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Availability and Performance Optimization of Cement Manufacturing Plant using GA and PSO

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Abstract: *The main aim of the present study is to optimize the availability and profit of cement manufacturing plant using genetic algorithm and particle swarm optimization. For this purpose, a mathematical model has been developed using Markovian birth-death process. The differential-difference equation has been optimized by GA and PSO. 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. Numerical and graphical results have been obtained to highlight the importance of the study.*

Keywords: *Cement Manufacturing Plant, Genetic Algorithm, Particle Swarm Optimization, Availability.*

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I. Introduction:

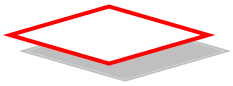
Cement is a vital development material in industrialization and human civic establishments. It sets, solidifies, and ties different materials and blended in with sand and items concrete. India is second spot in the creation of cement after China. India utilizes enormous measure of cement in the lodging, 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. A lot of researchers have examined the reliability and availability in the manner to improve the performance of their models. Kumar e al. (2019) analyzed the availability for an engineering system in which all subsystems are in series configuration.Saini and Kumar (2018), Kumar and Saini (2019), Dahiya et al. (2019), Goyal et al. (2020)and Gupta et al. (2020) developed a lot of reliability and performance models for serial process of various industries by adopting various techniques.

By keeping above facts and figures in mind, herean effort has been made to obtain the optimum values of availability and performance using metaheuristic approaches like genetic algorithm and particle swarm optimization. Initially, a mathematical model for cement manufacturing plant has been developed in which seven subsystems arranged in series structure. The failure of any subsystem causes the complete failure of plant. The system has sufficient repair facilities available to perform maintenance and repair activities. The failure and repair of all subsystems are independent to each other. The failure rate of subsystems follows exponential distribution while repair rates are considered as arbitrarily distributed. Using Markovian birth-death model differential-difference equations has been derived. Now, applying various metaheuristic approaches optimum values of the various failure and repair rates has been obtained and corresponding to these values numerical and graphical values of availability and profit have been depicted.

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

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
$\lambda_i \ (1 \le i \le 7)$	:	Respectively failure rates in subsystems A, B, C, C_1, D, E, D_1
$\gamma_i(x)(1 \le i \le 7)$	:	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
$P_i(x,t), (i = 1, \ldots\ldots, 19)$	:	Probability of subsystem on i[th]state at time t with repair time x
$S_i, (i = 1, 2, \ldots\ldots, 19)$	:	State of the subsystem

