AVAILABILITY AND PERFORMANCE ANALYSIS OF A CEMENT PLANT

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ABSTRACT

Cement is a significant material in the development and industrialization as it sets, solidifies and ties different materials blended in with sand and items concrete. Indian government is working for the financial improvement of the nation by building lodging offices, streets and advancement in the framework ventures. So the demand of cement has boosted form the past few decades. As cement assume significant job in development for this great nature cement is required else it can reason for infraction breakdown, mishaps and some hazardous and hurting frequencies. In cement plant seven subsystems are arranged in series. Availability and performance of cement plant has been analyzed with the assistance of supplementary variable technique. Failure rate of the system are exponentially distributed and repair rates are considered as arbitrary. Markov birth and death process has utilized in the derivation of Chapman-Kolmogorov differential equations. Variation in the profit and availability of system has been analyzed based on variation in the failure and repair rates of the system. By utilizing this strategy kiln subsystem is profoundly delicate so it need exceptionally consideration regarding improve the performance of the complete system.

KEYWORDS: Supplementary Variable Technique, Markovian Birth Death Process, Availability, Failure Rates, Repair Rates

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1. INTRODUCTION

Cement is a vital development material in industrialization and human civic establishments. It sets, solidifies and ties different materials and blended in with sand and items concrete. India is has second spot in the creation of cement after China. India utilizes enormous measure of cement in the lodging, foundation, streets, air terminals and in other development for its economy improvement. Low quality of framework can cause in building breakdown, street mishaps and other destructive occurrences. So with the proper planning and management great nature of materials is required. Nature of any material can be improved by examining its availability and performance. In India cost of cement has expanded because of huge interest in industrialization. There is need to discover the system for giving great quality of cement at least expense and make it increasingly gainful.

In past researches about researchers has examined the reliability and availability in the manner to improve the performance of their models. Gupta et al. (2007) has analyzed the reliability and availability of the plastic pipe manufacturing plant in which all the components has been arranged in series configuration. Barabady and Kumar (2008) has analyzed the reliability of mining equipment of crushing plant in the Jajarm bauxite mine in Iran. Carazas et al. (2011) has analyzed the availability of heat recovery steam generators in thermal power plant to identify the critical components in the way to enhance the reliability and availability of the system. Sharma et al.

In cement plant (Fig 1) seven components has been used in series configuration. All components in the systems are as: raw mill, coal mill, pre-heater, kiln, cooler, cement mill, packaging where silo is the storage unit of raw mill and pyro and bin is the storage unit of coal mill. These units are connected in series so failure in any one unit can cause in failure in complete system. These seven subsystems are described below:

i.Subsystem ‘A’ (Raw Mill)

Raw mill consist only one unit in series configuration connected with other subsystem preheater. Failure in this subsystem can cause in failure of complete system. Raw mill supplies limestone to the preheater. Silo is the storage unit of raw mill where material stores after processing

ii.Subsystem ‘B’ (Coal Mill)

Coal mill consist only one unit in series configuration connected with other subsystem preheater. Failure in this subsystem can cause in failure of complete system. Coal mill supplies coal to the preheater. Pyro and bin is the storage unit of coal mill where material store after processing.

iii.Subsystem ‘C’ (Preheater)

Preheater consist only one unit in series configuration connected with other subsystems raw mill, coal mill and kiln. Failure in this subsystem can cause in failure of complete system. Preheater is used to heat the raw material and remove the carbon dioxide and water before it supplies to kiln.

iv.Subsystem ‘D’ (Kiln)

Kiln consist only one unit in series configuration connected with other subsystems preheater and cooler. Failure in this subsystem can cause in failure of complete system. Kiln is a chamber that produced temperature in the process of hardening, drying and chemical change in raw materials.

v.Subsystem ‘E’ (Cooler)

Cooler consist only one unit in series configuration connected with other subsystems kiln and cement mill. Failure in this subsystem can cause in failure of complete system. Cooler is used to remove heat from material and cool down the material temperature.

vi.Subsystem ‘F’ (Cement Mill)

Cement mill consist only one unit in series configuration connected with other subsystems cooler and packaging. Failure in this subsystem can cause in failure of complete system. Cement mill grind the material and make its powder.

vii.Subsystem ‘G’ (Packaging)

Packaging consist only one unit in series configuration connected with other subsystem cement mill. Failure in this subsystem can cause in failure of complete system. In packaging unit materials are supplies by the cement mill for the packaging.

