Failure rate analysis of four agricultural tractor models in southern Iran

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Abstract: Tractors play an important role in agricultural mechanization. A repairable mechanical system (as agricultural tractor) is prone to deterioration or repeated failures. In this study, the owners of three hundred tractors, which include Massey Ferguson (MF285 model and MF399 model), John Deere (JD3140 model) and Universal (U650 model), were interviewed, from five regions of Khouzestan Province. A regression model was used to predict the tractors failure rate. The machine failure pattern was carefully studied and key factors affecting the failure rate were identified in these regions. The data obtained from farm records valid by using questionnaire was separated into two groups according to how those tractors were stored. Results showed that the majority of recorded failures were observed in the electrical system for all tractors. According to the results of the research, different storage policies significantly affected the failure rate for MF285, MF399 and JD3140 tractors (63%, 55.5% and 61.6% respectively), whereas inside storage of U650 tractors slightly decreased the failure rate (7.4%). Also, closed storage condition was found to reduce annual repair and maintenance costs by 33.6%, 33.6%, 29.6% and 2.56% in comparison with open air storage condition for the study tractors respectively. The observational estimate showed that all tractors were in the wear out period under outside storage conditions, against inside storage had a considerable effect on the failure rate of MF285, MF399 tractors and they were commonly in a randomized breakdown period within their useful life, JD3140 tractors were in the beginning of wear out period, but U650 tractors were in the wear out period for both storage conditions. Therefore, it can be said that by storing the tractors out of the weather conditions slowly exposed by failure and breakdowns, especially in warm climate and presented of dust haze phenomenon.

Keywords: failure rate, tractor, storage condition, Khouzestan

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1 Introduction

One of the most important factors in obtaining the highest crop yield is timeliness, as an operation performed at an improper time may cause the loss of potential yield (Say and Sumer, 2011). In other words, under a particular combination of weather, soil type, topography and other related factors, there is an appropriate time to perform a particular field operation so that both the quality and quantity of a product reaches an optimum level (Kumar and Gross, 1977).

Today, tractor is one of the most important power sources in agriculture and represents a major component of farm fixed costs with its main share in planting,

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retaining and harvesting operations as well as in mechanization sector (Sonekar and Jaju, 2011; Asadi et al., 2010). The use of modern technology during latter decades resulted in rapid growth of farm production. Tractors and farm machinery are important examples of this modern technology (Singh, 2000). The quality of mechanization inputs, and consequently land and labor productivity in both situations, may differ considerably (Gifford and Rijk, 1980; Singh, 1997; Singh and Chandra, 2002).

Management of farm machinery is one of the important branches of farm management. Tractor break down can be very costly, not only from the stand point of the expenditure necessary to repair, but also because of the disastrous effect on crop productivity and the fact that idle staff must still be paid (Musa Abbas et al, 2011).

The storing place during the year is an important factor, since short duration periodic usage in agricultural production and prolonged storage are typical characteristics of agricultural machine operations (Severnev, 1984). In particular, the dimensions and properties of parts during prolonged storage change, as a result of corrosion (Say and Sumer, 2011). Parts such as belts, tires and hoses deteriorate rapidly when unprotected. Machinery stored inside had 7.6% downtime, while unhoused equipment was down 14.3% of the time it should have been working (Grisso and Pitman, 2009). Unavailability of the shed was the primary reason for tractors being stored outdoors (Paman et al., 2012). In addition, Khouzestan province is extremely affected by dust haze phenomenon (Fattahi et al., 2012). Dust storms can carry up to 100 million tons of sand over very long distances (Hassini et al., 2012). Dirt and dust in both the fuel and oil would cause excessive wear of the components (Paman et al., 2008). Jacobs et al (1983) claimed that dirty oil, a lack of oil or foreign objects can cause scratches and scores on pistons. If diesel engines work in very hostile conditions (such as a dusty environment), this will shorten the engine's service life due to the wear problem of the sliding parts, and consequently the combustion process will also be adversely affected, raising the possibility of forming combustion products that might mix with the lubricating oil cause corrosive wear of engine bores due to the formation of sulfuric acid (Al-Rousan, 2006). For example, if dust particles in the air range from 0.7 to 1.2 g m^{-3}, this means that 6-23 mg of dust particles would enter into the cylinder (Maev and Panomarev, 1971). The average concentration of all floating particles in Khouzestan province during the three years will amount to 7,576 μg per cubic meter. Furthermore, this province air temperature achieved up to 50°C at the summer, and for this reason, the storage places were considered in different grouping. In this paper, failure rate versus storing place of tractor during the year were modeled according to the exponential relationship of regression for four current types of agricultural tractors.

