Technical and economical comparison of different maintenance conditions for MF 399 tractor in southwest of Iran

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Abstract: The use of tractors for agricultural works showed an important role to mechanized agricultural sector. A repairable mechanical system (as agricultural tractor) is subject to deterioration or repeated failure. In this study, the regression model was used to predict the failure rate of MF399 tractor. The machine failure pattern was carefully studied and key factors affecting the failure rate were identified in five regions of Khouzestan province. The tractors grouped in four sub groups according to annual use hours and maintenance policies (corrective maintenance and preventive maintenance). Results showed that the majority of recorded failures were observed in the electrical system (20.3%) for each machine sub-group. Maximum and minimum annual repair and maintenance costs were related to other (tire, ring, ball bearing and operator seat) and brake system respectively. According to the results of the research, different annual use hours and maintenance policies affected failure rate. The tractors included in 300-1,000$_{PM}$ subgroup were mostly in the useful life period while the machines were towards the wearing out period of machine life for 300-1,000$_{CM}$ subgroup. The tractors maintained under 1,200-2,000$_{PM}$ subgroup showed an obvious indication of wear-out period entrance, while the tractors were mostly in the wear-out period for the 1,200-2,000$_{CM}$ sub group. The tractors included in 300-1,000 annual use hours were commonly in a randomized breakdown period during their useful life but these tractors tend to enter the wear out period in the 1,200-2,000 annual use hours. So, annual use hours were more effective on failure rate in comparison with maintenance policies.

Keywords: failure rate, maintenance condition

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1 Introduction

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, retaining and harvesting operations and then in mechanization sector (Sonekar and Jaju, 2011; Asadi et al., 2010). For modern farming, for example, it makes up as much as 40% of the total investment (Henderson and Guericke, 1985). The success of the investment depends greatly on operating costs, which, in turn, are influenced greatly by the quality of repair and maintenance. Rahmoo et al. (1979) stated that the economic benefits from a tractor depend upon the efficient manner of its use. Therefore, tractor should be maintained correctly to ensure effectively working for a long period without any breakdown and thus provide a much benefit to its owners. A tractor that breaks down must be prematurely replaced incurs large expenses and wastes the investment. From an economic point of view,

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idleness due to machinery breakdowns can be very costly as a result of lost working time (Jacobs et al., 1983). Repairs of broken down machines are also expensive (Hunt, 1971), because the breakdowns consume resources: manpower, spare parts, and even lose of production (Dodson, 1994). Consequently, the repair costs become an important component of the total machine ownership costs (Ward et al., 1985). Traditional maintenance policies include corrective maintenance (CM) and preventive maintenance (PM). With CM policy, maintenance is performed after a breakdown or the occurrence of an obvious fault. With PM policy, maintenance is performed to prevent equipment breakdown (Amari et al., 2006). As an example, it is indicated that in developing countries approximately 53% of total machine expenses have gone to repair machine breakdown ascompared to 8% in developed countries (Inns, 1978), that these costs could be decreased up to 50% by establishing the effective repair and maintenance program (Khodabakhshian et al., 2008).

The use of tractors instead of hand tools and animal-drawn implements requires special management ability and skills as well as adequate service support facilities. However, the use of the farm machines in Khouzestan province has increased considerably without a corresponding program for training farmers and agricultural extension officials, and without sufficient service and maintenance facilities to support efficient and economic tractor use at the farm level. Under such circumstances, the average life of a machine therefore becomes shorter because it is difficult for farmers to repair tractors when they break down. Tractor breakdown was found to be one of the main problems in hand tractors operation in Khouzestan province. There fore, failure rate versus accumulated use hours of tractor were modeled according to the exponential relationship of regression for four groups using annual use hours and maintenance programin this paper.