3. Assumptions

- a) No waiting time between failure and repair

- b) Systems works as new after repair with full capacity
 c) Failure rates are exponentially distributed, and repair rates are considered as arbitrary

4. NOTATIONS

:	Subsystem works with full capacity
:	Subsystem is in failure state
L, M, N, O, P, Q, R	:	All subsystems are working with full capacity
l, m, n, o, p, q, r	:	Subsystem has failed
$\lambda_i (1 \leq i \leq 7)$	:	Respectively failure rates in subsystems A, B, C, C_1, D, E, D_1
$\gamma_i(x) (1 \leq i \leq 7)$	:	Respectively repair rate in subsystems A, B, C, C_1, D, E, D_1
$P_0(t)$	:	Probability that system is working with full capacity
$P_i(x, t), (i = 1, \dots, 19)$	:	Probability of subsystem on i^{th} state at time t with repair time x
$S_i, (i = 1, 2, \dots, 19)$	:	State of the subsystem

Figure 2: State progression diagram of the system

5. MATHEMATICAL MODELING OF THE SYSTEM

A technique namely supplementary variable technique has been used to solve the developed mathematical model related to state progression diagram (Fig-2) and derived the Chapman-Kolmogorov differential difference equations by Markov birth

$$P_0(t + \Delta t) = (1 - \varsigma_1 \Delta t - \varsigma_2 \Delta t - \varsigma_3 \Delta t - \varsigma_4 \Delta t - \varsigma_5 \Delta t - \varsigma_6 \Delta t - \varsigma_7 \Delta t) P_0(t) + \int_0^\infty \theta_1(x) P_1(x, t) dx \Delta t$$

death process.

$$+ \int_0^\infty \theta_2(x) P_2(x, t) dx \Delta t + \int_0^\infty \theta_3(x) P_3(x, t) dx \Delta t + \int_0^\infty \theta_4(x) P_4(x, t) dx \Delta t$$

$$+ \int_0^\infty \theta_5(x) P_5(x, t) dx \Delta t + \int_0^\infty \theta_6(x) P_6(x, t) dx \Delta t + \int_0^\infty \theta_7(x) P_7(x, t) dx \Delta t$$

$$P_0(t + \Delta t) - P_0(t) = [(-\varsigma_1 - \varsigma_2 - \varsigma_3 - \varsigma_4 - \varsigma_5 - \varsigma_6 - \varsigma_7) P_0(t) + \int_0^\infty \theta_1(x) P_1(x, t) dx + \int_0^\infty \theta_2(x) P_2(x, t) dx$$

$$+ \int_0^\infty \theta_3(x) P_3(x, t) dx + \int_0^\infty \theta_4(x) P_4(x, t) dx + \int_0^\infty \theta_5(x) P_5(x, t) dx + \int_0^\infty \theta_6(x) P_6(x, t) dx$$

$$+ \int_0^\infty \theta_7(x) P_7(x, t) dx]$$

By dividing Δt both side and limit $\Delta t \rightarrow \infty$

$$\lim_{\Delta t \rightarrow 0} \frac{P_0(t + \Delta t) - P_0(t)}{\Delta t} = \lim_{\Delta t \rightarrow 0} [(-\varsigma_1 - \varsigma_2 - \varsigma_3 - \varsigma_4 - \varsigma_5 - \varsigma_6 - \varsigma_7) P_0(t) + \int_0^\infty \theta_1(x) P_1(x, t) dx$$

$$+ \int_0^\infty \theta_2(x) P_2(x, t) dx + \int_0^\infty \theta_3(x) P_3(x, t) dx + \int_0^\infty \theta_4(x) P_4(x, t) dx$$

$$+ \int_0^\infty \theta_5(x) P_5(x, t) dx + \int_0^\infty \theta_6(x) P_6(x, t) dx + \int_0^\infty \theta_7(x) P_7(x, t) dx]$$

$$\left[\frac{dP_0(t)}{dt} \right] + (\varsigma_1 + \varsigma_2 + \varsigma_3 + \varsigma_4 + \varsigma_5 + \varsigma_6 + \varsigma_7) P_0(t) = \int_0^\infty \theta_1(x) P_1(x, t) dx + \int_0^\infty \theta_2(x) P_2(x, t) dx$$

$$+ \int_0^\infty \theta_3(x) P_3(x, t) dx + \int_0^\infty \theta_4(x) P_4(x, t) dx$$

$$+ \int_0^\infty \theta_5(x) P_5(x, t) dx + \int_0^\infty \theta_6(x) P_6(x, t) dx$$

