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Evaluation of Reliability Parameters of a Cement Manufacturing Plant by using Supplementary Variable Technique

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ABSTRACT

This paper presents reliability and availability of a cement manufacturing plant by using supplementary variable technique. In a cement manufacturing plant ten sub systems are arranged in a series. After working of maximum time, the system undergoes preventive maintenance and after this maintenance work as new. The time to failure of each subsystem follows a negative exponential distribution while preventive maintenance and repair time distributions are taken as arbitrary. All random variables are statistically independent.

Keywords: Cement manufacturing plant, Reliability, Availability, Preventive maintenance and supplementary variable technique.

1.INTRODUCTION

The process of manufacturing cement can either be a wet process or a dry process. In this paper author considered the manufacturing of cement by using dry process. In the dry process, the raw materials are crushed first and dry mixed. Due to the complexity of cement manufacturing plant (dry process), which involve high risks, the concept of reliability has become a very important factor in the overall system design. Arekar et al. (7), Kharoufeh et al. (4), Proctor and Singh (1), Shakuntla et al. (6), Malik (3) and Uematsu and Nishida (2) have analyzed single-unit systems under a common assumption that the unit works continuously till failure without undergoing PM. The continued operation of the systems may reduce performance and reliability of the system. Therefore, PM of the unit is necessary after a specific period of time at any stage of operation to improve the reliability and availability of the system because the cost to repair the system after its failure is greater than the cost of maintaining the system before its failure. Thus, the method of preventive maintenance can be adopted to improve the reliability and profit of system. The concept of preventive maintenance has been used by many researchers such as Malik and Nandal (5), Kumar et al. (7) and Kumar and Malik (8) while analyzing the redundant systems with maximum operation time and Ashish Kumar, Monika Saini, S.C. Malik (9) have analyzed Stochastic Modeling of a Concrete Mixture Plant with Preventive Maintenance.

Most of the authors discussed the system processing Markovian properties. The system having non-Markovian property can be converted into a system having Markovian nature by introducing a new variable called a supplementary variable. In the present study, we have considered ten subsystems of the cement manufacturing plant with constant failure and arbitrary repair rates of the subsystems and discussed the reliability modeling of cement manufacturing plant with preventive maintenance using supplementary variable technique. Finally, discussed the availability of this plant with respect to different failure and repair rates.

2. System Description, Notations and Assumptions:

In this paper, we consider cement manufacturing plant consisting of ten subsystems namely, Raw materials unit, crushers unit, Grinders unit, Compressed air blenders unit, Raw material+15% water unit, Flakes of material unit, Kiln(calcination) unit, Clinkers unit, Addition of Gypsum (Grinders + ball mill) unit, Collection of Ordinary Portland cement unit. This process is made a preference when available raw materials are quite hard and are to be crushed separately and mixed. Although the final product manufactured is costly and the process is time-taking, the dry process proves advantageous when employed for quite hard raw materials. The steps involved are enlisted below:

1. Once the dry ingredients are mixed post crushing, a small amount of water is added to the mix to supplement the moisture content to about 14%. Consequently, the addition of water propels the cohesion process and small lumps begin to form.
2. The cake-like lumps are dried and fed to a rotary kiln, where they are subjected to a very high temperature. A chemical reaction known as calcination takes place inside the kiln as a result of which the volatiles evaporate and oxidation of the mass occurs.
3. Subsequently, small balls are formed inside the kiln called clinkers.
4. The clinkers are aerated to slake the free lime present and during this, some moisture and carbon dioxide present in the atmosphere get absorbed into the clinkers.
5. Once the clinkers are cooled, they are ground to a powered form in tube mills. At this stage, a minuscule quantity (2-3%) of gypsum is added to the mix to coat the cement particles and retard the setting of cement.
6. The desired cement powder is ready and is finally packed and transported.

3. Assumptions:

i. Repair and failure rates are independent of each other and their unit is taken as per day.
ii. Failure and repair rates of the subsystems are taken respectively as constant and variable.
iii. Performance wise, a repaired unit is as good as new one for a specified duration.
iv. Sufficient repair facilities are provided.
v. Service of the subsystem includes repair and/or replacement.
vi. Switch devices, repairs and preventive maintenances are perfect.
vii. The distribution of the preventive maintenance is considered as arbitrary.