2 Material and Methods

The experiment was conducted in Khouzestan province, one of the arid and semiarid agricultural region in southwest ofIran. Data was collected from agricultural mechanization service enterprisesin 2012. The five regions including Dezful, Andimeshk, Shush, Ahvaz and Behbahan were selected for this study. These locations were selected specifically to represent the main tractor operational conditions encountered in Khouzestan province. 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. Sixty seven tractors and their owners were selected for sample. The corrective maintenance (CM) and preventive maintenance (PM) were considered in different groups. All tractors were used in the same operating environment. Since, the repair – maintenance policies of the machinery during the year was selected as an effective factor. The relationship between failure rate and accumulated use hours of tractor were graphed and analyzed by regression analysis according to the following subgroups:

1) 300 to 1,000 $_{\mathrm{PM}}$ (14 machines)
2) 300 to 1,000 $_{\mathrm{CM}}$ (19 machines)
3) 1,200 to 2,000 $_{\mathrm{PM}}$ (9 machines)
4) 1,200 to 2,000 $_{\mathrm{CM}}$ (25 machines)

Failure rate (λ) was equal to the reciprocal of the mean time between failures (MTBF) defined in hours, and its Equation (1) and Equation (2) was as follows (Tufts, 1985; Billinton and Allan, 1992):

$$MTBF = \frac{T}{n} \tag{1}$$

$$\lambda = \frac{1}{MTBF} \tag{2}$$

where, $MTBF$ is mean time between failures in hour; T is total time in hour; n is number of failures; λ is failure rate, failures per 10^3 hour.

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 escaped from 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).

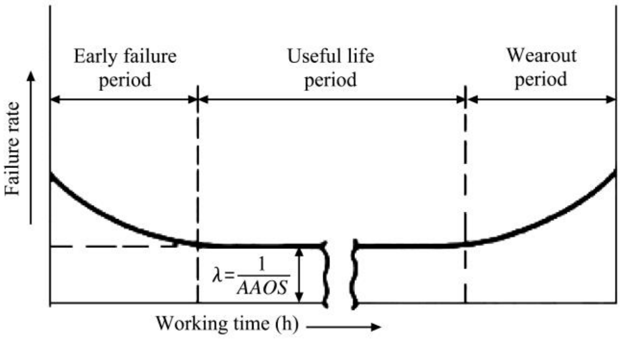

Figure 1 Failure rate curve (bathtub) for an ideal machine or machine part (Say and Sumer, 2011)

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 (3):

$$Y = ae^{bx} \tag{3}$$

The mean working hours in per year was obtained, separately, for per class, after stratifying samples, which included the following Equation (4):

$$X_n = \sum_{i=1}^{n} x_i \tag{4}$$

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/y).

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 meanvalues were based on Duncan’s multiple range tests (Duncan, 1955). Different letters in the columns ofcurves 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

Table 1 presents failure types and their distribution in different systems of the MF399 tractors included engine, hydraulic, transmission, electrical, brakes, steering, fuel, cooling, other systems (tire, ring, ball bearing and operator seat) as a percentage of total failures data derived from farm records. As indicated, the electrical system caused the majority of recorded failures, 20.3%. Also, the electrical system failures made up the majority in each machine sub-group. The reasons for the electrical system failures generally were due to short life of the battery (24.33%) and dynamo (11.57%) in this type of tractor. 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 failures of cooling system (14.3%) had the secondary share within the total recorded failures in this tractor. Other failures occurred in transmission, other systems, hydraulic, engine, fuel, steering and brake systems. Most failures of transmission system occurred in gear systems (44%). Their failure types were fracture, surface fatigue, abrasion and plastic deformation in gear mechanisms. Fracture damage resulted from surface fatigue, high loads or abrasions. Surface fatigue results from tensile stress, compression stress and sliding stress under the gear surface. Abrasion damage is defined as loss of material at touching gear surfaces (Akinci et al., 2005). The most failures in other systems related to tires (33.51%), wheel bearings and wheel bolts/nuts (32.44%) which suffered excessive wear due to operation. Therefore 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. The hydraulic system failures were mainly due to ruptures and cracking in the hydraulic hoses (25.39%), especially in provinces where exposed to sunlight was intense and temperatures were high. Interviews with farmers revealed that failure to change oil at the correct times had caused the engine troubles. Meanwhile, most injection nozzles suffered damages due to fuel and oil. These also caused plunger, piston, and piston ring defects (32.96%). Presumably, dirt and dust in both the fuel and oil would have caused excessive wear of the components. Jacobs et al. (1983) claimed that dirty oil, a lack of oil, or foreign objects can cause the scratches and scores on the pistons. The most of fuel, steering, brake and cooling systems failures referred to fuel transfer pump (26%), steering box (80.64%), lining (66%)and fan belt (37.1%) respectively.