$$+ \int_0^\infty \theta_7(x) P_7(x, t) dx$$

$$\left[\frac{d}{dt} + \omega_0 \right] P_0(t) = \rho_0 \quad \dots (1)$$

Where

$$\omega_0 = \varsigma_1 + \varsigma_2 + \varsigma_3 + \varsigma_4 + \varsigma_5 + \varsigma_6 + \varsigma_7 \quad ; \rho_0 = \int_0^\infty \theta_1(x)P_1(x,t)dx + \int_0^\infty \theta_2(x)P_2(x,t)dx + \int_0^\infty \theta_3(x)P_3(x,t)dx \\ + \int_0^\infty \theta_4(x)P_4(x,t)dx + \int_0^\infty \theta_5(x)P_5(x,t)dx + \int_0^\infty \theta_6(x)P_6(x,t)dx \\ + \int_0^\infty \theta_7(x)P_7(x,t)dx$$

$$\left[\frac{d}{dt} + \frac{d}{dx} + \theta_1(x) \right] P_1(x,t) = \varsigma_1 P_0(t) \quad \dots (2)$$

$$\left[\frac{d}{dt} + \frac{d}{dx} + \theta_2(x) \right] P_2(x,t) = \varsigma_2 P_0(t) \quad \dots (3)$$

$$\left[\frac{d}{dt} + \frac{d}{dx} + \theta_3(x) \right] P_3(x,t) = \varsigma_3 P_0(t) \quad \dots (4)$$

$$\left[\frac{d}{dt} + \frac{d}{dx} + \theta_4(x) \right] P_4(x,t) = \varsigma_4 P_0(t) \quad \dots (5)$$

$$\left[\frac{d}{dt} + \frac{d}{dx} + \theta_5(x) \right] P_5(x,t) = \varsigma_5 P_0(t) \quad \dots (6)$$

$$\left[\frac{d}{dt} + \frac{d}{dx} + \theta_6(x) \right] P_6(x,t) = \varsigma_6 P_0(t) \quad \dots (7)$$

$$\left[\frac{d}{dt} + \frac{d}{dx} + \theta_7(x) \right] P_7(x,t) = \varsigma_7 P_0(t) \quad \dots (8)$$

The related boundary conditions are as follows:

$$P_1(0,t) = \varsigma_1 P_0(t) \quad P_2(0,t) = \varsigma_2 P_0(t) \quad P_3(0,t) = \varsigma_3 P_0(t) \quad P_4(0,t) = \varsigma_4 P_0(t) \\ P_5(0,t) = \varsigma_5 P_0(t) \quad P_6(0,t) = \varsigma_6 P_0(t) \quad P_7(0,t) = \varsigma_7 P_0(t)$$

The primary conditions are as follows:

$$P_0(0) = 1 \\ P_i(0) = 0, \quad i = 1 \text{ to } 7$$

This all above differential equations in the system with the boundary and initial conditions are together known as Chapman-Kolmogorov differential difference equations.

6. PARTICULAR CASE

The mathematical expression of the model in the system by taking repair time as exponentially distributed reduced as follow:

$$\left[\frac{d}{dt} + \varsigma_1 + \varsigma_2 + \varsigma_3 + \varsigma_4 + \varsigma_5 + \varsigma_6 + \varsigma_7 \right] P_0(t) = \theta_1 P_1(t) + \theta_2 P_2(t) + \theta_3 P_3(t) + \theta_4 P_4(t) \quad \dots (9)$$

$$+ \theta_5 P_5(t) + \theta_6 P_6(t) + \theta_7 P_7(t)$$

$$\left[\frac{d}{dt} + \theta_i \right] P_i(t) = \varsigma_i P_0(t) \quad i = 1, 2, 3, 4, 5, 6, 7 \quad \dots (10)$$

Initial Conditions:

$$P_0(0) = 1$$

$$P_i(0) = 0, \quad i=1 \text{ to } 7$$

For the calculation of long run availability $\frac{d}{dt} = 0$ can take as $t \rightarrow \infty$ and $P_i(t) = P_i$

From eq. (9 & 10), steady state probabilities are:

$$P_1 = \frac{\varsigma_1}{\theta_1} P_0 \quad P_2 = \frac{\varsigma_2}{\theta_2} P_0 \quad P_3 = \frac{\varsigma_3}{\theta_3} P_0 \quad P_4 = \frac{\varsigma_4}{\theta_4} P_0$$

$$P_5 = \frac{\varsigma_5}{\theta_5} P_0 \quad P_6 = \frac{\varsigma_6}{\theta_6} P_0 \quad P_7 = \frac{\varsigma_7}{\theta_7} P_0$$

