Determining the reliability function of farm tractors

M. Poozesh, S.S. Mohtasebi, H. Ahmadi and A. Asakereh

Agricultural Machinery Engineering Department, University of Tehran, Karaj, Iran.

ABSTRACT

There is an optimum time for implementing field operation of various crops in each region. If the operation is accomplished sooner or later, it will cause a reduction in yield quantity and quality. The cost of this reduction is named "timeliness cost". Annual timeliness cost is estimated by an equation reported in ASAE standards. MF285 tractors have low reliability in Iran. Generally, low tractor reliability has an uncertainty in implementation of farm operation which it is not considered in ASAE equation for calculating of timelines cost. This uncertainty causes a cost being a part of timeliness cost and is produced due to tractor failure within farm operation. The purpose of this study was to determine the reliability function of MF285 tractors operated in Debal Khazaei Agro-Industry Co. in Khuzestan province of Iran. Thus, in this study a function-fit model for reliability of farm tractors was determined. Afterwards, tractors working times to a failure (hours) in tenth year of tractor life were fitted with normal, exponential, lognormal, poisson and weibull age distribution functions using moment estimation. Depending on Chi square test, the best reliability function for this given situation was exponential distribution function with $\lambda = 0.025$.

Introduction

Today, tractor is one of the most important power sources in agriculture (Singh, 2006). Farm tractors must be maintained and kept in good repair condition if they would render efficient service (Beppler and Hummeida, 1985). Its versatility and high efficiency have made it suitable for most field and barnyard operations. However, the need for high management skills and susceptibility of tractors to breakdown has made its maintenance very imperative. Timeliness in farm operations is a crucial factor for successful agricultural operations. Farm tractors failure, especially, during the engaged part of the season, causes delays which result in losses and inefficient labour utilisation. As more and more capital in the form of machinery replaces manual labour on the farm, the reliability of this equipment assumes greater importance. Indeed, deeper insight into failures and their prevention is to be gained by comparing and contrasting the reliability characteristics of systems that make up the tractor (Amjad and Chaudhary, 1988). Reliability is defined as the probability that the equipment or system will complete a specific task under specified conditions for a stated period of time (Ebeling, 1997). Hence, reliability is a mathematical expression of the likelihood of satisfactory operation. A failure may be referred to as any condition which prevents operation of a machine or which causes or results in a level of performance below expectation. The failure rate of a population of items for a period of time t_1 to t_2 is the number of items which fail per unit time in that period expressed as a fraction of the number of non-failed items at time t_1. Hence, in reliability, the reciprocal of failure rate is the mean time to failure [MTTF] (Wingate-Hill, 1981). Amjad and Chaudhary (1988) reported that machine failures can be categorised into: early life failures, random failures and wear-out. Likewise, Lewis (1987) asserted that reliability considerations appear throughout the entire life cycle of a system. He claimed that the data collection on field failures are particularly invaluable because they are likely to provide the

only estimate of reliability that incorporates the loading, environmental effects and imperfect maintenance found in practice. At both component and system levels, such a database is invaluable for predicting the reliability of future design and for improving design. Owing to the importance of timeliness of operations in obtaining high yields, machinery breakdown especially at busy period such as sowing or harvest can lead to large losses of revenue quite apart from the cost of repairing the equipment. If estimates could be made of when equipment is likely to fail, this would assist in planning machinery purchases and spare parts inventories and reduce costs.

The results of numerous individual experiments confirm that the crop yield changes in a predictable way related to the timing of various filed operations (witeny, 1985). Unless the enterprise is on a very small scale or the machine used is very large, it is unlikely that the operation can be completed at the scheduling time. This inability to complete an operation within a short period incurs a penalty which increases on a daily basis as the duration of the period is extended (Fig. 1). The evaluation of this penalty cost requires the selection of a unique yield/time response for a multiplicity of crop yield experiments (witeny, 1985).
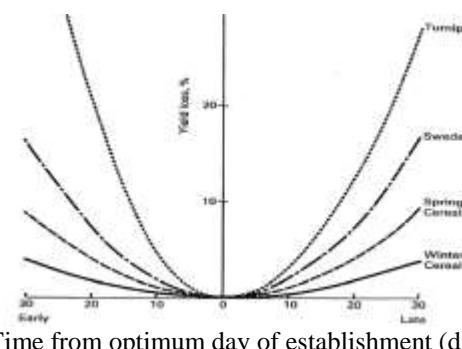
Time from optimum day of establishment (day)
Fig 1. Percentage yield loses from untimely crop establishment

