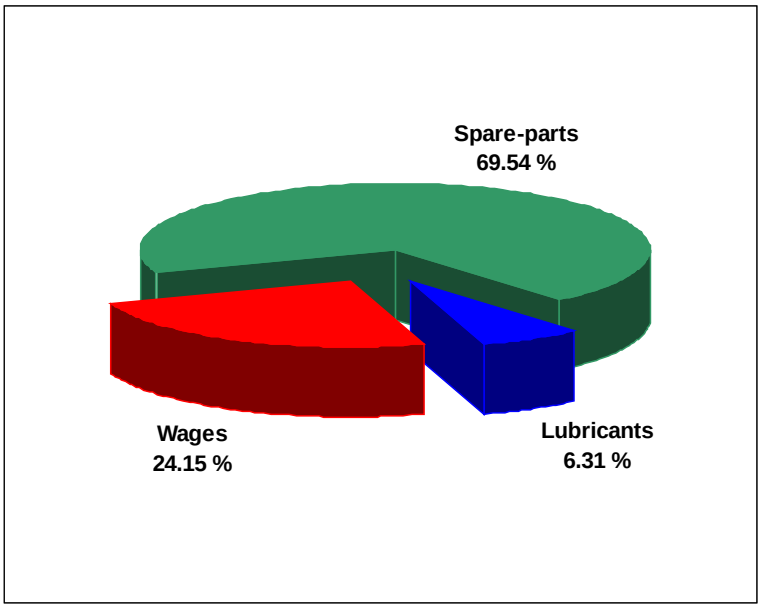

Figure 1. Mean R&M costs fractions, i.e. spare-parts, wages and lubricants for all tractors under study.

Table 2. Mean accumulated usage hours and mean accumulated R&M costs as percentage of initial purchase price per unit of all tractors for different ages of them.

Age (years)	Mean accumulated usage hours (h)	Mean accumulated R&M costs as percentage of initial purchase price (%)
1	988.00	0.970
2	2078.0	2.050
3	3367.0	4.040
4	4750.0	6.580
5	6122.0	10.05
6	7526.0	14.18
7	8962.0	19.80
8	10370	26.61
9	11729	35.42
10	12970	46.72
11	14056	58.85
12	15015	68.67
13	16027	79.20
14	17079	89.45
15	18082	102.1

Table 3 shows linear, exponential, power and polynomial models which are modeling of accumulated R&M costs as percentage of initial purchase price (Y) based on accumulated usage hours (X). Considering F values, there is a significant correlation between X and Y variables in all four models. However, R^2 values indicate that the power and polynomial models have higher conformity with actual data trend in comparison with the linear and exponential models. For prediction of accumulated R&M costs, the power model can be applied because of its simple structure and easiness of calculating procedure, but this model has lower R^2 value than the polynomial model. However, as the polynomial model shows accumulated R&M costs to be lower than the actual data for the first period of machine life, and also predicts some fixed amount of costs before binging service life of tractor, the power model can be suitably applied for the first period of machine life, i.e. accumulated usage hours up to 2260 h as:

$$Y = 0.013\ (X/100)^{1.677} \qquad (X < 2260\ h) \tag{1}$$

On the other hand, as the polynomial model conforms well to actual data trend particularly at later life time of tractors, polynomial model is preferred to power one for the remaining service life of tractor, i.e. accumulated usage hours above 2260 h as:

$$Y = 0.004\ (X/100)^2 - 0.180\ (X/100) + 4.373 \qquad (X > 2260\ h) \tag{2}$$

Table 3. Description, coefficient, coefficient of determination (R^2) and F test results of four regression models obtained for all tractors.

Model	Description	a	b	c	R^2	F	MS
Linear	$Y = a X + b$	-20.26**	0.582**	---	0.910	131**	114.45
Exponential	$Y = a e^{bX}$	1.581**	0.025**	---	0.957	291**	0.0970
Power	$Y = a X^{b}$	0.013**	1.677**	---	0.976	527**	0.0540
Polynomial	$Y = a X^2 + b X + c$	0.004**	-0.181**	4.373**	0.998	3241**	2.5400

** = Significant at probability level of 1%

MS = Mean square of residuals

Figure 2 indicates the curves of predicted accumulated R&M costs for all tractors based on accumulated usage hours using the power and polynomial models together with the actual data and the line of X = 2260 h. Differences of repair factors on different types of tractors may be attributed to the nature of different farm operations, skill of operators, annual service hours of tractor, wage-rate of operator, spare-part costs and some other factors alike.

