The Effect of Failure Rate on Repair and Maintenance Costs of Four Agricultural Tractor Models

Fatemeh Afsharnia, Mohammad Amin Asoodar, Abbas Abdeshahi

***Abstract*—**In economical evaluation literature, although the combination of some variables such as repair and maintenance costs and accumulated use hours has been widely considered in determining of optimum life for tractor, no investigation has indicated the influence of failure rate on repair and maintenance costs. In this study, the owners of three hundred tractors, which include Massey Ferguson, John Deere and Universal, were interviewed, from five regions of Khouzestan Province. A regression model was used to predict the tractors annual repair and maintenance costs based on failure rate. Results showed that the maximum percentage of annual repair and maintenance costs occurred in engine parts for MF285, JD3140 and U650 tractors while these costs for tire, ring, ball bearing and operator seat were higher compared to other MF399 tractor systems. According to the results of the regression, the failure rate increase would lead to annual repair and maintenance costs increase for all tractors. But, of all the tractors, repair and maintenance costs of JD3140 tractors extremely affected by the failure rate increase.

***Keywords*—**Failure rate, tractor, annual repair and maintenance costs, regression model, Khouzestan.

I. INTRODUCTION

TODAY, tractor is one of the most important power sources in agriculture. Effect of tractor power on agriculture is considerable [1]. The use of modern technology during last decades resulted in rapid growth of farm production. Tractors and farm machinery are important samples of this modern technology [2]-[4]. The quality of inputs of mechanization and consequently land and labor productivity in both situations may differ considerably [5]-[7]. Reduced machine performance, combined with the incorrect size selection during the busiest part of the season, can cause delays in the completion of operations and result in the loss of crop yields and inefficient labor utilization. To make allowance for machinery failures in planning, the probability of machine failure needs to be estimated before plans are made. There are very limited studies in relevant literature regarding the analysis of machinery failures. In this literature, failure probabilities of different kinds of machinery were determined, and their effects on cost load, the use of the data in the planning stage were examined [8]-[11]. If properly and given the necessary field maintenance tractors will operate for long period and do a great deal of work before major repairs are required [12]. Tractor break down can be of high cost not only from the stand point of the expenditure necessary to effect repair, but also because of the disastrous effect on crop productivity and the fact that idle staff must still be paid. The extent of the problem of tractor failure in developing countries is more serious compared with developed countries. This is due to acute shortages in genuine spare parts, affecting preventive maintenance, absence of future planning for integrated maintenance management and programs that strive to identify incipient faults before they become critical to enable more accurate planning of preventive actions. As such system performance can be improved by developing optimal maintenance prediction models that minimize overall maintenance cost or maximize system performance measures [13].

In practice, most farmers face a number of problems in using the tractors. Breakdowns which are field stoppage due to sudden failure of a part [8] are major problems found in the Khouzestan Province. From an economic point of view, idleness due to machinery breakdowns can be very costly as a result of lost working time [14]. Repairs of broken down machines are also expensive [15], because the breakdowns consume resources; manpower, spare parts, and even lose of production [16]. Consequently, the repair costs become an important component of the total machine ownership costs [17]. It was found that about 53% of total machine expenses in developing countries were for repairs of machine breakdowns [18]. Specifically, the causes of breakdowns can be different from one country to another due to differences in maintenance regimes, operator skills, infrastructure and working conditions, and other factors. Jacobs et al. [14] stated that machines may break down due to a design defect, physical damage, or normal wear and tear, but many times machines fail because of neglect and the lack of properly scheduled maintenance [14]. It was reported that the high frequency of breakdowns may be attributed to the high cost of imported spare parts, misuse of tractors, and a failure of operators to carry out routine maintenance [19]. While a lack of spare parts and poor tractor maintenance were found to be the major causes of tractor breakdowns in Nigeria [20], these problems subsequently caused around 50% of tractors in the country to become unserviceable [21]. Costs of owning and operating of farm machinery represent 35 to 50% of the costs of

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agricultural production when excluding the land [2]. The repair and maintenance cost is an important item in costs of owning and operation. In general, the costs other than those for repair and maintenance usually decrease with increasing usage, but the reverse is true with respect to repair and maintenance costs. The cost of repair and maintenance 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 of farm machines [7]. Agricultural engineers have done many studies regarding repair and maintenance of farm machines. Several studies were conducted in both developed and undeveloped countries either to develop models to determine the cost during annual repair and maintenance costs certain period or to get absolute numbers to represent owning and operating certain equipment [5], [6], [17], [22]-[25], while no investigation has indicated the influence of failure rate on repair and maintenance costs. This study attempts to uncover specific issues associated to the costs of the tractor breakdowns by investigating the frequency of breakdowns in field operations to obtained models for study tractors based on their failure rate.

