JOURNAL OF MECHANICS OF CONTINUA AND MATHEMATICAL SCIENCES
www.journalimcms.org

ISSN (Online) : 2454 -7190 Vol.-19, No.-01, January (2024) pp 1-14 ISSN (Print) 0973-8975

RELIABILITY OPTIMIZATION OF A DEGRADED SYSTEM UNDER PREVENTIVE MAINTENANCE USING GENETIC ALGORITHM

Shakuntla Singla[1], Diksha Mangla[2], Poonam Panwar[3], S Z Taj[4]

[1]Associate Professor, Department of Mathematics and Humanities, MMEC, Maharishi Markandeshwar University, India

[2]Research Scholar, Department of Mathematics and Humanities, MMEC, Maharishi Markandeshwar University, India

[3]Associate Professor, MMICT and BM, Maharishi Markandeshwar University, India

[4]Senior Lecturer, Department of Applied Mathematics and Science, COE, National University of Science and Technology, Oman

E-Mail: [1]shakuntla.singla@mmumullana.org, [2]dikshamangla1995@gmail.com [3]rana.poonam1@gmail.com, [4]syedtaj@nu.edu.om

Corresponding Author: **S. Z. Taj**

https://doi.org/10.26782/jmcms.2024.01.00001

(Received: November 08, 2023; Revised: January 3, 2024; Accepted: January 12, 2024)

Abstract

The reliability parameters of a Mathematical model are analyzed for a system with three identical units and a standby. In this study, the primary unit is considered more important due to its high cost and working in two types of degraded conditions before a complete malfunction. Under the concept of preventive maintenance, the states of deterioration are reversed. The working of the system under two different efficiencies is discussed. The reliability of the Mathematical model, depending on the availability and working time, has been optimized using the Mathematical tool "Genetic Algorithm". The optimum values of all parameters based on the exponential distribution are considered to optimize the reliability, and thus provide maximum benefits to the industry. Sensitivity analysis of the availability and the working time is carried out to understand the effects of changing parameters. Graphical and tabular analyses are presented to discuss the results and to draw conclusions about the system's behavior.

Keywords: deteriorated state, genetic algorithm, malfunction rate, preventive maintenance, regenerative point graphical technique, sensitivity analysis.

Acronym

-full working state -Degraded state -failed state

- $\alpha \rightarrow$ Malfunction time from S_0 to S_1 and A to (A).
- $\alpha_2 \rightarrow$ Malfunction time from B to b.
- α_3 / $\alpha_4 \rightarrow$ Malfunction time from D to D_1, and D_1 to D_2 respectively.
- $\alpha_5 \rightarrow$ Malfunction time from D_2 to d.
- $\beta \rightarrow$ Rate of preventive maintenance from S_1 to S_0 and (A) to A.
- $\beta_2 \rightarrow$ Rate of preventive maintenance from b to B.
- β_3 / β_4 / $\beta_5 \rightarrow$ Rate of preventive maintenance from D_1 to D, D_2 to D_1, and d to D respectively.
- $q_{i\rightarrow j}(t) \rightarrow$ Probability density function (p.d.f.) for change in states, i.e. from state 'i' to state 'j' in the time interval (0, t].
- $p_{i\rightarrow j} \rightarrow q^*_{i\rightarrow j}(0)$, where * denotes the Laplace transformation.
- $R_i(t) \rightarrow$ Reliability of the system in state i.
- $\mu_i \rightarrow$ Mean sojourn time in state i, i.e. $\mu_i = \int_0^\infty R_i\,(t)dt.$
- $\mu_i^1 \rightarrow$ Time gap in starting preventive maintenance work in the regenerative state i.
- GA $\rightarrow$ Genetic algorithm.
- RPGT $\rightarrow$ Regenerative point graphical technique.
- ATSF $\rightarrow$ Average time to system failure.

I. Introduction

The majority of industrial production is contingent on the reliability of systems used for testing the final product's quality. From the industry's perspective, it is unsettling to have an unexpected system failure or work stoppage. For this reason, the reliability parameters are enhanced by employing the concept of corrective maintenance thus reducing the collapse chances of the system. In this paper, we have employed the concept of degradation based on preventive maintenance with two states of poor effectiveness. The Mathematical framework contains three units: A (with a standby), B (with a perfect preventive maintenance facility), and D (with two states of degradation). The operational effectiveness of unit D was reduced to 70% after the first deterioration, whereas it worked at a 50-55% efficiency after the second deterioration. The standby used here is not in perfect condition, i.e., it functions at a decreased level. Unit 'B' can break down in one mode of operation, i.e., complete collapse. The standby is called right away, without any hesitation. The preventive maintenance concept is implemented in two degraded states: D_1 (first degraded state) and D_2 (second degraded state). Flawless fixing and perfect switching of the standby system result in an effortless operation. In the previous investigations, the majority of research was based on corrective maintenance of the units comprising the system with an increasing malfunction rate and repair frequency. In this study, the computations are optimized to obtain the most appropriate parameters for achieving a progressively more reliable system under preventive as well as corrective measures.

