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Modeling and Availability Analysis of Cement Manufacturing Plant Subject to Coverage Factor and Human Failure

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ABSTRACT
The main aim of the present study is to perform availability analysis of a cement manufacturing plant using concepts of coverage factor and human failure. For this purpose, a mathematical model has been developed using Markovian birth-death process. In cement manufacturing plant various subsystems arranged in series structure. Sufficient repair facility always available with plant. All time dependent random variables are statistically independent and exponentially distributed. The repairs are perfect. The differential-difference equation has been solved using R-K method of fourth order. Numerical and graphical results have been obtained to highlight the importance of the study.

Keywords
Cement Manufacturing Plant, Coverage Factor, Availability, Mathematical Model.

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. 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. A lot of researchers have examined the reliability and availability in the manner to improve the performance of their models. Saini and Kumar (2019) analysed performance of evaporation system in sugar industry using RAMD analysis. Kumar et al. (2019) analyzed rreliability, maintainability and sensitivity analysis of physical processing unit of sewage treatment plant. Kumar and Saini (2018) performed fuzzy availability evaluation of a marine power plant. Dahiya et al. (2019) developed a mathematical modeling and performance evaluation of A-Pan crystallization system in a sugar industry. Gupta et al. (2020) suggested stochastic model for operational availability analysis of generators in steam turbine power plants. Goyal, et al. (2020) carried out rreliability, maintainability and sensitivity analysis of biological and chemical processing unit of sewage treatment plant. Saini et al. (2020) proposed a study of microprocessor systems using RAMD approach. Saini and Kumar (2020) developed a stochastic model of a single-unit system operating under different environmental conditions subject to inspection and degradation. Dahiya et al. (2019a, 2019b) analysed processed industries like feeding system and harvesting system. Garg et al. (2020) developed stochastic model for a two non-identical units' redundant system with preventive maintenance and priority. Barak et al. (2017) studied a cold standby system with conditional failure of server.

By keeping all facts in mind, here an effort has been made to analyze the availability of a cement manufacturing plant under the concepts of coverage factor and human failure. The concept of coverage factor plays an important role in performance and availability of systems. The human failure also influences the system's performance. It is assumed that in the beginning of the system the human failure can occurs. Suitable redundancy concepts have been utilized as and when required and standby unit reduced the capacity of the plant. It is assumed that sufficient repair facility always available with system to do repair, maintenance of the plant and treatment of human failure. All the failure and repair rates follow exponential distribution. The Markovian birth-death process has been utilized to develop a mathematical model for the cement manufacturing plant and Chapman-Kolmogorov differential difference equation have been derived. The numerical results for availability and profit function have been derived for a particular set for parameters. The derived results can be proved helpful for system designers and management personals.

2. STATE TRANSITION DIAGRAM AND PATH PARAMETER
The failure and repair rates between states are considered as follows:

Table 1: Failure and repair rates

S.No.	State i	State j	Path Parameter $i\,to\,j$	Path Parameter $j\,to\,i$
1	$ABCDEF$	$ABCD_1EF$	$\alpha_4\gamma$	μ_4
2	$ABCD_1EF$	$ABCDEF$	μ_4	$\alpha_4\gamma$

3	$ABCDEF$	$aBCDEF$	$\alpha_1(1-\gamma)$	μ_1
4	$ABCDEF$	$AbCDEF$	$\alpha_2(1-\gamma)$	μ_2
5	$ABCDEF$	$ABcDEF$	$\alpha_3(1-\gamma)$	μ_3
6	$ABCDEF$	$ABCDeF$	$\alpha_5(1-\gamma)$	μ_5
7	$ABCDEF$	$ABCDEf$	$\alpha_6(1-\gamma)$	μ_6
8	$ABCDEF$	Human Failure	$\alpha_H(1-\gamma)$	μ_H
9	$ABCD_1EF$	$AbCD_1EF$	$\alpha_2(1-\gamma)$	μ_2
10	$ABCD_1EF$	$aBCD_1EF$	$\alpha_1(1-\gamma)$	μ_1
11	$ABCD_1EF$	$ABCD_1eF$	$\alpha_5(1-\gamma)$	μ_5
12	$ABCD_1EF$	$ABcD_1EF$	$\alpha_3(1-\gamma)$	μ_3
13	$ABCD_1EF$	$ABCdEF$	$\alpha_7(1-\gamma)$	μ_7
14	$ABCD_1EF$	$ABCD_1Ef$	$\alpha_6(1-\gamma)$	μ_6