By using normalized condition $\sum P_i = 1$

$$P_0 = \left[1 + \frac{\varsigma_1}{\theta_1} + \frac{\varsigma_2}{\theta_2} + \frac{\varsigma_3}{\theta_3} + \frac{\varsigma_4}{\theta_4} + \frac{\varsigma_5}{\theta_5} + \frac{\varsigma_6}{\theta_6} + \frac{\varsigma_7}{\theta_7} \right]^{-1}$$

long run availability (A_v)

$$A_v = P_0 = \left[1 + \frac{\varsigma_1}{\theta_1} + \frac{\varsigma_2}{\theta_2} + \frac{\varsigma_3}{\theta_3} + \frac{\varsigma_4}{\theta_4} + \frac{\varsigma_5}{\theta_5} + \frac{\varsigma_6}{\theta_6} + \frac{\varsigma_7}{\theta_7} \right]^{-1} \quad \dots (11)$$

7. PERFORMANCE ANALYSIS

In this segment, a formula has been suggested for performance analysis where K_1 appear for the total revenue taken as per unit time, A_v appear for the derived long run availability and K_2 appear for the total repair cost.

$$\text{Performance} = K_1 A_v - K_2$$

$$= 3000 \left[1 + \frac{\varsigma_1}{\theta_1} + \frac{\varsigma_2}{\theta_2} + \frac{\varsigma_3}{\theta_3} + \frac{\varsigma_4}{\theta_4} + \frac{\varsigma_5}{\theta_5} + \frac{\varsigma_6}{\theta_6} + \frac{\varsigma_7}{\theta_7} \right]^{-1} - 300 \quad \dots (12)$$

$$= 3000 \left[1 + \frac{\varsigma_1}{\theta_1} + \frac{\varsigma_2}{\theta_2} + \frac{\varsigma_3}{\theta_3} + \frac{\varsigma_4}{\theta_4} + \frac{\varsigma_5}{\theta_5} + \frac{\varsigma_6}{\theta_6} + \frac{\varsigma_7}{\theta_7} \right]^{-1} - 300$$

8. NUMERICAL ANALYSIS & DISCUSSIONS

In this segment, variation in availability of the system has been analyzed due to variation in failure rates of all the subsystems with respect to failure rate ς_1 from 1.47 to 1.29 and failure rates are consider as exponentially distributed. The variation in failure rates are as: $\varsigma_2 = 1.51$ to 1.53 , $\varsigma_3 = 1.55$ to 1.57 , $\varsigma_4 = 1.38$ to 1.4 , $\varsigma_5 = 1.74$ to 1.76 , $\varsigma_6 = 1.95$ to 1.97 and $\varsigma_7 = 1.79$ to 1.81 with repair rates: $\theta_1 = 16.9$, $\theta_2 = 17.3$, $\theta_3 = 18.2$, $\theta_4 = 15.7$, $\theta_5 = 19.6$, $\theta_6 = 21.5$ and $\theta_7 = 20.7$. Percentage change in the availability of the system is 0.000716% decreased with the increased ς_2 from 1.51 to 1.53. Percentage change in the availability of the system is 0.00068% decreased with the increased ς_3 from 1.55 to 1.57. Percentage change in the availability of the system is 0.00079% decreased with the increased ς_4 from 1.38 to 1.4. Percentage change in the availability of the system is 0.00063% decreased with the increased ς_5 from 1.74 to 1.76. Percentage change in the availability of the system is 0.00058% decreased with the increased ς_6 from 1.95 to 1.97. Percentage change in the availability of the system is 0.000598% decreased with the increased ς_7 from 1.79 to 1.81.

