Analysis of various reliability parameters for rice industry

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Abstract. The present study deals with the analysis of various parameters in view of reliability for a manufacturing plant namely rice manufacturing plant, for considered conditions as well as availability during the season for the regenerating Markov model. The Laplace transformation has been used to simplify and for the explicit expressions of Availability, Reliability, MTTF. The numerical illustrations have been carried out for the data available in the literature. The profit analysis, sensitivity analysis carried out for the considered model.

Keywords: Markov model, Availability, Reliability, Profit analysis

1. Introduction

Rice mill is a food processing industry which converts paddy into rice. Many machines and equipment are installed in the mill for the processing of the paddy. In reliability engineering, a system or a machine is considered as a unique entity which is not further subdivided, although there may be many components in the machine. Failure free operation of the machine is required to get the required output. But failure of a machine is a random phenomenon which can occur at any point of time in the life period of a machine which may affect the working of the system. This may have bad affects on the environment or on the people working in the mill etc. Therefore, reliability engineering is the thrust area which deals with these problems of the industry and reliability engineers make their efforts to improve the reliability of the product and the engineering system. If system is reliable and available, then system can perform its intended task within specified period of time under operating conditions. Tewari and Kumar [1] presented the availability analysis of the milling system of rice manufacturing plants using Markov modelling. Dahiya et al. [2] analyzed the A-pan crystallization system in the sugar industry using Markov modeling. Bansal et al. [3] discussed the Boolean function technique for the evaluation of reliability parameters for milk powder plant manufacturing plant. Numerical method approach was adopted by [4], [5]. Runge-Kutta fourth-order method was used for solving the ordinarily differential equation for obtaining the availability, reliability and MTTF of the system. Sharma and Vishwakarma [6] used genetic algorithm technique for the optimization analysis of the feeding system of the sugar industry. Evaluation of the reliability parameter using Laplace transformation was carried out by [7], [8], [9], [10]. Besides this redundancy in the system also plays a very important role. Redundancy in the systems just helps to increase the reliability of the system and reduce the downtime of the system. Li [11] presented a comparative analysis of active and standby redundancy. Another type of redundancy is k-out-of-n redundancy, in this system, all the n units are connected in parallel connection. The system fails when the at least k component fails. Reliability analysis of the k-out-of-n system was presented by [12], [13], [14]. A very good industrial system which works under cost-free warranty and rest policy was presented by Kumar and Kumar [15]. This system after working for some time takes rest this policy reduces the failure of the system. Reliability of the system was evaluated for different failure rates. Kumar and Kumar [16] analyzed the performance of the wireless communication system by taking its main components into consideration. Markov modeling was
utilized to determine the various performance indicator of the system. Critical components of the system were determined in their analysis.

In the present paper, authors carried out the reliability analysis of the rice mill by taking various important units of the rice mill like cleaning unit, Husking unit, Separation unit, Polishing unit and Packing unit. No one in the above studies has carried out the reliability analysis of the mill by taking all its units into consideration. Markov Model has been used for modeling the system. For the complete analysis of the system failure rates and repair rates have been assigned particular values.

1.1 Problem statement
For the failure free operation of the rice mill, it is necessary to carry out the reliability analysis of the mill. As we know that system is composed of many components. It has been observed that failure of the main components of the system may hamper the working of the entire system which increase the downtime of the system and increase the cost of the system. Sometimes failures are so disastrous that they may affect the environment and the health of the people working in the mill. With this problem in our mind, we intend to carry out the reliability analysis of the rice manufacturing plant.

2. Description of the system
In the present paper main units of the “Rice mill” have been chosen namely, i.e. cleaning unit, husking unit, separation unit, polishing unit, packing unit. All these units are in mixed configuration. The system can be in good state, or in degraded state or in failed state due to the failure of the units of the system. Fig.1 is the flow diagram of the considered system.