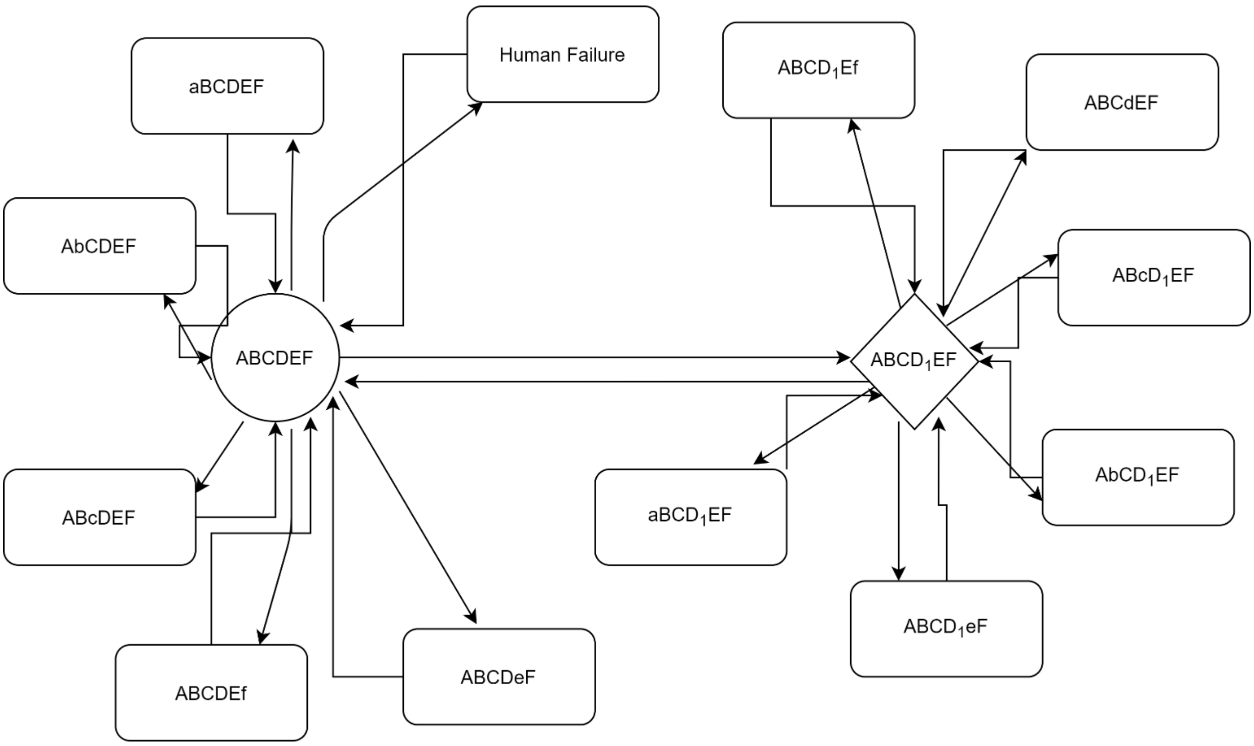


Fig.-1: State progression diagram of the system

3. ASSUMPTIONS

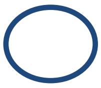
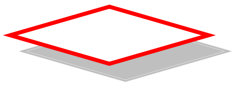
a) No waiting time between failure and repair

b) Systems works as new after repair with full capacity

c) Failure and repair rates are exponentially distributed, and no simultaneous failures occurs.

d) Human failure can occur at the initial state.

4. NOTATIONS

	System works with full capacity
	Subsystem works with reduced capacity
	Subsystem is in failure state
A, B, C, D, E, F	All subsystems are working with full capacity
a, b, c, d, e, f	Subsystem has failed
D_1	Partial operative state
$\alpha_i \; (1 \le i \le 7)$	Respectively failure rates in subsystems A, B, C, D, E, F, D_1
α_H & μ_H	Human failure and treatment rate
$\mu_i \; (1 \le i \le 7)$	Respectively repair rate in subsystems A, B, C, D, E, F, D_1
$P_0(t)$	Probability that system is working with full capacity
$P_i(t), (i = 1, \ldots\ldots, 14)$	Probability of subsystem on i^{th} state at time t
$S_i, (i = 1, 2, \ldots\ldots, 14)$	State of the subsystem
γ	Represent the coverage factor

5. MATHEMATICAL MODELING OF THE SYSTEM

A mathematical model for a cement manufacturing plant has been formulated using Markov birth-death process. The following Chapman-Kolmogorov equations have been derived:

$$P_1(t+\Delta t) = [1-(\alpha_1(1-\gamma)+\alpha_2(1-\gamma)+\alpha_3(1-\gamma)+\alpha_4 \gamma+\alpha_5(1-\gamma)+\alpha_6(1-\gamma)+\alpha_H(1-\gamma))]\Delta t P_1(t) + \mu_1 \Delta t P_3(t)+\mu_2 \Delta t P_4(t)+\mu_3 \Delta t P_5(t)+ \Delta t \mu_6 P_7(t)+\Delta t \mu_5 P_6(t)+\Delta t \mu_H P_8(t)+\Delta t \mu_4 P_2(t)$$

$$P_1(t+\Delta t)-P_1(t)+[\alpha_1(1-\gamma)+\alpha_2(1-\gamma)+\alpha_3 (1-\gamma)+\alpha_4\gamma+\alpha_5(1-\gamma)+\alpha_6(1-\gamma)+\alpha_H(1-\gamma)]\Delta t P_1(t) = \mu_1 \Delta t P_3(t)+\mu_2 \Delta t P_4(t)+\mu_3 \Delta t P_5(t)+ \Delta t \mu_6 P_7(t)+\Delta t \mu_5 P_6(t)+\Delta t \mu_H P_8(t)+\Delta t \mu_4 P_2(t) \quad (*)$$

Dividing equation (*) both sides by Δt, we get

$$\frac{P_1(t+\Delta t)-P_1(t)}{\Delta t}+[\alpha_1(1-\gamma)+\alpha_2(1-\gamma)+ \alpha_3(1-\gamma)+\alpha_4\gamma+\alpha_5(1-\gamma)+\alpha_6(1-\gamma)+ \alpha_H(1-\gamma)]P_1(t) = \mu_1 P_3(t)+\mu_2 P_4(t)+\mu_3 P_5(t)+\mu_6 P_7(t)+\mu_5 P_6(t)+\mu_H P_8(t)+\mu_4 P_2(t) \quad (**)$$