Table 1: consequences of failure rates on availability w.r.t. failure rate ς_1

ς_1	$S0 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S2 = \mathbf{\varsigma_2 = 1.53},$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S3 = \varsigma_2 = 1.51,$ $\mathbf{\varsigma_3 = 1.57},$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S4 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\mathbf{\varsigma_4 = 1.4},$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S5 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\mathbf{\varsigma_5 = 1.76},$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S6 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\mathbf{\varsigma_6 = 1.97},$ $\varsigma_7 = 1.79$	$S7 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\mathbf{\varsigma_7 = 1.81}$
1.47	0.619857	0.6194132	0.6194352	0.619368	0.6194653	0.6194999	0.6194861
1.49	0.619403	0.6189595	0.6189814	0.6189144	0.6190115	0.6190461	0.6190323
1.51	0.618949	0.6185065	0.6185283	0.6184614	0.6185584	0.6185929	0.6185791
1.53	0.618496	0.6180541	0.6180759	0.6180091	0.6181059	0.6181404	0.6181266
1.55	0.618044	0.6176024	0.6176242	0.6175574	0.6176541	0.6176885	0.6176748
1.57	0.617592	0.6171513	0.6171731	0.6171064	0.617203	0.6172373	0.6172236
1.59	0.617141	0.6167009	0.6167226	0.6166561	0.6167525	0.6167868	0.6167731
1.61	0.61669	0.6162511	0.6162728	0.6162064	0.6163026	0.6163369	0.6163232
1.63	0.616241	0.615802	0.6158237	0.6157573	0.6158535	0.6158877	0.615874
1.65	0.615792	0.6153536	0.6153752	0.615309	0.6154049	0.6154391	0.6154255

Figure 3: consequences of failure rates on availability w.r.t. failure rate ζ_1

Variation in availability of the system has been analyzed due to variation in repair rates of all the subsystems with respect to repair rate θ_1 from 16.9 to 18.7 and repair rates are consider as exponentially distributed. The variation in repair rates are as: $\theta_2 = 17.3$ to 17.5 , $\theta_3 = 18.2$ to 18.4 , $\theta_4 = 15.7$ to 15.9 , $\theta_5 = 19.6$ to 19.8 , $\theta_6 = 21.5$ to 21.7 and $\theta_7 = 20.7$ to 20.9 with failure rates: $\zeta_1 = 1.47$, $\zeta_2 = 1.51$, $\zeta_3 = 1.55$, $\zeta_4 = 1.38$, $\zeta_5 = 1.74$, $\zeta_6 = 1.95$ and $\zeta_7 = 1.79$. Percentage change in the availability of the system is 0.00062% increased with the increased θ_2 from 17.3 to 17.5. Percentage change in the availability of the system is 0.00057% increased with the increased θ_3 from 18.2 to 18.4. Percentage change in the availability of the system is 0.00069% increased with the increased θ_4 from 15.7 to 15.9. Percentage change in the availability of the system is 0.00056% increased with the increased θ_5 from 19.6 to 19.8. Percentage change in the availability of the system is 0.00052% increased with the increased θ_6 from 21.5 to 21.7. Percentage change in the availability of the system is 0.00051% increased with the increased θ_7 from 20.7 to 20.9.

Table 2: consequences of repair rates on availability w.r.t. repair rate θ_1

θ_1	$P0 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P2 = \theta_2 = 17.5,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P3 = \theta_2 = 17.3,$ $\theta_3 = 18.4,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P4 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.9,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P5 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.8,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P6 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.7,$ $\theta_7 = 20.7$	$P7 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.9$
16.9	0.619857	0.6202406	0.620213	0.6202822	0.6202018	0.6201785	0.6201752
17.1	0.620248	0.6206322	0.6206046	0.6206739	0.6205934	0.62057	0.6205668
17.3	0.620631	0.6210153	0.6209876	0.621057	0.6209764	0.620953	0.6209497
17.5	0.621005	0.62139	0.6213623	0.6214318	0.6213511	0.6213276	0.6213244
17.7	0.621371	0.6217567	0.621729	0.6217985	0.6217178	0.6216943	0.621691
17.9	0.62173	0.6221157	0.6220879	0.6221575	0.6220766	0.6220531	0.6220499
18.1	0.622081	0.6224671	0.6224392	0.6225089	0.622428	0.6224044	0.6224012

18.3	0.622424	0.6228112	0.6227833	0.6228531	0.6227721	0.6227485	0.6227452
18.5	0.622761	0.6231482	0.6231203	0.6231902	0.6231091	0.6230854	0.6230822
18.7	0.623091	0.6234784	0.6234505	0.6235204	0.6234392	0.6234156	0.6234123