Table 1 Failure types and their distribution

Failure types	Failure numbers				Total	%
	1	2	3	4		
Engine	10	22	12	61	105	11.64
Hydraulic	19	18	10	59	106	11.75
Transmission	9	17	25	62	113	12.52
Electric	24	40	27	92	183	20.3
Brake	2	6	11	22	41	4.54
Steering	4	9	10	24	47	5.21
Fuel	4	16	16	32	68	7.54
Cooling	6	19	20	84	129	14.3
Other	8	27	18	57	110	12.2
Total	86	174	149	493	902	100

The average annual use hours and average age are presented in Table 2. As depicted in the table, the average annual use hours for 300-1,000 and 1,200-2,000 main groups were 753.03 and 1,445.73 respectively. The average age for all sub-groups was almost close to each other. The machine numbers in the CM sub-groups in the both main groups were higher than that of the PM. It was due to about 66% operators kept their tractors in the CM conditions. Because of only a minority of farmers performed maintenance on a regular basis. Hose leaks were maintained most frequently by the farmers, while air cleaners were maintained least frequently. Other maintenance targets, such as oil levels, belt tension, fuel sediment bowls, and lubrication were only occasionally checked (Paman et al., 2012). Maintenance before failure is a key part of safe and efficient operation in the field (Butterworth, 1984). For example, low oil levels reduce the degree of lubrication and thus cause premature failure (Jain and Rai, 1980). However, most farmers are accustomed to sending a tractor to a repair shop for service only after it has limited functionality or has stopped operating completely. In addition, it was also found that inadequate finances led many farmers to ignore tractor maintenance (Paman et al., 2008).

Table 2 Some descriptive data related use hours for given sub-groups

Sub group	Average annual use hours (h)	Average age (y)	Number of machines
1	721.428±59	7.64±0.85	14
2	776.31±47.35	8.47±1.32	19
Average/Total	753.03±36.73	7.81±0.7	33
3	1420.22±49.08	8.33±0.91	9
4	1465.2±41.01	8.96±0.57	25
Average/Total	1453.42±32.65	8.79±0.48	34

Some descriptive statistics of failures data in given sub-groups are summarized in Table 3. Average failure numbers calculated in the CM groups and also for 1,200-2,000 groups were higher than the PM and 300-1,000 groups, respectively. The maximum and the minimum values of the failure numbers for the 1,200-2,000 $_{\text{CM}}$ sub-group were greater when compared to other sub-groups. Most machines fail because of neglect and the lack of properly scheduled maintenance (Paman et al., 2008). In addition, according to Say and Sumer (2011) that increased annual use hours will increase the future failure frequency.

The average failure rates calculated in Table 4 specified the effects of the annual working hours and maintenance conditions. As indicated, the average failure rate values in the 1,200-2,000 sub-groups were higher than the 300-1,000 sub-groups. Additionally, these values in the CM sub-groups were most of the PM sub-groups. Therefore, it seems that the PM conditions of the machinery decreased the failure occurrence frequency. Timely preventative maintenance and inspection will not only help reduce major problems and downtime, it will also help identify problems when they can be corrected with relatively minor repairs (Grisso and Pitman, 2009; Lane, 2007). Aneke (1994) and Amari et al. (2006) reported that poor maintenance caused the major failures.