2 Materials and Methods

2.1 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, including Dezful, Andimeshk, Shush, Ahwaz and Behbahan. These regions were chosen because tractors are predominantly and frequently used in crop production and land preparation. 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 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 1.

Table 1 Technical feature 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, L	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, L 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, r min^{-1}	540	540/1000	540/1000	540
3-Point Hitch	Rear type II	Rear	Rear type II	Front and rear

Randomly 60 MF285, 102 MF399, 49 JD3140 and 89 U650 tractors were selected so as the total sample size was 300 tractors to represent whole state. While selecting the number of tractors from each model, statistical tool of stratified sampling method (proportional allocation based on the number of tractors in each model) was used. Stratified sampling method as given in Equation (1) was used to decide the number of tractors from each model.

$$\frac{n_1}{n} = \frac{N_1}{N} \tag{1}$$

where, n is the number of sample size; N is the population size (300 in this case of study); n_1 is the population unit (in this study it was number of tractors from each model); and, N_1 is the number of sample units (in this study it is the number of tractors in the province). Thus, the number of tractors from each model was calculated and is shown in Table 2. The number of surveyed MF399 tractors considered more than MF285 tractors because of MF399 tractors were more population compared to MF285 tractors in this province.

Table 2 Effective sampling size from each model

Tractor model	No. of tractors in each model	Effected sample size, No. of tractors surveyed
Massey Ferguson	8024	162
John Deere	2426	49
Universal	4441	89
Other	813	-
Total tractors	15704	300

2.2 Data collection

The tractor operators (also farmers) were interviewed at home or workplace by using face-to-face survey questionnaire. It was widely accepted that the failure frequency of farm machinery was mainly affected by annual hour used, repair – maintenance policies and operating environment (Severnev, 1984). All tractors were used in the same operating environment; hence, the storage place of the machinery during the year was selected as an effective factor and open air storage and closed storage of tractors were considered in grouping. Information was sought on tractor characteristics such as tractor age, use of tractor each year, failure number of each system, methods of storing tractors during fieldwork and off-season and economic costs. All definable failures causing any delay in different systems of the tractors excluding engine, hydraulic, transmission, electrical, brakes, steering, fuel, cooling, other systems (tire, ring, ball bearing and operator seat) were recorded. Furthermore, agricultural extension officers, local repair shop workers, and spare part shop owners were also asked to provide supplementary information. These data represented enough information for each given group.

2.3 Failure rate and failure types

The reliability of a machine is its probability to perform its function within a defined period with certain restrictions under certain conditions (ASABE, 2006; Billinton and Allan, 1992). 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 (Tufts, 1985). 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 Equation (2). 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 (3) as is suggested by Tufts (1985) and Billinton and Allan (1992).

$$MTBF = \frac{T}{n} \tag{2}$$

$$\lambda = \frac{1}{MTBF} \tag{3}$$

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.

Failures, in general, can be categorized into three basic types, though there may be more than one cause for a particular case. The three types are 1) early failures 2) random failures and 3) wear out failures. Failures in the early life stage, often referred to as infant mortality, are generally related to defects that escape the manufacturing process. The number of failures related to manufacture problems generally decrease as the defective parts fail leaving a group of defect free products. Thus, the early stage failure rate decreases with age. During the useful life, failures may occur due to freak accidents and mishandling that subject the product to unexpected stress conditions. The failure rate over the useful life is generally assumed to be very low and constant. As the product approaches the wear-out stage, the product degrades due to repetitive or sustained stress conditions. The failure rate during the wear out stage increases dramatically as more and more products fail due to wear out failures. When plotting the failure rate over time as depicted in the Figure 1, these stages form the so-called "bath tub" curve (Humphrey et al., 2002).