4. Notations:

A, B, C, D, E, F, G, H, I and J	Indicate that the subsystem is working in full capacity.
a, b, c, d, e, f, g, h, i, and j	Indicate the failed state of the subsystem.
α_i	denotes the constant failure rate of the units, where $i = 1,2,3,4,5,6,7,8,9,10$.
α_m	denotes the constant transition rate of the system
$\beta_i(x), S_i(x)$	denote the repair rate of the unit and probability density function, respectively, for the elapsed repair time $'x'$, where $i = 1,2,3,4,5,6,7,8,9,10$.
$p_0(t)$	denotes the probability that at time t the system is in good state.
$p_i(x,t)$	denotes the probability that at time t the system is in failed state the elapsed repair time lies in the interval $(x, x+\Delta)$, $i = 1,2,3,4,5,6,7,8,9,10$

$p_m(y,t)$	denotes the probability that at time t the system is under preventive maintenance, the elapsed preventive maintenance time is $'y'$.
$\beta_m(y), S_{10}(y)$	denote the preventive maintenance rate of the unit and Probability density function, for the elapsed maintenance time $'y'$, respectively.
$p(s)$	Laplace transform of $p(t)$.
$S_i(x) = \beta_i(x) e^{\left[-\int_0^x \beta_i(x)dx\right]}$, $i = 1,2,3,4,5,6,7,8,9,10$	
$S_{10}(y) = \beta_m(y) e^{\left[-\int_0^y \beta_{10}(y)dy\right]}$	
$\int$	denotes the definite integral from 0 to χ.

Flow diagram for the manufacturing of cement by using dry process:

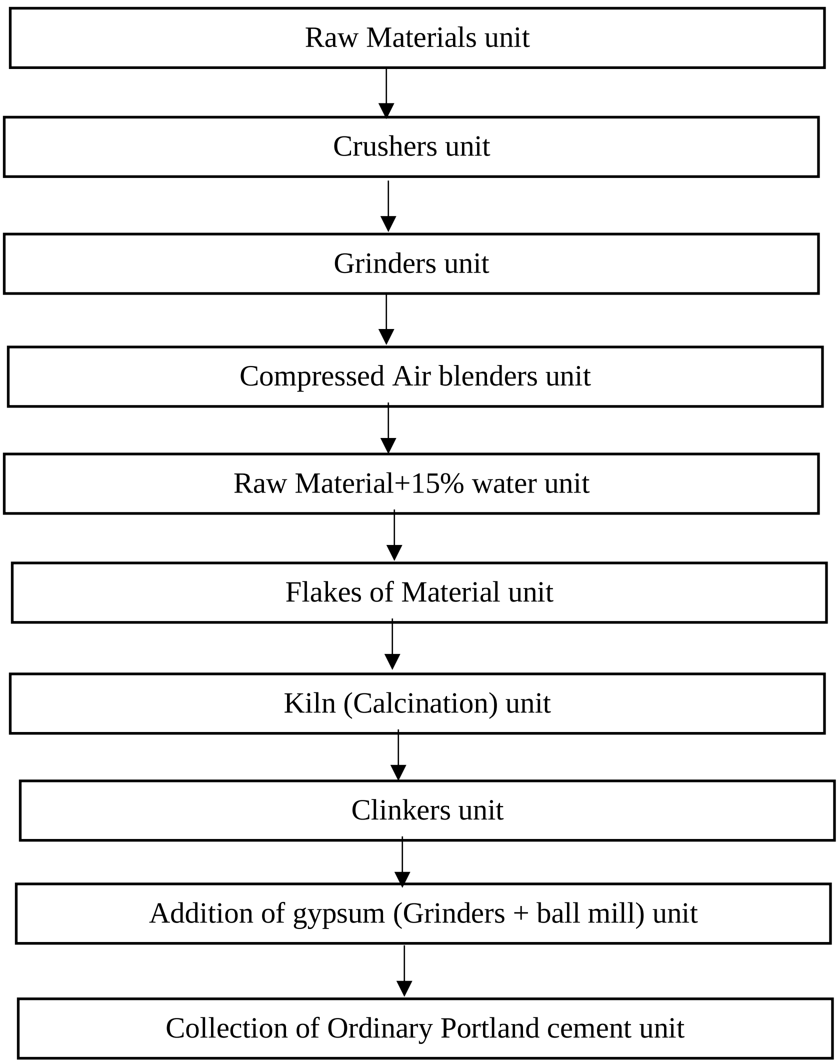

Fig.1

5. State Transition diagram:

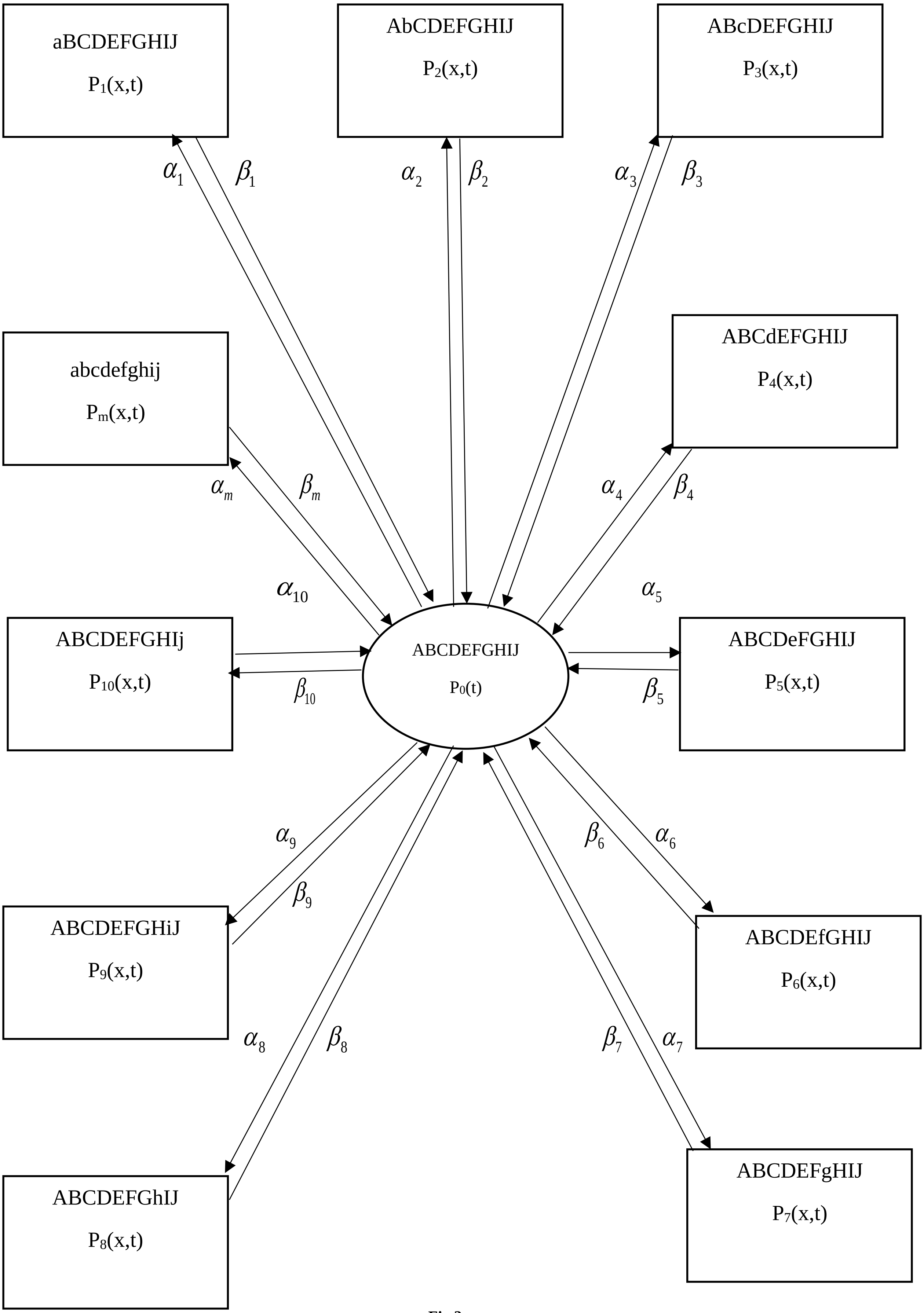
aBCDEFGHIJ
P1(x,t)
AbCDEFGHIJ
P2(x,t)
ABcDEFGHIJ
P3(x,t)
abcdefghij
Pm(x,t)
ABCdEFGHIJ
P4(x,t)
ABCDEFGHIj
P10(x,t)
ABCDEFGHIJ
P0(t)
ABCDeFGHIJ
P5(x,t)
ABCDEFGHiJ
P9(x,t)
ABCDEfGHIJ
P6(x,t)
ABCDEFGhIJ
P8(x,t)
ABCDEFgHIJ
P7(x,t)
α1 β1 α2 β2 α3 β3 αm βm α4 β4 α10 β10 α5 β5 α9 β9 α6 β6 α8 β8 α7 β7