Tele:
E-mail addresses: Asakereh@ut.ac.ir

Generally, three factors cause to timeliness of operation: machines reliability decrease, absence of accurate or optimum scheduling and needed machines false prediction. If field scheduling is optimum and needed machines for field operation are predicted properly but tractor reliability is low, due to field failures, field operation would break down and a part of scheduled times would loss (Almasi et al., 2008).Tractor is the most determinant implement in on time accomplishment of field operation (Girard and Hubert, 1999). Today, tractor is one of the most important power sources in agriculture (Singh, 2006). Financial losses coming from machine reliability decrease and also continual machine failures and farm breakdowns, aren't included by Iranian farmers (Ashtiani et al., 2006). According to Iran Tractor Manufacturing Company (ITMCO) reports the number of MF285 tractor manufacturing is greater than the other one. Averagely, 17000 MF285 tractors and 5000 MF399 tractors are produced per year. On the other hand the most popular tractor of farmers is MF285 in Iran. Therefore, it's better to determine reliability function of MF285 tractors in Iran.

Khodabakhshian et. al (2009) did a study in order to recognize the causes of tractor parts failure and also to determine the approximate failure statistics for MF285 tractors in Kerman province of Iran. Overall results of this research showed that in MF285 tractors, the parts being subjected to failure are: Injector pump, internal engine parts, starter, clutch, break, steering pump and jack, rear axle, front axle, oil pump, hydraulic pump, auxiliary gear, differential, alternator, propeller shaft and differential lock.

Reliability has been known as a number between 0 and 1 indicating a probability in agricultural machinery management topics. Operational reliability is defined as the statistical probability that a machine will function satisfactorily under specified conditions at any given time in ASABE standards. The operational reliability is computed as one minus the probability for downtime when both probabilities are in decimal form the reliability probability for the next minute of machine operation is essentially one, but decreases when the time span under consideration lengthens. The probability of having a complex machine continually operational for several seasons on a large farm is essentially zero (ASAE Standards, 2006). Midwestern US reported by farmers (1970) of field failures determined the probability of failure (tractors and implements combined) per 40 ha (100 acres) of use and the average SD of the total downtime per year for farms of over 200 ha showed in Table 1 (ASAE Standards, 2006b).

Table 1. Reliability per 40 hectares mission for several farm operations

Operation	Breakdown time		Breakdown probability per 40 ha	Reliability per 40 ha
	h/yr	SD		
Tillage	13.6	24.1	0.109	0.89
Planting corn	5.3	5.4	0.133	0.87
Planting soybeans	3.7	2.4	0.102	0.90
Row cultivation	5.6	6.3	0.045	0.96
Harvest soybeans, SP	8.2	9.6	0.363	0.64
Harvest corn, SP	12.3	12.6	0.323	0.68

Breakdown probabilities for machine systems increase with an increase in the size of the farm. In Table 2 the reliability of tractor-machine system for several crop areas show that reliability values vary from 0.56 to 0.22 by crop area variation.

Table 2. Probability of at least one failure and reliability for crop areas

Crop area (ha)	Probability of at least one failure per year	Reliability of tractor-machine system
0 to 80	0.435	0.56
80 to 160	0.632	0.30
160 to 240	0.713	0.29
240+	0.780	0.22

Downtime and reliability appear to be independent of use for some machines while others have shown an increase with accumulated use. Midwestern US data showed: Moldboard plows average one hour of downtime for each 400 ha (1000 acres) of use; row planters average one hour of downtime for each 250 ha (600 acres) of use; SP combines had little downtime for the first 365 ha (900 acres) of use. Downtime was a constant one hour for each 30 ha (70 acres) afterward; and tractors had a constantly increasing downtime rate with use. The accumulated hours of downtime depend upon the accumulated hours of use that it showed in equation blew:

$$\text{Spark ignition} \quad 0.0000021\,X^{1.9946} \tag{1}$$

$$\text{Diesel} \quad 0.0003234\,X^{1.4173} \tag{2}$$

Where;

X is the accumulated hours of use (ASAE Standards, 2006b).