Figure 4: consequences of repair rates on availability w.r.t. repair rate θ_1

Variation in profit of the system has been analyzed due to variation in failure rates of all the subsystems with respect to failure rate ς_1 from 1.47 to 1.29 and failure rates are consider as exponentially distributed. The variation in failure rates are as: $\varsigma_2 = 1.51$ to 1.53 , $\varsigma_3 = 1.55$ to 1.57 , $\varsigma_4 = 1.38$ to 1.4 , $\varsigma_5 = 1.74$ to 1.76 , $\varsigma_6 = 1.95$ to 1.97 and $\varsigma_7 = 1.79$ to 1.81 with repair rates: $\theta_1 = 16.9$, $\theta_2 = 17.3$, $\theta_3 = 18.2$, $\theta_4 = 15.7$, $\theta_5 = 19.6$, $\theta_6 = 21.5$ and $\theta_7 = 20.7$. Percentage change in the profit of the system is 0.00084% decreased with the increased ς_2 from 1.51 to 1.53. Percentage change in the profit of the system is 0.000797% decreased with the increased ς_3 from 1.55 to 1.57. Percentage change in the profit of the system is 0.00092% decreased with the increased ς_4 from 1.38 to 1.4. Percentage change in the profit of the system is 0.00074% decreased with the increased ς_5 from 1.74 to 1.76. Percentage change in the profit of the system is 0.00067% decreased with the increased ς_6 from 1.95 to 1.97. Percentage change in the profit of the system is 0.000701% decreased with the increased ς_7 from 1.79 to 1.81.

Table 3: consequences of failure rates on profit w.r.t. failure rate ς_1

ς_1	$S0 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S2 = \varsigma_2 = \mathbf{1.53},$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S3 = \varsigma_2 = 1.51,$ $\mathbf{\varsigma_3 = 1.57},$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S4 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\mathbf{\varsigma_4 = 1.4},$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S5 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\mathbf{\varsigma_5 = 1.76},$ $\varsigma_6 = 1.95,$ $\varsigma_7 = 1.79$	$S6 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\mathbf{\varsigma_6 = 1.97},$ $\varsigma_7 = 1.79$	$S7 = \varsigma_2 = 1.51,$ $\varsigma_3 = 1.55,$ $\varsigma_4 = 1.38,$ $\varsigma_5 = 1.74,$ $\varsigma_6 = 1.95,$ $\mathbf{\varsigma_7 = 1.81}$
1.47	1745.528	1744.0637	1744.1361	1743.9145	1744.2355	1744.3497	1744.3042
1.49	1744.029	1742.5664	1742.6387	1742.4175	1742.738	1742.852	1742.8065
1.51	1742.532	1741.0714	1741.1435	1740.9226	1741.2426	1741.3565	1741.3111
1.53	1741.037	1739.5785	1739.6505	1739.43	1739.7495	1739.8632	1739.8179

1.55	1739.544	1738.0878	1738.1597	1737.9395	1738.2585	1738.3721	1738.3268
1.57	1738.053	1736.5992	1736.6711	1736.4512	1736.7698	1736.8831	1736.8379
1.59	1736.565	1735.1129	1735.1846	1734.965	1735.2831	1735.3963	1735.3512
1.61	1735.079	1733.6287	1733.7003	1733.481	1733.7987	1733.9117	1733.8667
1.63	1733.594	1732.1467	1732.2182	1731.9992	1732.3164	1732.4293	1732.3843
1.65	1732.112	1730.6668	1730.7382	1730.5196	1730.8363	1730.949	1730.9041

Figure 5: consequences of failure rates on profit w.r.t. failure rate ζ_1

Variation in profit of the system has been analyzed due to variation in repair rates of all the subsystems with respect to repair rate θ_1 from 16.9 to 18.7 and repair rates are consider as exponentially distributed. The variation in repair rates are as: $\theta_2 = 17.3$ to 17.5 , $\theta_3 = 18.2$ to 18.4 , $\theta_4 = 15.7$ to 15.9 , $\theta_5 = 19.6$ to 19.8 , $\theta_6 = 21.5$ to 21.7 and $\theta_7 = 20.7$ to 20.9 with failure rates: $\zeta_1 = 1.47$, $\zeta_2 = 1.51$, $\zeta_3 = 1.55$, $\zeta_4 = 1.38$, $\zeta_5 = 1.74$, $\zeta_6 = 1.95$ and $\zeta_7 = 1.79$. Percentage change in the profit of the system is 0.00072% increased with the increased θ_2 from 17.3 to 17.5. Percentage change in the profit of the system is 0.00067% increased with the increased θ_3 from 18.2 to 18.4. Percentage change in the profit of the system is 0.000804% increased with the increased θ_4 from 15.7 to 15.9. Percentage change in the profit of the system is 0.00065% increased with the increased θ_5 from 19.6 to 19.8. Percentage change in the profit of the system is 0.000608% increased with the increased θ_6 from 21.5 to 21.7. Percentage change in the profit of the system is 0.000602% increased with the increased θ_7 from 20.7 to 20.9.