Table 3 Some descriptive statistics of failures encountered in given sub groups

Sub group	Number of failures			
	Min	Max	Average	Total
1	3	15	6.14±0.9	86
2	3	20	9.16±1.14	174
Average/Total	3	17.5	7.87±0.79	260
3	13	21	16.55±0.93	149
4	13	32	19.72±1.18	493
Average/Total	13	26.5	18.88±0.93	642

Table 4 Average failure rates and mean time between failures for sub-groups

Sub group	Average failure rate (failures per 10^3 h)	Mean time between failures (h)
1	0.0082±0.00077	132.21±9.34
2	0.0113±0.00094	100.93±9.23
Average/Total	0.0093±0.00056	114.2±7.08
3	0.0117±0.0006	87.48±5.08
4	0.0134±0.00064	78.37±3.36
80.78±2.86	Average/ Total	0.013±0.0005

The relationship between the calculated failure rate and the accumulated use hours of tractor for each sub-group with their equations are given in Figure 2, Figure 3, Figure 4 and Figure 5. Predicted failure rate in the 1,200-2,000 and CM sub-groups were higher than that the 300-1,000 and PM sub-groups, respectively. It showed the annual use hours and type of maintenance conditions slightly affected MF399 tractor failure rate.

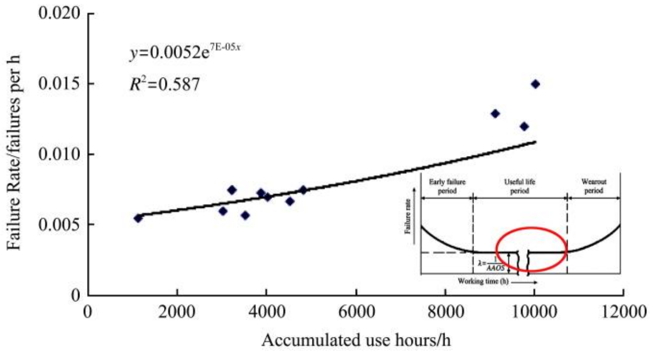

Figure 2 Calculated failure rates vs. accumulated use hours of tractor for 300-1,000$_{PM}$ subgroup

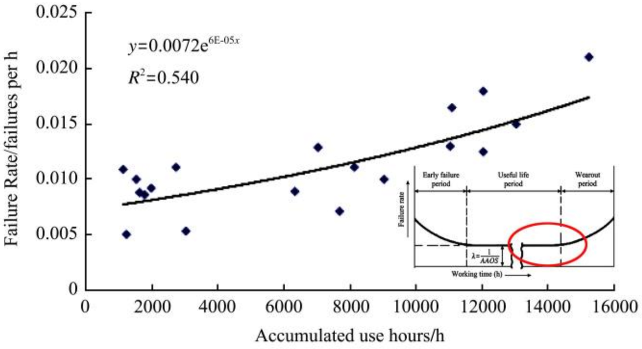

Figure 3 Calculated failure rates vs. accumulated use hours of tractor for 300-1,000$_{CM}$ subgroup

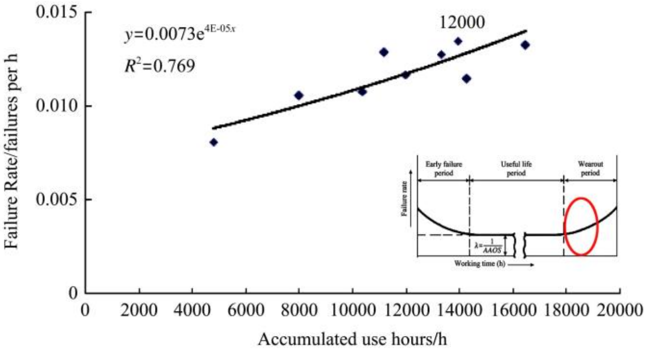

Figure 4 Calculated failure rates vs. accumulated use hours of tractor for 1,200-2,000$_{PM}$ subgroups