II. Materials And Methods

A. Sampling Method

The survey was made in 2012-2013 by interviewing the tractor operators in Khouzestan Province, one of the arid and semiarid agricultural regions in southwest of Iran that the abundance of water and fertility of soil have transformed this province into a rich and well-endowed land. Data for the study was collected from agricultural tractor operators in five famous agricultural regions. These selected regions were named Dezful, Andimeshk, Shush, Ahvaz and Behbahan. These regions were chosen for survey locations because of their high tractor uses and the importance of crop production which uses predominantly tractors to mechanized land preparation and crop harvesting. The details of the tractor models and number of tractors in each model were obtained from the Census Department, Agricultural ministry, Government of Iran; Khouzestan Centre based on the 2011 census. A total of 300 tractors from 30 villages -six villages from each region- were selected randomly from lists of tractors in each village. Data were collected from Massey Ferguson (MF285 model and MF399 model), John Deere (JD3140 model) and Universal (U650 model) tractor operators and derived from farm records valid in the study region. These tractors were chosen because of their population were higher compared to other tractor models and also they were all still serviceable. Technical features of all tractors are shown in Table I.

TABLE I
Technical Features of All Tractors

Technical Features	Tractor Type			
	MF 285	MF 399	JD 3140	U 650
Factory	ITM	ITM	Mannheim	Tractorul
Rated Engine Power /HP	75	110	97	65
Maximum Torque /Nm	278	376	297.92	252.84
Weight /Kg	2812	3677	3991	2980
Fuel	Gasoil	Gasoil	Gasoil	Gasoil
Fuel Tank Capacity /Lit	90	118	125.9	98
Engine Model	Perkins A4-248	Perkins A 63544	John Deere	D- 110
No. Of Cylinders	4	6	6	4
Bore ×Stroke /Mm	100×127	100×127	106×110	108×130
Hydraulic Pump Type	4 Piston Scotch-Yoke	4 Piston Scotch-Yoke	Radial (8 Pistons)	Gear
Pump Flow /Lit Min^{-1}	26.5	27.6	68.1	40
Transmission	Sliding	Synchronizer	Synchromesh	Mechanical
Gears /Forward + Reverse	8+2	12+4	16+8	5+1
Steering	Hydro Mechanic	Hydrostatic	Hydrostatic	Hydraulic
Brakes	Wet Disc	Oil Cooled Disc	Wet Disc	Dry Friction Disc
Rear PTO	Independent	Independent	Independent	Independent Or Synchronous
Rear /Rpm	540	540/1000	540/1000	540
3-Point Hitch	Rear Type II	Rear	Rear Type II	Front And Rear

B. Data Collection

The tractor operators (also farmers) were personally interviewed through home or workplace visits by using a face-to-face questionnaire. Information was sought on tractor characteristics such as tractor age, use of tractor each year, failure number of each system and economic costs. All definable failures causing any delay in different systems of the tractors excluding engine, hydraulic, transmission, electrical, brakes, steering, fuel, cooling, etc (tire, ring, ball bearing and operator seat) were recorded.

C. Failure Rate

The reliability of a machine is its probability to perform its function within a defined period with certain restrictions under certain conditions [26], [27]. A machine's operational availability is the proportional expression of reliability; therefore, it is the period during which a machine can perform its function without any breakdowns [28]. The reliability of any equipment is related to frequency of failures, which is expressed by the "mean time between failures (MTBF)." The MTBF was determined using (1). The parameter defining a machine's reliability is the failure rate (λ), and this value is the characteristic of breakdown occurrence frequency. Failure rate which is equal to the reciprocal of the mean time between failures (MTBF) defined in hours (λ) was calculated by using the equation (2) as is suggested by Tufts (1985) and Billinton and Allan (1992) [28], [27].

$$MTBF = \frac{T}{n} \quad (1)$$

$$\lambda = \frac{1}{\mathrm{MTBF}} \quad (2)$$

where, MTBF is mean time between failures (h); T is total time (h); n is number of failures; λ is failure rate (failures per10^3 h).

D. Modeling Method and Data Analysis

Repair and maintenance costs for the study tractors were investigated to present an appropriate mathematical model in order to predict these costs versus failure rate. Power model gave better cost prediction with higher confidence and less variation than that of polynomial, exponential and logarithmic models [29]. Because of, easiness in calculations, the high correlation coefficients of power model and using of this model by other researchers, in the present study, power model as given in (3) was suggested as final form of the repair and maintenance cost model.

$$Y = ax^b \quad (3)$$

The data was analyzed using the computer software SPSS 21.0. These data were tabulated and then analyzed using simple descriptive techniques including percentages and means. Differences between mean values were based on Duncan's multiple range tests [30]. Different letters in the columns of curves indicate significant differences by Duncan test. Then Basic information on failure rate and annual repair and maintenance costs were entered into Excel's spreadsheet and evaluated by the computer software SPSS 21.0.