Table 4: consequences of repair rates on profit w.r.t. repair rate θ_1

θ_1	$P0 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P2 = \theta_2 = 17.5,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P3 = \theta_2 = 17.3,$ $\theta_3 = 18.4,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P4 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.9,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P5 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.8,$ $\theta_6 = 21.5,$ $\theta_7 = 20.7$	$P6 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.7,$ $\theta_7 = 20.7$	$P7 = \theta_2 = 17.3,$ $\theta_3 = 18.2,$ $\theta_4 = 15.7,$ $\theta_5 = 19.6,$ $\theta_6 = 21.5,$ $\theta_7 = 20.9$
16.9	1745.528	1746.7941	1746.7029	1746.9313	1746.6661	1746.5889	1746.5782
17.1	1746.819	1748.0864	1747.9951	1748.2238	1747.9583	1747.881	1747.8703
17.3	1748.082	1749.3504	1749.259	1749.488	1749.2221	1749.1448	1749.134
17.5	1749.317	1750.587	1750.4955	1750.7248	1750.4586	1750.3812	1750.3704
17.7	1750.525	1751.7972	1751.7056	1751.9351	1751.6686	1751.591	1751.5803
17.9	1751.708	1752.9817	1752.8899	1753.1198	1752.8529	1752.7753	1752.7645
18.1	1752.867	1754.1413	1754.0495	1754.2795	1754.0124	1753.9347	1753.9239
18.3	1754.001	1755.2768	1755.1849	1755.4152	1755.1478	1755.07	1755.0592
18.5	1755.112	1756.389	1756.297	1756.5276	1756.2599	1756.182	1756.1712
18.7	1756.2	1757.4786	1757.3865	1757.6173	1757.3493	1757.2713	1757.2605

Figure 6: consequences of repair rates on profit w.r.t. repair rate θ_1

9. CONCLUSIONS

This considered model is very useful for system engineers in the development of system performance and establishment in the maintenance strategy of the cement plant. The analyzed numerical results appeared in table 1-4, explained that availability and performance in cement plant are highly affected by failure and repair rates of the system. This methodology concludes that availability of the system has high variation from 0.00058% to 0.00079% based on variation in failure rates. Availability of the system decreases 0.00079% approximately as failure rate of kiln increases. So the subsystem kiln is highly sensitive and causes of highly variation in availability of the system. Availability of the system varies from 0.00051% to 0.00069 and subsystem is less sensitive on its repair rates.

REFERENCES

1. Gupta, P., Lal, A.K., Sharma, R.K. and Singh, J. (2007), "Analysis of reliability and availability of serial processes of plastic-pipe manufacturing plant", *International Journal of Quality & Reliability Management*, Vol. 24 No. 4, pp. 404-419.
2. Barabady, J. and Kumar, U. (2008), "Reliability analysis of mining equipment: a case study of a crushing plant at Jajarm bauxite mine in Iran", *Reliability Engineering & System Safety*, Vol. 93, pp. 647-653.
3. Carazas, F.J.G., Salazar, C.H. and Souza, G.F.M. (2011), "Availability analysis of heat recovery steam generators used in thermal power plant", *Energy*, Vol. 36, pp. 3855-3870.
4. Sharma, V., Kumari, M. and Kumar, S. (2011), "Reliability improvement of modern aircraft engine through failure modes and effects analysis of rotor support system", *International Journal of Quality & Reliability Management*, Vol. 28 No. 6, pp. 675-687.
5. Khanduja R, Tewari PC, Kumar D (2012), " Steady state behavior and maintenance planning of bleaching system in a paper plant", *Int J Indust Eng* 7(12):39-44
6. Upadhyay, K.S. and Srinivasan, N.K. (2012), "Availability estimation using simulation for military systems", *International Journal of Quality & Reliability Management*, Vol. 29 No. 8, pp. 937-952.
7. Wang, J.J., Fu, C., Yang, K., Zhang, X.T., Shi, G.H. and Zhai, J. (2013), "Reliability and Availability Analysis of Redundant BCHP System", *International Journal of Energy*, 60, 531540.
8. Gowid S, Dixon R, Ghani S (2014), "Optimization of reliability and maintenance of liquefaction system on FLNG terminals using Markov modeling", *Int J Qual Reliab Manage* 31(3):293-310
9. Saini M and Kumar A (2019) Performance analysis of evaporation system in sugar industry using RAMD analysis. *J Braz Soc Mech Sci Eng* 41:4
10. Kumar, A. Goyal, D., Saini, M., Joshi. H. (2019). Reliability, maintainability and sensitivity analysis of physical processing unit of sewage treatment plant. *SN Appl. Sci.* 1: 1507. <https://doi.org/10.1007/s42452-019-1544-7>
11. Kumar A, Saini M (2018) Fuzzy availability analysis of a marine power plant. *Materials Today: Proceedings*. 5 (11P3): 25195-25202.
12. Dahiya O, Kumar A, Saini M (2019) Mathematical modeling and performance evaluation of A-Pan crystallization system in a sugar industry. *SN Applied Sciences*, <https://doi.org/10.1007/s42452-019-0348-0>
13. Gupta, N., Saini, M. & Kumar, A. Operational availability analysis of generators in steam turbine power plants. *SN Appl. Sci.* 2, 779 (2020). <https://doi.org/10.1007/s42452-020-2520-y>
14. Goyal, D., Saini, M., Kumar, A. (2020). Reliability, Maintainability and Sensitivity Analysis of Biological and Chemical Processing Unit of Sewage Treatment Plant. *International Journal of Advanced Science and Technology*, 29(3), 5399 - 5415.
15. Saini M, Kumar A (2019) Performance analysis of evaporation system in sugar industry using RAMD analysis. *J Braz Soc Mech Sci Eng* 41:4
16. Goyal, D., Kumar, A., Saini, M., Joshi. H. (2019). Reliability, maintainability and sensitivity analysis of physical processing unit of sewage treatment plant. *SN Appl. Sci.* 1: 1507. <https://doi.org/10.1007/s42452-019-1544-7>
17. Saini, M., Kumar, A. & Shankar, V.G. A study of microprocessor systems using RAMD approach. *Life Cycle Reliab Saf Eng* 9, 181-194 (2020). <https://doi.org/10.1007/s41872-020-00114-3>