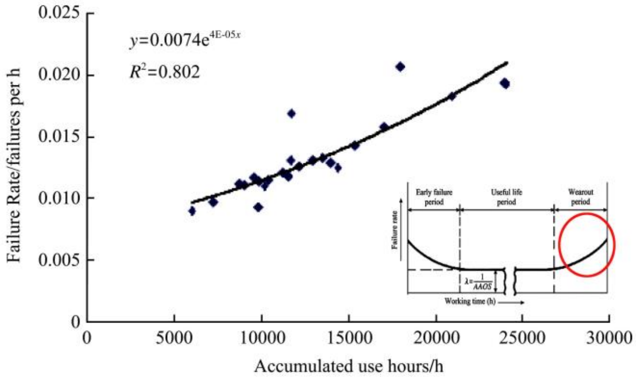

Figure 5 Calculated failure rates vs. accumulated use hours of tractor for 1,200-2,000$_{CM}$ subgroup

According to the Figure 2 pattern, MF399 tractors in the 300 to 1,000$_{PM}$ sub-group were mostly in the useful life period. The randomized failure period with a mean time between failures value of 132.21 h is valid due to a proper maintenance conditions and a slightly decreased accumulated use hour comparing with the 300-1,000$_{CM}$ sub-group. As Figure 3 indicated, there is a general trend that fits the exponential relationship towards the wearing out period of machine life for the 300 to 1,000$_{CM}$ sub-group. Additionally, MF399 tractors working under given conditions at 14,000 accumulated use hours were almost in the beginning of wear-out period with a mean time between failures value of 100.93 h. In the 1,200-2,000$_{PM}$ sub-group with a mean time between failures value of 87.48 provides an obvious indication of wear-out period entrance based on the exponential regression model (Figure 4). Lastly, the relationship between failure rates versus accumulated use hours for the 1,200 to 2,000$_{CM}$ sub-group was depicted in Figure 5. It shows that MF399 tractors in this sub-group were mostly in the wear-out period with a mean time between failures value of 78.37 h. Machines in the 1,200 to 2,000 annual use hours main group were obviously in a nearer position to the wear-out period, than that of the 300 to 1,000 annual use hours main group, since increased Annual use hours have an effect on failure frequency increase.

According to Figure 6, a significant difference between annual repair and maintenance costs was recorded where four sub groups were compared for different systems of MF399 tractors ($P \le 0.05$), as highest difference was illustrated at engine, hydraulic, transmission and other systems (tire, ring, ball bearing and operator seat). Annual repair and maintenance cost of brake system was lower than the others in all sub groups. Other systems (tire, ring, ball bearing and operator seat) showed maximum annual repair and maintenance costs in sub groups 2, 3 and 4, while electric system had been found as highest annual repair and maintenance costs in 300-1,000$_{PM}$ subgroup. Annual repair and maintenance costs were increased for systems of machinery applied under 1,200-2,000$_{PM}$ and 1,200-2,000$_{CM}$ subgroups compared to 300-1,000$_{PM}$ and 300-1,000$_{CM}$ sub groups (Figure 6). Tractors applied under 1,200-2,000 h significantly had more annual repair and maintenance costs than the same tractors applied under 300-1,000 ($P \le 0.05$). As is shown in Figure 6, annual use hours was more effective on annual repair and maintenance costs in comparison with maintenance policies (CM and PM), implying that there was significant difference between both annual use hours groups for different systems.