III. Results And Discussion

The average annual use hours, average age and failure rate at the overall of the machine´s life are presented in Table II. The average age and annual use hours of tractors were 11.61 years & 1079.16h, 9.74 years & 1227.37h, 25.04 years & 1460.61h and 23.02 years & 1242.13h for MF285, MF399, JD3140 and U650 tractors respectively. The average tractors failure rate were 12.2, 12.7, 14.5 and 15.5 failures per 10^3 h for MF285, MF399, JD3140 and U650 tractors respectively. As depicted in this table, the average failure rate of the MF tractors was quite near each other and U650 tractors had the highest failure rate in compared to all tractors.

TABLE II
Some Descriptive Data for Tractor Types

Tractor Type	Average Annual Use Hours/ h	Average Age/ Year	Failure Rate/ Failures Per10^3 h	Tractor Number
MF 285	1079.16±60.36*	11.61± 0.87	12.2± 0.00053	60
MF 399	1227.37±38.55	9.74±0.38	12.7± 0.00041	102
JD 3140	1460.61±62.25	25.04±0.57	14.5± 0.00063	49
U 650	1242.13±30.04	23.02±0.36	15.5± 0.00044	89

*: Standard error=standard deviation/√n

Table III summarizes some descriptive information regarding Annual repair and maintenance costs data derived from valid records for the study tractors. The maximum average Annual repair and maintenance costs occurred in JD3140 and U650 tractors respectively while MF285 and MF399 tractors had the lowest values. This difference was due to JD3140 and U650 tractors were aged. This value encountered for MF285, MF399, JD3140 and U650 tractors was US$395.11, US$561.01, US$776.98 and US$616.58.

TABLE III
Some Descriptive Statistics of Annual Repair and Maintenance Costs

Tractor Type	Annual Repair and Maintenance Costs/ US$		
	Minimum	Maximum	Average
MF 285	4.13	1111.57	395.11±34.03
MF 399	46.83	1747.93	561.01±37.75
JD 3140	133.06	1832.78	776.98±62.52
U 650	115.15	1794.77	616.58±39.2

Fig. 1 presents failure types and their distribution as a percentage of total failure recorded in different systems of the tractors included engine, hydraulic, transmission, electrical, brakes, steering, fuel, cooling, etc (tire, ring, ball bearing and operator seat). As indicated, the electrical system caused the majority of recorded failures in given groups for all tractors.

The electrical system failures generally resulted from short life of the battery and dynamo in these tractors. Therefore this result coinciding with Ishola and Adeoti (2004) who revealed that the electrical systems were more prone to failure than the engine, cooling, transmission, fuel and hydraulic systems [31]. Fig. 2 shows percentage of annual repair and maintenance costs recorded in different systems of tractors surveyed. The maximum percentage of annual repair and maintenance costs occurred in engine parts for MF285, JD3140 and U650 tractors while these costs for tire, ring, ball bearing and operator seat were higher compared to other MF399 tractor systems. The annual repair and maintenance costs of Transmission system had the secondary share within the total recorded data of MF285, MF399 and JD3140 tractors while it occurred in tire, ring, ball bearing and operator seat for U650 tractors.

The most percentage of annual repair and maintenance costs for engine parts and steering systems were in JD3140 tractors, hydraulic and brake systems in U650 tractors, Transmission system and etc (tire, ring, ball bearing and operator seat) in MF399 tractors and electrical, fuel and cooling systems in MF285 tractors but The minimum percentage of these costs for engine parts, electrical and cooling systems were in MF399 tractors, hydraulic and brake systems in MF285 tractors, Transmission and steering system in U650 tractors and fuel system and etc (tire, ring, ball bearing and operator seat) in JD3140 tractors.