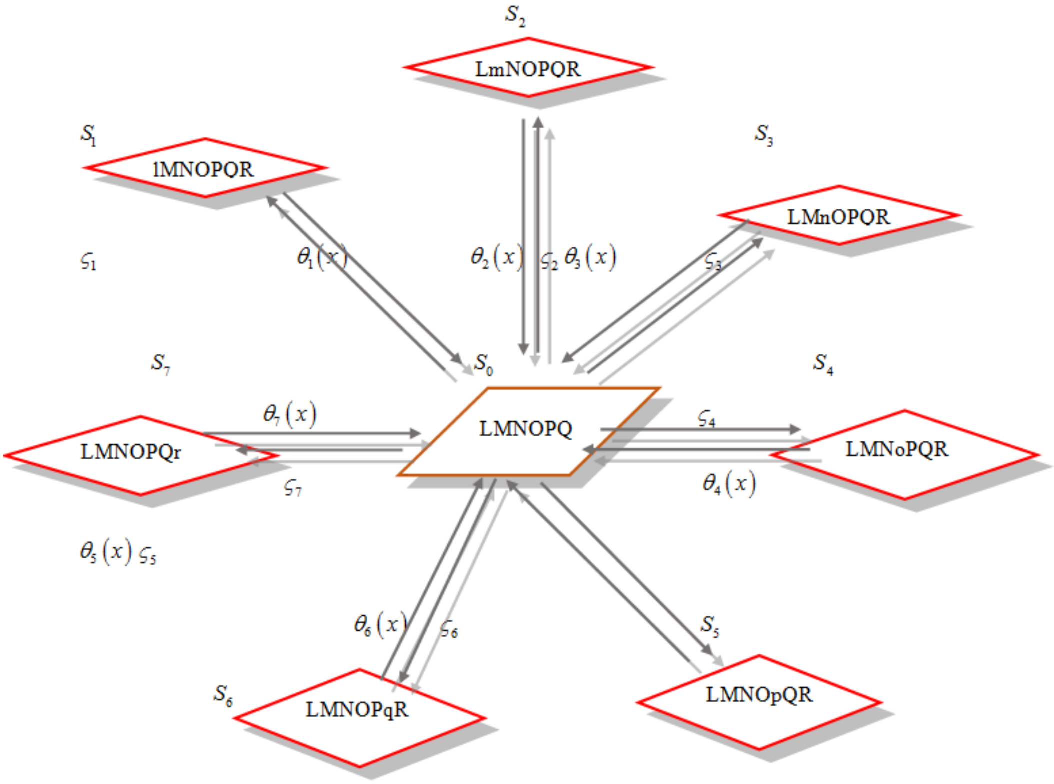


Fig.-1: State progression diagram of the system

Mathematical modeling of the system

A technique, supplementary variable technique has been used to develop a mathematical model related to state progression diagram (Fig-7.1) and derived the Chapman-Kolmogorov differential difference equations by Markov birth death process.

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

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

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

$$P_0(t+\Delta t) - P_0(t) = [(-\varsigma_1 - \varsigma_2 - \varsigma_3 - \varsigma_4 - \varsigma_5 - \varsigma_6 - \varsigma_7)P_0(t) + \int_0^\infty \theta_1(x)P_1(x,t)dx + \int_0^\infty \theta_2(x)P_2(x,t)dx$$
$$+ \int_0^\infty \theta_3(x)P_3(x,t)dx + \int_0^\infty \theta_4(x)P_4(x,t)dx + \int_0^\infty \theta_5(x)P_5(x,t)dx + \int_0^\infty \theta_6(x)P_6(x,t)dx$$
$$+ \int_0^\infty \theta_7(x)P_7(x,t)dx]$$

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

$$\lim_{\Delta t \to 0} \frac{P_0(t+\Delta t) - P_0(t)}{\Delta t} = \lim_{\Delta t \to 0} [(-\varsigma_1 - \varsigma_2 - \varsigma_3 - \varsigma_4 - \varsigma_5 - \varsigma_6 - \varsigma_7)P_0(t) + \int_0^\infty \theta_1(x)P_1(x,t)dx$$
$$+ \int_0^\infty \theta_2(x)P_2(x,t)dx + \int_0^\infty \theta_3(x)P_3(x,t)dx + \int_0^\infty \theta_4(x)P_4(x,t)dx$$
$$+ \int_0^\infty \theta_5(x)P_5(x,t)dx + \int_0^\infty \theta_6(x)P_6(x,t)dx + \int_0^\infty \theta_7(x)P_7(x,t)dx]$$

$$\left[\frac{dP_0(t)}{dt}\right] + (\varsigma_1 + \varsigma_2 + \varsigma_3 + \varsigma_4 + \varsigma_5 + \varsigma_6 + \varsigma_7)P_0(t) = \int_0^\infty \theta_1(x)P_1(x,t)dx + \int_0^\infty \theta_2(x)P_2(x,t)dx$$
$$+ \int_0^\infty \theta_3(x)P_3(x,t)dx + \int_0^\infty \theta_4(x)P_4(x,t)dx$$
$$+ \int_0^\infty \theta_5(x)P_5(x,t)dx + \int_0^\infty \theta_6(x)P_6(x,t)dx$$
$$+ \int_0^\infty \theta_7(x)P_7(x,t)dx$$

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

Where

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

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

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

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

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

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

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

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

The related boundary conditions are as follows:

$P_1(0,t)=\varsigma_1 P_0(t)$ $P_2(0,t)=\varsigma_2 P_0(t)$ $P_3(0,t)=\varsigma_3 P_0(t)$ $P_4(0,t)=\varsigma_4 P_0(t)$

$P_5(0,t)=\varsigma_5 P_0(t)$ $P_6(0,t)=\varsigma_6 P_0(t)$ $P_7(0,t)=\varsigma_7 P_0(t)$

The primary conditions are as follows:

$P_0(0)=1$

$P_i(0)=0\ ,\ i=1\,to\,7$

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

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)

$$A_v=P_0=\left[1+\frac{\varsigma_1}{\theta_1}+\frac{\varsigma_2}{\theta_2}+\frac{\varsigma_3}{\theta_3}+\frac{\varsigma_4}{\theta_4}+\frac{\varsigma_5}{\theta_5}+\frac{\varsigma_6}{\theta_6}+\frac{\varsigma_7}{\theta_7}\right]^{-1} \quad \ldots (9)$$

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.

$$\text{Performance}=K_1A_v-K_2$$

$$=3000\left[1+\frac{\varsigma_1}{\theta_1}+\frac{\varsigma_2}{\theta_2}+\frac{\varsigma_3}{\theta_3}+\frac{\varsigma_4}{\theta_4}+\frac{\varsigma_5}{\theta_5}+\frac{\varsigma_6}{\theta_6}+\frac{\varsigma_7}{\theta_7}\right]^{-1}-300 \quad \ldots (10)$$

Availability and Performance Optimization of Cement Manufacturing Plant using Metaheuristics

The availability and performance of any system depends upon failure and repair rates of its subsystems. In this paper, we have analyzed the performance and availability of Physical Processing Unit in Sewage Treatment Plant using failure and repair rates of different subsystems of PPU. As there are six subsystems in the PPU, a total of twelve parameters are considered. Out of these twelve parameters, six parameters $(k1, k2, \ldots. k6)$ are representing failure rates, whereas remaining six $(v1, v2, \ldots., v6)$ represents repair rates of respective subsystems. The range (constraints) of these parameters is provided in Table 1 as follows:

Table 1: Cement Manufacturing plant failure and repair rates range for various subsystems

Sub-system	*Range of failure-rate*	*Range of repair-rate*
L	ς_1 = 0.91 -2.01	θ_1 = 2.01- 18.1
M	ς_2 = 0.81-1.97	θ_2 = 3.5 – 18.4
N	ς_3 = 0.99 -1.91	θ_3 = 4.91 -16.1
O	ς_4 = 0.87 -2.1	θ_4 = 3.71 -20.1

P	ς_5 = 0.88 -2.5	θ_5 = 3.29 -22.01
Q	ς_6 = 0.81 -1.87	θ_6 = 3.11 -21.2
R	ς_7 = 0.9 -2.21	θ_7 = 4.11 -16.5

In present study, system availability and performance analysis are carried out using two famous as well as powerful techniques of metaheuristics viz. Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). The main goal of this optimization is to maximize the value of availability and profit incurred by system. Equations (9 & 10) are used to obtain the availability and profit of the system.

Table-2: Effect of population size on availability and performance of CMP subsystem using GA (mutation probability=0.2, crossover rate= 0.6, No. of evolutions= 150, population size=220)

Best values of failure rates	**Best values of repair rates**
ς_1 = 1.91	θ_1 = 16.5
ς_2 = 1.7	θ_2 = 8.5
ς_3 = 1.9	θ_3 = 15.6
ς_4 = 2.01	θ_4 = 13.7
ς_5 = 1.56	θ_5 = 20.4
ς_6 = 1.87	θ_6 = 5.9
ς_7 = 2. 2	θ_7 = 15.6
Optimum Availability = 0.9513	**Optimum Profit = 6722.4**

Table-3 Effect of no. of swarm on availability and profit of PPU subsystem using PSO (Maximum No. of iterations=200, Inertia Weight=1, Inertia Weight Damping Ratio=0.99, Personal Learning Coefficient=1.5, Global Learning Coefficient=2)