Figure. 1: Configuration of the System

- **Cleaning Unit (A):** Cleaning machine is used to clean the paddy grain. This unit is used to remove all impurities. Due to the failure of this system the whole system fails.
- **Husking Unit (B):** This unit is used to remove husk from paddy. Failure of this unit causes the failure of the whole unit.
• **Separation Unit (C):** This machine is used to separate unhusked paddy from the brown rice. There are two separators. One is active and the other is on stand by redundancy. When the main unit fails, the whole load is transferred to the standby unit. This standby unit has the same working capacity as that of the active unit.

• **Polishing Unit (D):** The main function of this unit is to remove the bran layer or germ from the brown rice. Rice is polished white in this unit.

• **Packing Unit (E):** The packing of the rice is done by this unit. This process is completed in three steps. First, rice is put into plastic bags. After that, a printing machine prints the rice bag. In the third step, the heat seal is done by the machine. The failure of this process results in the complete failure of the system.

3. **Assumptions of the system**
   - Initially, the system is in good state.
   - Each component of the system has only two states i.e., good or failed.
   - The whole system may be in any of the three states i.e., good, degraded, and failed at any time t.
   - System repair and failure rate are independent of each other.
   - The system units have constant failure and repair rates.
   - Repair facility is always available with the system.
   - When the main unit of the separation unit fails, the whole load is transferred to the standby unit.

4. **Notations and state description**

The following notations/state description are used throughout the manuscript:

**Table 1(a): Notations.**

- All components of the system are in good working condition.
- System is in degraded state.
- System is in failed state.
- \( \alpha_i \) (\( i = 1, 2, 3, 4, 5 \): Failure rate of Cleaning unit (A), Husking unit (B), Separation unit (C), Polishing unit (D), Packing unit (E)
- \( \beta_i \) (\( i = 1, 2, 3, 4, 5 \): Repair rate of Cleaning unit (A), Husking unit (B), Separation unit (C), Polishing unit (D), Packing unit (E)
- \( P_i(t) \): Probability that the system is in the state \( S_i \)
- \( \tilde{P}_i(s) \): Laplace transformation of \( P_i(t) \)

**Table 1(b): State description.**

| State \( S_i \) | State description |
|-----------------|-------------------|
| \( S_0 \) | The system is in good working condition. |
| \( S_1 \) | The system fails when the cleaning unit of the system fails. |
| \( S_2 \) | The system fails when the husking unit of the system fails. |
| \( S_3 \) | The system continues to work when the active separator unit of the system fails and the standby unit take over failed unit. |
$S_4$  The system fails when the polishing unit of the system fails.
$S_5$  The system fails when the packing unit of the system fails.
$S_6$  The system fails when the cleaning unit of the system fails after the failure of the active separator unit.
$S_7$  The system fails when the husking unit of the system fails after the failure of the active separator unit.
$S_8$  The system fails when the standby separator unit of the system fails after the failure of the active separator unit.
$S_9$  The system fails when the polishing unit of the system fails after the failure of the active separator unit.
$S_{10}$  The system fails when the polishing unit of the system fails after the failure of the active separator unit.

5. Reliability block diagram of the system

A reliability block diagram is a diagram which represents the different state and transition between them throughout its working and non-working condition, given below the different failures and repairs which may occur during the transition from one state to another state in time $(t, t+\Delta t)$ are shown in the following Fig. 2.
5.1 Kolmogorov differential equations