Bhunia and Sahoo [I] applied two different real-coded GA to optimize the reliability in an interval environment and compared the results over different operations used in GA. Naithani et al. [VIII] examined the induced draft fans with a standby thermal plant to check their reliability over failure and repair time using semi-Markov processes. The overview of reliability analysis of different manufacturing industries, such as sugar, milk, petroleum, etc., was discussed by Kumar et al. [II]. Kumari et al. [IV] analyzed a harvester plant to find its benefits for agribusinesses using a technique called RPGT. The mist group of a coal-fired thermal impact shrub was optimized by Malik et al. [VI]. RPGT was further utilized to understand the effect of malfunctioning units on the reliability of systems by Singla and Dhawan [X]. Semi-Markov processes and regenerative point techniques were applied by Naithani et al. [VII] to understand the behaviour of a system consisting of a main unit that works with the property of substituting two sub-units on demand after a failing process, arranged in parallel mode. To optimize the cost of rubber plants, a nature-inspired algorithm for particle swarm optimization was addressed by Kumari et al. [V]. Taj and Rizwan [XI] performed the reliability analysis of a three-unit parallel system with a single maintenance facility. Kumari and Poonia [III] focused on the availability parameter regarding the reliability of a cast iron industry using the genetic algorithm tool to depict the behaviour concerning the number of generations and population size.

II. Model Description

The state transformation diagram of the system is shown in Figure 1.

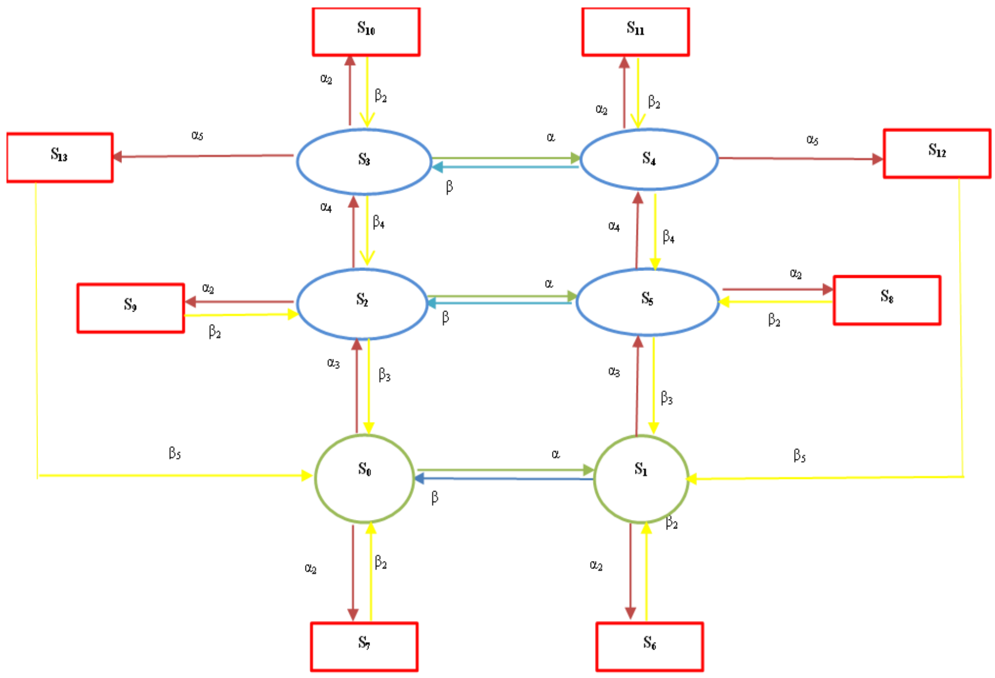

Fig. 1. State transformation diagram of the system.

The arrangement of units in various states is given as follows:

S_0 = ABD

S_1 = (A)BD

S_2 = ABD_1

S_3 = ABD_2

S_4 = $(A)BD_1$

S_5 = $(A)BD_2$

S_6 = (A)bD

S_7 = AbD

S_8 = $(A)bD_1$

S_9 = AbD_1

S_{10} = AbD_2

S_{11} = $(A)bD_2$

S_{12} = (A)Bd

S_{13} = ABd

Note that:

- Small letters denote the malfunctioning units.
- Capital letters within brackets denote the standby units.