Taking limit $\Delta t \to 0$ on equation (**), we obtained

$$\frac{dP_1(t)}{dt}+[\alpha_1(1-\gamma)+\alpha_2(1-\gamma)+\alpha_3(1-\gamma)+\alpha_4\gamma +\alpha_5(1-\gamma)+\alpha_6(1-\gamma)+\alpha_H(1-\gamma)]P_1(t) = \mu_1 P_3(t)+\mu_2 P_4(t)+\mu_3 P_5(t)+ \mu_6 P_7(t)+\mu_5 P_6(t)+\mu_H P_8(t)+\mu_4 P_2(t) \quad (1)$$

$$\frac{dP_2(t)}{dt}+[\alpha_1(1-\gamma)+\alpha_2(1-\gamma)+\alpha_3(1-\gamma)+\alpha_7(1-\gamma)$$
$$+\alpha_5(1-\gamma)+\alpha_6(1-\gamma)+\alpha_H(1-\gamma)+\mu_4]P_2(t)$$
$$=\alpha_4 P_1(t)+\mu_1 P_{10}(t)+\mu_2 P_9(t)+\mu_3$$
$$P_{12}(t)+\mu_7 P_{13}(t)+\mu_5 P_{11}(t)+\mu_H P_8(t)+\mu_6 P_{14}(t) \qquad (2)$$

$$\frac{dP_3(t)}{dt}+\mu_1 P_3(t)=\alpha_1(1-\gamma)P_1(t) \qquad (3)$$

$$\frac{dP_4(t)}{dt}+\mu_2 P_4(t)=\alpha_2(1-\gamma)P_1(t) \qquad (4)$$

$$\frac{dP_5(t)}{dt}+\mu_3 P_5(t)=\alpha_3(1-\gamma)P_1(t) \qquad (5)$$

$$\frac{dP_6(t)}{dt}+\mu_5 P_6(t)=\alpha_5(1-\gamma)P_1(t) \qquad (6)$$

$$\frac{dP_7(t)}{dt}+\mu_6 P_7(t)=\alpha_6(1-\gamma)P_1(t) \qquad (7)$$

$$\frac{dP_8(t)}{dt}+\mu_H P_8(t)=\alpha_H(1-\gamma)P_1(t) \qquad (8)$$

$$\frac{dP_9(t)}{dt}+\mu_2 P_9(t)=\alpha_2(1-\gamma)P_2(t) \qquad (9)$$

$$\frac{dP_{10}(t)}{dt}+\mu_1 P_{10}(t)=\alpha_1(1-\gamma)P_2(t) \qquad (10)$$

$$\frac{dP_{11}(t)}{dt}+\mu_5 P_{11}(t)=\alpha_5(1-\gamma)P_2(t) \qquad (11)$$

$$\frac{dP_{12}(t)}{dt}+\mu_3 P_{12}(t)=\alpha_3(1-\gamma)P_2(t) \qquad (12)$$

$$\frac{dP_{13}(t)}{dt}+\mu_7 P_{13}(t)=\alpha_7(1-\gamma)P_2(t) \qquad (13)$$

$$\frac{dP_{14}(t)}{dt}+\mu_6 P_{14}(t)=\alpha_6(1-\gamma)P_2(t) \qquad (14)$$

with initial conditions:

$$P_i(0)=\begin{cases}1, & if \;\; i=1\\ 0, & if \;\; i\neq 1\end{cases} \qquad (15)$$

Thus, the system availability and profit have been given by

$$A(t) = P_1(t) + P_2(t) \qquad (16)$$

$$P_{down}(t) = \sum_{i=3}^{14} P_i(t) \qquad (17)$$

$$\Pr ofit = K\,A(t) - E\,P_{down}(t) \qquad (18)$$

Where K=10000 and E=100.

6. PERFORMANCE ANALYSIS

In this section, numerical analysis has been done for a cement manufacturing plant using equation (18) for a particular set of failure and repair rates corresponding to various values of coverage factor.

Impact of coverage factor (γ) on profit and availability of cement manufacturing plant

Numerical results for availability and profit function have been derived for a particular set of failure and repair rates of various subsystems. The availability values of system for various values of coverage parameter has been derived and appended in table 2. The fixed values of the parameters are as follows: $\alpha_1 = 0.005,\ \alpha_2 = 0.002$ $,\alpha_3 = 0.001,\ \alpha_4 = 0.0012\ ,\alpha_5 = 0.009$, $\alpha_6 = 0.006,\ \alpha_7 = 0.004$ and $\mu_1 = 0.55,\ \mu_2 = 0.81\ ,\mu_3 = 0.6,\ \mu_4 = 0.65,$ $\mu_5 = 0.75$,

$\mu_6 = 0.65,\ \mu_7 = 0.71$. The availability analysis has been done for a time duration of 240 hours with a gap of 60 hours. It is observed that approximately 11% variation exists in the availability with respect to coverage factor. The highest value attains at $\gamma = 1$ while minimum value at $\gamma = 0$.

Table 2: Impact of coverage factor (γ) on profit and availability of cement manufacturing plant w.r.t. time

Time	γ =0	γ =0.1	γ =0.2	γ =0.4	γ =0.5	γ =0.6	γ =0.8	γ =0.9	γ =1
40	0.886	0.896	0.9078	0.9276	0.9376	0.9486	0.9686	0.9796	0.9904
80	0.886	0.896	0.9078	0.9276	0.9376	0.9486	0.9686	0.9796	0.9904
120	0.886	0.896	0.9058	0.9268	0.9368	0.9478	0.99686	0.99796	0.9904
160	0.886	0.896	0.9058	0.9268	0.9368	0.9478	0.9686	0.9796	0.9904
200	0.886	0.896	0.9058	0.9268	0.9368	0.9478	0.9686	0.9796	0.9904

Influence of raw mill failure and repair rate on availability and profit of cement manufacturing plant has been investigated for various values of failure and repair parameters. It is observed from table 3 & 4 that availability and profit increases with respect to increase of repair rate while decrease with respect to failure rates.