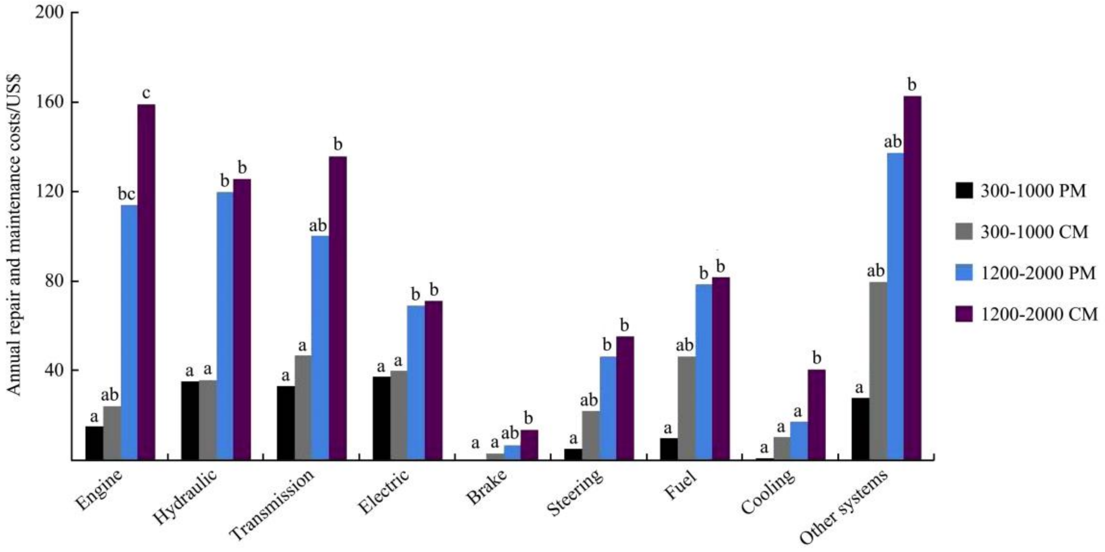

Figure 6 Annual repair and maintenance costs comparison for different systems of MF399 tractors

4 Conclusions

Based on the present study the following conclusions are drawn:

1) The majority of recorded failures were observed in the electrical system for each machine sub-group.

2) Maximum and minimum annual repair and maintenance cost was related to other (tire, ring, ball bearing and operator seat) and brake system respectively.

3) The tractors included in 300-1,000$_{PM}$ subgroup were mostly in the useful life period while the machines were towards the wearing out period of machine life for 300-1,000$_{CM}$ subgroup. The tractors maintained under 1,200-2,000$_{PM}$ subgroup showed an obvious indication of wear-out period entrance, while the tractors were mostly in the wear-out period for the 1,200-2,000$_{CM}$ sub group.

4) The tractors included in 300-1,000 annual use hours were commonly in a randomized breakdown period

during their useful life but these tractors tend to enter the wear out period in the 1,200-2,000 annual use hours 4.5. The annual use hours and maintenance policies affected failure rate, as annual use hours were more effective on failure rate in comparison with maintenance policies.

References

Akinci, I., D. Yilmaz, and M. Canakci. 2005. Failure of a rotary tiller spur gear. *Engineering Failure Analysis*, 12(2005): 400–404.

Amari, V., L.McLaughlin, and H. Pham. 2006. Cost-effective condition-based maintenance using Markov decision processes. Reliability and Maintainability Symposium 2006 (RAMS '06). In *The Institute of Electrical and Electronics Engineers (IEEE) Conference,* 464-469.

Aneke, D. O. 1994. A Survey of farm power problem in Nigeria. *Applied Engineering in Agriculture,* 10(5): 623-626.

Asadi, M. R., M. Rasekh, A. Golmohammadi, A. Jafari, K. kheiralipour, and A. M. Borghei. 2010. Optimization of connecting rod of MF-285 tractor. *Journal of Agricultural Technology,* 6(4): 649-662.

Billinton, R., and R. N. Allan. 1992 . *In Reliability evaluation of engineering systems (Concepts and techniques),* 453. New York, London: Plenum Press.

Butterworth, B. 1984. In Farm tractors: *The case guide to tractor selection, operation, economic and maintenance.* London: E & F N Spon (An imprint of Routledge); 1st edition.