III. Mathematic Modelling

Transformation Probabilities

The steady-state probabilities of transformation from one state to another are given in Table 1.

Table 1: Transformation probabilities.

$q_{i\to j}(t)$	$p_{i\to j} = q^*_{i\to j}(t)$
$q_{0\to 1} = \alpha e^{-kt}$	$p_{0\to 1} = \alpha/k$
$q_{0\to 2} = \alpha_3 e^{-kt}$	$p_{0\to 2} = \alpha_3/k$
$q_{0\to 7} = \alpha_2 e^{-kt}$	$p_{0\to 7} = \alpha_2/k$
$q_{1\to 0} = \beta e^{-lt}$	$p_{1\to 0} = \beta/l$
$q_{1\to 4} = \alpha_3 e^{-lt}$	$p_{1\to 4} = \alpha_3/l$
$q_{1\to 6} = \alpha_2 e^{-lt}$	$p_{1\to 6} = \alpha_2/l$
$q_{2\to 0} = \beta_3 e^{-mt}$	$p_{2\to 0} = \beta_3/m$
$q_{2\to 3} = \alpha_4 e^{-mt}$	$p_{2\to 3} = \alpha_4/m$
$q_{2\to 4} = \alpha e^{-mt}$	$p_{2\to 4} = \alpha/m$

$q_{2\to9} = \alpha_2 e^{-mt}$	$p_{2\to9} = \alpha_2/m$
$q_{3\to2} = \beta_4 e^{-nt}$	$p_{3\to2} = \beta_4/n$
$q_{3\to5} = \alpha e^{-nt}$	$p_{3\to5} = \alpha/n$
$q_{3\to10} = \alpha_2 e^{-nt}$	$p_{3\to10} = \alpha_2/n$
$q_{3\to13} = \alpha_5 e^{-nt}$	$p_{3\to13} = \alpha_5/n$
$q_{4\to1} = \beta_3 e^{-rt}$	$p_{4\to1} = \beta_3/r$
$q_{4\to2} = \beta e^{-rt}$	$p_{4\to2} = \beta/r$
$q_{4\to5} = \alpha_2 e^{-rt}$	$p_{4\to5} = \alpha_2/r$
$q_{4\to8} = \alpha_4 e^{-rt}$	$p_{4\to8} = \alpha_4/r$
$q_{5\to3} = \beta e^{-st}$	$p_{5\to3} = \beta/s$
$q_{5\to4} = \beta_4 e^{-st}$	$p_{5\to4} = \beta_4/s$
$q_{5\to11} = \alpha_2 e^{-st}$	$p_{5\to11} = \alpha_2/s$
$q_{5\to12} = \alpha_5 e^{-st}$	$p_{5\to12} = \alpha_5/s$
$q_{i\to1} = \beta_2 e^{-\beta_2 t}$	$p_{i\to1} = 1$
$q_{12\to1} = \beta_5 e^{-\beta_5 t}$	$p_{12\to1} = 1$
$q_{13\to0} = \beta_5 e^{-\beta_5 t}$	$p_{13\to0} = 1$

where,

$k = \alpha + \alpha_2 + \alpha_3, \quad l = \beta + \alpha_2 + \alpha_3, \quad m = \alpha + \beta_3 + \alpha_2 + \alpha_4,$

$n = \beta_4 + \alpha + \alpha_2 + \alpha_5, \quad r = \beta_3 + \beta + \alpha_2 + \alpha_4, \quad s = \beta + \beta_4 + \alpha_2 + \alpha_5.$

Mean Sojourn Times

The mean sojourn times in various states are given in Table 2.

Table 2: Mean sojourn times.

$R_i(t)$	μ_i
$R_0(t) = e^{-kt}$	$\mu_0 = 1/k$
$R_1(t) = e^{-lt}$	$\mu_1 = 1/l$
$R_2(t) = e^{-mt}$	$\mu_2 = 1/m$
$R_3(t) = e^{-nt}$	$\mu_3 = 1/n$
$R_4(t) = e^{-rt}$	$\mu_4 = 1/r$
$R_5(t) = e^{-st}$	$\mu_5 = 1/s$
$R_i(t) = e^{-\beta_2 t}$, i=6 to11	$\mu_6 = 1/\beta_2$
$R_{12}(t) = e^{-\beta_5 t}$	$\mu_{12} = 1/\beta_5$
$R_{13}(t) = e^{-\beta_5 t}$	$\mu_{13} = 1/\beta_5$

Path Probabilities

Using Tables 1 and 2, the transition probabilities from state S_0 to other states can be written as follows.