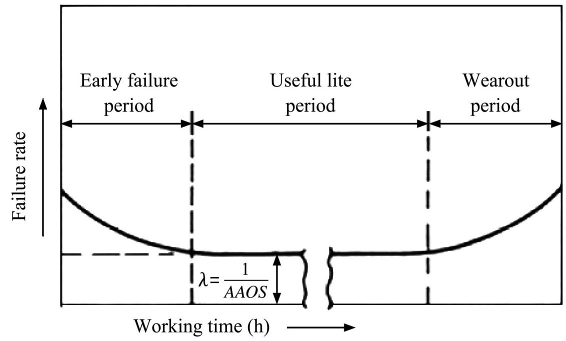


Figure 1 Failure rate curve (bathtub) for an ideal machine or machine part

2.4 Modeling method

In order to determine mathematical model for the study tractors, regression analysis was performed on the data. Exponential distribution is one of the most commonly used approaches to evaluate failure rates (Kumar and Gross, 1977; Billinton and Allan, 1992). For this reason, failure rate versus accumulated use hours were modeled according to the exponential relationship of regression. On the other hand, this modeling gave the highest R^2 values (depicted in each figure) in comparisons of each group to other regression models. Failure rate was estimated as the dependent variable and the accumulated use hours were obtained as independent variable. The relationship between failure rate and accumulated use hours of tractor were graphed and analyzed in Exponential model that it was specified in the following Equation (4).

$$Y = ae^{bx} \tag{4}$$

The mean working hours in per year was obtained, separately, for per class, after stratifying samples, which included the following Equation (5):

$$X_n = \sum_{i=1}^{n} x_i \qquad (5)$$

where, X is the accumulated use hours for the class n (h); n is the class number or age of the class tractors in unit year; x is the mean annual use hours for per class (h/year).

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 (Khoub bakht et al., 2010). 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 Equation (6) was suggested as final form of the repair and maintenance cost model.

$$Y = ax^b \qquad (6)$$

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 (Duncan, 1955). Different letters in the columns of curves indicate significant differences by Duncan test. Basic information on failure rate and accumulated use hours were then entered into Excel's spreadsheet and simulated by the computer software SPSS 21.0.

3 Results and Discussion

The average annual use hours, average age and accumulated hours of use in the machine's life are presented in Table 3. The average age and annual use hours of tractors while keeping the machine in outside storage were 14 years & 1,211 h, 10 years & 1,290 h, 26 years & 1,758 h and 22 years & 1,234 h for MF285, MF399, JD3140 and U650 tractors respectively. Correspondingly, the average age and annual use hours of machine during the inside storage were 14 years & 2,013 h, 11 years & 2,116 h, 26 years & 2,717 h and 24 years & 1,257 h for the above mentioned tractors respectively. As depicted in this table, the average annual use hours and age of the tractors for open air storage and closed storage are quite near each other. According to this table about 53% of the operators kept their tractors in outdoors. The lack of attention of some operators towards tractor care and maintenance was, in fact, caused not only by poor skill and knowledge, but also financial problems. Some farmers, for instance, have to leave their tractors outdoors even when they know the consequences of such action (Paman et al., 2012).

Table 3 Some descriptive data related hour used for groups

Group		Average annual use hours/h	Average age/year	Average accumulated use hours/h	Tractor number
Open–air storage	MF 285	1 211±72.40*	14± 1.25	17 764±1 889.43	29
	MF 399	1 290±49.46	10±0.51	14 239±949.50	59
	JD 3140	1 758±138.47	26±1.26	47 015±5 127.17	13
	U 650	1 234±39.50	22±0.55	27 780±1 316.08	58
Closed storage	MF 285	2 013±185.20	14±1.17	16 410±2 102.20	31
	MF 399	2 116±72.24	11±0.61	18 848±1 372.44	43
	JD 3140	2 717±120.48	26±0.71	33 717±2 079.80	36
	U 650	1 257±45.19	24±0.59	30 480±1 578.30	31

Note: *Standard error=standard deviation/ $\sqrt{\text{number}}$.

Table 4 presents failure types and their distribution as a percentage of total failure recorded in different systems of tractors including engine, hydraulic, transmission, electrical, brakes, steering, fuel, cooling, other systems (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 coincides 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. In addition, the cooling system caused the majority of recorded failures in open air storage group for MF285, MF399 and U650 tractors. Also, the most of failures occurred in this system for MF285, JD3140 and U650 tractors in closed storage conditions. The reason for the cooling system failures mostly involved ruptures in the fan belt. The failures of hydraulic system and other systems (tire, ring, ball bearing and operator seat) had the secondary share within the total recorded failures in open air storage conditions of JD3140 tractors and closed storage conditions of MF399 tractors, respectively. The hydraulic system failures were mainly due to ruptures and cracking in the hydraulic hoses, especially in provinces where exposed to sunlight was intense and temperatures were high. Breaks on the bearings were found as the most important reason for the failures connected to other systems (tire, ring, ball bearing and operator seat) of MF399 tractors, because belts, tires and hoses deteriorate rapidly when unprotected (Grisso and Pitman, 2009).