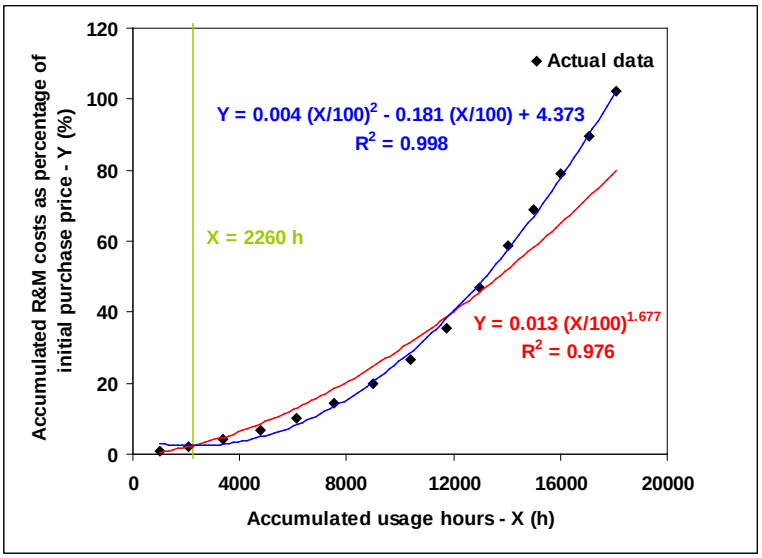

Figure 2. Curves of predicted accumulated R&M costs as percentage of initial purchase price based on accumulated usage hours using the power and polynomial regression models for all tractors under study.

Figure 3 shows the curves of predicted accumulated R&M costs for all types of tractors based on accumulated usage hours using the power model for the first period of machine life and the polynomial model for the remaining service life of tractors. It can be observed that the rate of accumulated R&M costs for all tractor types at earlier life time of them was low and fairly similar. However, trend of R&M costs was rapidly increasing thereafter. The rate of increase was lowest for JD-4955 tractor model and highest for U-650 tractor model. Differences in increasing rate of R&M costs may be attributed to the facts like quality in design and manufacturing, scarcity and higher cost of some spare-parts as compared to new price of tractor type, and also much frequent need for repair in some models. Steepness of accumulated R&M costs curves for MF-285 and U-650 tractor models was higher than JD-3140 and JD-4955 tractor models. This can be related to more frequent break-downs, inferior production technology, inherent deficiencies, and also incompatible field operations to their power and efficiencies.

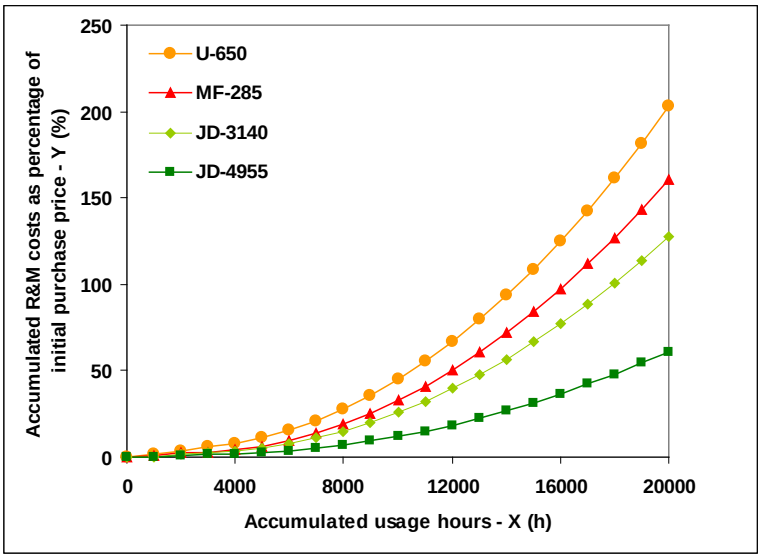

Figure 3. Comparison of accumulated R&M costs as percentage of initial purchase price based on accumulated usage hours on four different tractors models under study.