$V_{0\to0} = 1$ (verified)

$V_{0\to1} = p_{0\to1} = [\alpha/k]$

$V_{0\to2} = p_{1\to2} = [\alpha_3/k]$

$V_{0\to3} = [2\alpha_2\alpha_4^2(1+\alpha_3)(\beta\,\beta_5)]/[lkn^2]$

$V_{0\to4} = [\alpha_4^2\alpha_4(3+2\alpha_2)(1+\beta_4)]/[(k+\alpha^2+2\beta_3)(5+4\alpha_2+3\beta^2)]$

$V_{0\to5} = [(\alpha_2\alpha_5\,\beta\,\beta_4)(2\beta+3\alpha^2)]/[(3\alpha_4+\alpha_2+\beta)(\beta_4+\alpha_2+4\alpha_3+k)^2(\alpha_2+\alpha_3)]$

$V_{0\to6} = [(\alpha\alpha_2)/kl]/[(\alpha_3+\beta)/l]$

$V_{0\to7} = p_{1\to7} = [\alpha_2/k]$

$V_{0\to8} = (0,1,4,8)/[(1-L_3)(1-L_4)] = (p_{0\to1}p_{1\to4}p_{4\to8})/[(1-p_{1\to6}p_{6\to1})(1-p_{1\to4}p_{4\to1})]$

$= [(2\alpha+3\beta_4+\alpha^2+2\beta)/(1+\alpha_2+\beta)^2(4\alpha_2+3\alpha_5)^3]$

$V_{0\to9} = (0,2,9)/[(1-L_4)(1-L_2)] = (p_{0\to2}p_{2\to9})/[(1-p_{0\to7}p_{7\to0})(1-p_{2\to4}p_{4\to2})]$

$= [(\alpha_3\alpha_2)/km]/[(\alpha+\alpha_3)k\{(r/3\alpha_3\}]$

$V_{0\to10} = (2\alpha_2+\alpha_2+\alpha_4\alpha_2^2)/(\beta+2\alpha_4+\alpha_3+4\beta_4)^2(3\alpha+\beta_4)]$

$V_{0\to11} = (s+\beta)/(\beta_4+\alpha_2+3\alpha+\alpha_5)^2$

$V_{0\to12} = (0,1,4,5,12)/[(1-L_3)(1-L_5)]+(0,2,3,5,12)/[(1-L_1)]$

$= (2\alpha^2+\beta_4+3\alpha+\alpha_5)/(3\alpha+\beta_4)(3\beta_2+3\alpha_5+4\alpha)^2$

$V_{0\to13} = (0,2,3,13,)/[(1-L_1)(1-L_5)(1-L_3)]$

$= (p_{0\to2}\,p_{2\to3}\,p_{3\to13})/[(1-p_{0\to7}\,p_{7\to0})(1-p_{2\to4}\,p_{4\to2})(1-p_{2\to9}\,p_{9\to2})]$

$= (2\alpha+\beta_4+\beta_2+5\alpha_3)/(\alpha^2+\beta_4+9\beta_2+\beta\alpha_5)$

IV. Modeling System Parameters

For evaluating the reliability parameters, the process of RPGT is implemented with exponentially distributed malfunction and preventive maintenance times under the consideration that the standby unit is available for operation without any elapsed time.

Average Time to System Failure

Taking the base state as i = 0, the average time of working of the system in the good state (i = 1, 2, 3, 4, 5) is given as follows.

$$ATSF\ (T_0) = \left[\sum_{i,sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr(sff)}i\right)\right\}\mu i}{\Pi_{m_{1\neq\xi}}\left\{1\text{-}V_{\overline{m_1m_1}}\right\}}\right\}\right] \div \left[1\text{-}\sum_{sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr(sff)}\xi\right)\right\}}{\Pi_{m_{2\neq\xi}}\left\{1\text{-}V_{\overline{m_2m_2}}\right\}}\right\}\right]$$

$$= [(0,0)\mu_0]+[\{(0,0)\mu_1\}/(1\text{-}L_3)]+[\{(0,2)\mu_2\}/(1\text{-}L_1)]/[\{1\text{-}(0,1,0)\}/(1\text{-}L_3)(1\text{-}L_4)]$$

$$= [\mu_0+\{(p_0\rightarrow_1\mu_1)/(1\text{-}L_3)\}+\{(p_0\rightarrow_2\mu_2)/(1\text{-}L_1)\}]/[1\text{-}\{(p_0\rightarrow_1 p_1\rightarrow_0)/(1\text{-}L_3)(1\text{-}L_4)\}]$$

$$= [\beta(\alpha_2+\alpha_3+\alpha)^2]+[(2\alpha_2+\beta_3+\alpha_4)/(3\alpha^2+3\beta+\beta\alpha_4+\alpha_2^3)]$$

Availability of the System

The system is available in the states 0, 1, 2, 3, 4, and 5, in which it performs its intended function under the fuzzy logic, so we get the following.

