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Research article

RAM (reliability, availability and maintainability) of threshing machine in agriculture

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Abstract

The performance of agricultural machinery is affected by their reliability, availability, the environment where a machine is operated, the process, the efficiency of maintenance and most of all, the technical expertise of the user. The impacts of increased machinery failure rates have become more important as the size and complexity of farm equipment has increased, which makes reliability, availability and maintainability analysis more important. Three states of the system were considered in this paper: good state, reduced state and failed state. The formulation of the problem involved using a supplementary variable technique and the solution was obtained by applying Lagrange's method. The results indicated there was scope to increase the efficiency of any system by reducing its failure rate, specifically, the mean time between failures, the mean time to failure and the mean down time.

Introduction

Today is the era of multi-operating machinery, such as the harvesting, threshing and reaping processes being combined in one machine —a combined harvester. Threshing begins in a concave cylinder that has sharp serrated bars and rotates at high speed (about 500 revolutions per minute, rpm), so that the bars beat against the grain. The curve of threshing concave is adjusted to match the curve of the cylinder so as to hold the grain as it is beaten against. The beating releases the grain from the straw and chaff with the majority of the grain falling through the concave bars. The straw is carried by a set of 'walkers' to the rear of the machine. Below the straw walkers, a fan blows a stream of air across the grain, removing any dust and fines by blowing them away. The grain, either coming through the concave bars or the walkers, passes through a set of sieves mounted on an assembly called a shoe, which is shaken mechanically. However, the major problem is the cost of this system, making it problematic for farmers as one machine is too expensive for one farm to buy and keep solely for their own use. The second disadvantage lies in the machine's size as it is difficult to transport and cannot be used indoors. Another issue is seed breakage.

Reliability techniques may be used to judge the availability and maintainability of a system. Maintainability and availability are two main features that are closely related to reliability. The aim of reliability theory is to evaluate errors in measurement and suggest ways of improving the tests so that the errors are minimized and reliability, availability and maintainability

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(RAM) theory is suited to this objective. Reliability technology was first introduced by Singh (1976) to analyze a production system. Gupta and Kumar (1987) developed a mathematical model to evaluate availability and the mean time to failure (MTTF) of a two-unit, cold stand based on three possible system states: good, reduced and failed. Kumar etal. (1997) discussed steady state behavior and maintenance planning for a desulphurization system in a urea fertilizer production system. Since failure cannot be controlled completely, it is necessary to reduce its probability of occurrence and any impact of failure (Barabady and Kumar, 2008). Shakuntla et al. (2011) discussed reliability in a polytube manufacturing plant. Different scientists have utilized RAM theory for various multi-function machines in agricultural use. For example, reliability analysis of a sugarcane chopper harvester was discussed by Najafi et al. (2015) who concluded that reliability analysis was very useful for deciding maintenance intervals. Similarly, Kadyan and Kumar (2017) analyzed the availability and profit of a feeding system in the sugar industry using a supplementary variable technique. Many methods have been applied to solve partial differential equations to determine reliability and availability. For example, Kaur et al. (2013) implemented a numerical method to solve partial differential equations in a stochastic model for two states. Similarly, Gupta and Ram (2018) presented a finite difference solution to solve stochastic partial differential equations regarding reliability. Verma and Tamhankar (1997) and Ram and Singh (2010) discussed Laplace transform state probabilities and different reliability measures such as reliability, availability and MTTF. Thus, the current study was conducted at Maharishi Markandeshwar University, Sadopur, India.

Farm mechanization has replaced intensive labor, maximized profit, reduced the cost of production, minimized risk, reduced processing times and increased yields (Sharma and Kumar, 2008).

Some mechanization has relied heavily on one machine having multi-operational capacity, such as a combined harvester that can harvest, reap and thresh as one continuous process. As the size and the complexity of the farm equipment continue to increase, the implications of equipment failure become critical. Therefore, reliability analysis is required to identify the bottlenecks of the system and to find subsystems or components with low reliability for the given designed performance (Najafi et al., 2015).

