Reliability analysis of agricultural machinery: A case study of sugarcane chopper harvester

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Abstract: The performance of agricultural machines depends on the reliability of the machinery used, the operating environment, the maintenance efficiency, the operating process, the technical expertise of the farmers, etc. As the size and complexity of farm equipment continue to increase, the implications of equipment failure become over more critical. Therefore, reliability analysis is required to identify the bottlenecks in the system and to find the components or subsystems with low reliability for a given designed performance. It is important to select a suitable method for data collection as well as for reliability analysis. This paper presents a case study describing reliability and availability analysis of the sugarcane 7000 series chopper harvester at Hakim Farabi agro- industry in Iran. In this study, the harvester is divided into nine subsystems. The parameters of some probability distributions, such as weibull, exponential and lognormal distributions have been estimated by using ReliaSoft Weibull++6 software. The results of the analysis show that feed rollers and hydraulic subsystems are critical in reliability point, and the wheels subsystem and hydraulic subsystem are critical in an availability point of view. The study also shows that the reliability analysis is very useful for deciding maintenance intervals.

Keywords: Agricultural machinery, availability, reliability analysis, sugarcane harvester.

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1 Introduction

Sugarcane harvesting includes cutting, loading and transport. These are the most important operations, with the highest costs and the biggest work input.Hand sugarcane harvesting is too laborious and needs too many number of workers in long period of time. The cost and lack of availability of hand labor have led to an increase in mechanized harvesting.Chopper harvesters are machines that carry out all the operations including loading (Figure 1). The cane is cut at the base, then chopped into lengths of 20 to 40 cm, and finally loaded directly into a trailer that accompanies the machine. These cutter-choppers are very powerful machines that have either pneumatic tire ortracks, depending on the type of land (CIGR, 1999).

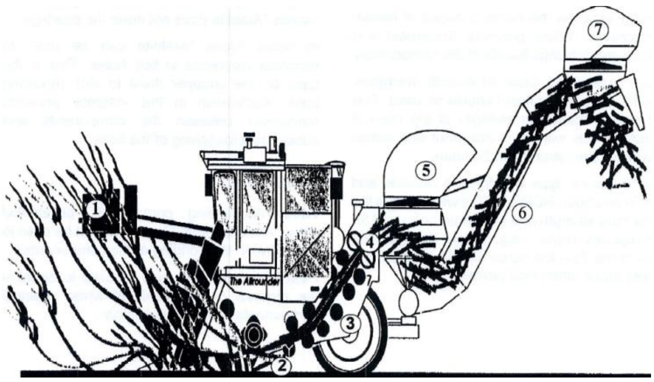

Figure 1 Cane flow diagram in sugarcane harvester machine
1- Topper, 2- Base cutter, 3- Feed rollers, 4- Chopper, 5- Primary extractor fan, 6- Elevator, 7- Secondary extroctor fan

Many reasons related to field and crop condition influence the sugarcane harvester performance including soil type, soil humidity, cane variety, crop yield and operator skill (Anonymous, 1999).Whereas machine failures occur regularly in indefinite locations of the field,

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manager's ability to record the time, location, and the reason of failures could be diminished in process of time (Kahle, 2007). The optimization of each subsystem of machine in relation to one another is imperative to make the system profitable and viable for operation. Since failure cannot be prevented entirely, it is important to minimize both its probability of occurrence and the impact of failures when they occur (Barabadi and Kumar, 2008). In order to control and reduce failure and to plan and schedule the harvester operations in optimum time, we have to know how many failures occur in each term of machine performance and to know the mean time between failures.

Machine failing probability is (1-R) and R is machine reliability that 0<R<1 (Vafaei et al., 2010). Moreover, system reliability is the probability that an item will perform a required function without failure under stated conditions for a stated period of time (Billinton and Allan, 1992).Therefore, it must be able to create anappropriate compromise between maintenance methods and acceptable reliability level.