$$A_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\rightarrow}j)\}fj,\mu j}{\Pi_{m_{1\neq\xi}}\left\{1\text{-}V_{\overline{m_1m_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\rightarrow}i)\}\mu_i^1}{\Pi_{m_{2\neq\xi}}\left\{1\text{-}V_{\overline{m_2m_2}}\right\}}\right\}\right]$$

$$= \left[\sum_j V_{\xi\rightarrow j}, f_j, \mu_j\right] \div \left[\sum_i V_{\xi\rightarrow i}, f_j, \mu_i^1\right]$$

$$= (\sum V_{0\rightarrow i} f_i \mu_i) \div (\sum V_{0\rightarrow j} f_j \mu_j),\ \text{where } 1\leq i \leq 5,\ f_i = 1 \text{ and } 1\leq j \leq 13,\ f_j = 0, \text{ for } i \neq j.$$

$$=1/k+[\alpha/k(\beta_3+\alpha_2+\alpha+\alpha_4)]+[2\alpha_2\alpha_4^2(1+\alpha_3)(\beta\beta_5)]/[(\alpha_2+\alpha_3+\beta)(\alpha_2+\alpha_3+\alpha)(\alpha+\alpha_2+\alpha_5+\beta_4)^2][1/n]$$

$$+[\{\alpha_4^2\alpha_4(3+2\alpha_2)(1+\beta_4)(r+\alpha^2+\beta_3)(5+4\alpha_2+3\beta^2)\}/r]+[\{(\alpha_2\alpha_5\beta\beta_4)(2\beta+3\alpha^2)\}/$$

$$\{(3\alpha_4+\alpha_2+\beta)(\beta_4+2\alpha_2+5\alpha_3+\alpha)^2(\alpha_2+\alpha_3)\}]/s$$

$$= (3\alpha_2+5\beta+\alpha_2^2\beta_4+4\alpha)/[3\alpha_4+(\beta+\beta 4)^2+3\alpha_2^2\beta+4\alpha\beta_2)]$$

V. Methodology

In computer science and operations research, a genetic algorithm (GA) is a metaheuristic inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms. Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on biologically inspired operators such as mutation, crossover, and selection.

In this research, GA is used to optimize the ATSF and availability of the two-unit system. GA is a computational tool used to arrive at an optimal solution for constrained and unconstrained problems. This algorithm follows the natural process of biological evolution. GA is experimented with the concept of population which corresponds to a subset of solutions in the current generation. After the selection of the initial population, several iterations are carried out which are referred to as the generations. In generations, various genetic processes such as selection, crossover, and mutation take place. These processes are identical to natural selection, reproduction, and genetic variation as observed in biological evolution to find offspring. Figure 2 shows a general flowchart that illustrates how genetics can be applied to biological evolution.

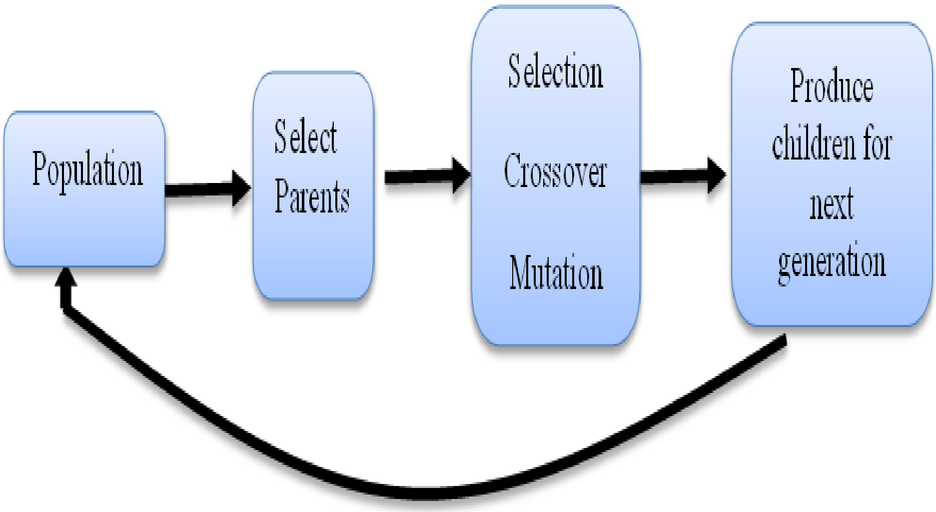

Fig. 2. Application of genetics to biological evolution - flowchart.

In this study, the decision variables are confined by initial and final bounds. Various bounds for the decision variables are given in Table 3. Following the choice of the population, the objective function (expressions for ATSF and availability) is optimized to achieve its maximum for various parameter values by altering the number of generations.