Table 4 Failure types and their distribution for tractors

System failure types	Failure numbers in Group/%							
	Open–air storage				Closed storage			
	MF 285	MF 399	JD 3140	U 650	MF 285	MF 399	JD 3140	U 650
Engine parts	12.73	13.40	14.00	12.65	6.27	8.19	13.16	11.77
Hydraulic	12.16	12.11	17.15	10.60	11.83	11.18	15.27	13.06
Transmission	11.40	13.07	10.40	12.42	11.30	12.63	8.32	10.30
Electrical	20.01	17.80	19.90	19.98	19.62	23.00	19.60	21.70
Brakes	3.12	5.15	7.66	6.50	4.30	4.82	5.53	6.27
Fuel	10.01	8.29	5.40	9.50	9.76	8.19	9.48	10.28
Steering	5.11	5.74	8.13	5.90	6.63	6.12	6.00	5.96
Cooling	16.48	14.19	13.54	13.83	18.46	11.48	16.22	15.06
Other systems	8.98	10.25	3.82	8.62	11.83	14.39	6.42	5.60

In open air storage conditions, the failure numbers of engine parts were higher than that of closed storage conditions for MF285, MF399, JD3140 and U650 tractors due to excessive wear of the components affected by dust haze phenomenon occurrence. The motor parts wear of MF285 and MF399 tractors had significant difference in open air storage conditions compared to closed storage conditions. Because of, the wear of sliding parts of diesel engines caused by ingress of particles getting into the system as contaminates from the dust will cause a significant wear to these parts. This wear increases with increasing particles amount and size (Al-Rousan, 2006).

Table 5 summarizes descriptive information regarding failure data derived from valid records for given groups. The maximum average failure numbers occurred in JD3140 and U650 tractors in open air storage conditions, while MF285 and MF399 tractors had the lowest values in both groups. This value encountered for open air storage groups of MF285, MF399, JD3140 and U650 tractors was 17.59, 18.82, 34.05 and 21.33 while it was 11.16, 13.06, 18.99 and 19.45 respectively for closed storage conditions.

Table 5 Some descriptive statistics of failures encountered in given groups

Group		Failure numbers		
		Minimum	Maximum	Average
Open–air storage	MF 285	2	29	17.59
	MF 399	2	41	18.82
	JD 3140	10	71	34.05
	U 650	3	62	21.33
Closed storage	MF 285	2	27	11.16
	MF 399	3	31	13.06
	JD 3140	6	35	18.99
	U 650	4	38	19.45

The average tractors failure rate while keeping the machines in outside was 13.8, 13.7, 17.7 and 16.3 failures per 10^3 h for MF285, MF399, JD3140 and U650 tractors respectively. Correspondingly, this value for inside storage was 5.1, 6.1, 6.8 and 15.1 failures per10^3 h for these tractors respectively. According to the results of the research, closed storage conditions was able to reduce the failure rate by 63%, 55.5%, 61.6% and 7.4% for MF285, MF399, JD3140 and U650 tractors, respectively as compared to open air storage conditions (Table 6). Therefore, closed storage conditions of the machinery clearly decreased the frequency of failure occurrence. Say and Sumer (2011) were agreed with these results. In open air storage conditions, JD3140 tractors had the highest failure rate among the other tractors in this province, while maximum failure rate was observed for U650 tractors compared to other machines in closed storage conditions. The minimum failure rate was found for MF tractors.

The calculated mean time between failures showed that failure occurrence for JD3140 and U650 tractors was greater where compared to MF285 and MF399 tractors. Several independent studies across various industries indicated that about 15% to 20% of equipment failures were age-related (Amari et al. 2006). Also, this study showed that the average age of JD3140 and U650 tractors was much more than the others. Presumably, the age increased tractors would cause excessive breakdowns. It can be stated that U650 and JD3140 tractors had the maximum failure rate resulted worn out and technological disabling.