Fig.2

6. Formulation and Solution of Mathematical model:

By probability considerations and continuity arguments, we obtain the following difference-differential equations governing the behaviour of the system:

$$\left(\frac{\partial}{\partial t}+\sum_{i=1}^{10}\alpha_i+\alpha_m\right)P_0(t)=\sum_{i=1}^{10}\left[\int_0^{\infty}P_i(x,t)\beta_i(x)dx\right]+\int_0^{\infty}P_m(y,t)\beta_m(y)dy \quad (1)$$

$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\beta_i(x)\right)P_i(x,t)=0 \quad (2)$$

$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\beta_m(y)\right)P_m(y,t)=0 \quad (3)$$

The boundary and initial conditions to be satisfied are given below boundary conditions:

$$P_i(0,t)=\alpha_i P_0(t) \qquad i=1,2,3,4,5,6,7,8,9,10 \quad (4)$$

$$P_m(0,t)=\alpha_m P_0(t) \quad (5)$$

Initial conditions:

$P_i(0)=1$ when $i=0$

$P_i(0)=0$ when $i\neq 0$ (6)

By taking Laplace transforms of (1)-(5) and using in (6) we get

$$\left(s+\sum_{i=1}^{10}\alpha_i+\alpha_m\right)P_0(s)=1+\sum_{i=1}^{10}\left[\int_0^{\infty}P_i(x,s)\beta_i(x)dx\right]+\int_0^{\infty}P_m(y,s)\beta_m(y)dy \quad (7)$$

$$\left(\frac{\partial}{\partial x}+s+\beta_i(x)\right)P_i(x,s)=0 \qquad \text{where } i=1,2,3,4,5,6,7,8,9,10 \quad (8)$$

$$\left(\frac{\partial}{\partial y}+s+\beta_m(y)\right)P_m(y,s)=0 \quad (9)$$

$$P_i(0,s)=\alpha_i P_0(s) \qquad \text{where } i=1,2,3,4,5,6,7,8,9,10 \quad (10)$$

$$P_m(0,s)=\alpha_m P_0(s) \quad (11)$$

Now integrating equation (8) and further using in equation (10) we get

$$P_i(x,s)=P_i(0,s)e^{\left[-sx-\int_0^{x}\beta_i(x)dx\right]} \qquad \text{Where } i=1,2,3,4,5,6,7,8,9,10 \quad (12)$$

Integrating equation (9) and further using equation (11) we get

$$P_m(y,s)=P_m(0,s)e^{\left[-sy-\int_0^{y}\beta_m(y)dy\right]} \quad (13)$$

By using equations (12-13) in equation (7) we get

$$\left(s+\sum_{i=1}^{10}\alpha_i+\alpha_m\right)P_0(s)=1+\sum_{i=1}^{10}\left[\int_0^{\infty}\alpha_i P_0(s)S_i(s)\right]+\alpha_m P_0(s)S_m(s) \quad (14)$$

Where $S_i(s)=e^{-sx-\int_0^{x}\beta_i(x)dx}$

$$S_m(s) = e^{-sy-\int_0^y \beta_m(y)dy}$$

$$\left[s+\sum_{i=1}^{10}\alpha_i\left(1-S_i(s)\right)\right]P_0(s)=0 \tag{15}$$

$$\left[s+\alpha_m\left(1-S_m(s)\right)\right]P_0(s)=0 \tag{16}$$

$$P_0(s)=\frac{1}{T(S)} \tag{17}$$

Where $T(s)=s+\sum_{i=1}^{10}\alpha_i\left(1-S_i(s)\right)+\alpha_m\left(1-S_m(s)\right)$ (18)

$$P_1(s)=\int_0^\infty P_1(x,s)dx=\alpha_1 P_0(s)\frac{1-S_1(s)}{s}=\alpha_1\frac{A_1(s)}{T(s)} \tag{19}$$

Where $A_1(s)=\dfrac{1-S_1(s)}{s}$

Similarly, $P_i(s)=\int_0^\infty P_i(x,s)dx=\alpha_i P_0(s)\dfrac{1-S_i(s)}{s}=\alpha_i\dfrac{A_i(s)}{T(s)}$ (20)