Precision Failure data gathering in farm is a worthwhile work, because these can represent a good estimate of machine reliability combining the effects of; machine loading, surrounding effects and incorrect repair and maintenance. Each machine based on work conditions, parts combination and making process followed to failures distribution function depended on surrounding machine work and machine specifications (Meeker and Escobar, 1998). General failures distributions for contiguous data are normal, log-normal, exponential and weibull (Shirmohamadi, 2002). Each machine can represent proportionate behavior with these functions in short or long time.

Nowadays, weibull function is a current used model in reliability researches. This function has been used for failing times modeling.Functions shape depends on its parameters and it can match to each distribution of data with parameters changing (Luss and Jammer, 2005; Bartkute and Sakalauskas, 2008). Also, shape parameter at weibull function distinct life performance of machine(Figure 2).

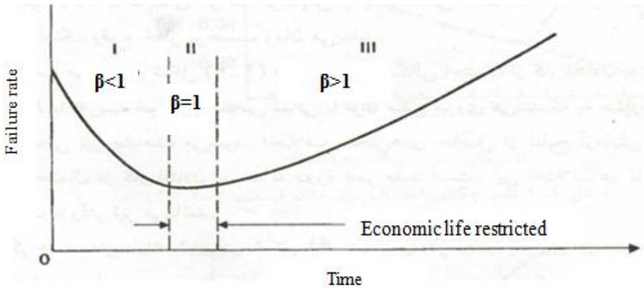

Figure2Relation between shape parameter and life performance on mechanical equipment (Billinton and Allan, 1992).

The aim of this researchis the study of reliability analysis for repairable systemsvia appropriate distribution functions have chosen for different parts of sugarcane harvester and usethefunctionsfor computing machine reliability.

2 Materials and methods

2.1 Basic concepts and approach for reliability analysis

Usually, two methodsareusedfor machine reliability modeling. The first is Pareto analysis and second is statistical modeling of failures distribution (Barabadi and Kumar, 2007). Failures distribution modeling data need to be found,whichare independent and identically distributed(iid) or not. For this, trend test and serial correlation tests are used. If the data has a trend, those are notiid and its parameters are computed from power law process. For the data that does not havetrend, serial correlation testare performed.If correlation coefficientis less than 0.05, the data is not iid.Therefore, its parameters reach via branching poison process or other similar methods; if correlation coefficient was more than 0.05 the data are iid. Therefore, the classical statistical methods will be used for reliability modeling.

Military Handbook Test (MIL-HDBK-189, 1981) as one of the applicable analytic tests is better method in finding significance when the choice is between no trend and Power Law process model(Hoseinie et al, 2013).Trend test results compare with statistical parameter U(Equation1).

$$\mathbb{U} = 2\sum_{i=1}^{n-1} \ln(Tn/Ti) \quad (1)$$

Where, *n* is total number of failures, *Tn* is time of the nth failure and *Ti* time of the*ith*failure.

A test for serial correlation was also done by plotting the*ith* TBF against the *(i-1)th* TBF, i¼ 1; 2; . . . ; n: If the plotted points are randomly scattered without any pattern, it can be interpreted that there is no correlation in general among the TBFs data and the data is independent.

To continue, one must choose the best fit distribution for TBF data. Few tests can be used for best fit distribution that including chi square test and Kolmogorov–Smirnov (K-S) test.Chi square test is not valid when the data are less than 50. Therefore, when the TBF data are less than 50 must use from K-S test. Furthermore, the K-S test can be used for each TBF data numbers. When the failure distribution has been determined reliability model is computedbyEquation 2.

$$R = \int_0^\infty f(t)dt (2)$$

Where, *R* is reliability, *f* is failures distribution and *t* is operation time.

However, total reliability for series systems is calculatedfromEquation 3.

$$R_T = \prod_{i=1}^{n} Ri (3)$$

Where R_T is total reliability, R_i is reliability of each subsystem and n is number of subsystems.