Table 3: Bounds for decision variables.

$0.01 \le \alpha \le 1$	$0.02 \le \beta \le 0.99$
$0.02 \le \alpha_2 \le 0.8$	$0.03 \le \beta_2 \le 0.98$
$0.025 \le \alpha_3 \le 0.97$	$0.05 \le \beta_3 \le 0.96$
$0.03 \le \alpha_4 \le 0.9$	$0.04 \le \beta_4 \le 0.97$

To help comprehend the reasoning behind the outcome, the methodology's flow chart is shown in Figure 3.

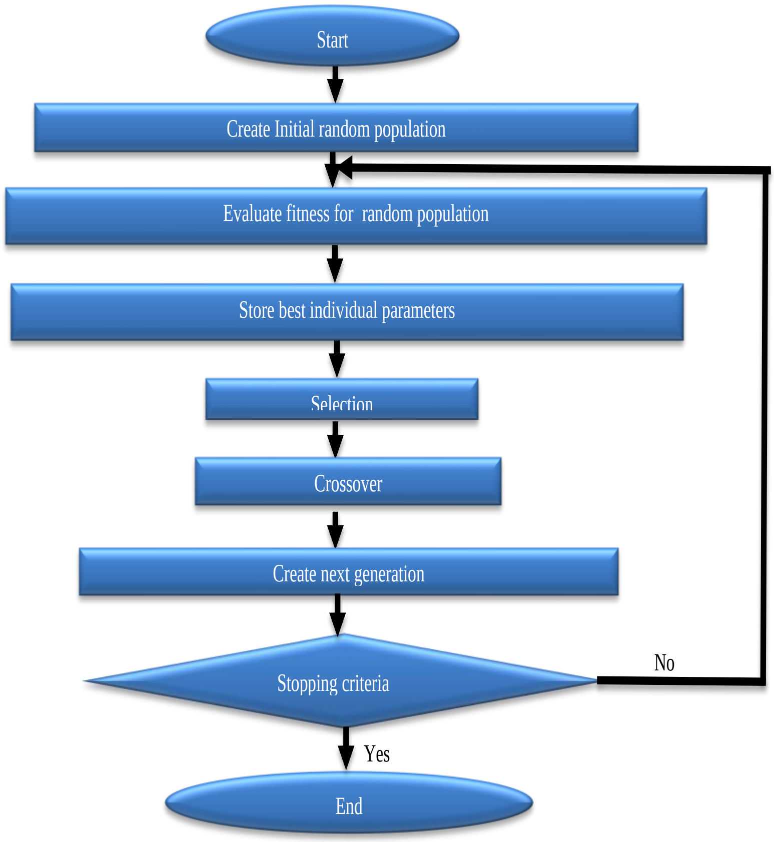

Fig. 3. Flowchart of the methodology used.

Table 4 shows the effect of the number of generations on the ATSF of the system.

Table 4: Effect of number of generations on ATSF.

Sr. No.	No. of generations	ATSF	α	α_2	α_3	α_4	β	β_3
1	10	0.805356	0.463	0.273	0.396	0.067	0.254	0.078
2	20	0.978292	0.521	0.043	0.3	0.496	0.833	0.742
3	30	1.038777	0.609	0.08	0.653	0.492	0.33	0.356
4	40	1.085978	0.656	0.342	0.256	0.516	0.213	0.363
5	50	1.265516	0.047	0.205	0.688	0.683	0.463	0.381
6	60	1.273820	0.664	0.297	0.279	0.478	0.492	0.509
7	70	1.110024	0.366	0.301	0.345	0.341	0.58	0.276
8	80	1.157690	0.473	0.391	0.085	0.42	0.658	0.48 6
9	90	1.146288	0.29	0.22	0.375	0.098	0.71	0.916
10	100	1.038439	0.38	0.316	0.329	0.084	0.403	0.334

11	120	1.027753	0.948	0.384	0.771	0.336	0.078	0.954
12	**140**	**1.275321**	**0.279**	**0.182**	**0.557**	**0.412**	**0.433**	**0.643**
13	160	1.165921	0.984	0.061	0.711	0.895	0.237	0.651
14	180	0.968699	0.289	0.352	0.085	0.097	0.856	0.726
15	200	1.115047	0.613	0.326	0.203	0.533	0.304	0.423

Table 5 shows the effect of the number of generations on the availability of the system.

Table 5: Effect of number of generations on availability.