Where $A_i(s)=\dfrac{1-S_i(s)}{s}$ $\quad i=2,3,4,5,6,7,8,9,10$

$$P_m(s)=\int_0^\infty P_m(x,s)dx=\alpha_m P_0(s)\frac{1-S_m(s)}{s}=\alpha_m\frac{A_m(s)}{T(s)} \tag{21}$$

Where $A_m(s)=\dfrac{1-S_m(s)}{s}$

It is worth noting that

$$\sum_{i=0}^{\infty}P_i(s)+P_m(s)=\frac{1}{s} \tag{22}$$

7. Evaluation of Laplace transforms of up and down state probabilities:

The Laplace transform of the probabilities that the system is in up (i.e., good) and down (i.e., failed) state at time ‘t’ are as follows

$$P_{up}(s)=P_0(s)=\frac{1}{T(s)}$$

$$P_{down}(s)=\sum_{i=1}^{10}P_i(s)+P_m(s)=\frac{\sum_{i=1}^{10}A_i(s)+A_m(s)}{T(s)} \tag{23}$$

8. Steady state probabilities:

Using Abel’s lemma in Laplace transform,

$\underset{s\to 0}{Lt}\, sz(s)=\underset{t\to\infty}{Lt}\, z(t)=z \quad (say)$

Provided the limit on the right-hand side exists, the following time independent probabilities have been obtained.

$$P_{up} = \frac{1}{1-\sum_{i=1}^{10}\left[\alpha_i S_i^1(0) - \alpha_m S_m^1(0)\right]}$$

$$P_{down} = \frac{-\sum_{i=1}^{10}\alpha_i S_i^1(0)}{1-\sum_{i=1}^{10}\left[\alpha_i S_i^1(0) - \alpha_m S_m^1(0)\right]} \tag{24}$$

9. Reliability indices:

To get system reliability, consider repair rates (i.e., $\beta_i(x)$) equal to zero. Using the method similar to that in section 2, the differential difference equations are

$$\left(\frac{\partial}{\partial t} + \sum_{i=1}^{10}\alpha_i + \alpha_m\right)P_0(t) = 0 \tag{25}$$

Taking Laplace transform of (25) and using (6) we get

$$\left(s + \sum_{i=1}^{10}\alpha_i + \alpha_m\right)P_0(s) = 1$$

$$P_0(s) = \frac{1}{\left(s + \sum_{i=1}^{10}\alpha_i + \alpha_m\right)}$$

$$R(s) = \frac{1}{\left(s + \sum_{i=1}^{10}\alpha_i + \alpha_m\right)}$$

Taking inverse Laplace transform, we get the expression for **Reliability**

$$R(t) = e^{-\left(\sum_{i=1}^{10}\alpha_i + \alpha_m\right)t} \tag{26}$$

The mean time to system failure (MTSF) is $MTSF = \dfrac{1}{\sum_{i=1}^{10}\alpha_i + \alpha_m}$ (27)

Availability: When repair rates follow exponential time distribution. Setting $S_m(s) = \dfrac{\beta_m}{s+\beta_m}$ and $S_i(s) = \dfrac{\beta_i}{s+\beta_i}$

Where $\beta_i,\ i = 1,2,3,4,5,6,7,8,9,10$ are constant repair rates. Putting these values in equation (17), we get

$$\frac{\prod_{i=1}^{10}(s+\beta_i)(s+\beta_m)}{s(s+\beta_m)\prod_{i=1}^{10}(s+\beta_i) + \sum_{j=1}^{10}\left[s\alpha_j(s+\beta_m)\prod_{i\neq j,i=1}^{10}(s+\beta_i)\right] + s\alpha_m\prod_{i\neq m,i=1}^{10}(s+\beta_i)} \tag{28}$$

10. Numerical Analysis:

Table-1: Effect of failure rate (α_1) on Reliability $R(t)$

Time	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_m	R(t) for $\alpha_1 = 0.001$	R(t) for $\alpha_1 = 0.011$
1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.6831	0.5706
2	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.4667	0.3256
3	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.3188	0.1858
4	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.2178	0.1060
5	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.4188	0.0605
6	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.1016	0.0345
7	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0694	0.0197
8	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0474	0.0112
9	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0324	0.0064
10	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0221	0.0036