Table 3: Influence of failure rate (α_1) and repair rate (μ_1) of Raw mill on system's availability with respect to time

Coverage Factor	Time (days)	Failure rate of Raw Mill $\alpha_1 = 0.005$	$\alpha_1 = 0.03$	$\alpha_1 = 0.3$	Repair rates of Raw Mill $\mu_1 = 0.55$	$\mu_1 = 0.97$	$\mu_1 = 1.3$
$\gamma = 1$	40	0.9904	0.9234	0.926	0.9904	0.9944	0.9968
	80	0.9894	0.9234	0.924	0.9894	0.9944	0.9968
	120	0.9894	0.9234	0.923	0.9894	0.9944	0.995
	160	0.9894	0.9208	0.922	0.9894	0.9934	0.995
	200	0.9894	0.9208	0.920	0.9894	0.9934	0.995
$\gamma = 0.07$	40	0.9686	0.9128	0.9132	0.9686	0.9734	0.9738
	80	0.9686	0.912	0.9132	0.9686	0.9724	0.9738
	120	0.9686	0.911	0.9122	0.9686	0.9716	0.9728
	160	0.9686	0.91	0.9122	0.9686	0.9716	0.9728

	200	0.9686	0.91	0.9114	0.9686	0.9716	0.9728
$\gamma = 0.4$	40	0.9376	0.906	0.902	0.9376	0.94	0.94
	80	0.9376	0.90	0.902	0.9376	0.9392	0.939
	120	0.9368	0.90	0.902	0.9368	0.9392	0.939
	160	0.9368	0.90	0.902	0.9368	0.9384	0.939
	200	0.9368	0.90	0.90	0.9368	0.9374	0.939
$\gamma = 0$	40	0.886	0.885	0.885	0.886	0.886	0.886
	80	0.886	0.885	0.885	0.886	0.886	0.886
	120	0.886	0.884	0.884	0.886	0.886	0.886
	160	0.886	0.884	0.884	0.886	0.886	0.886
	200	0.886	0.884	0.884	0.886	0.886	0.886

Table 4 : Influence of failure rate (α_1) and repair rate (μ_1) of Raw mill on system's profit with respect to time

Coverage Factor	Time (days)	Failure rate of Raw Mill $\alpha_1 = 0.005$	$\alpha_1 = 0.03$	$\alpha_1 = 0.3$	Repair rates of Raw Mill $\mu_1 = 0.55$	$\mu_1 = 0.97$	$\mu_1 = 1.3$
$\gamma = 1$	40	9904	9234	9260	9904	9944	9968
	80	9894	9234	9240	9894	9944	9968
	120	9894	9234	9230	9894	9944	9950
	160	9894	9208	9220	9894	9934	9950
	200	9894	9208	9200	9894	9934	9950
$\gamma = 0.07$	40	9686	9128	9132	9686	9734	9738
	80	9686	9120	9132	9686	9724	9738
	120	9686	9110	9122	9686	9716	9728
	160	9686	9100	9122	9686	9716	9728
	200	9686	9100	9114	9686	9716	9728
$\gamma = 0.4$	40	9376	9060	9020	9376	9400	9400
	80	9376	9000	9020	9376	9392	9390
	120	9368	9000	9020	9368	9392	9390
	160	9368	9000	9020	9368	9384	9390
	200	9368	9000	9000	9368	9374	9390
$\gamma = 0$	40	8860	8850	8850	8860	8860	8860
	80	8860	8850	8850	8860	8860	8860
	120	8860	8840	8840	8860	8860	8860
	160	8860	8840	8840	8860	8860	8860

	200	8860	8840	8840	8860	8860	8860

Influence of coal mill failure and repair rate on availability and profit of cement manufacturing plant has been investigated for various values of failure and repair parameters. It is observed from table 5 & 6 that availability and profit increases with respect to increase of repair rate while decrease with respect to failure rates.

Table 5: Influence of failure rate (α_2) and repair rate (μ_2) of coal mill on system's availability with respect to time

Coverage Factor	Time (days)	Failure rate of Coal Mill $\alpha_2 = 0.3$	$\alpha_2 = 0.6$	$\alpha_2 = 0.002$	Repair rates of Coal Mill $\mu_2 = 0.81$	$\mu_2 = 1.21$	$\mu_2 = 1.91$
$\gamma = 1$	40	0.9904	0.9098	0.9702	0.9904	0.9906	0.9898
	80	0.9894	0.9098	0.9692	0.9894	0.9906	0.9898
	120	0.9894	0.9098	0.9692	0.9894	0.9906	0.9898
	160	0.9894	0.9088	0.9692	0.9894	0.9896	0.9898
	200	0.9894	0.9088	0.9692	0.9894	0.9888	0.9898
$\gamma = 0.07$	40	0.9686	0.9004	0.8803	0.9686	0.969	0.9688
	80	0.9686	0.9004	0.8803	0.9686	0.968	0.9688
	120	0.9686	0.8996	0.8803	0.9686	0.968	0.9688
	160	0.9686	0.8986	0.8803	0.9686	0.967	0.9688
	200	0.9686	0.8986	0.8803	0.9686	0.967	0.9688
$\gamma = 0.4$	40	0.9376	0.8912	0.8256	0.9376	0.9378	0.937
	80	0.9376	0.8912	0.8246	0.9376	0.9378	0.937
	120	0.9368	0.8912	0.8246	0.9368	0.9378	0.937
	160	0.9368	0.8902	0.8246	0.9368	0.9378	0.937
	200	0.9368	0.8902	0.8246	0.9368	0.9378	0.937
$\gamma = 0$	40	0.886	0.885	0.85	0.886	0.886	0.886
	80	0.886	0.885	0.85	0.886	0.886	0.886
	120	0.886	0.884	0.84	0.886	0.886	0.886
	160	0.886	0.884	0.84	0.886	0.886	0.886
	200	0.886	0.884	0.84	0.886	0.886	0.886