About determining of the tractors and heavy machinery reliability no case was reported but Ebrahimi (2005) in a study on real failure data from cars generator determined reliability function for this systems. Age distribution function of cars generator was modeled using the reliability relationships and finally the reliability function of such distribution was determined.

The objective of this article is to determine a function-fit model for MF285 tractors working in the in Debal Khazaei Agro-Industry Co. in khuzestan province of Iran.

Materials and method

Reliability

In evaluating productivity facilities of a system, reliability is defined as: probability of healthy and well function of a system for a given time and determinate situation. For achieving reliability function, early age distribution function must be estimated. In reliability, machine age is "interval of machine function between two consecutive reparations". The design life of components is often denominated as a mean time to failure (MTTF[1]), which tells the user that they may expect the average component to last for the specified time. Age distribution function is a function such as f(t) that t is machine healthy and well function time and f(t) is frequency of each intervals. The value under of reliability in expected work time to failure (or in other words, tractor mission time) is the area of density distribution function from mission time (t) to infinity. F(t) is the cumulative distribution function (CDF) which is area under the f(t) curve from 0 to t (Sometimes called the unreliability, or the cumulative probability of failure). All other functions related to reliability can be derived from the f(t). For example:

---

[1] Also called the mean time to failure, expected time to failure, or average life

$$F(t) = \int_0^t f(t)dt \qquad (3)$$

$$R(t) = 1 - F(t) = 1 - \int_0^t f(t)dt = \int_t^\infty f(t)dt \quad (4)$$

$$h(t) = \frac{f(t)}{R(t)} \qquad (5)$$

$$H(t) = \int_0^t h(t)dt \qquad (6)$$

$$MTTF = \int_0^t tf(t)dt = \int_0^\infty R(t)dt \qquad (7)$$

Reliability evaluation methods are analytical method and simulation method. In analytical method the problem is solved in case of mathematical frames. This method is quick and needs to have accurate data over time. The simulation method is assimilating of real system process and its haphazard and variant treatment. This method needs the complex and prolix experiments in controlled situations and is able to cover the whole system impressibilities (Billinton and Allan, 1992).

Study area

Debal Khazaei Agro-Industry Co. is located in 25 kilometers south of Ahvaz in Iran. Arable lands of this company are located in 31° to 31°10′S latitude and 45° to 48°36′E longitude. This region has dry and warm climate. Soil of this region is heavy and semi-heavy and each farm size is 25 ha in regular forms. Totally, 65 tractors MF285 model, 20 tractors MF399 model and 15 tractors MF8160 model are used in this company. MF285 tractors were purchased in 2000 and were entered in farms. Reports of service and maintenance of tractors had been recorded since 10 years ago. These reports were available and ready to be studied.

Tractor mission time and work conditions

Midwestern US reports by farmers of field failures showed the probability of failure (tractors and implements combined) per 40 ha of use (ASAE Standards, 2006b). Therefore, tractor mission in ASAE standard D497.5 is equal to 40 ha operation of tractors and implements combined. However in this study, mission time was assumed as 125 hours of tractor operation. Indeed, 125 hours of operation, was 50 ha of use with 0.4 ha/h field capacity.

The reliability function was determined based on analytical method. Farm tractor supposed a mission oriented system against continuously operated system. Mission oriented systems must have healthy and well function without any breakdown within mission time. Thus, farm tractors were assumed as a non-repairable system. Non-repairable systems are those that do not get repaired when they fail. Specifically, the components of the system are not repaired or replaced when they fail. In Debal Khazayi Agro-Industry Company MF285 tractors were operated in implementing of harvesting and transportation and their economic life was supposed to be 10 years and that is the time when tractors must be replaced. Thus, the model was determined for tenth year of MF285 tractors life.