Table-2: Effect of failure rate (α_2) on Reliability $R(t)$

Time	α_1	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_m	R(t) for $\alpha_2 = 0.002$	R(t) for $\alpha_2 = 0.012$
1	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.6237	0.5210
2	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.3890	0.2714
3	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.2426	0.1414
4	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.1513	0.0736
5	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0944	0.0383
6	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0588	0.0200
7	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0367	0.0104
8	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0299	0.0054
9	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0142	0.0028
10	0.1	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0089	0.0014

Table-3: Effect of failure rate (α_3) on Reliability $R(t)$

Time	α_1	α_2	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_m	R(t) for $\alpha_3 = 0.003$	R(t) for $\alpha_3 = 0.013$
1	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.6293	0.5257
2	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.3961	0.2763
3	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.2493	0.1452
4	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.1569	0.0763
5	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0987	0.0401
6	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0621	0.0211
7	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0391	0.0110
8	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0246	0.0058
9	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0154	0.0030
10	0.1	0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0097	0.0016

Table-4: Effect of failure rate (α_4) on Reliability $R(t)$

Time	α_1	α_2	α_3	α_5	α_6	α_7	α_8	α_9	α_{10}	α_m	R(t) for $\alpha_4 = 0.004$	R(t) for $\alpha_4 = 0.014$
1	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.5357	0.5304
2	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.2870	0.2813
3	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.1538	0.1492
4	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0824	0.0791
5	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0441	0.0420
6	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0236	0.0222
7	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0126	0.0118
8	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0067	0.0062
9	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0036	0.0033
10	0.1	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.0019	0.0017

Table-5: Effect of failure rate (α_5) on Reliability $R(t)$

Time	α_1	α_2	α_3	α_4	α_6	α_7	α_8	α_9	α_{10}	α_m	R(t) for $\alpha_5 = 0.005$	R(t) for $\alpha_5 = 0.015$
1	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.5406	0.5352
2	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.2922	0.2865
3	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.1580	0.1533
4	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.0854	0.0820
5	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.0461	0.0439
6	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.0249	0.0235
7	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.0135	0.0125
8	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.0072	0.0067
9	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.0039	0.0036
10	0.1	0.01	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.1	0.0021	0.0019

Table-6: Effect of failure rate (α_6) on Reliability $R(t)$

Time	α_1	α_2	α_3	α_4	α_5	α_7	α_8	α_9	α_{10}	α_m	R(t) for $\alpha_6 = 0.006$	R(t) for $\alpha_6 = 0.016$
1	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.5455	0.5401
2	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.2976	0.2917
3	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.1623	0.1575
4	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.0885	0.0850
5	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.0483	0.0459
6	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.0263	0.0248
7	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.0143	0.0134
8	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.0078	0.0072
9	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.0042	0.0039
10	0.1	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.1	0.0023	0.0021

Table-7: Effect of failure rate (α_7) on Reliability $R(t)$

Time	α_1	α_2	α_3	α_4	α_5	α_6	α_8	α_9	α_{10}	α_m	R(t) for $\alpha_7 = 0.007$	R(t) for $\alpha_7 = 0.017$
1	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.5504	0.5449
2	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.3030	0.2970
3	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.1667	0.1618
4	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.0918	0.0882
5	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.0505	0.0480
6	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.0278	0.0261
7	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.0153	0.0142
8	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.0084	0.0077
9	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.0046	0.0042
10	0.1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.1	0.0025	0.0023

Table-8: Effect of failure rate (α_8) on Reliability $R(t)$

Time	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_9	α_{10}	α_m	R(t) for $\alpha_8 = 0.008$	R(t) for $\alpha_8 = 0.018$
1	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.5554	0.5499
2	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.3085	0.3024
3	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.1713	0.1662
4	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.0951	0.0914
5	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.0528	0.0502
6	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.0293	0.0276
7	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.0163	0.0152
8	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.0090	0.0083
9	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.0050	0.0045
10	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.0027	0.0025

Table-9: Effect of failure rate (α_9) on Reliability $R(t)$

Time	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_{10}	α_m	R(t) for $\alpha_9 = 0.009$	R(t) for $\alpha_9 = 0.019$
1	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.5604	0.5548
2	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.3141	0.3078
3	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.1760	0.1708
4	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.0986	0.0947
5	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.0552	0.0526
6	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.0309	0.0291
7	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.0173	0.0161
8	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.0097	0.0089
9	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.0054	0.0049
10	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.0030	0.0027