Table 6: Influence of failure rate (α_2) and repair rate (μ_2) of coal mill on system's profit with respect to time

Coverage Factor	Time (days)	Failure rate of Coal Mill $\alpha_2 = 0.3$	$\alpha_2 = 0.6$	$\alpha_2 = 0.002$	Repair rates of Coal Mill $\mu_2 = 0.81$	$\mu_2 = 1.21$	$\mu_2 = 1.91$
$\gamma = 1$	40	9904	9098	9702	9904	9906	9898
	80	9894	9098	9692	9894	9906	9898

	120	9894	9098	9692	9894	9906	9898
	160	9894	9088	9692	9894	9896	9898
	200	9894	9088	9692	9894	9888	9898
$\gamma = 0.07$	40	9686	9004	8803	9686	9690	9688
	80	9686	9004	8803	9686	9680	9688
	120	9686	8996	8803	9686	9680	9688
	160	9686	8986	8803	9686	9670	9688
	200	9686	8986	8803	9686	9670	9688
$\gamma = 0.4$	40	9376	8912	8256	9376	9378	9370
	80	9376	8912	8246	9376	9378	9370
	120	9368	8912	8246	9368	9378	9370
	160	9368	8902	8246	9368	9378	9370
	200	9368	8902	8246	9368	9378	9370
$\gamma = 0$	40	8860	8850	8500	8860	8860	8860
	80	8860	8850	8500	8860	8860	8860
	120	8860	8840	8400	8860	8860	8860
	160	8860	8840	8400	8860	8860	8860
	200	8860	8840	8400	8860	8860	8860

Influence of preheater's failure and repair rate on availability and profit of cement manufacturing plant has been investigated for various values of failure and repair parameters. It is observed from table 7 & 8 that availability and profit increases with respect to increase of repair rate while decrease with respect to failure rates.

Table 7: Influence of failure rate (α_3) and repair rate (μ_3) of Preheater on system's availability with respect to time

Coverage Factor	Time (days)	Failure rates of Preheater $\alpha_3 = 0.3$	$\alpha_3 = 0.9$	$\alpha_3 = 0.001$	Repair rates of Preheater $\mu_3 = 0.6$	$\mu_3 = 0.9$	$\mu_3 = 1.6$
$\gamma = 1$	40	0.9904	0.9904	0.9904	0.9904	0.9904	0.9904
	80	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	120	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	160	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	200	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
$\gamma = 0.07$	40	0.9686	0.8786	0.6844	0.9686	0.9746	0.9756
	80	0.9686	0.8786	0.6844	0.9686	0.9746	0.9756
	120	0.9686	0.8786	0.6834	0.9686	0.9736	0.9746
	160	0.9686	0.8786	0.6834	0.9686	0.9736	0.9746

	200	0.9686	0.8786	0.6834	0.9686	0.9736	0.9746
$\gamma = 0.4$	40	0.9376	0.7522	0.4976	0.9376	0.9528	0.9568
	80	0.9376	0.7522	0.4964	0.9376	0.9518	0.9568
	120	0.9368	0.7522	0.4964	0.9368	0.9518	0.9558
	160	0.9368	0.7522	0.4964	0.9368	0.9518	0.9558
	200	0.9368	0.7522	0.4964	0.9368	0.9518	0.9558
$\gamma = 0$	40	0.886	0.594	0.371	0.886	0.914	0.924
	80	0.886	0.594	0.371	0.886	0.914	0.924
	120	0.886	0.594	0.371	0.886	0.914	0.924
	160	0.886	0.594	0.37	0.886	0.914	0.924
	200	0.886	0.594	0.37	0.886	0.914	0.924

Table 8: Influence of failure rate (α_3) and repair rate (μ_3) of Preheater on system's profit with respect to time

Coverage Factor	Time (days)	Failure rates of Preheater $\alpha_3 = 0.3$	$\alpha_3 = 0.9$	$\alpha_3 = 0.001$	Repair rates of Preheater $\mu_3 = 0.6$	$\mu_3 = 0.9$	$\mu_3 = 1.6$
$\gamma = 1$	40	9904	9904	9904	9904	9904	9904
	80	9894	9894	9894	9894	9894	9894
	120	9894	9894	9894	9894	9894	9894
	160	9894	9894	9894	9894	9894	9894
	200	9894	9894	9894	9894	9894	9894
$\gamma = 0.07$	40	9686	8786	6844	9686	9746	9756
	80	9686	8786	6844	9686	9746	9756
	120	9686	8786	6834	9686	9736	9746
	160	9686	8786	6834	9686	9736	9746
	200	9686	8786	6834	9686	9736	9746
$\gamma = 0.4$	40	9376	7522	4976	9376	9528	9568
	80	9376	7522	4964	9376	9518	9568
	120	9368	7522	4964	9368	9518	9558
	160	9368	7522	4964	9368	9518	9558
	200	9368	7522	4964	9368	9518	9558
$\gamma = 0$	40	8860	5940	3710	8860	9140	9240
	80	8860	5940	3710	8860	9140	9240
	120	8860	5940	3710	8860	9140	9240
	160	8860	5940	3710	8860	9140	9240