Then availability of subsystems is calculatedfromEquation 4.

$$Availability = \frac{MTBF}{MTBF+MTTR} \times 100 \quad (4)$$

The failure data analysis processwhich was used in this study for selecting the best reliability modeling method is shown in Figure3.

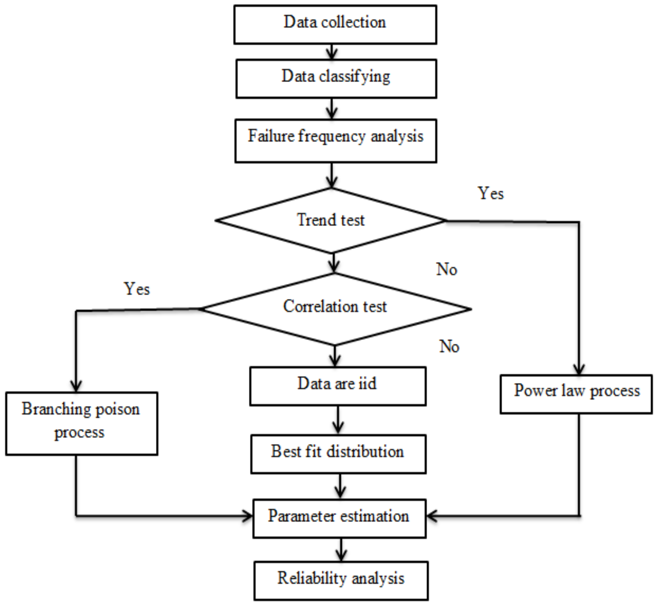

Figure3Reliability analysis process of a repairable system (Barabadi and Kumar, 2008).

2.2 Case study

Study area was Hakim Farabi agro-industry Company located in 35 km south of Ahvaz in Iran. Arable lands of this company are located in 31°to 31°10' N latitude and 45°to 48°36 E longitudes. The 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. Total, 24 Austoft 7000 sugarcane chopper harvester are being used in the company. Data are from maintenance reports of harvesters which have been recordedwithin 1800 h. In this study sugarcane harvester as a system was divided into nine subsystems (Figure 4).

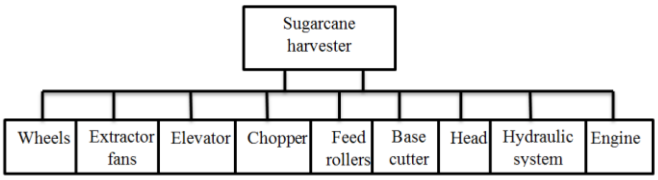

Figure 4 Sugarcane chopper harvester subsystems

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If every one of subsystems stopped, the whole machine performance would be stopped, thus relation among harvester subsystems is series.

Figure 4 Sugarcane chopper harvester subsystems

3 Results and discussions

3.1 Pareto analysis

Pareto chart shows which subsystems in machine have maximum or minimum failures. According to the Figure 5, feed rollers and hydraulic subsystems have maximum recorded failures and engine and extractor fans subsystems have minimum recorded failures in machines worked hours.