In this section of the paper, we develop Kolmogorov differential equation from the block diagram Fig. 2 in the time interval \((t, t + \Delta t)\). The equations (1) – (12) can be written as follows:

\[
\begin{align*}
\frac{d}{dt} P_1(t) & = \alpha_1 P_0(t) + \beta_1 P_1(t) + \beta_2 P_2(t) + \beta_3 P_3(t) + \beta_4 P_4(t) + \beta_5 P_5(t) \\
\alpha_2 \frac{d}{dt} P_2(t) & = \alpha_1 P_0(t) \\
\beta_1 \frac{d}{dt} P_3(t) & = \alpha_2 P_0(t)
\end{align*}
\]
\[
\begin{align*}
\left[ \frac{d}{dt} + \beta_3 + \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 \right] P_3(t) &= \alpha_3 P_0(t) + \beta_1 P_0(t) + \beta_2 P_2(t) + \beta_3 P_3(t) + \beta_4 P_4(t) + \beta_5 P_5(t) \\
\left[ \frac{d}{dt} + \beta_4 \right] P_4(t) &= \alpha_4 P_4(t) \\
\left[ \frac{d}{dt} + \beta_5 \right] P_5(t) &= \alpha_5 P_5(t)
\end{align*}
\]

(4) \quad \begin{align*}
\left[ \frac{d}{dt} + \beta_1 \right] P_1(t) &= \alpha_1 P_1(t) \\
\left[ \frac{d}{dt} + \beta_2 \right] P_2(t) &= \alpha_2 P_2(t) \\
\left[ \frac{d}{dt} + \beta_3 \right] P_3(t) &= \alpha_3 P_3(t) \\
\left[ \frac{d}{dt} + \beta_4 \right] P_4(t) &= \alpha_4 P_4(t) \\
\left[ \frac{d}{dt} + \beta_5 \right] P_5(t) &= \alpha_5 P_5(t)
\end{align*}

(5) \quad \begin{align*}
(6) \quad \begin{align*}
(7) \quad \begin{align*}
(8) \quad \begin{align*}
(9) \quad \begin{align*}
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\end{align*}

Initial conditions:

\[ P_0(t) = 1 \quad \text{at} \quad t = 0 \quad \text{and} \quad P_j(t) = 0 \quad \text{at} \quad t = 0 \quad \text{and} \quad j = 1, \ldots, 10 \]

(12)

On taking Laplace transformation of equation (1)-(10), we get,

\[
\left[ s + \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 \right] \tilde{P}_0(s) = 1 + \beta_1 \tilde{P}_1(s) + \beta_2 \tilde{P}_2(s) + \beta_3 \tilde{P}_3(s) + \beta_4 \tilde{P}_4(s) + \beta_5 \tilde{P}_5(s)
\]

(13)

\[
\left[ s + \beta_3 + \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 \right] \tilde{P}_3(s) = \alpha_3 \tilde{P}_0(s) + \beta_1 \tilde{P}_0(s) + \beta_2 \tilde{P}_1(s) + \beta_3 \tilde{P}_2(s) + \beta_4 \tilde{P}_3(s) + \beta_5 \tilde{P}_5(s)
\]

(14)

\[
\left[ s + \beta_i \right] \tilde{P}_i(s) = \alpha_i \tilde{P}_0(s) \quad (i = 1, 2, 4, 5)
\]

(15)
\[ [s + \beta_i] \overline{P}_j(s) = \alpha_i \overline{P}_3(s) \quad (i = 1, 2, \ldots, 5, \ j = 6, 7, \ldots, 10) \]  

On solving the above equations, we get

\[ \overline{P}_i(s) = \frac{\alpha_i}{[s + \beta_i]} \overline{P}_0(s) \quad (i = 1, 2, 4, 5) \]  

\[ \overline{P}_j(s) = \frac{\alpha_i}{[s + \beta_i]} \overline{P}_3(s) \quad (i = 1, 2, \ldots, 5, \ j = 6, 7, \ldots, 10) \]  

\[ \overline{P}_3(s) = \frac{\alpha_3}{H_2} \overline{P}_0(s) \]  

\[ \overline{P}_0(s) = \frac{1}{H_1} \]  