Table-10: Effect of failure rate (α_{10}) on Reliability $R(t)$

Time	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_m	R(t) for $\alpha_{10} = 0.01$	R(t) for $\alpha_{10} = 0.02$
1	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.5655	0.5598
2	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.3198	0.3134
3	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.1808	0.1755
4	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.1022	0.0982
5	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.0578	0.0550
6	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.0327	0.0308
7	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.0184	0.0172
8	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.0104	0.0096
9	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.0059	0.0054
10	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.0033	0.0030

Table-11: Effect of failure rate (α_m) on Reliability $R(t)$

Time	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	R(t) for $\alpha_m = 0.035$	R(t) for $\alpha_m = 0.045$
1	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.5571	0.5515
2	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.3103	0.3042
3	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1729	0.1677
4	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.0963	0.0925
5	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.0536	0.0510
6	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.0298	0.0281
7	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.0166	0.0155
8	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.0092	0.0085
9	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.0051	0.0047
10	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.0028	0.0026

Table-12: Availability of Cement Manufacturing plant with respect to failure rate (α_1)

Set 1: $\alpha_2 = 0.01, \alpha_3 = 0.02, \alpha_4 = 0.03, \alpha_5 = 0.04, \alpha_6 = 0.05, \alpha_7 = 0.06, \alpha_8 = 0.07,$
$\alpha_9 = 0.08, \alpha_{10} = 0.09, \alpha_m = 0.1, \beta_1 = 0.001, \beta_2 = 0.002, \beta_3 = 0.003, \beta_4 = 0.004$
$\beta_5 = 0.005, \beta_6 = 0.006, \beta_7 = 0.007, \beta_8 = 0.008, \beta_9 = 0.009, \beta_{10} = 0.01, \beta_m = 0.015$

α_1	Set 1	if $\alpha_2 = 0.09$	if $\alpha_3 = 0.08$	if $\alpha_4 = 0.07$	if $\alpha_5 = 0.06$	if $\alpha_6 = 0.055$	if $\alpha_7 = 0.04$	if $\alpha_8 = 0.03$	if $\alpha_9 = 0.02$	if $\alpha_{10} = 0.01$	if $\alpha_m = 0.001$
0.01	0.9518	0.8847	0.9007	0.9172	0.9342	0.9474	0.9700	0.9889	1.0084	1.0286	0.6860
0.02	0.9429	0.8770	0.8927	0.9088	0.9256	0.9385	0.9607	0.9792	0.9983	1.0182	0.6813
0.03	0.9341	0.8694	0.8848	0.9007	0.9171	0.9298	0.9516	0.9697	0.9885	1.0079	0.6767
0.04	0.9254	0.8619	0.8770	0.8927	0.9088	0.9212	0.9426	0.9604	0.9788	0.9979	0.6721
0.05	0.9170	0.8545	0.8694	0.8848	0.9006	0.9128	0.9339	0.9513	0.9694	0.9880	0.6677
0.06	0.9087	0.8473	0.8619	0.8770	0.8926	0.9046	09252	0.9424	0.9601	0.9784	0.6632
0.07	0.9005	0.8402	0.8546	0.8694	0.8847	0.8965	0.9168	0.9336	0.9510	0.9689	0.6589
0.08	0.8925	0.8332	0.8474	0.8619	0.8770	0.8885	0.9085	0.9250	0.9420	0.9596	0.6546
0.09	0.8846	0.8263	0.8402	0.8546	0.8694	0.8807	0.9003	0.9165	0.9332	0.9505	0.6503
0.1	0.8768	0.8196	0.8333	0.8474	0.8619	0.8731	0.8923	0.9082	0.9246	0.9416	0.6461

Table-13: Availability of Cement Manufacturing plant with respect to failure rate (β_1)

Set 1: $\beta_2 = 0.1, \beta_3 = 0.2, \beta_4 = 0.3, \beta_5 = 0.4, \beta_6 = 0.5, \beta_7 = 0.6, \beta_8 = 0.7,$ $\beta_9 = 0.8, \beta_{10} = 0.9, \beta_m = 0.15, \alpha_1 = 0.01, \alpha_2 = 0.02, \alpha_3 = 0.03, \alpha_4 = 0.04$ $\alpha_5 = 0.05, \alpha_6 = 0.06, \alpha_7 = 0.07, \alpha_8 = 0.08, \alpha_9 = 0.09, \alpha_{10} = 0.11, \alpha_m = 0.15$