Sr. No.	No. of generations	Availability	α	α_2	α_4	β	β_2	β_4
1	10	0.730714	0.572	0.166	0.509	0.099	0.886	0.882
2	20	0.709653	0.092	0.238	0.846	0.199	0.698	0.131
3	**30**	**0.971924**	**0.019**	**0.684**	**0.761**	**0.126**	**0.976**	**0.605**
4	40	0.870411	0.223	0.291	0.692	0.21	0.228	0.779
5	50	0.806286	0.010	0.020	0.488	0.641	0.980	0.970
6	60	0.832041	0.620	0.041	0.823	0.553	0.735	0.917
7	70	0.931294	0.932	0.024	0.264	0.04	0.921	0.228
8	80	0.861439	0.579	0.498	0.882	0.244	0.795	0.959
9	90	0.889587	0.268	0.185	0.754	0.566	0.503	0.912
10	100	0.882030	0.272	0.191	0.771	0.57	0.512	0.92
11	120	0.957653	0.827	0.547	0.888	0.981	0.98	0.97
12	140	0.933115	0.144	0.573	0.9	0.148	0.573	0.261
13	160	0.837675	0.352	0.352	0.766	0.323	0.898	0.831
14	180	0.751431	0.357	0.39	0.864	0.163	0.98	0.613
15	200	0.706654	0.507	0.044	0.826	0.565	0.975	0.969

Graphs portraying the variation in ATSF of the system and availability of the system concerning the number of generations are shown in Figures 4 and 5 respectively.

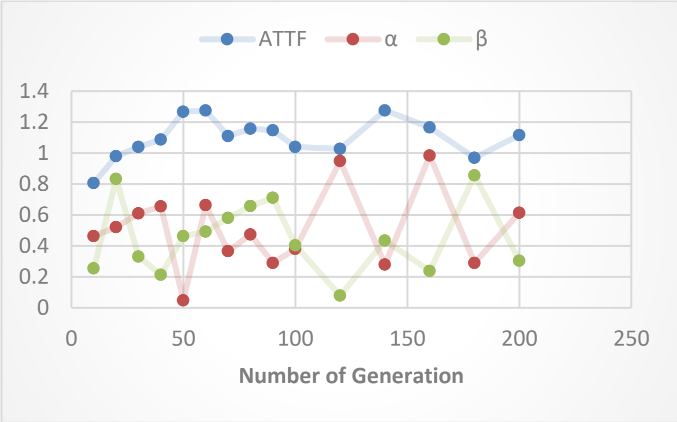

Fig. 4. Variation in ATSF w.r.t. no. of generations.

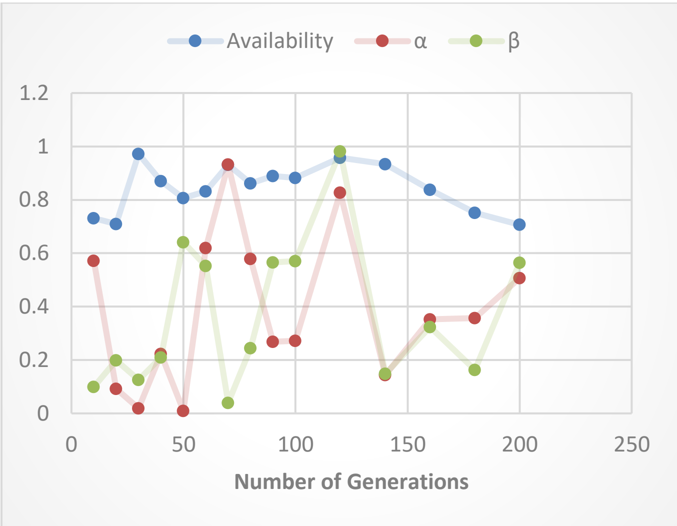

Fig. 5. Variation in availability w.r.t. no. of generations.

VI. Sensitivity Analysis

Sensitivity analysis is a novel approach for examining the level of impact a parameter has on a derived measure (Sachdeva et al. [IX]). As the parameters may have a wide range of numerical values, relative sensitivity analysis is also performed to compare the effects of various parameters. A relative sensitivity function is a standardized version of a sensitivity function. The sensitivity function Δ_x and the relative sensitivity function $\boldsymbol{y}_x$ are defined as follows, respectively:

$$\Delta_x = \frac{\partial(M)}{\partial x}$$

and

$$y_x = \frac{\Delta_x * x}{M}$$

where

M and x are the derived measure and parameter respectively.

Sensitivity analysis for the ATSF of the system for different parameters is shown in Table 6.

Table 6: Sensitivity analysis for ATSF.

Parameter (x)	Sensitivity $\Delta_x = \frac{\partial(T_0)}{\partial x}$	Relative Sensitivity $y_x = \frac{\Delta_x * x}{T_0}$
α	0.0758	0.01658
α_2	1.9986	0.28525
α_3	0.8816	0.38508
α_4	0.3740	0.12083
β	-0.6061	-0.20580
β_3	0.5824	0.29367

Sensitivity analysis for the availability of the system for different parameters is shown in Table 7.