In open air storage conditions, the annual repair and maintenance costs for MF285, MF399, JD3140 and U650 tractors were US$479.30, US$647.95, US$995.21 and US$658.64 respectively, against the value of these costs while keeping the tractors in closed storage conditions were 318.28, 430.29, 700.49 and 641.73 for the above mentioned tractors respectively. It has been an established fact that equipment stored inside has a significantly higher trade-in value compared to the same equipment stored outside (Grisso and Pitman, 2009). In this study, inside storage increased the trade-in value by US$10 to US$320, US$21 to US$529, US$5 to US$173 and US$13 to US$144 per year for MF285, MF399, JD3140 and U650 tractors respectively. Also, closed storage conditions was found to reduce these costs by 33.6%, 33.6%, 29.6% and 2.56% in comparison with open air storage conditions for the study tractors respectively. It is evident that reduction in these costs for U650 tractors was very low against other tractors. Furthermore, the effect of inside storage on reduction of repair and maintenance costs per year was found similar for MF tractors.

Table 6 Average failure rates and mean time between failures for groups

Group		Average failure rate, failures per10^3 h	Mean time between failures, h	Annual repair and maintenance costs, US$
Open–air storage	MF 285	13.8±0.73*	83±7.37*	479.30±50.59
	MF 399	13.7±0.61	85±5.34	647.95±53.36
	JD 3140	17.7±2.17	67±7.92	995.21±133.16
	U 650	16.3±0.74	69±3.26	658.64±53.96
Closed storage	MF 285	5.1±0.30	222±14.25	318.28±43.15
	MF 399	6.1±0.38	200±17.13	430.29±43.18
	JD 3140	6.8±0.25	155±6.33	700.49±68.70
	U 650	15.1±0.65	73±6.51	641.73±58.65

Note: *Standard error=standard deviation/ $\sqrt{\text{number}}$.

According to Figure 2, a significant difference was recorded where four types of tractors were compared for both storage conditions ($P \leq 0.01$). Failure rate of MF285 tractors was lower than the others in both storage conditions. Closed storage of U650 tractors showed maximum failure rate, while JD3140 tractors had been found as highest failure rate in open air storage group.

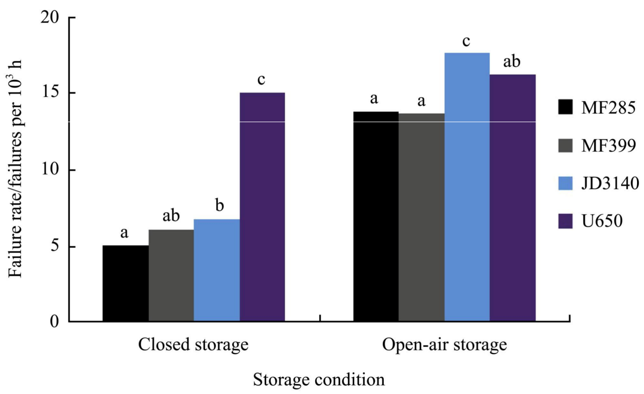


Figure 2 Effect of storage condition on tractors failure rate

Failure rate was increased for machinery stored outside compared to inside storage (Figure 3). Tractors stored outside significantly had more failure rate than the same tractors stored inside ($P \leq 0.01$). But as is shown in Figure 3, no storage condition was effective on U650 tractors failure rate, implying that there was no significant difference in different storage conditions for U650 tractors.

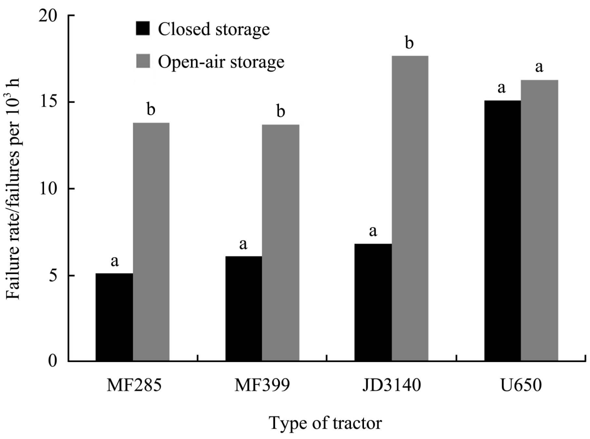


Figure 3 Comparative analyses for closed storage with open air storage for tractor types