β_1	Set 1	if $\beta_2 = 0.09$	if $\beta_3 = 0.08$	if $\beta_4 = 0.07$	if $\beta_5 = 0.06$	if $\beta_6 = 0.05$	if $\beta_7 = 0.04$	if $\beta_8 = 0.03$	if $\beta_9 = 0.02$	if $\beta_{10} = 0.01$	if $\beta_m = 0.001$
0.11	0.6721	0.6720	0.6708	0.6691	0.6669	0.6644	0.6616	0.6585	0.6552	0.6498	0.6634
0.22	0.6724	0.6724	0.6712	0.6695	0.6673	0.6648	0.6620	0.6589	0.6556	0.6501	0.6638
0.33	0.6728	0.6727	0.6715	0.6698	0.6676	0.6651	0.6623	0.6592	0.6559	0.6504	0.6641
0.44	0.6730	0.6729	0.6718	0.6700	0.6679	0.6653	0.6625	0.6594	0.6561	0.6507	0.6643
0.55	0.6732	0.6732	0.6720	0.6703	0.6681	0.6656	0.6627	0.6596	0.6563	0.6509	0.6645
0.66	0.6734	0.6734	0.6722	0.6704	0.6683	0.6657	0.6629	0.6598	0.6565	0.6511	0.6647
0.77	0.6736	0.6735	0.6723	0.6706	0.6684	0.6659	0.6631	0.6600	0.6567	0.6512	0.6649
0.88	0.6737	0.6737	0.6725	0.6708	0.6686	0.6661	0.6632	0.6601	0.6568	0.6514	0.6650
0.99	0.6739	0.6738	0.6726	0.6709	0.6687	0.6662	0.6633	0.6603	0.6570	0.6515	0.6652

Table-14 Mean time to system failure (MTSF):

α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_m	MTSF
0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.2597
0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	0.1515

CONCLUSION

The results and system reliability are shown in tables (1-11) which indicates that the reliability of the system decreases with the increase of failure rates (α_i) and transition rate (α_m) with respect to time and for fixed values of other parameters. Table 12, shows that the availability of the system decreases with the increase of the failure rate (α_1). Table 13, shows the behaviour of steady state availability with respect to repair rate (β_1). Table 14, we calculated the MTSF of the system with two different sets of failure rates.

Declaration by Authors

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REFERENCES

1. Proctor, C.L., Singh, B. (1976), A repairable 3-state device, IEEE Trans. Reliab., R-25, pp.210-211
2. Uematsu, K, Nishida, T. (1987). One unit system with a failure rate depending upon the degree of repair, Mathematica Japonica, Vol.32, No.1, pp.139-147.
3. Malik, S.C. (2008): Reliability modelling and profit analysis of a single-unit system with inspection by a server who appears and disappears randomly, Journal of Pure and Applied Mathematica Sciences, Vol. LXVII, No.1-2, pp. 135-146.
4. Kharoufeh, J.P., Solo, C.J. and Ulukus, M.Y. (2010), Semi-Markov models for degradation-based reliability, IIE Transactions. Vol.42, pp.599-612.
5. Malik, S.C. Nandal, P. (2010), Cost–Analysis of Stochastic Models with Priority to Repair Over Preventive Maintenance Subject to Maximum Operation Time, Edited Book, Learning Manual on Modelling, Optimization and Their Applications, Excel India Publishers, pp.165-178.
6. Shakuntla S., Lal, A.K., Bhatia, S.S. and Singh, J. (2011). Reliability analysis of polytube industry using supplementary variable technique, Applied Mathematics and computation, Vol.281, pp.3981-3992.
7. Arekar, K., Ailawadi, S. and Jain, R. (2012), Reliability modelling for wear out failure period of a single unit system, Journal of

Statistical and Econometric Methods, Vol.1(1), pp.33-41.

8. Kumar, A., Malik, S.C. (2012), stochastic Modelling of a computer system with Priority to PM over S/W replacement Subject to Maximum Operation and Repair Times. International Journal of Computer Applications, Vol.43(3), pp.27-34.
9. Kumar, A., Malik, S.C. and Barak, M.S. (2012). Reliability Modelling of a Computer System with Independent H/W and S/W Failures Subject to Maximum Operation and Repair Times, International Journal of Mathematical Achieves, Vol.3, No.7, pp.2622-2630.
10. Ashish Kumar, Monika Saini, S.C. Malik (2014). Stochastic Modelling of a CONCRETE Mixture Plant with Preventive Maintenance, Applications and Applied Mathematics: An International Journal (AAM), Vol.9, Issue 1, Article 2, pp.13-27.

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