Table 7: Sensitivity analysis for availability.

Parameter (x)	Sensitivity $\Delta_x = \frac{\partial(A_0)}{\partial x}$	Relative Sensitivity $y_x = \frac{\Delta_x * x}{A_0}$
α	0.04262	0.00082
α_2	1.08042	0.74564
α_4	-0.96900	-0.74403
β	0.70394	0.08937
β_2	-0.02455	-0.02418
β_4	-0.31975	-0.19519

VII. Results and Discussion

- From Table 4 it can be observed that the ATSF of the system is maximum when the number of generations is 140.
- From Table 5 it can be observed that the availability of the system is maximum when the number of generations is 30.
- From Table 6 it has been confirmed that the ATSF of the system is substantially influenced by α_3.

- From Table 7 it has been confirmed that the availability of the system is substantially influenced by α_2.
- Sensitivity analysis shows that the order in which various parameters impact the ATSF and availability of the system is as follows:

  ATSF: $\alpha_3 > \beta_3 > \alpha_2 > \beta > \alpha_4 > \alpha$

  Availability: $\alpha_2 > \alpha_4 > \beta_4 > \beta > \beta_2 > \alpha$

VIII. Conclusion

Using a genetic algorithm, the reliability optimization of a degraded system under preventive maintenance has been discussed in this paper.

Relationships between the number of generations and reliability characteristics have been depicted. The effects of various genetic algorithm boundaries such as populations, generations, and crossover functions, have been presented. It has been observed that the ATSF and availability of the system maximize when the number of generations is 140 and 30 respectively, for optimized values of various rates. Thus, the industry may adopt these values to achieve higher levels of ATSF and availability.

Sensitivity and relative sensitivity analysis have been conducted to measure the level of impact of various parameters on the reliability characteristics. It has been observed that the ATSF and availability of the system are most affected by the malfunction times from D to D1, and B to b respectively. Thus, the industry may review its maintenance policies to reduce these rates to increase the ATSF and availability.

Conflict of Interest:

The author declares that there was no conflict of interest regarding this paper.

References

I. Bhunia, A.K. and Sahoo, L. (2011). Genetic algorithm based reliability optimization in interval environment. In: Nedjah, N., dos Santos Coelho, L., Mariani, V.C., de Macedo Mourelle, L. (eds) Innovative Computing Methods and Their Applications to Engineering Problems. Studies in Computational Intelligence, 357. Springer, Berlin, Heidelberg.

II. Kumar, J., Bansal, S.A., Mehta, M. and Singh, H. (2020). Reliability analysis in process industries - an overview. GIS Sci J., 7(5), 151-168.

III. Kumari, K. and Poonia, M.S. (2023). Availability optimization of cylinder block in cast iron manufacturing plant using GA. European Chemical Bulletin, 12(4), 17784-17792.

IV. Kumari, S., Khurana, P. and Singla, S. (2022). Behaviour and profit analysis of a thresher plant under steady state. International Journal of System Assurance Engineering and Management, 13, 166-171.

V. Kumari, S., Singla, S. and Khurana, P. (2022). Particle swarm optimization for constrained cost reliability of rubber plant. Life Cycle Reliability and Safety Engineering, 11(3), 273-277.

VI. Malik, S., Verma, S., Gupta, A., Sharma, G. and Singla, S. (2022). Performability evaluation, validation and optimization for the steam generation system of a coal-fired thermal power plant. MethodsX, 9.

VII. Naithani, A., Khanduri, S. and Gupta, S. (2022). Stochastic analysis of main unit with two non-identical replaceable sub-units working with partial failure. International Journal of System Assurance Engineering and Management, 13, 1467-1473.

VIII. Naithani, A., Parashar, B., Bhatia, P.K. and Taneja G. (2013). Cost benefit analysis of a 2-out-of-3 induced draft fans system with priority for operation to cold standby over working at reduced capacity. Advanced Modelling and Optimization, 15(2), 499-509.

IX. Sachdeva, K., Taneja, G, and Manocha, A. (2022). Sensitivity and economic analysis of an insured system with extended conditional warranty. Reliability: Theory and Applications, 17, 24–31.

X. Singla, S. and Dhawan, P. (2022). Mathematical analysis of regenerative point graphical technique (RPGT). Mathematical Analysis and its Contemporary Applications, 4(4), 49-56.

XI. Taj, S. Z. and Rizwan, S. M. (2022). Reliability analysis of a 3-unit parallel system with single maintenance facility. Advanced Mathematical Models & Applications, 7(1), 93-103.