Dodson, B. 1994. Determining the optimum schedule for preventive maintenance. *Quality Engineering*, 6(4): 667-679.

Duncan, D. B. 1955. Multiple range and multiple F tests. *Biometrics,* 11: 1-42.

Grisso, R. D., and R. Pitman. 2009. In Five strategies for extending machinery life.Communications and Marketing, College of Agriculture and Life Sciences,Virginia Polytechnic Institute and State University:442-451.

Henderson, H. D., and W. Guericke. 1985. Economics of tractor operation in Swaziland. *Agricultural Mechanization in Asia, Africa and Latin America*, 16(4): 11-16.

Humphrey, D., W. Shawlee, P. Sandborn, and D. Lorenson. 2002. *Utilization life of electronic systems-aging avionics usable life and wear out issues.* Society of Automotive Engineers (SAE) Technical Paper, Inc.

Hunt, D. 1971. Equipment reliability: Indiana and Illinois data. *Transactions of the ASAE*, 14(5): 742-746.

Inns, F. M. 1978. Operational aspect of tractor use in developing countries: a case for the small tractor. *The Agriculture Engineer,* Summer Issue: 52-54.

Ishola, T. A., and J. S. Adeoti. 2004. A study of farm tractors reliability in Kwarastate of Nigeria. In *Proc.5th International Conference and 26TH Annual General Meeting Ilorin 2004*: 75-84.Ilorin, Nigeria, 28 November– 2 December.

Jacobs, C. O., W. R. Harrell, and G. C. Shinn. 1983. *In Agricultural power and machinery.* New York: McGraw-Hill, Inc.

Jain, S. C., and C. R. Rai. 1980. *In Tractor engine maintenance and repair*. New Delhi: Tata McGraw-Hill Publishing Company Limited.

Khodabakhshian Kargar, R., M. Shakeri, and J. Baradaranmotie. 2008. Preventive maintenance engineering and conditionmonitoring in the road construction equipment. In *Proc. 5thInternational Conference on Maintenance*: 44-55. Tehran, Iran, 28 - 29 October.

Kumar, R. J., and R. Gross. 1977. A study of combine harvester reliability. *Transactions of the ASAE,* 20(1): 30-34.

Lane, P. 2007. *Evaluation of the mechanical condition of agricultural vehicles*. BAGMA Cranfield University. Health and Safety Executive (HSE) books. 37 pp.

Paman, U., S. Uchida, and S. Inaba. 2012. Operators' capabilityand facilities availability for repair and maintenance of smalltractors in Riau province, Indonesia: a case study. *Journal ofAgricultural Science*, 4(3): 71-78.

Paman, U., S. Uchida, S. Inaba, and T. Kojima. 2008. Causes oftractor breakdowns and requisite solutions a case study of smalltractor use in Riau province, Indonesia. *ASEAN Journal on Science and Technology for Development (AJSTD),* 25(1): 27-36.

Rahmoo, A. A., H. D. Henderson, and G. E. Thierstein. 1979. Costs of owning and operating tractors in Tharparkar District of Sind, Pakistan. *Agricultural Mechanization in Asia*, 10(4): 27-30.

Say, S. M., and S. K. Sumer. 2011. Failure rate analysis of cereal combined drills. *African Journal of Agricultural Research,* 6(6): 1322-1329.

Sonekar, M. M., and S. B. Jaju. 2011. Fracture analysis of exhaust manifold stud of mahindra tractor through finite element method (FEM) - A past review. *International Journal of Engineering and Technology*, 3(2): 131-135.

Ward, S. M., P. H. McNulty, and M.B. Cunney. 1985. Repair costs of 2 and 4 WD tractors. *Transactions of the ASAE,* 28(4): 1074-1076.

Tufts, R. A. 1985. Failure cause, frequency, and repair for forest harvesting equipment. *Transactions of the ASAE*, 28(4): 1673-1677.