One of the main objectives of this study was to explore the relationship between failure rate and accumulated use hours in some details. The relationship between calculated failure rate and accumulated use hours for each group are given in Figures 4, 5, 6 and 7 to provide a detailed evaluation of failure rate trends towards the wearing out period of machines. As Figure 4 indicates, there is a general trend that fits the exponential relationship towards the wearing out period of machine life in open air storage conditions for MF285 tractors, but with regards to replacement time for MF285 tractors 18,316 h was predicted (Khoub bakht et al., 2010), these tractors working under given conditions at 17764 accumulated use hours should be in the beginning of wear-out period with a mean time between failures value of 83 h, while outside storing caused wearing out of these tractors, against accumulated use hours in closed storage conditions (=16410 h) were lower than replacement time, these tractors were mostly in the useful life period. The randomized failure period, with a mean time between failures value of 222 h, is valid due to a closed storage environment comparing to open air storage. As it is shown in Figure 5, while machine accumulated working hours is raised, failure rate is increased for MF399 tractors in open air storage. Therefore, MF399 tractors with a mean time between failures value of 85 h provides an obvious indication of wear out period entrance based on the exponential regression model, while these tractors were clearly in the randomized failure period, with a mean time between failures value of 200 h in closed storage conditions.

According to the pattern shown in Figure 6, JD3140 tractors provide an obvious indication of wear-out period entrance, with a mean time between failures value of 67 h, based on the exponential regression model in open air storage conditions, but machines in closed storage group obviously tend to enter the wear out period with a mean time between failures value of 155 h. Despite that these tractors were aged, they were at the beginning of wear out period under closed storage conditions. As can be seen from this case, closed storage conditions could be decreased wearing out of tractors, against U650 tractors were in the wear out period for open air storage and closed storage conditions (Figure 7). As depicted in Table 4, the average failure rate and mean time between failures were quite near each other at 16.3 failures per 10^3 h and 69 h for open air storage conditions and 15.1 failures per 10^3 h and 73 h for closed storage conditions respectively. Therefore, the storage conditions did not show different effect on the failure rate due to the age increase and wear outing in this model of tractors.

It seems that storage conditions had effective impact on reducing failure rates in four agricultural tractor models, as this effect was significant on failure rate of MF285, MF399 and JD3140 tractors, but closed storage conditions slightly decreased the failure rate for U650 tractors. Therefore, by out of weather storing tractors during working season and off-season coinciding with Say and Sumer (2011) who found that decreased machine failure rate.

Figure 8 is shown the changes on annual repair and maintenance costs based on failure rate for all tractors. In this figure, the failure rate increase would lead to annual repair and maintenance costs increase for all tractors in both storage conditions. But, of all the tractors, repair and maintenance costs of U650 tractors affected by the storage conditions. There was no considerable difference between storage conditions for MF285, MF399 and JD3140 tractors. Since, it was seen that storage conditions have slightly affected the trends of repair and maintenance costs.