Where

\[ H_1 = \left[ s + \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 - \frac{\beta_1 \alpha_1}{s + \beta_1} - \frac{\beta_2 \alpha_2}{s + \beta_2} - \frac{\beta_3 \alpha_3}{s + \beta_3} - \frac{\beta_4 \alpha_4}{s + \beta_4} - \frac{\beta_5 \alpha_5}{s + \beta_5} \right] \]  

\[ H_2 = \left[ s + \beta_3 + \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 - \frac{\beta_1 \alpha_1}{s + \beta_1} - \frac{\beta_2 \alpha_2}{s + \beta_2} - \frac{\beta_3 \alpha_3}{s + \beta_3} - \frac{\beta_4 \alpha_4}{s + \beta_4} - \frac{\beta_5 \alpha_5}{s + \beta_5} \right] \]  

After finding state transition probabilities we can find system’s upstate, means the probability that system is in the working condition. It may be working in its full capacity or in its reduced capacity. Therefore, the system upstate and down state are given below:

\[ P_{up}(s) = \overline{P}_0(s) + \overline{P}_3(s) \]  

\[ P_{down}(s) = P_1(s) + P_2(s) + P_4(s) + P_6(s) + P_7(s) + P_8(s) + P_9(s) + P_{10}(s) \]  

6. Reliability measures of the system

6.1 Availability of the system

System availability has direct relationship with the production of the organization. When system is available then more production can be done. This is one of the measures of the system reliability. To obtain the time dependent availability of the system set \( \alpha_1 = 0.01, \alpha_2 = 0.03, \alpha_3 = 0.25, \alpha_4 = 0.06, \alpha_5 = 0.02, \beta_1 = 1 \), \( \beta_2 = 1, \beta_3 = 1, \beta_4 = 1, \beta_5 = 1 \), in (23) and taking Inverse Laplace Transform of (23), we obtain the time dependent availability of the system.

\[ A(t) = 0.107142857 e^{-1.12000000t} + 0.8928571429 \]  

Now, vary time \( t \) from 0 to 10 in (25), we obtain the following table.

**Table 2(a): Availability of the system**
| Time t | Availability |
|--------|--------------|
| 0      | 1.0000       |
| 1      | 0.9278       |
| 2      | 0.9042       |
| 3      | 0.8965       |
| 4      | 0.8940       |
| 5      | 0.8932       |
| 6      | 0.8929       |
| 7      | 0.8928       |
| 8      | 0.8928       |
| 9      | 0.8928       |
| 10     | 0.8928       |
Figure. 2(a): Availability of the system

6.2 Reliability of the system

System reliability is the probability the system will perform its intended task under specified operating condition for a specified period of time. For the reliability of the system, we set,$\alpha_1 = 0.01, \alpha_2 = 0.03, \alpha_3 = 0.25, \alpha_4 = 0.06, \alpha_5 = 0.02$ and repair rate equal to zero in (23). Taking the Inverse Laplace of the expression obtained, we get,

$$R(t) = e^{-0.37000000t} + 2e^{-0.24500000} \sinh(0.1250000000t)$$

(26)

Now, vary time $t$ from 0 to 10 in (26), we obtain the following Table.

| Time t | Reliability |
|--------|-------------|
| 0      | 1           |
| 1      | 0.8869      |
| 2      | 0.7866      |
| 3      | 0.6976      |
| 4      | 0.6187      |
| 5      | 0.5488      |
| 6      | 0.4867      |
| 7      | 0.4317      |
| 8      | 0.3828      |
| 9      | 0.3395      |
| 10     | 0.3011      |
MTTF is another metric for the reliability of the system. It is the length of time the system a device or component expected to last in operation. To obtain the MTTF of the system set all repair rates equal to zero in (23) and taking limit $s \rightarrow 0$, we get the MTTF of the system.

$$\text{MTTF}= \int_{0}^{\infty} R(t)dt = \lim_{s \rightarrow 0} R(s)$$  \hspace{1cm} (27)
\[ MTTF = \frac{\alpha_1 + \alpha_2 + 2\alpha_3 + \alpha_4 + \alpha_5}{(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5)} \]  

(28)

Now on varying failure rates one by one from 0.01 to 0.09 we obtain the following Table.