Of interest is not only the availability of the system to be able to operate at any given time or its reliability during a specified period, but also a measure of how quickly the system can put back into the service after each failure. Asante et al. (2017) applied RAM analysis to a cowpea thresher. Adhikary et al. (2012) investigated the time between failures and the time to repair in coal-fired thermal plants using statistical analysis.

If threshing is the limiting factor in a complete crop season, then farmer can lose not only yield but also profit per unit cost if there is no working threshing equipment available.In such a case, the completed output depends on the last operation, namely threshing.

Both the farmer and maintenance personnel involved in the system must be studied. As agriculture is a major contributor to the gross domestic product of a country such as India the importance of a sound agricultural sector is clearly apparent for a healthy economy. Consequently, this study used the RAM approach to analyze the failure rate and availability of the important farm operation of threshing.

Materials and Methods

To express system availability in measurable terms, it is essential to develop a mathematical model for the system and subsystems and to analyze overall behavior to evaluate the performance under real operating conditions. This approach was applied specifically to threshing defined as the separation of grain from a harvested crop using striking, beating or rubbing action.

The main components (Fig. 1) studied in the threshing system were: 1) threshing drum (T): a cylinder with sharp, serrated bars that rotates at high speed (500 rpm); 2) feeding hopper (F): placed on the top of the threshing cylinder to feed in the harvested material and consisting of a rotating star wheel mechanism between the hopper and threshing drum to facilitate the uniform feeding of the crop into the drum; concave threshing bars (C): separates the grain from the crop and removes the grain from the straw; and 4) blower (B): uses fan-forced air to clean and separate of straw from the grain.

Notation

T, C, B = good working state of threshing drum, concave threshing bars, blower;

$\overline{T}$, $\overline{C}$ = T and B working at reduced capacity;

t, c, b = failed states of T, C and B, respectively;

λ_i = mean constant failure rate from states C, B, T, $\overline{T}$, $\overline{C}$, C and T to $\overline{C}$, b, $\overline{T}$, t, c, c and t, respectively, where $_i$ = 1,2…7;

μ_i = mean constant repair rate from states $\overline{C}$, b, $\overline{T}$, tand c, to C, B, T, $\overline{T}$, C, and T, respectively, where $_i$=1, 2…7;

$P_i(t)$ =probability states that the system is in the i^{th} state at time t.

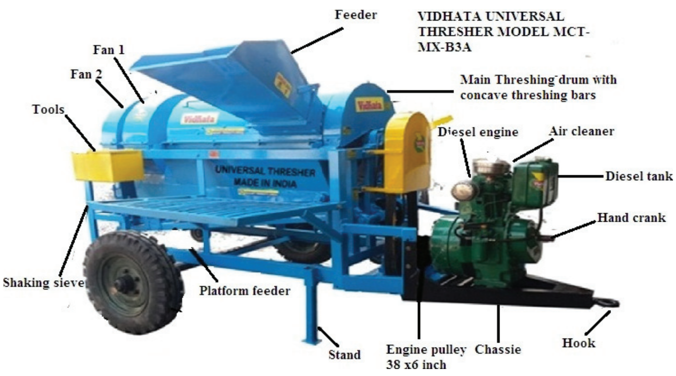

Fig. 1 Vidhata multifunction thresher

Assumptions

The following assumptions were applied: 1) there are no simultaneous failures among subsystems and the repair process begins soon after a unit fails; 2) the failure rate is constant and the repair rate of the subsystems is variable; 3) failure and repairs events are all statistically independent; 4) a repaired unit is as good as a new one; 5) all units of the system in good working order at time t = 0, so that $P_0(0) = 1$, otherwise it equals 0.