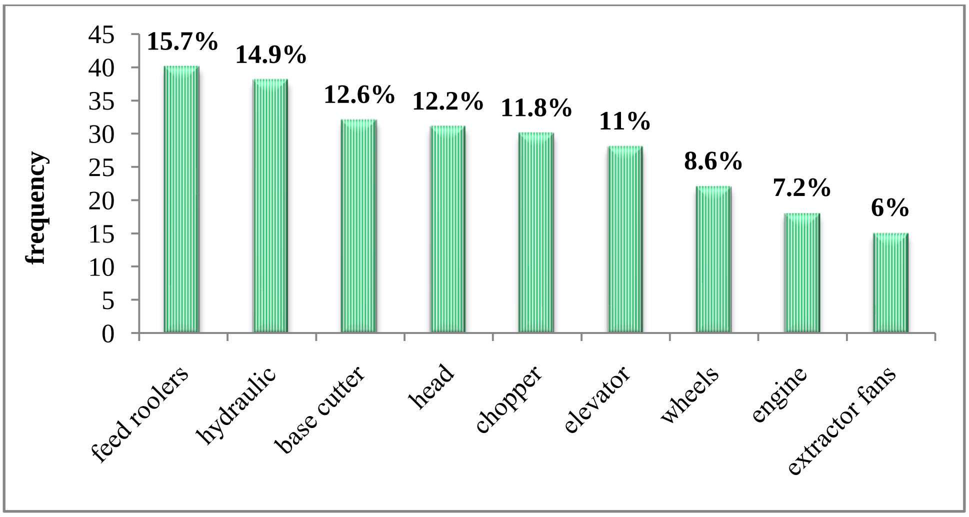

Figure5 Pareto chart for sugarcane chopper harvester subsystems

3.2 Trend and correlation analysis

Results of trend analysis for TBFdata of sugarcane harvester machine showed calculated statistic U for all subsystems was more than chi square value that reach from chi square table with 2(n-1) degrees of freedom and 5 %level of significance, Table 1.

Table 1 Trend test's results for TBF data of sugarcane harvester machine subsystems

Subsystems	Degree of freedom	Calculated statistic U	Rejection of null hypothesis at 5% level of significance
Engine	34	26.9	Not rejected > (22.5)
Hydraulic	72	78.4	Not rejected > (53.5)
Head	60	72.6	Not rejected > (43.2)
Feed rollers	78	81	Not rejected > (59.4)
Base cutter	62	55.5	Not rejected > (45.2)
Chopper	58	59.2	Not rejected > (42.2)
Elevator	54	53.3	Not rejected > (38.8)
Wheels	44	41.4	Not rejected > (30.5)
Extractor fans	28	24.9	Not rejected > (16.9)

Therefore, it is possible, that all subsystems TBF data have identically and independent distribution. For validation this hypothesis, correlation testwas performed on TBF data, Table 2.

Table 2 correlation test's results for TBF data of sugarcane harvester machine subsystems

Subsystems	Correlation coefficient	Rejection of null hypothesis at 5% level of significance
Engine	0.91	Not rejected > 0.05
Hydraulic	0.60	Not rejected > 0.05
Head	0.58	Not rejected > 0.05
Feed rollers	0.91	Not rejected > 0.05
Base cutter	0.20	Not rejected > 0.05
Chopper	0.58	Not rejected > 0.05
Elevator	0.79	Not rejected > 0.05
Wheels	0.88	Not rejected > 0.05
Extractor fans	0.70	Not rejected > 0.05

Whereas, correlation coefficient was more than 0.05 for all subsystems, all subsystems TBF data haveindependentand identically (iid) distribution. Then, Kolmogorov- Simonovtestwas done on TBF data and test results are tabulated in Table 3.