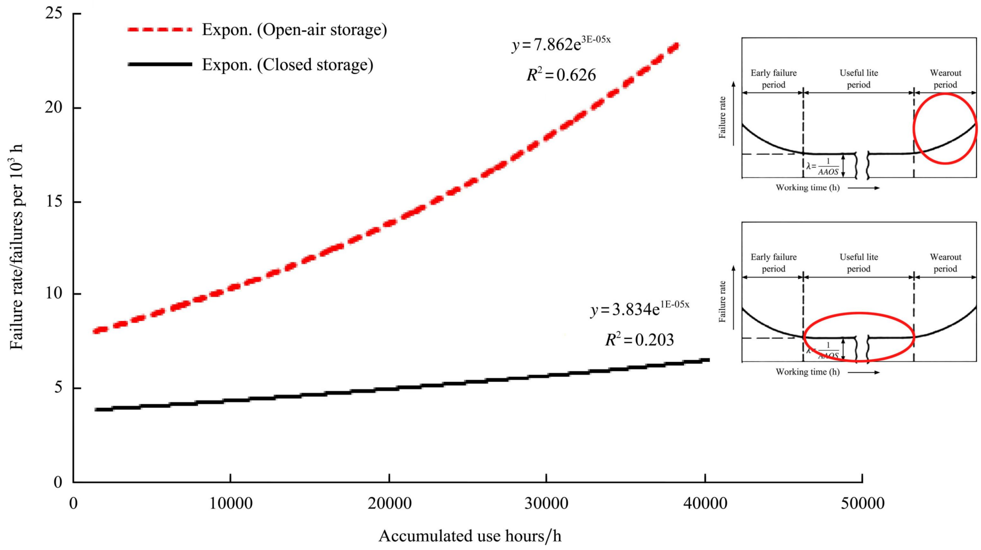


Figure 4 Calculated failure rates vs. accumulated use hours for MF285 tractors

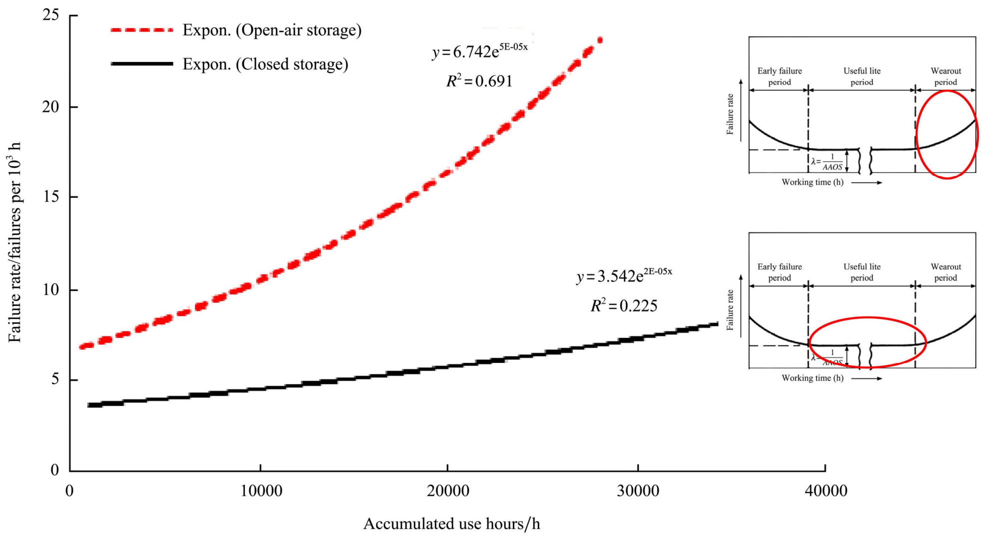


Figure 5 Calculated failure rates vs. accumulated use hours for MF399 tractors

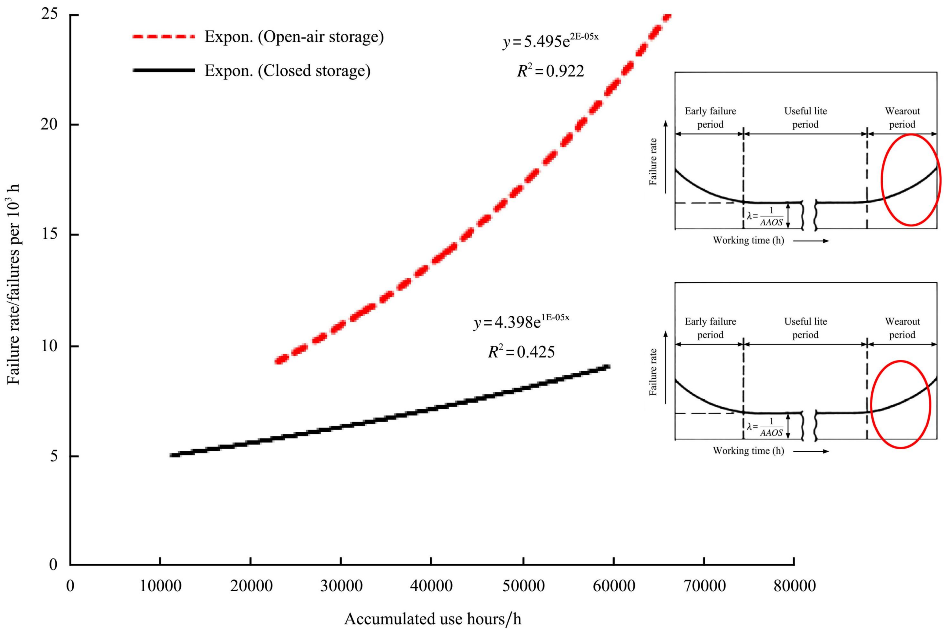


Figure 6 Calculated failure rates vs. accumulated use hours for JD3140 tractors

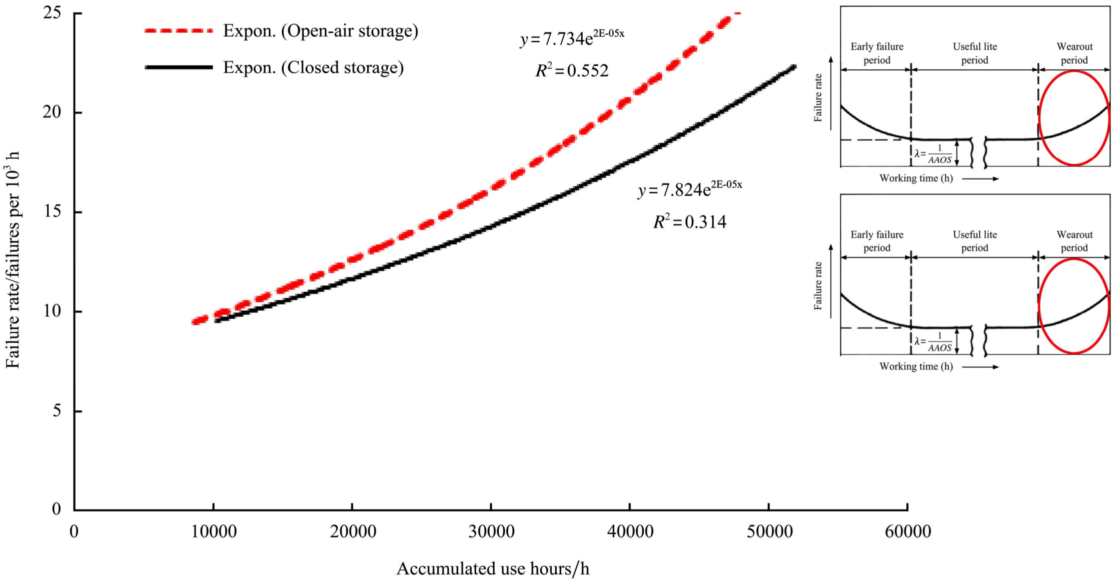
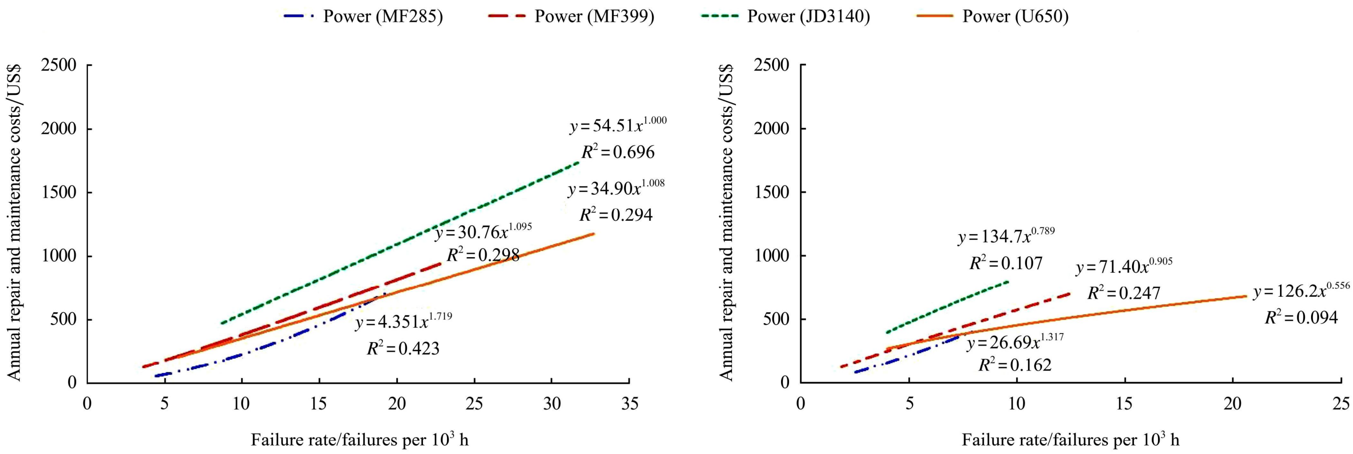


Figure 7 Calculated failure rates vs. accumulated use hours for U650 tractors



a. Open-air storage b. Closed storage

Figure 8 Calculated annual repair and maintenance costs vs. failure rate for all tractors

4 Conclusions

An effective model to predict the failure rate of farm machinery is crucial for accurately estimating the number of spare parts required. It also helps to decrease extra repair and maintenance costs caused by delay. As this study shows, keeping tractors out of the weather can decrease failure rates, especially in warm climate and phenomenon dust haze. Therefore, farmers should be encouraged to perform good care and maintenance by storing tractors in storage place during the working season and off-season due to wear out tractors different parts in open air storage condition, particularly for new tractors. Therefore, storing new tractors inside is in the first degree of importance and keeping the old tractors out of the weather conditions is the second degree of importance.

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