Definitions

The following definitions were applied: 1) reliability: the probability of normal operation of a system per unit time without any failure, measured using the mean time between failures (MTBF); 2) availability: the probability of proper working conditions for a system when in demand for use, measured using the mean time to repair (MTTR); 3) maintainability: the rate of a system to return from a repair to proper working conditions after each failure.

Maintainability and availability are closely related to reliability.

MTBF was calculated using Equation 1:

$$\text{MTBF} = \frac{\text{Total operational time}}{\text{Total number of failures}} \tag{1}$$

MTTR includes the repair time, testing period and restoring the original functional condition and was calculated using Equation 2:

$$\text{MTTR} = \frac{\text{Total maintenance time}}{\text{Total number of repairs}} \tag{2}$$

Thus, MTTR measures availability and MTBF measures availability and reliability.

The mean time to failure (MTTF)identifies the total life span in a non-repairable system and was calculated using Equation 3:

$$\text{MTTF} = \frac{\text{Total hours of operation}}{\text{Total number of units}} \tag{3}$$

The mean down time (MDT)includes all delays in repairing the repairable system compared to MTTR that includes just the repair time and not all the associated delays. Thus, MDT is time that the system is not in working condition after a failure.

The steady state availability is the probability of availability of the system in a functional form for a long period.

The aim of reliability theory is to evaluate errors in measurement and to suggest ways of improving testing so that errors are minimized.

To express system availability in measurable terms, it is essential to develop mathematical models for the system and subsystems and to analyze their behavior to evaluate performance under real operating conditions.

The transition rates of all subsystems that could degrade the system (the thresher) to reach a failed state were arbitrarily distributed.

Transition model

The state transition model of the thresher is shown in Fig. 2.

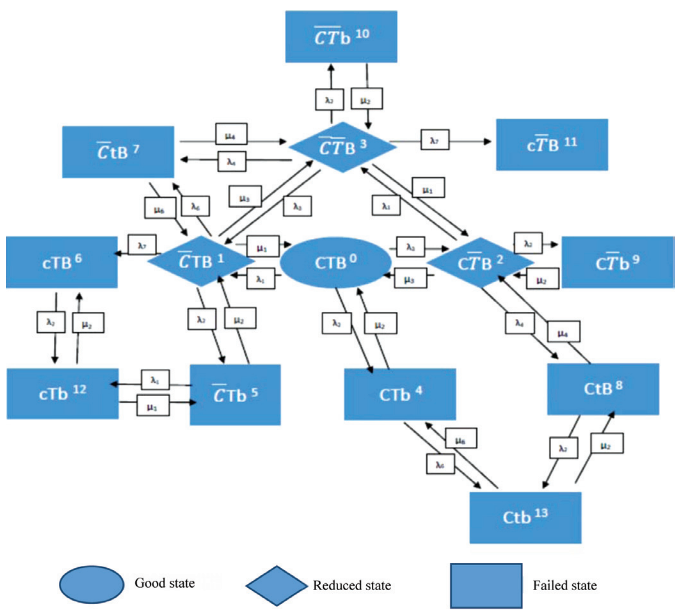

Fig. 2 State transition model of thresher, where terms are provided in the notation section above

Mathematical modelling of system in transient state

The mathematical model of the system is provided in Equations (1)–(38), when the fail rate is constant and the repair rate is variable:

$$\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\lambda_3+\lambda_7+\lambda_6+\mu_1(x)+\lambda_2]P_1(x,t)=\mu_3(x)P_3(x,t)+\mu_6(x)P_7(x,t)+\lambda_1P_0(t)+\mu_2(x)P_5(x,t) \quad (1)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\lambda_1+\lambda_2+\lambda_4+\lambda_6+\mu_3(x)]P_2(x,t)=\mu_1(x)P_3(x,t)+\mu_2(x)P_9(x,t)+\lambda_3P_0(t)+\mu_4(x)P_8(x,t)+\mu_6(x)P_{11}(x,t) \quad (2)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\lambda_2+\lambda_4+\lambda_7+\mu_3(x)+\mu_1(x)]P_3(x,t)=\mu_2(x)P_{10}(x,t)+\mu_4(x)P_7(x,t)+\lambda_3P_1(x,t)+\mu_1(x)P_2(x,t) \quad (3)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\lambda_6+\mu_2(x)]\ P_4(x,t)=\mu_6(x)P_{13}(x,t)+\lambda_2P_0(t) \quad (4)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\lambda_1+\mu_2(x)]P_5(x,t)=\mu_1(x)P_{12}(x,t)+\lambda_2P_1(x,t) \quad (5)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\lambda_2]P_6(x,t)=\mu_2(x)P_{12}(x,t)+\lambda_7P_1(x,t) \quad (6)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_4(x)+\mu_6(x)]P_7(x,t)=\lambda_4P_3(x,t)+\lambda_6P_1(x,t) \quad (7)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_4(x)+\lambda_2]P_8(x,t)=\lambda_4P_2(x,t)+\mu_2P_{13}(x,t) \quad (8)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_2(x)]P_9(x,t)=\lambda_2P_2(x,t) \quad (9)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_2(x)]P_{10}(x,t)=\lambda_2P_3(x,t) \quad (10)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_6(x)]P_{11}(x,t)=\lambda_7P_3(x,t)+\lambda_6P_2(x,t) \quad (11)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_2(x)+\mu_1(x)]P_{12}(x,t)=\lambda_2P_6(x,t)+\lambda_1P_5(x,t) \quad (12)$$
$$[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_6(x)+\mu_2(x)]P_{13}(x,t)=\lambda_2P_8(x,t)+\lambda_6P_4(x,t) \quad (13)$$

For the boundary conditions:

$$P_1(0,t) = \lambda_1 P_0(t) \quad (14)$$
$$P_2(0,t) = \lambda_3 P_0(t) \quad (15)$$
$$P_3(0,t) = \int \lambda_3P_1(x,t)dx + \int \lambda_1P_2(x,t)dx \quad (16)$$
$$P_4(0,t) = \lambda_2 P_0(t) \quad (17)$$
$$P_5(0,t) = \int \lambda_2P_1(x,t)dx \quad (18)$$
$$P_7(0,t) = \int \lambda_4P_3(x,t)dx + \int \lambda_6P_1(x,t)dx \quad (19)$$
$$P_8(0,t) = \int \lambda_4P_2(x,t)dx \quad (20)$$
$$P_9(0,t) = \int \lambda_2P_2(x,t)dx \quad (21)$$
$$P_{10}(0,t) = \int \lambda_2P_3(x,t)dx \quad (22)$$
$$P_{11}(0,t) = \int \lambda_7P_3(x,t)dx + \int \lambda_6P_2(x,t)dx \quad (23)$$
$$P_{12}(0,t) = \int \lambda_2P_6(x,t)dx \quad (24)$$
$$P_{13}(0,t) = \int \lambda_6P_4(x,t)dx + \int \lambda_2P_8(x,t)dx \quad (25)$$

And the initial conditions,

$$P_i(x,0) = 0\ ; i = 1,\ldots\ldots\ldots\ldots\ldots\ldots 13 \quad (26)$$

The system of differential equations (Equations 1–13), together with the boundary condition (Equations14–25) and the initial conditions (Equation 26) are components of the so-called Chapman-Kolmogorov differential difference equations. To identify the reliability of the system, the governing Equations 1–13 along with the boundary conditions Equations 14–25 were solved using Lagrange's method:

$$P_1(x, t) =\varphi_1 (t-x) + e^{-\int T1(x)\,dx}[\lambda_1P_0(t) + \int S_1(x, t)\, e^{\int T1(x)\,dx}\, dx \quad (26)$$
$$P_2(x, t) =\varphi_2 (t-x) + e^{-\int T_2(x)\,dx}\ [\lambda_2P_1(t) + \int S_2(x, t)\, e^{\int T2(x)\,dx}\, dx] \quad (27)$$
$$P_3(x, t) =\varphi_3 (t-x) + e^{-\int T_3(x)\,dx}\ [\int \lambda_3P_1(t) + \int \lambda_1P_2(t) +\int S_3(x, t)\, e^{\int T3(x)\,dx}\, dx] \quad (28)$$
$$P_4(x, t) =\varphi_4(t-x) + e^{-\int T_4(x)dx} [\int \lambda_2P_0(t)+\int S_4(x, t)\, e^{\int T4(x)\,dx}\, dx] \quad (29)$$
$$P_5(x, t) =\varphi_5(t-x) + e^{-\int T_5(x)dx} [\int \lambda_2P_1(x,t)+\int S_5(x, t)\, e^{\int T5(x)\,dx}\, dx] \quad (30)$$
$$P_6(x, t) =\varphi_6(t-x) + e^{-\int \lambda_2dx} [\int \lambda_7P_1(x,t)+\int S_6(x, t)e^{\int \lambda_2dx}\, dx] \quad (31)$$
$$P_7(x, t) =\varphi_7(t-x) + e^{-\int T_7dx} [\int \lambda_4P_3(x,t)+ \int \lambda_6P_1(x,t) +\int S_7(x, t)\, e^{\int T7(x)\,dx}\, dx] \quad (32)$$
$$P_8(x, t) =\varphi_8(t-x) + e^{-\int T_8dx} [\int \lambda_4P_2(x,t)+\int S_8(x, t)\, e^{\int T8(x)\,dx}\, dx] \quad (33)$$
$$P_9(x, t) =\varphi_9(t-x) + e^{-\int T_9(x)dx} [\int \lambda_2P_2(x,t)dx +\int S_9(x, t)e^{\int T_9(x)dx}\ dx] \quad (34)$$
$$P_{10}(x, t) =\varphi_{10}(t-x) + e^{-\int T_{10}(x)dx}\ \int \lambda 2P3(x,t)dx +S_{10} \int (x, t)\, e^{\int T_{10}(x)dx}\ dx] \quad (35)$$
$$P_{11}(x, t) =\varphi_{11}(t-x)+e^{-\int \mu_6dx} [\int \lambda_7P_3(x,t)dx + \int \lambda_6P_2(x,t)dx+\int S_6(x, t)e^{\int \mu_6dx}\, dx] \quad (36)$$
$$P_{12}(x, t) =\varphi_{12}(t-x)\ +e^{-\int T_{12}dx}\ \int \lambda 2P6(x,t)dx + +S_12e^{\int T_{12}(x)dx}\ dx] \quad (37)$$
$$P_{13}(x, t) =\varphi_{13}(t-x)+e^{-\int T_{13}dx} [\int \lambda_6P_4(x,t)dx + \int \lambda_2P_8(x,t)dx + +\int S_{13}(x, t)e^{\int T_{13}dx}\, dx] \quad (38)$$