Distribution fitting

In this research analytical method was used owing to loss the experimental facilities and on the other hand existence of registered data for maintenance of MF285 tractors. It is necessary that early, the probability in which system age is lower "t" is estimated. In other words, the probability that system age isn't lower t (machine age>t) must be calculated. If

f(t) was assumed age distribution function and area of whole diagram was supposed 1, the result diagram is named "density distribution function". Relation between density distribution function and reliability function can be showed as follow (Haj Shirmohammadi, 2008):

In this research, tractors entree and exit from shooting gallery were elicited. Hours of work from a failure to next one was determined. In order to develop the age distribution function, tractors work time to failure was calculated. Afterwards, distribution fitting test of these times using the method of "moments estimation" was carried out. The best distribution function based on Chi-square test was determined. H_0 in the Chi-square test is "the sample follows the distribution function" and H_1 is "the sample does not follow the distribution function". Distribution fitting was carried out in MATLAB version 7 (R2007b). Mainly, age distribution functions are as normal, exponential, log-normal, poisson and weibull:

Normal $\qquad f(t) = \dfrac{1}{2\sigma^2} exp\left(-\dfrac{(x-\mu)^2}{2\sigma^2}\right)$ (8)

Exponential $\quad f(x) = \lambda e^{-\lambda t}$ (9)

Log-normal $\quad f(t) = \dfrac{1}{st\sqrt{2x}} e^{-\frac{1}{2s^2}\left(Ln\frac{t}{t\,med}\right)^2}$ (10)

Poisson $\qquad f(t) = \dfrac{(\lambda t)^x e^{-\lambda t}}{x!}$ (11)

Weibull $\qquad f(t) = \dfrac{\beta}{\theta}\left(\dfrac{t}{\theta}\right)^{\beta-1} e^{-\left(\frac{t}{\theta}\right)^\beta}$ (12)

Each machine follows an age distribution function based on working conditions, quality of parts combination, manufacturing process and many other ingredients. Age distribution function depended on indigenous and exogenous characteristics of machine (Billinton and Allan, 1992).

Results

The result of this paper showed that the best model for age distribution function of MF285 tractors was exponential function. Comparison between the observed and theoretical frequencies is shown in Table 3. WTTF was grouped in 10 classes. This grouping is based on Chi-square test that must no more than 20 percentages of all expected frequencies be in classes with less 5% frequencies.

Table 3. Comparison between the observed and theoretical frequencies						
class	Lower bound	Upper bound	Observed Frequency	Expected Frequency in Distribution		
				normal	exponential	log-normal	weibull
1	0	13	25	10.7	31.7	19.3	18.7
2	13	26	26	15.7	22.8	31.6	27.5
3	26	39	14	19.0	16.4	21.4	21.6
4	39	52	15	19.1	11.8	13.4	15.5
5	52	65	8	16.0	8.5	8.4	10.6
6	65	78	12	11.0	6.1	5.5	7.1
7	78	91	6	6.3	4.4	3.7	4.6
8	91	104	2	3.0	3.2	2.5	2.9
9	104	117	3	1.2	2.3	1.8	1.8
10	117	130	2	0.4	1.6	1.3	1.1

Density distribution function as intuitive was shown (Fig. 2) that exponential and weibull had a good fitness with observed data. The Normal and Log-normal distribution wasn't matched observed data distribution and the Poisson distribution was very different.
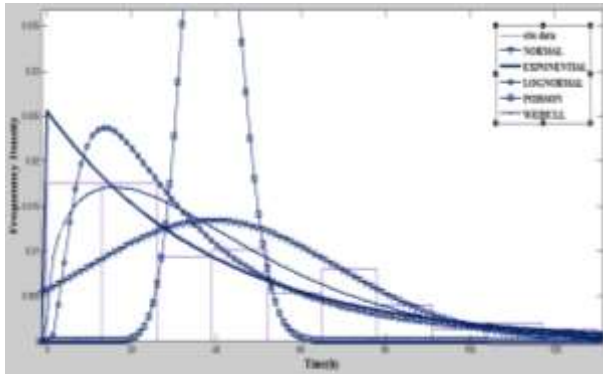

Fig 2. Density distribution functions and observed data

As is shown in Table 4 some statistics estimated on the input data and computed using the estimated parameters of the distribution functions was calculated.