The results obtained in this study were compared with results of the previous studies and presented using in Figure 4. Moreover, accumulated R&M costs predicted using the polynomial model developed in current study and previous models for 4000, 8000 and 12000 accumulated usage hours of tractors are shown in Table 4. Accumulated R&M costs predicted by the polynomial model developed in this study over the range of 8000 to 12000 service hours gave prediction of accumulated R&M costs to be 40.30% of initial purchase price at full life of tractor which is higher than 32.20% of Ajabshirchi et al. (2006) and comparatively lower than 77.30% of Almassi & Yeganeh (2002) and 88.30% of Ashtiani-Eraghi et al. (2006) in Iran, and 259.0% of Ward et al. (1985), 100.8% of Rotz (1987), 106.0% of Morris (1988) and 102.2% of Zeidy et al. (1992) in USA and Europe.

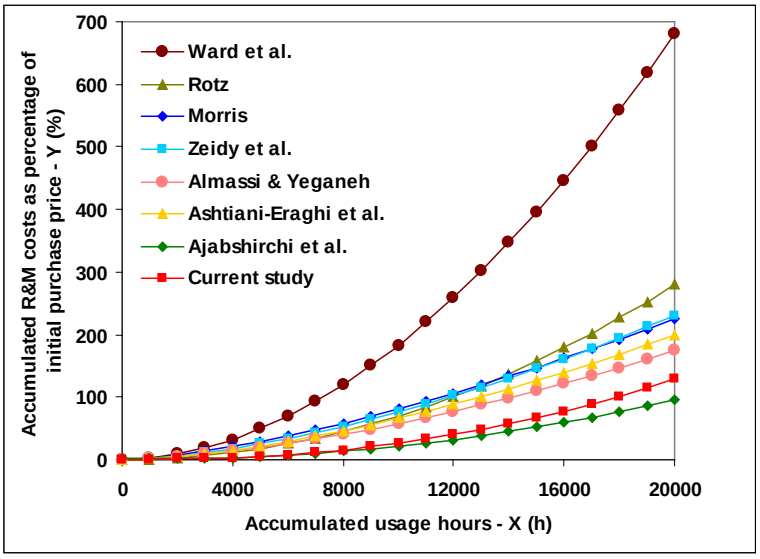

Figure 4. Comparison of accumulated R&M costs as percentage of initial purchase price based on accumulated usage hours obtained in current study with those of the previous studies.

Table 4. Accumulated R&M costs as percentage of initial purchase price predicted using the polynomial model developed in current study and previous models for three different accumulated usage hours of tractors.

Source	**Model**	**Accumulated R&M costs as percentage of initial purchase price for three different usage hours (%)**		
		4000	8000	12000
Ward *et al.*	$Y = 0.042\ (X/120)^{1.895}$	32.30	120.1	259.0
Rotz	$Y = 0.007\ (X/100)^{2}$	11.20	44.80	100.8
Morris	$Y = 0.0000996\ (X^{1.4775})$	20.90	58.20	106.0
Zeidy *et al.*	$Y = 0.067\ (X/120)^{1.592}$	17.80	53.60	102.2
Almassi & Yeganeh	$Y = 0.052\ (X/120)^{1.5865}$	13.50	40.60	77.30
Ashtiani-Eraghi *et al.*	$Y = 0.042\ (X/100)^{1.599}$	15.20	46.20	88.30
Ajabshirchi *et al.*	$Y = 0.003\ (X/100)^{2} - 0.069\ (X/100) + 1.660$	3.200	13.40	32.20
Current study	$Y = 0.004\ (X/100)^{2} - 0.181\ (X/100) + 4.373$	3.600	15.50	40.30

CONCLUSION 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 there are considerable variations in R&M costs among tractor models as well as individual ones. For circumstances similar to this study, estimates suggest that annual R&M costs increase with age of tractor. This method is more useful for replacement decisions than annual charge method. In summary, lower R&M costs in this study can be related to lower wages in Iran, especially in comparison with USA and Europe. Other reasons may be the use of polynomial model which inherently shows the costs to be lower than usual power model especially in the first period of machine life. Subsided low cost machine parts used by Misagh-e-Sabz Agribusiness Farm Company and allocation of financial bank credits with low or even with zero interest rates also influence the situations.

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