where,

$T_1(x) = \lambda_2+ \lambda_3 + \lambda_6 + \lambda_7+\mu_1(x)$
$S_1 = \lambda_1 P_0(t) + \mu_2P_5(x, t) + \mu_3P_3(x, t)+ \mu_6P_7(x, t)$
$T_2(x) = \lambda_1 + \lambda_2 + \lambda_4+ \lambda_6 +\mu_3(x)$
$S_2 = \lambda_3 P_0(t) + \mu_1P_3(x, t) + \mu_2P_9(x, t)+ \mu_4P_8(x, t)+ \mu_6P_{11}(x, t)$
$T_3(x) = \lambda_2+ \lambda_4 + \lambda_7+\mu_1(x) + \mu_3(x)$
$S_3 = \lambda_3 P_1(x,t) + \mu_1P_2(x, t) + \mu_2P_{10}(x, t)+ \mu_4P_7(x, t)$
$S_4 = \lambda_2P_0(t) + \mu_6 (x)P_{13}(x, t)$
$T_5(x) = \lambda_1 +\mu_2(x)$
$S_5 = \lambda_2 P_1(x,t) + \mu_1(x)P_{12}(x, t)$
$S_6= \lambda_7 P_1(x,t) + \mu_2 (x)P_{12}(x, t)$
$T_7(x) = \mu_4(x)+\mu_6(x)$
$S_7 = \lambda_4 P_3(x,t) + \lambda_6P_1(x, t)$
$T_8(x) = \lambda_2 +\mu_4(x)$
$S_8 = \lambda_4 P_2(x,t) + \mu_2(x)P_{13}(x, t)$
$S_9= \lambda_2 P_2(x,t)$
$S_{10}= \lambda_2 P_3(x,t)$
$S_{11}= \lambda_7 P_3(x,t) + \lambda_6 P_2(x,t)$
$T_{12}(x) = \mu_1(x)+\mu_2(x)$
$S_{12} = \lambda_1 P_5(x,t) + \lambda_2P_6(x, t)$
$T_{13}(x) = \mu_2(x)+\mu_6(x)$
$S_{13} = \lambda_2P_8(x,t) + \lambda_6P_4(x, t)$

Results and Discussion

RAM analysis of thresher

Reliability, availability and maintainability of repairable industrial systems as well as critical engineering systems is analysed by taking uncertain data in various reported case studies (Sharma and Kumar, 2008; Komal et al., 2010). Any type of efficiency in the system (thresher in this case study) can be improved through the computations discussed in the current study. The mean time to failure can be reduced by reducing λ_2 (Equations 1–6, 8–10 and 12 and 13), which indicates that the failure rate of the blower is the part in the thresher most affected by failures most of the time. By reducing the repair time (μ_2 in the same equations), the efficiency of the thresher could be improved. Furthermore, one common observation on farmers using the thresher was that the threshing drum is not repaired from a reduced to a failed state (Equations 2, 3, 7 and 8), which is one of the main reasons for reduced efficiency. Whenever the threshing drum is working in a reduced efficiency state, it can either be repaired without delay (to reduce the time in the repair rate, μ_2) or alternatively, continue operation in the reduced efficiency state until it fails and then replace the failed parts with assured quality spares to reduce the MTTR and MTBF. In turn, this would affect the failure rate in the boundary equations (17, 18, 21, 22, 24 and 25 for the blower and 19 and20 for threshing drum). The failure rate of the concave blades (λ_1 and λ_7) had the least effect in the model. In conclusion, the availability $A_v(t)$ in terms of probability $P_0(t)$, failure and repair rates can be calculated by fitting data in the model in Equation (39):

$$\left[\frac{d}{dt}+\sum_{i=1}^{13}\lambda_i\right] P_0(t) = \int \sum_{i=1}^{13}\mu_i(x)\, P_i(x, t)\, dx \tag{39}$$

In addition, the parameters that can be used to improve thresher efficiency are summarized in Table 1.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

Basant products (India), supplied the diagram of their multifunction thresher. Dr. Shakuntala Singla and Dr. Parveen Ailawalia provided guidance and support.

Table 1 Parameters to improve thresher efficiency

Affected component	State to improve thresher efficiency	Reference
Mean time to failure λ_2 (MTTF)	Should be reduced	Equations 1–6, 8–10 and 12 and 13
Failure rate of blower (MTBF)	Should be reduced	Equations 17, 18, 21, 22, 24 and25
Failure rate of threshing drum	Should be reduced	Equations 2, 3, 7, 8, 19 and20
Failure rate of concave blades	Least affected	λ_1 and λ_7 in Equations 11, 16, 23, 26, 28, 31 and 36

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