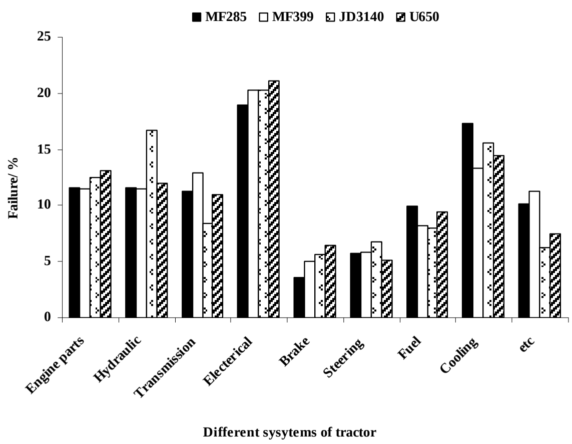

Fig. 1 Failure types and their distribution for tractors

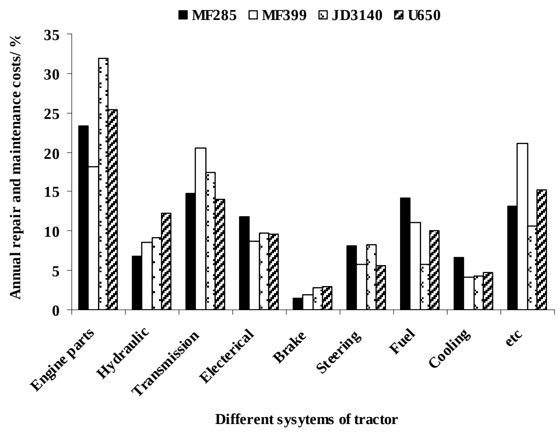

Fig. 2 Annual repair and maintenance costs types and their distribution for tractors

According to Fig. 3, a significant difference was recorded where four types of tractors were compared for annual repair and maintenance costs (P≤0.01). The annual repair and maintenance cost of MF285 tractor was lower than the others. JD3140 tractors showed maximum annual repair and maintenance costs, while the annual repair and maintenance costs of MF399 and U650 tractors had been found quite near each other, implying that there was no significant difference in annual repair and maintenance costs for MF399 and U650 tractors.

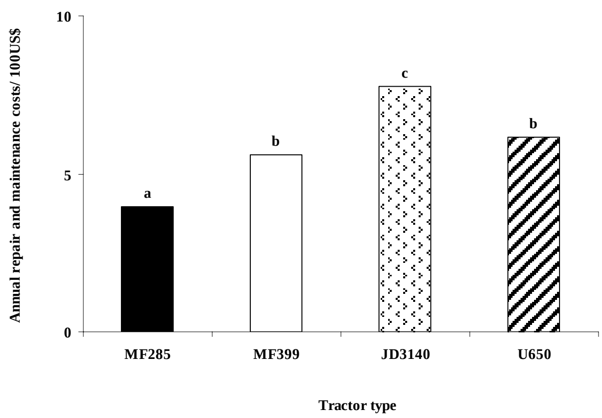

Fig. 3 Comparative analyses of annual repair and maintenance costs for tractor types

Fig. 4 is shown the changes on annual repair and maintenance costs based on failure rate for all tractors and the relationship between the calculated annual repair and maintenance costs and failure rate of tractors are given in equations. In this figure, the failure rate increase would lead to annual repair and maintenance costs increase for all tractors. But, of all the tractors, repair and maintenance costs of JD3140 tractors extremely affected by the failure rate increase, because of, JD3140 tractors were aged in comparison to other tractors surveyed and the most of their failures were major overhaul.

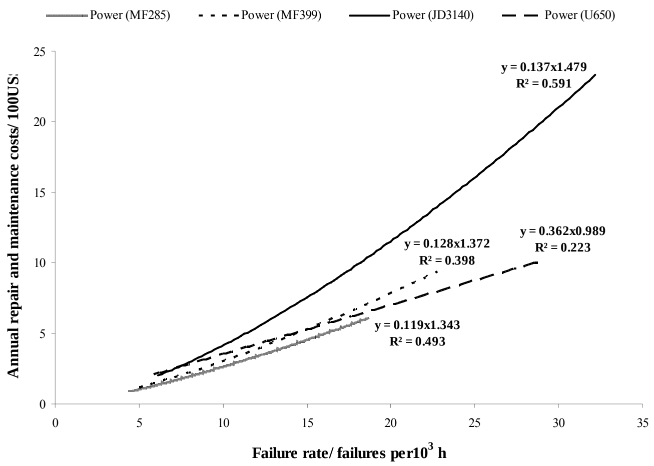

Fig. 4 Calculated annual repair and maintenance costs vs. failure rate for tractors surveyed

IV. Summary

Conclusions from this study can be summarized as follows:

1) The average failure rate of the MF tractors was quite near each other and U650 tractors had the highest failure rate in compared to all tractors.
2) The maximum average Annual repair and maintenance costs occurred in JD3140 and U650 tractors respectively while MF285 and MF399 tractors had the lowest values.
3) The failure rate increase would lead to annual repair and maintenance costs increase for all tractors. But, of all the tractors, repair and maintenance costs of JD3140 tractors extremely affected by the failure rate increase.

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