	200	8860	5940	3710	8860	9140	9240

Influence of klin's failure and repair rate on availability and profit of cement manufacturing plant has been investigated for various values of failure and repair parameters. It is observed from table 9 and 10 that availability and profit increases with respect to increase of repair rate while decrease with respect to failure rates.

Table 9: Influence of failure rate (α_4) and repair rate (μ_4) of Klin on system's availability with respect to time

Coverage Factor	Time (days)	Failure rates of Klin			Repair rates of Klin		
		$\alpha_4 = 0.0012$	$\alpha_4 = 0.5$	$\alpha_4 = 0.83$	$\mu_4 = 0.65$	$\mu_4 = 0.9$	$\mu_4 = 1.3$
$\gamma = 1$	40	0.9904	0.9904	0.9904	0.9904	0.9904	0.9904
	80	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	120	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	160	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	200	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
$\gamma = 0.07$	40	0.9686	0.8386	0.6616	0.9686	0.9686	0.9686
	80	0.9686	0.8378	0.6616	0.9686	0.9686	0.9686
	120	0.9686	0.837	0.6616	0.9686	0.9686	0.9686
	160	0.9686	0.837	0.6616	0.9686	0.9686	0.9686
	200	0.9686	0.837	0.6616	0.9686	0.9686	0.9686
$\gamma = 0.4$	40	0.9376	0.6444	0.578	0.9376	0.9378	0.9378
	80	0.9376	0.6444	0.578	0.9376	0.9378	0.9378
	120	0.9368	0.6434	0.578	0.9368	0.9368	0.9368
	160	0.9368	0.6434	0.578	0.9368	0.9368	0.9368
	200	0.9368	0.6434	0.578	0.9368	0.9368	0.9368
$\gamma = 0$	40	0.886	0.507	0.368	0.886	0.886	0.887
	80	0.886	0.507	0.368	0.886	0.886	0.887
	120	0.886	0.506	0.368	0.886	0.886	0.886
	160	0.886	0.506	0.368	0.886	0.886	0.886
	200	0.886	0.506	0.368	0.886	0.886	0.886

Table 10: Influence of failure rate (α_4) and repair rate (μ_4) of Klin on system's profit with respect to time

Coverage Factor	Time (days)	Failure rates of Klin			Repair rates of Klin		
		$\alpha_4 = 0.0012$	$\alpha_4 = 0.5$	$\alpha_4 = 0.83$	$\mu_4 = 0.65$	$\mu_4 = 0.9$	$\mu_4 = 1.3$
$\gamma = 1$	40	9904	9904	9904	9904	9904	9904
	80	9894	9894	9894	9894	9894	9894
	120	9894	9894	9894	9894	9894	9894

	160	9894	9894	9894	9894	9894	9894
	200	9894	9894	9894	9894	9894	9894
$\gamma = 0.07$	40	9686	8386	6616	9686	9686	9686
	80	9686	8378	6616	9686	9686	9686
	120	9686	8370	6616	9686	9686	9686
	160	9686	8370	6616	9686	9686	9686
	200	9686	8370	6616	9686	9686	9686
$\gamma = 0.4$	40	9376	6444	5780	9376	9378	9378
	80	9376	6444	5780	9376	9378	9378
	120	9368	6434	5780	9368	9368	9368
	160	9368	6434	5780	9368	9368	9368
	200	9368	6434	5780	9368	9368	9368
$\gamma = 0$	40	8860	5070	3680	8860	8860	8870
	80	8860	5070	3680	8860	8860	8870
	120	8860	5060	3680	8860	8860	8860
	160	8860	5060	3680	8860	8860	8860
	200	8860	5060	3680	8860	8860	8860

Influence of cooler's failure and repair rate on availability and profit of cement manufacturing plant has been investigated for various values of failure and repair parameters. It is observed from table 11-12 that availability and profit increases with respect to increase of repair rate while decrease with respect to failure rates.

Table 11: Influence of failure rate (α_5) and repair rate (μ_5) of cooler on system's availability with respect to time

Coverage Factor	Time (days)	Failure rate of Cooler $\alpha_5 = 0.4$	$\alpha_5 = 0.91$	$\alpha_5 = 0.009$	Repair rates of Cooler $\mu_5 = 0.92$	$\mu_5 = 1.5$	$\mu_5 = 0.75$
$\gamma = 1$	40	0.9904	0.9904	0.9904	0.9904	0.9904	0.9904
	80	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	120	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	160	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	200	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
$\gamma = 0.07$	40	0.9686	0.8876	0.7994	0.9686	0.9716	0.9756
	80	0.9686	0.8876	0.7994	0.9686	0.9716	0.9746
	120	0.9686	0.8876	0.7994	0.9686	0.9706	0.9746
	160	0.9686	0.8876	0.7994	0.9686	0.9706	0.9746