Table 3 Best- fit distribution of sugarcane harvester machine subsystems

Subsystems	k-s test (goodness of fit)						Best- fit	Parameters
	Weibull 3 parameter	Weibull 2 parameters	Log-normal	Normal	Exponential 2 parameter	Exponential		
Engine	$0.13*10^{-1}$	$0.12*10^{-1}$	$0.18*10^{-1}$	$0.71*10^{-1}$	0.61	0.99	Weibull 2 parameters	2.66β= 100.41α =
Hydraulic	$0.67*10^{-2}$	0.13	0.62	$0.40*10^{-1}$	0.98	0.99	Weibull 3 parameters	1.98β = 57.6α = = -6.67γ
Head	$0.21*10^{-5}$	$0.13*10^{-4}$	$0.96*10^{-1}$	0.12	0.49	0.80	Weibull 3 parameters	1.33β = 58.04α = 1.63γ =
Feed rollers	$0.45*10^{-6}$	$0.28*10^{-5}$	$0.89*10^{-1}$	0.16	0.95	0.99	Weibull 3 parameters	1.61β = 43.38α = = 2.45γ
Base cutter	0.26	0.38	0.72	0.51	0.99	0.99	Weibull 3 parameters	2.23β = 57.08α = = 2.34γ
Chopper	0.35	0.28	0.68	0.34	0.91	0.94	Weibull 2 parameters	1.70β = 62.38α =
Elevator	$0.11*10^{-7}$	$0.10*10^{-7}$	$0.37*10^{-1}$	$0.21*10^{-1}$	0.80	0.94	Weibull 2 parameters	1.78β = 67.08α =
Wheels	$0.13*10^{-3}$	$0.28*10^{-1}$	0.36	$0.55*10^{-2}$	0.94	0.99	Weibull 3 parameters	7.59β = 247.6α = = -157.9γ
Extractor fans	$0.80*10^{-2}$	$0.37*10^{-3}$	$0.34*10^{-1}$	$0.38*10^{-2}$	0.78	0.99	Weibull 2 parameters	2.56β = 116.07α =

According to Table 3 that reached with aid of Reliasoft`s software package, TBF data for hydraulic, head, feed rollers, base cutter and wheels subsystems followed of weibull three parameters function and for engine, chopper, elevator and extractor fans followed of weibull two parameters function.Furthermore, Reliability of the sugarcane harvester machine were computed from Equation 2 and tabulated in Table 4.

Table 4Reliability of the sugarcane chopper harvester subsystems at differential times (h)

Time	engine	hydraulic	head	base	feed	chopper	elevator	wheels	extractor	total
0	1	1	1	1	1	1	1	1	1	1
10	0.998	0.918	0.927	0.989	0.943	0.957	0.967	0.949	0.998	0.694
20	0.987	0.805	0.806	0.93	0.794	0.867	0.891	0.922	0.989	0.333
30	0.961	0.665	0.681	0.821	0.619	0.751	0.789	0.884	0.969	0.112
40	0.918	0.518	0.562	0.674	0.453	0.627	0.672	0.833	0.937	0.026
50	0.856	0.38	0.457	0.513	0.314	0.504	0.554	0.767	0.891	0.004
60	0.777	0.263	0.365	0.36	0.206	0.392	0.441	0.685	0.832	0.0005
70	0.683	0.172	0.288	0.232	0.129	0.296	0.34	0.587	0.761	$4.55*10^{-5}$
80	0.58	0.105	0.225	0.137	0.077	0.217	0.254	0.478	0.681	$2.59*10^{-6}$
90	0.474	0.061	0.173	0.073	0.044	0.154	0.185	0.365	0.594	$9.92*10^{-8}$
100	0.372	0.033	0.133	0.036	0.024	0.106	0.13	0.256	0.506	$2.52*10^{-9}$

The analysis showed that the feed rollers and hydraulic system are the most critical subsystems and their reliability reaches zero before any other subsystems (Figure 6).