18. Saini, M., Kumar, A. Stochastic Modeling of a Single-Unit System Operating Under Different Environmental Conditions Subject to Inspection and Degradation. *Proc. Natl. Acad. Sci., India, Sect. A Phys. Sci.* **90**, 319–326 (2020). <https://doi.org/10.1007/s40010-018-0558-7>
19. BARAK, M S.; YADAV, Dhiraj; BARAK, Sudesh K. Stochastic Analysis of a Cold Standby System with Conditional Failure of Server. *International Journal of Statistics and Reliability Engineering*, [S.l.], v. 4, n. 1, p. 65-69, aug. 2017.
20. Jolly, S.S. and Singh, B.J. (2014), "An approach to enhance availability of repairable systems: a case study of SPMs", *International Journal of Quality & Reliability Management*, Vol. 31 No. 9, pp. 1031-1051.
21. Mishra, S., Bhardwaj, P. and Bhadauria, N. (2016), "Optimal Availability Analysis of Brake Drum Manufacturing System by using Markov Approach" *International Journal of Engineering Technology, Management and Applied Sciences*, 4, 147-154
22. Sabouhi, H., Abbaspour A., Firuzabad, M. and Dehghanian, P. (2016), "Reliability Modeling and Availability Analysis of Combined Cycle Power Plants", *Electrical Power and Energy Systems*, 79, 108-119.
23. Dahiya OM, Kumar AS, Saini MO. An analysis of feeding system of sugar plant subject to coverage factor. *Int J Mech Prod Eng Res Dev (IJMPERD)*. 2019;9(1):495-508.
24. Dahiya O, Kumar A, Saini M. Performance evaluation and availability analysis of a harvesting system using fuzzy reliability approach. *Int J Recent Technol Eng*. 2019;7(5):248-54
25. GARG, Vikas; KADYAN, M S; KUMAR, Jitender. Stochastic Analysis of a Two Non-Identical Units Redundant System with Preventive Maintenance and Priority. *International Journal of Statistics and Reliability Engineering*, [S.l.], v. 7, n. 1, p. 107-113, jul. 2020.
26. Waghmode, L.Y. and Patil, R.B. (2016), "Reliability analysis and life cycle cost optimization: a case study from Indian industry", *International Journal of Quality & Reliability Management*, Vol. 33 No. 3, pp. 414-429.
27. Ghosh, C., Maiti, J., Shafiee, M. and Kumaraswamy, K.G. (2017), "Reduction of life cycle costs for a contemporary helicopter through improvement of reliability and maintainability parameters", *International Journal of Quality & Reliability Management*, Vol. 35 No. 2, pp. 545-567.
28. Kumar, A., Pant, S. and Singh, S.B. (2017), "Availability and cost analysis of an engineering system involving subsystems in series configuration", *International Journal of Quality & Reliability Management*, Vol. 34 No. 6, pp. 879-894.