	200	0.9686	0.8876	0.7994	0.9686	0.9706	0.9746
$\gamma = 0.4$	40	0.9376	0.627	0.5708	0.9376	0.9458	0.9538
	80	0.9376	0.627	0.5698	0.9376	0.9458	0.9538
	120	0.9368	0.6262	0.5698	0.9368	0.9458	0.9538
	160	0.9368	0.6262	0.5698	0.9368	0.9458	0.9538
	200	0.9368	0.6262	0.5698	0.9368	0.9458	0.9538
$\gamma = 0$	40	0.886	0.670	0.457	0.886	0.903	0.919
	80	0.886	0.669	0.457	0.886	0.903	0.919
	120	0.886	0.669	0.457	0.886	0.903	0.919
	160	0.886	0.669	0.456	0.886	0.902	0.919
	200	0.886	0.669	0.456	0.886	0.902	0.919

Table 12: Influence of failure rate (α_5) and repair rate (μ_5) of cooler on system's profit with respect to time

Coverage Factor	Time (days)	Failure rate of Cooler		$\alpha_5 = 0.009$	Repair rates of Cooler		
		$\alpha_5 = 0.4$	$\alpha_5 = 0.91$		$\mu_5 = 0.75$	$\mu_5 = 0.92$	$\mu_5 = 1.5$
$\gamma = 1$	40	9904	9904	9904	9904	9904	9904
	80	9894	9894	9894	9894	9894	9894
	120	9894	9894	9894	9894	9894	9894
	160	9894	9894	9894	9894	9894	9894
	200	9894	9894	9894	9894	9894	9894
$\gamma = 0.07$	40	9686	8876	7994	9686	9716	9756
	80	9686	8876	7994	9686	9716	9746
	120	9686	8876	7994	9686	9706	9746
	160	9686	8876	7994	9686	9706	9746
	200	9686	8876	7994	9686	9706	9746
$\gamma = 0.4$	40	9376	6270	5708	9376	9458	9538
	80	9376	6270	5698	9376	9458	9538
	120	9368	6262	5698	9368	9458	9538
	160	9368	6262	5698	9368	9458	9538
	200	9368	6262	5698	9368	9458	9538
$\gamma = 0$	40	8860	6700	4570	8860	9030	9190
	80	8860	6690	4570	8860	9030	9190
	120	8860	6690	4570	8860	9030	9190
	160	8860	6690	4560	8860	9020	9190

	200	8860	6690	4560	8860	9020	9190

Influence of cement mill's failure and repair rate on availability and profit of cement manufacturing plant has been investigated for various values of failure and repair parameters. It is observed from table 13- 14 that availability and profit increases with respect to increase of repair rate while decrease with respect to failure rates.

Table 13: Influence of failure rate (α_6) and repair rate (μ_6) of cement mill on system's availability with respect to time

Coverage Factor	Time (days)	Failure rates of cement mill			Repair rates of cement mill		
		$\alpha_6 = 0.006$	$\alpha_4 = 0.51$	$\alpha_4 = 0.82$	$\mu_6 = 0.65$	$\mu_6 = 1.9$	$\mu_6 = 2.3$
$\gamma = 1$	40	0.9904	0.9904	0.9904	0.9904	0.9904	0.9904
	80	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	120	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	160	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
	200	0.9894	0.9894	0.9894	0.9894	0.9894	0.9894
$\gamma = 0.07$	40	0.9686	0.8386	0.6616	0.9686	0.9686	0.9686
	80	0.9686	0.8378	0.6616	0.9686	0.9686	0.9686
	120	0.9686	0.837	0.6616	0.9686	0.9686	0.9686
	160	0.9686	0.837	0.6616	0.9686	0.9686	0.9686
	200	0.9686	0.837	0.6616	0.9686	0.9686	0.9686
$\gamma = 0.4$	40	0.9376	0.6444	0.578	0.9376	0.9378	0.9378
	80	0.9376	0.6444	0.578	0.9376	0.9378	0.9378
	120	0.9368	0.6434	0.578	0.9368	0.9368	0.9368
	160	0.9368	0.6434	0.578	0.9368	0.9368	0.9368
	200	0.9368	0.6434	0.578	0.9368	0.9368	0.9368
$\gamma = 0$	40	0.886	0.507	0.368	0.886	0.886	0.887
	80	0.886	0.507	0.368	0.886	0.886	0.887
	120	0.886	0.506	0.368	0.886	0.886	0.886
	160	0.886	0.506	0.368	0.886	0.886	0.886
	200	0.886	0.506	0.368	0.886	0.886	0.886

Table 14: Influence of failure rate (α_6) and repair rate (μ_6) of cement mill on system's profit with respect to time

Coverage Factor	Time (days)	Failure rates of cement mill			Repair rates of cement mill		
		$\alpha_6 = 0.006$	$\alpha_4 = 0.51$	$\alpha_4 = 0.82$	$\mu_6 = 0.65$	$\mu_6 = 1.9$	$\mu_6 = 2.3$
$\gamma = 1$	40	9904	9904	9904	9904	9904	9904
	80	9894	9894	9894	9894	9894	9894
	120	9894	9894	9894	9894	9894	9894

	160	9894	9894	9894	9894	9894	9894
	200	9894	9894	9894	9894	9894	9894
$\gamma = 0.07$	40	9686	8386	6616	9686	9686	9686
	80	9686	8378	6616	9686	9686	9686
	120	9686	8370	6616	9686	9686	9686
	160	9686	8370	6616	9686	9686	9686
	200	9686	8370	6616	9686	9686	9686
$\gamma = 0.4$	40	9376	6444	5780	9376	9378	9378
	80	9376	6444	5780	9376	9378	9378
	120	9368	6434	5780	9368	9368	9368
	160	9368	6434	5780	9368	9368	9368
	200	9368	6434	5780	9368	9368	9368
$\gamma = 0$	40	8860	5070	3680	8860	8860	8870
	80	8860	5070	3680	8860	8860	8870
	120	8860	5060	3680	8860	8860	8860
	160	8860	5060	3680	8860	8860	8860
	200	8860	5060	3680	8860	8860	8860

Influence of klin's partial failure and repair rate on availability and profit of cement manufacturing plant has been investigated for various values of failure and repair parameters. It is observed from table 15-16 that availability and profit increases with respect to increase of repair rate while decrease with respect to failure rates.