MTTF of the system is given in the Table below:

| Variation in failure rates | $\alpha_1$  | $\alpha_2$  | $\alpha_3$  | $\alpha_4$  | $\alpha_5$  |
|----------------------------|-------------|-------------|-------------|-------------|-------------|
| 0.01                       | 4.5288      | 4.8979      | 8.2840      | 5.5664      | 4.7067      |
| 0.02                       | 4.3628      | 4.7067      | 8.1632      | 5.3259      | 4.5288      |
| 0.03                       | 4.2077      | 4.5288      | 8.0000      | 5.1038      | 4.3628      |
| 0.04                       | 4.0625      | 4.3628      | 7.8125      | 4.8979      | 4.2077      |
| 0.05                       | 3.9262      | 4.2077      | 7.6124      | 4.7067      | 4.0625      |
| 0.06                       | 3.7981      | 4.0625      | 7.4074      | 4.5288      | 3.9262      |
| 0.07                       | 3.6776      | 3.9262      | 7.2022      | 4.3628      | 3.7981      |
| 0.08                       | 3.5640      | 3.7981      | 7.0000      | 4.2077      | 3.6776      |
| 0.09                       | 3.4567      | 3.6776      | 6.8027      | 4.0625      | 3.5640      |
Figure. 2(c): MTTF of the system

### 6.4 Sensitivity of MTTF

The objective of the sensitivity analysis is to determine the input variable which affect the system most. We perform the sensitivity analysis on the MTTF. Table 2(d) shows change in the meantime to failure MTTF of the system resulting from changes in parameters $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$. Differentiate the equation (28) w.r.t failure rates $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$. Now one by one vary failure rates from 0.01 to 0.09 in these derivative we obtain the following Table:
Table 2(d): Sensitivity of the MTTF

| Variation in failure rates | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ | $\alpha_5$ |
|---------------------------|------------|------------|------------|------------|------------|
| 0.01                      | -17.1756   | -19.8250   | -9.1033    | -25.0244   | -18.4327   |
| 0.02                      | -16.0373   | -18.4327   | -14.5772   | -23.0959   | -17.1756   |
| 0.03                      | -15.0036   | -17.1756   | -17.7777   | -21.3718   | -16.0373   |
| 0.04                      | -14.0625   | -16.0373   | -19.5312   | -19.8250   | -15.0036   |
| 0.05                      | -13.2035   | -15.0036   | -20.3541   | -18.4327   | -14.0625   |
| 0.06                      | -12.4176   | -14.0625   | -20.5761   | -17.1756   | -13.2035   |
| 0.07                      | -11.6970   | -13.2035   | -20.4111   | -16.0373   | -12.4176   |
| 0.08                      | -11.0349   | -12.4176   | -20.0000   | -15.0036   | -11.6970   |
| 0.09                      | -10.4252   | -11.6970   | -19.4363   | -14.0625   | -11.0349   |
Figure 2(d): Sensitivity of the system

6.5 Expected profit

Expected profit of company, organization is that profit that it can earn at any point of time if the system works as expected. The expected profit of the mill is calculated using the formula given below

$$E_P(t) = K_1 \int_0^t p_{up}(t) \, dt - K_2 t$$  (29)

Set, $K_1 = 1$, equation (29) reduces to,

$$E_P(t) = \int_0^t p_{up}(t) \, dt - K_2 t$$  (30)

After integration, we get the expression,
\[ E_p(t) = -K_2 t - 0.09566326527 e^{-1.20000000} + 0.8928571429 + 0.095666527 \]  

(31)