Best values of failure rates	**Best values of repair rates**
ς_1 = 1.81	θ_1 = 14.5785
ς_2 = 1.077	θ_2 = 8.235
ς_3 = 1.119	θ_3 = 14.4576
ς_4 = 2.081	θ_4 = 13.3457
ς_5 = 1.1256	θ_5 = 17.894
ς_6 = 1.3487	θ_6 = 8.5639
ς_7 = 2. 5672	θ_7 = 15.9876
Optimum Availability = 0.99913	**Optimum Profit = 7735.4**

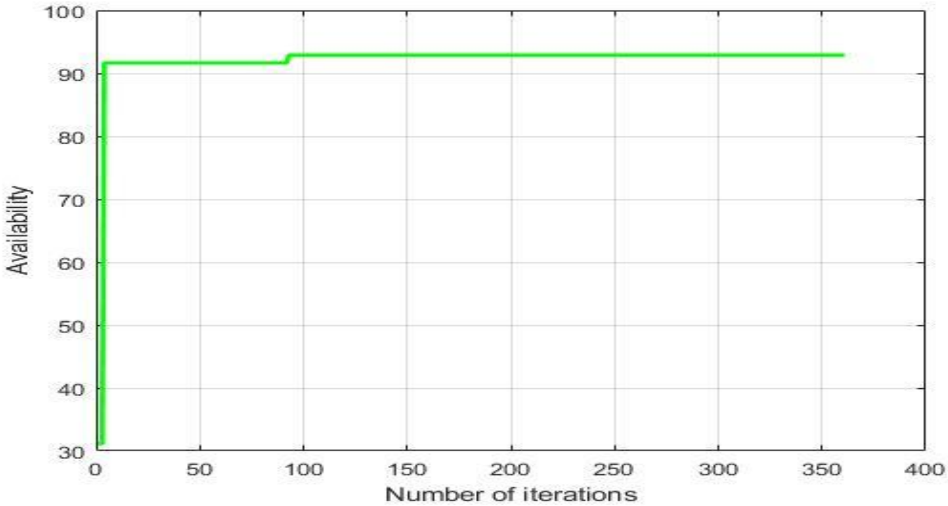


Fig. 2: Availability vs. Number of iterations using GA at population size=175

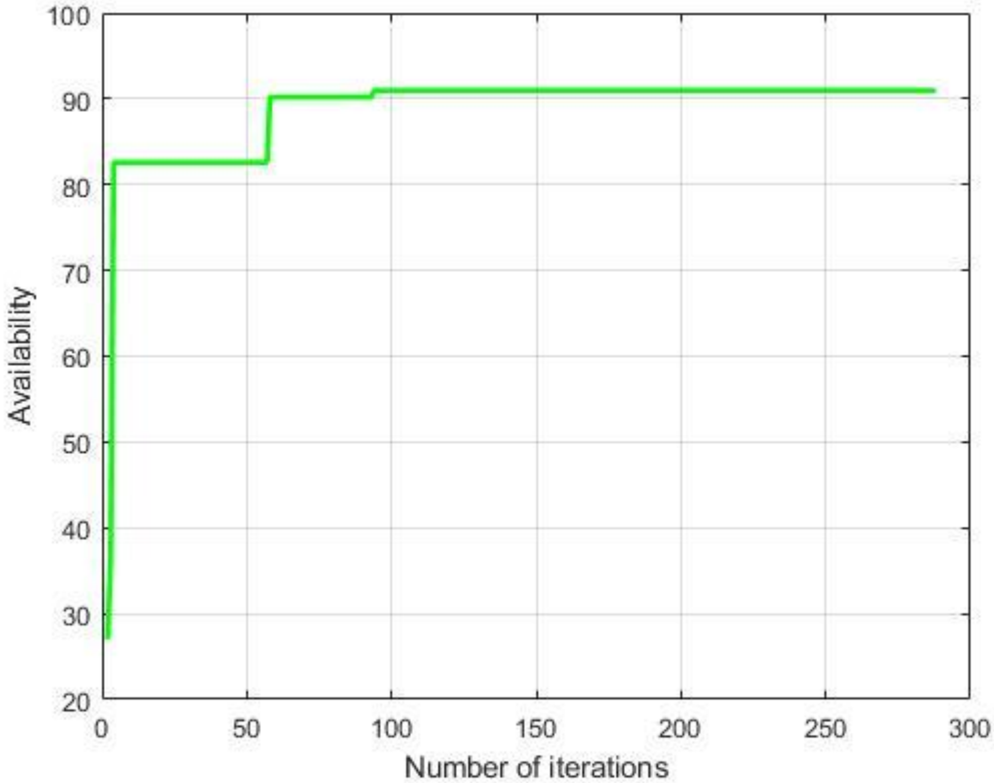


Fig. 3: Availability vs. Number of iterations using GA at evolution size=90

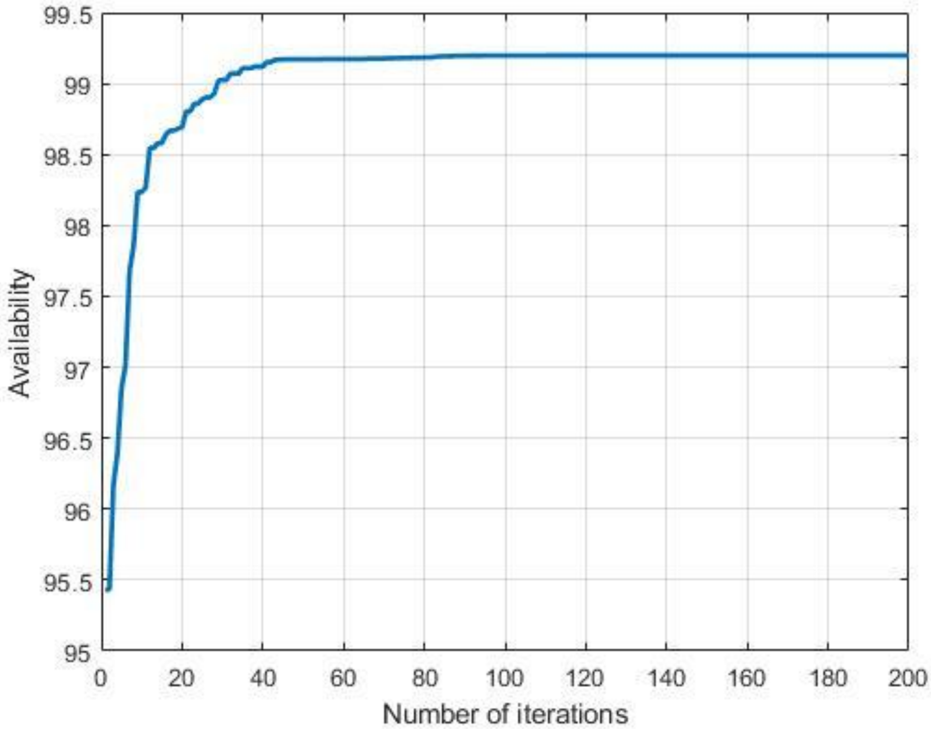


Fig. 4 (e): Availability vs. Number of iterations using GA at evolution size= 75

The optimized value of availability has been achieved to be 99.92%. The corresponding optimum values of failure rates and repair rates are shown in Table 3.

II. Conclusion:

System availability is directly proportional to the failure and repair rates of different subsystems of any plant or system. This paper has presented the optimum availability as well as corresponding performance of a cement manufacturing plant by applying the concept of metaheuristics in terms of Genetic Algorithm and Particle Swarm Optimization. The proposed model is helpful to system developers as it provides the availability and performance of the sewage treatment plant. Experimental results shown that PSO outperforms GA in terms of availability of sewage treatment plant. The optimized value of system availability has been observed to be 99.20% using PSO as compared to 95.38% using GA.

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