Table 15: Influence of klin's partial failure rate (α_7) and repair rate (μ_7) on system's availability with respect to time

Coverage Factor	Time (days)	Failure rate of klin's partial $\alpha_7 = 0.004$	$\alpha_7 = 0.41$	$\alpha_7 = 0.901$	Repair rates of klin's partial $\mu_7 = 0.71$	$\mu_7 = 0.9$	$\mu_7 = 1.15$
$\gamma = 1$	40	0.9904	0.9904	0.990	0.9904	0.990	0.990
	80	0.9894	0.9894	0.989	0.9894	0.989	0.989
	120	0.9894	0.9894	0.989	0.9894	0.989	0.989
	160	0.9894	0.9894	0.98	0.9894	0.989	0.989
	200	0.9894	0.9894	0.98	0.9894	0.989	0.989
$\gamma = 0.07$	40	0.9686	0.8876	0.779	0.9686	0.971	0.975
	80	0.9686	0.8876	0.779	0.9686	0.971	0.974
	120	0.9686	0.8876	0.779	0.9686	0.970	0.974

	160	0.9686	0.8876	0.779	0.9686	0.970	0.974
	200	0.9686	0.8876	0.779	0.9686	0.970	0.974
$\gamma = 0.4$	40	0.9376	0.627	0.587	0.9376	0.945	0.953
	80	0.9376	0.627	0.586	0.9376	0.945	0.953
	120	0.9368	0.6262	0.586	0.9368	0.945	0.953
	160	0.9368	0.6262	0.586	0.9368	0.945	0.953
	200	0.9368	0.6262	0.586	0.9368	0.945	0.953
$\gamma = 0$	40	0.886	.607	0.415	0.886	0.90	0.91
	80	0.886	0.607	0.415	0.886	0.90	0.91
	120	0.886	0.607	0.415	0.886	0.90	0.91
	160	0.886	0.607	0.415	0.886	0.90	0.91
	200	0.886	0.607	0.415	0.886	0.90	0.91

Table 16: Influence of klin's partial failure rate (α_7) and repair rate (μ_7) on system's profit with respect to time

Coverage Factor	Time (days)	Failure rate of klin's partial $\alpha_7 = 0.004$	$\alpha_7 = 0.41$	$\alpha_7 = 0.901$	Repair rates of klin's partial $\mu_7 = 0.71$	$\mu_7 = 0.9$	$\mu_7 = 1.15$
$\gamma = 1$	40	9904	9904	9900	9904	9900	9900
	80	9894	9894	9890	9894	9890	9890
	120	9894	9894	9890	9894	9890	9890
	160	9894	9894	9800	9894	9890	9890
	200	9894	9894	9800	9894	9890	9890
$\gamma = 0.07$	40	9686	8876	7790	9686	9710	9750
	80	9686	8876	7790	9686	9710	9740
	120	9686	8876	7790	9686	9700	9740
	160	9686	8876	7790	9686	9700	9740
	200	9686	8876	7790	9686	9700	9740
$\gamma = 0.4$	40	9376	6270	5870	9376	9450	9530
	80	9376	6270	5860	9376	9450	9530
	120	9368	6262	5860	9368	9450	9530
	160	9368	6262	5860	9368	9450	9530
	200	9368	6262	5860	9368	9450	9530
$\gamma = 0$	40	8860	6070	4150	8860	9000	9100
	80	8860	6070	4150	8860	9000	9100
	120	8860	6070	4150	8860	9000	9100
	160	8860	6070	4150	8860	9000	9100
	200	8860	6070	4150	8860	9000	9100

7. CONCLUSION

Here, numerical results for availability and profit function of cement manufacturing plant has been analyzed. The availability and profit of cement plant helps system designers to improve the design for enhancing the reliability of plant. It is identified that coverage factor plays a prominent role in the enhancing the reliability of the plant. It is revealed that profit and availability increased with the increase of failure rates while it sharply declines with the increase of time and failure rates. Preheater, cooler, cement mill and kiln are the prominent subsystems that highly influence the availability and profit of the plant. So, it is recommended that by increasing repair rates, adopting proper maintenance strategies and arranging redundant unit plant can be made more available and profitable.

8. REFERENCES

[1] 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

[2] 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

[3] Kumar A, Saini M (2018) Fuzzy availability analysis of a marine power plant. Materials Today: Proceedings. 5 (11P3): 25195-25202.

[4] 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

[5] 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

[6] 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.

[7] Saini M, Kumar A (2019) Performance analysis of evaporation system in sugar industry using RAMD analysis. J Braz Soc Mech Sci Eng 41:4

[8] 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

[9] 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

[10] 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

[11] 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.

[12] 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

[13] GARG, Vikas; KADYAN, M S; KUMAR, Jitender. Stochastic Analysis of aTwo 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.

[14] 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.