Table 4. Statistics estimated on the input data and computed using the estimated parameters of the distribution functions distribution

Statistic	Data	Normal	Exponential	Log-normal	Poisson	Weibull
Mean	39.4	39.4	39.4	43.8	39.4	5.2
Variance	886.9	886.9	1555.7	1962.8	39.4	0.9
Skewness (Pearson)	0.95	0.00	2.00	4.06	0.16	1.29
Kurtosis (Pearson)	0.13	0.00	6.00	39.44	0.02	2.19

For normal, log-normal, poisson and weibull distribution as the computed P-value was lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis H1. Therefore, with 95% confidence, normal, log-normal, poisson and weibull distribution were different from observed data. The risk to reject the null hypothesis H0 while it was true in normal, log-normal, poisson and weibull distributions were respectively lower than 0%, 2.4%, 0% and 4.3%. The exponential distribution as the computed p-value was greater than the significance level alpha=0.05, one should accept the null hypothesis H_0. Therefore, in 5% level it couldn't be rejected that the sample follows the exponential distribution function and this distribution had good adaptation with the observed data. Yet, estimated parameters from distribution fitting are given in Table 5 for all distribution functions.

Table 5. Chi-square test and estimated parameters for distribution functions

Distribution functions	χ^2 (Observed value)	$\chi^2(\alpha, df)$ (Critical value)	df	P-value	Estimated Parameter				
					μ	σ	λ	β	θ
Normal	42.1	14.1	7	0.000	39.4	29.8	-	-	-
Exponential	10.1	15.5	8	0.255	-	-	0.025	-	-
Log-normal	16.1	14.1	7	0.024	3.4	0.8	-	-	-
Poisson	432781	12.6	8	0.000	-	-	39.4	-	-
Weibull	14.5	14.1	7	0.043	-	-	-	1.34	38.6

The reliability function of MF285 tractors in Debal Khazayi Agro-Industry Co. in Khuzestan province and all other functions related to reliability are shown from 13 to 18:

$$f(t) = 0.025\, e^{-0.025t} \quad (13)$$

$$F(t) = 1 - e^{-0.025t} \quad (14)$$

$$R(t) = e^{-0.025t} \quad (15)$$

$$h(t) = 0.025 \quad (16)$$

$$H(t) = 0.025t \quad (17)$$

$$MTTF = 1/h(t) = 40 \quad (18)$$

Exponential cumulative distribution function (CDF or F(t) or Cumulative probability function) for exponential versus observed data was shown in Fig. 3.
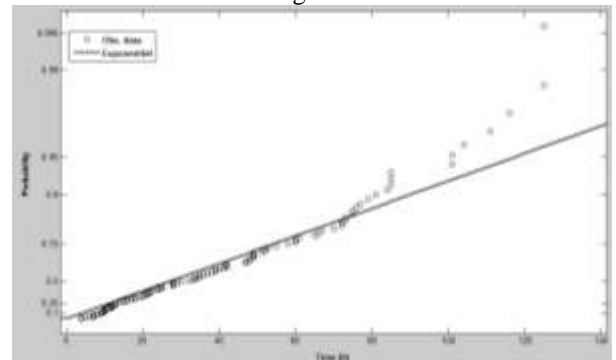

Fig 3. Cumulative probability function for exponential and observed data distribution

Discussion

Results from this investigation in order to develop a reliability model for farm tractors data were very promising. In present research, the reliability function of MF285 tractors worked in Debal Khazayi Agro-Industry Co. in Khuzestan province of Iran was obtained. This function was determined for 4000 to 4500 hours of tractor use and this provided the opportunity that tractors reliability after 4500 hours was predicted. Low tractor reliability has an uncertainty in implementation of harvesting operation and this uncertainty has some cost. This cost is a part of operation timeliness cost reported in ASABE EP496.3. In this study, effect of uncertainty on timeliness cost was indicated as (1-R)/R and was named *tractor coefficient*. Therefore, Eq. 19 was developed to survey timeliness cost in average workability probability method based on reliability function of MF285 tractors;

$$TC = \left(\frac{1-R}{R}\right)\frac{A.Y.V.K_t}{\lambda_0.C_e.P_{wd}.T} \quad (19)$$