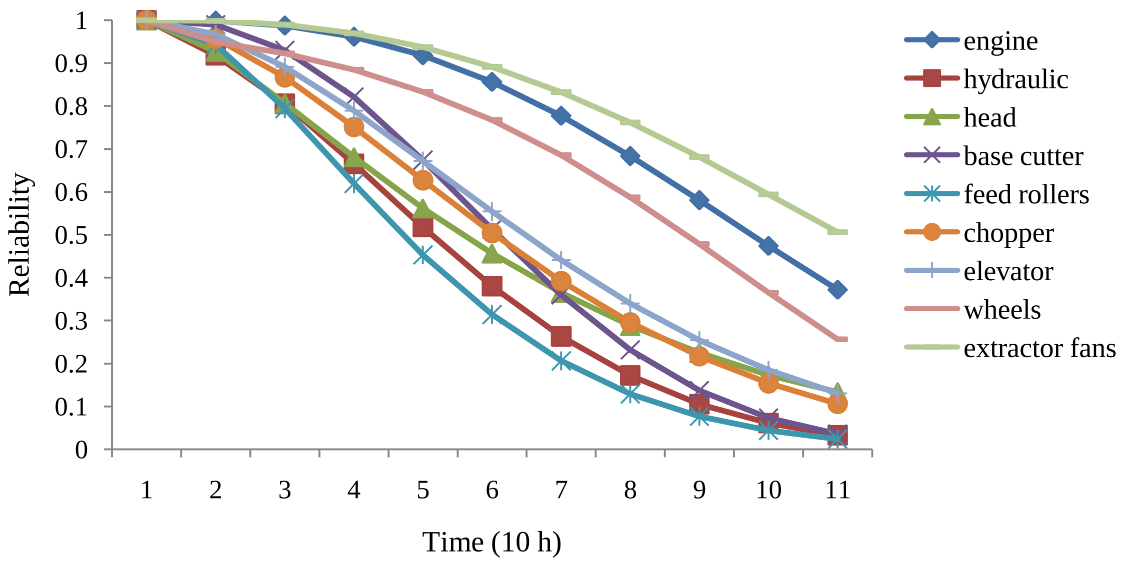

Figure 6 The reliability plots of each subsystem of sugarcane harvester machine

The reason is that the feed rollers are thirteen and each one has a hydro motor that performs under oil pressure. Therefore, failures numbers are more than other subsystems. For hydraulic system, whereas sugarcane harvester is a hydraulically operated machine, in the whole parts of machine hydraulic pipes are used which would be affected via oil pressure and fragment. The extractor fans and engine subsystems are the most reliable subsystems during the whole machine life. The reason may be that work load on extractor fans is lower than other subsystems. Also, the reason of few failures in engine is annually overhaul and aged parts replacement on time.Moreover, head, base cutter, chopper, elevator and wheels have a moderate reliability level in machine performance. To interpret this, it can besaid, whereas, work load over each one of these subsystems is moderate, therefore failures number for these subsystems are lower than hydraulic system and feed rollers and are more than engine and extractor fans. Therefore, to increase overall reliability it is very vital to improve reliability of feed rollers and hydraulic subsystems.

3.3 Availability analysis

The MTBF, MTTR and availability of sugarcane chopper harvester are shown in Table 5. Results showed extractor fans and hydraulic subsystems with respectively 103.26 h and 89.77 h, have the most time between failures and they can operate more time duration without failing proportion to other subsystems.Moreover, wheels and engine subsystems with respectively 3.5 h and 2.36 h, have most times to repairs. Then, spent time duration to repair for these subsystems were the most. Therefore, wheels and hydraulic subsystems are more critical and extractor fans and elevator subsystems are best from availability point of view.

Table 5 Availabilityof the sugarcane chopper harvester subsystems

Subsystem	MTBF (h)	MTTR (h)	Availability (%)
Engine	89.77	2.36	97.44
Hydraulic	43.81	1.84	95.97
Head	53.38	1.9	96.56
Base cutter	52.12	1.79	96.68
Feed rollers	40.72	1.46	96.54
Chopper	55.7	1.74	96.97
Elevator	59.17	1.24	97.95
Wheels	74.95	3.5	95.54
Extractor fans	103.26	2.06	98.04

4 Conclusions

In order to control and reduce failures and to plan and schedule the harvester operations in optimum time, machine reliability have being known.In this paper the operational structure of the sugarcane harvester was studied and the nine subsystems of the machine consists the engine, hydraulic system, head, feed rollers, base cutter, chopper, elevator, wheels and extractor fans were studied individually for the first time. From the trend analysis and serial correlation, it is seenthat the assumption of identically and independent distributedwas valid for allsubsystems TBF data of sugarcane chopper harvester. The analysis showed that the feed rollers and hydraulic are the most critical subsystems of machine from a reliability point of view, and the wheels subsystem and hydraulic subsystem are critical from an availability point of view.

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