In equation set service cost \( K_2 = 0.1, 0.2, ..., 0.5 \) and vary \( t \) from 0 to 10, we obtain the following Table:

| Time | \( K_2 = 0.1 \) | \( K_2 = 0.2 \) | \( K_2 = 0.3 \) | \( K_2 = 0.4 \) | \( K_2 = 0.5 \) |
|------|----------------|----------------|----------------|----------------|----------------|
| 0    | 0              | 0              | 0              | 0              | 0              |
| 1    | 0.8573         | 0.7573         | 0.6573         | 0.5573         | 0.4573         |
| 2    | 1.6711         | 1.4711         | 1.2711         | 1.0711         | 0.8711         |
| 3    | 2.4709         | 2.1709         | 1.8709         | 1.5709         | 1.2709         |
| 4    | 3.2660         | 2.8660         | 2.4660         | 2.0660         | 1.6666         |
| 5    | 4.0595         | 3.5595         | 3.0595         | 2.5595         | 2.0595         |
| 6    | 4.8526         | 4.2526         | 3.6526         | 3.0526         | 2.4526         |
| 7    | 5.6456         | 4.9456         | 4.2456         | 3.5456         | 2.8456         |
| 8    | 6.4385         | 5.6385         | 4.8385         | 4.0385         | 3.2385         |
| 9    | 7.2313         | 6.3313         | 5.4313         | 4.5313         | 3.6313         |
| 10   | 8.0242         | 7.0242         | 6.0242         | 5.0242         | 4.0242         |
In this paper, we developed a model of the rice mill to determine the performance measures of the rice mill. All the main units of the rice mill like cleaning unit, Husking unit, separation unit, Polishing unit and packing unit have been taken into consideration. Separation unit has one stand by unit, on the failure of the main separation unit stand by unit takes over and system works without failure. Markov model has been used to model the system and Kolmogorov-differential equations were developed from the transition state diagram of the system and the explicit expression of various performance measures were obtained like Availability, Reliability, MTTF, Sensitivity of MTTF and Expected profit. Based on above graphs and table we obtain the following important results.

7. Result and discussion

In this paper, we developed a model of the rice mill to determine the performance measures of the rice mill. All the main units of the rice mill like cleaning unit, Husking unit, separation unit, Polishing unit and packing unit have been taken into consideration. Separation unit has one stand by unit, on the failure of the main separation unit stand by unit takes over and system works without failure. Markov model has been used to model the system and Kolmogorov-differential equations were developed from the transition state diagram of the system and the explicit expression of various performance measures were obtained like Availability, Reliability, MTTF, Sensitivity of MTTF and Expected profit. Based on above graphs and table we obtain the following important results.
In Figure 2(a), it is observed that system availability decreases very slowly. From t=7 to t=10, system availability is 0.8928. In Fig. 2(b), it is observed that the reliability of the system decreases with the increase in time. At time t=10, reliability of the system is 0.3011. This may be due to various factors like aging of the components, corrosion, stress etc. In Fig. 2(c), MTTF of the system is more w.r.t the variation in the failure rate of separator unit. This implies that increase in failure of the third unit doesn’t affect the system much. In Fig. 2(d), MTTF is more sensitive w.r.t failure rate of polishing unit, when we slightly change in the value of failure rate of polishing unit, value of the sensitivity of the MTTF increases very rapidly. In Fig. 2(e), the system expected profit decreases as the service cost of the system increases. So, to earn more profit it is necessary to control the service cost of the system.

8. Conclusion

In this paper, we utilized the Markov model to obtain the reliability measure of the rice manufacturing plant. The failure and the repair rates have been taken constants. From the above discussion, we conclude the rice mill engineers should pay more attention to maintenance of the fourth unit of the system (Polishing unit). This unit mainly affects the working of the mill. Reliable equipment should be used for this unit for the minimum disruption in the system. Timely preventive maintenance will help to improve the system working. This research is quite useful for the rice mill for improving the performance of the rice mill and for improving their maintenance strategy.

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