Where: R is tractor reliability in determinant mission time and harvest operation, (decimal); TC is tractor timeliness cost for the operation involved, (R^2); A is crop area involved, (ha); Y is yield per area, (t/ha); V is value per yield, K_t is timeliness coefficient obtained from ASAE D497; (R/ton); λ_0 is 4 if the operation can be balanced evenly about the optimum time (balanced scheduling), and 2 for premature or delayed or premature schedules; C_e is machine capacity, (ha/h); P_{wd} is probability of a working day, (decimal) and T is expected time available for field work each day, (h/day).

---

1. Rial; is the currency of Iran, 10,000 Rials = 1 US Dollar

This equation is almost the same as ASAE equation (Eq. 1) however the difference is that this cost is only tractor timeliness cost. Tractor costs are divided into two categories, fixed costs and variable costs. Timelines cost is a variable cost that based on Eq. (4) increases with tractor reliability decreasing.

In working conditions of the most Agro-Industries upon a machine break down during farm operation, the stopping machine system is immediately replaced with the supporter (spare) machines. But in the individual farms and having no technical services, tractor has no supporter in farm and upon a machine break down, operation stops and is postponed to another time. The newest tractors have higher reliability and lower probability of failure during a farm operation. Thus, one of the most important advantages of old tractor replacement with the new one is on time completion of farm operation. It means the newest tractors have lower timeliness cost.

References

ASAE Standards, Agricultural Machinery Management, ASAE EP496.3, FEB, Forty-seventh Ed. 2006a. pp 384-390, St. Joseph, Michigan, USA.

ASAE Standards, Agricultural Machinery Management Data, ASAE D497.5, FEB, Forty-seventh Ed. 2006b. pp 391-398, St. Joseph, Michigan, USA.

Amjad SI, Chaudhary AP. Field reliability of farm machinery. Journal of Agricultural Mechanization in Asia, Africa and Latin America. 1988. 10(1): 73 -8.

Ashtiani AR, Ranjbar I, Toorchi M. Determining the economic life for three agricultural tractor models in Iran (Case Study: Mazandaran Dasht-e-Naz Farm Company), Journal of Agricultural Sciences, Islamic Azad University. 2006. 12(1): 221-30.

Billinton R, Allan NR. Reliability Evaluating of Engineering Systems, Concepts and Techniques, second edition. 1992.

Beppler, D.C., Hummeida, M. A., (1985), Maintaining and repairing agricultural equipment in developing nations, Agricultural Engineering Journal, 66(121): 11-13.

Ebeling CE. An Introduction to Reliability and Maintainability Engineering. McGraw- Hill, inc. 1997.

Ebrahimi BR. Modeling the reliability of cars generator, Paper presented at the 3th International Conference of Quality Managers, Jun. 2005, Tehran, Iran.

Girard N, Hubert B. Modeling expert knowledge with knowledge-based systems to design decision aids the example of a knowledge-based model on grazing management, Agricultural systems. 1999. 59: 123-44

Khodabakhshian R, Shakeri M, Motie AJ. Statistical analysis the causes of downtime and troubleshooting tractor, Paper presented at the 3th Conference on the condition monitoring and troubleshooting machinery Feb2009, Sharif University of Technology, Iran

Shirmohammadi HA. Industrial Planning and Control (Plant Engineering), 12th edition, Iran, Esfahan, Arkan publication. 2008.

Singh G. Estimation of a Mechanization Index and Its Impact on Production and Economic Factors-a Case Study in India, Biosystems Engineering. 2006. 93(1): 99-106.

Wingate-Hill R. Agricultural Engineering Conference, 30 September-2 October: Preprints of Papers, the Application of Reliability Engineering to Farm Machinery. 1980.

Witney B. Choosing and Using Farm Machines, Edinburgh, Scotland, UK: Land Technology Ltd. 1985.