Particle Swarm Optimization of a Wheel Manufacturing Plant for Solving Reliability Problem

Randhir Singh[1], Dr. Mahender Singh Poonia[2]

[1]Research Scholar, Department of Mathematics, OM Sterling Global University, Hisar, Haryana, India

[2]Professor, Department of Mathematics, OM Sterling Global University, Hisar, Haryana, India

Email: [1]sihag789@gmail.com,[2]drmahender@osgu.ac.in

Article Info
Page Number: 8078 - 8089
Publication Issue:
Vol 71 No. 4 (2022)

Article History
***Article Received**: 25 March 2022*
***Revised**: 30 April 2022*
***Accepted**: 15 June 2022*
***Publication**: 19 August 2022*

Abstract

One of the most popular methods for solving real-world optimization issues is the employment of nature-inspired algorithms. As a result, it has grown to be one of the most widely used and effective methods of optimization. This paper discusses the application of particle swarm optimization of a Wheel Manufacturing plant for solving reliability problem. The analysis of PSO on limited problems was put to the test through four different experimental designs. The following sections include a description of each experiment, as well as the objective function and restrictions that were used in each experiment. The proposed solution for each of these situations demonstrates the vast range of applications for PSO.

Keywords: nature inspired optimization, Particle swarm Optimization, Reliability

---

1. Introduction

Local optimization and global optimization are two terms used to describe different aspects of the optimization problem. By focusing on a small area of the role value space, local optimization aims to discover the highest or lowest possible value.

The goal of global optimization is to discover the best or worse value across the entire function value space. Deprived of loss of simplification, a single-objective optimization problem is expressed as shadows:

$$minx\epsilon sf(x), x = Li \leq xi \leq Ui$$

$$s.t. g_i(x) \leq 0, j = 1,2, \dots, J$$

$$h_k(x) = 0, k = 1,2 \dots., K$$

Anywhere f(x) is objective function

x is D-dimensional assessment vector

$\mathcal{J}$ shows the integer of inequity constraints

$\mathcal{K}$specifies the integer of equality restrictions, $L_{i;}$ U_i are the lower and upper bound of the ith variables, respectively.

Algorithms are employed to find a solution to the problem at hand using optimization approaches An optimal design variable value is determined using this method, which takes into account all equality, inequality, and side restrictions. There may be many optimum conditions (also known as local or relative optimum conditions) for various issues.

2. Particle Swarm Optimization (PSO)

PSO is an optimization method created on particle swarm behaviour. PSO was first planned by Kennedy and Eberhart in 1995. Fish and birds use their social and individual skills to acquire food. This phenomenon led to the development of the PSO stochastic optimization algorithm. The human tendency to seek for the optimal answer among the available possibilities can be mathematically expressed using the following two update equations:

2.1 Velocity updates equation: Swarm of particles move in multidimensional search space to find the optima. Each particle in swarm is affected by its neighbor and individual understanding. The velocity by which the particle moves from one place to another is given in the following equation:

vt+1x=vtx+C1*randPbest-xt+C2*randGbest-xt

Where vt+1x = velocity of x^{th} particle at t^{th} iteration.

C_1=the individual factor

C_2=social factor

Pbest=the individual best particle

Gbest=global best particle

Rand is the uniform random integer between 0 and 1

2.2 Particle update equation:

The particle's velocity indicates the direction in which the particle is travelling in quest of the optimal. PSO's particle update equation is as shadows:

$$x_{t+1} = x_t + v_{t+1}$$

Until a predetermined termination requirement is met, these two equations will keep updating the solution. As a population-based process, PSO considerssupplementary than unique possible solution. For each solution, the search space's global and local bests are used to guide it. Thus, it provides a robust algorithm that finds the right balance between exploration and exploitation. The following are some of the most important characteristics of PSO:

1. To begin with, PSO is a fairly easy algorithm to grasp and hence more suitable for use in real-world situations.
2. It uses swarm intelligence as its foundation. Such an approach can be applied to both science and engineering.
3. In contrast to GA, it does not overlap and does not do mutation calculations like this.

Pseudo Code of PSO Algorithm

Initialize the swarm of particles
For each particle
For each dimension
Update the velocity of every particle
Update the particle position by updated velocity
Repeat until the dissolution criteria is met
End

The paper is systematized as shadows: Section 1gives the outline of the optimization and its different techniques. Section 2 gives different nature inspired algorithms. Mathematics of different algorithms i.e. Genetic Algorithm, PSO techniques is given in this section. Section 3 designates the mathematics of the reliability problems using these techniques. Section 4 gives the numerical analysis of the solution. Finally, gives the conclusion and some future ideas are suggested.

3. Reliability Problem

The most pressing global issue is the impact of pollution and climate change. This article discusses the wheel manufacturing industry, which satisfies many of our wants and requirements on a daily basis. The subsystems of the wheel manufacturing facility include the gravity die casting machine, gate cutting machine, heat treatment machine, and turning machine. Eriesons (2014)analysed the mean value demonstrating of an EGR – structure. Kiureghianet al. (2007) examine the accessibility, consistency& down time of organizationthrough repairable gadget. Reifarth (2014)studied the effectiveness and mixing investigation of EGR-capacity. Abbasouret al. (2016)conferred the dependabilitymodelling and accessibility analysis of joint cycle power plants. Jieong et al. (2009) utilized a half and half calculation identified as GA/PSO for tackling multi-objective streamlining issues. Komal et al. (2009) discussed the dependability, accessibility, and maintainability analysis springscertain plan to carryout structure modification, assuming any required to accomplish superior of the complex mechanical systems. Kumari et al. (2021) talked about the benefit examination of an agribusiness harvester plant in consistent state utilizing RPGT. Kumar et al. (2017) the primary goal of this paper is to an inspected examination of a urea fertilizer plant using RPGT. Using a heuristic approach, Rajbala et al. (2022) investigated the redundancy allocation problem in the cylinder manufacturing plant.Kumari et al. (2022) studied on the PSO for constrained cost reliability of rubber Plant.Singla et al. (2022) studied on the mathematical model for finding the availability under the reduced capacity has been proposed using the Chapman Kolmogorov approach with the help of transition diagrams associated with various possible combinations of probabilities.Sinla et al. (2022) studied on the Mathematical analysis of regenerative point graphical technique. Malik et al. (2022) present paper talks over perform ability evaluation for a steam generation system of a Coal Fired Thermal Power Plant (CFTPP) using the concept of the Markov method.

3.1 The System

This article discusses the wheel manufacturing industry, which satisfies many of our wants and requirements on a daily basis. The subsystems of the wheel manufacturing facility include the gravity die casting machine, gate cutting machine, heat treatment machine, and turning machine. Each subsystem in this plant serves a specific purpose in the overall system's operation because each is essential to the plant's success. The subsystems are all linked together in sequence. The heat treatment machine, a subsystem of the wheel production facility, is detailed in this paper. The operation or failure of any one of the system's components has some effect on how the system functions.

3.2 Systems Description:

i. Sand Core Making Machine (SCMM): SCMM which is then utilized to create hollow bar from the interior. SCMM is made up of two parts. The first is active, and the second is in standby mode. When both units fail, the system fails.

ii. Gravity Die Casting Machine (GDC): In the GDC machine, a sand core is first installed, and then molten aluminium is manually poured into the die using a pouring spoon. Castings are removed from the machine for further processing. GDCM is a single entity, and the entire process fails if GDCM fails.

iii. Vibrator Machine (VM): VM is used to separate the sand core from the hollow. VM is made up of a single unit. When VM crashes, the arrangement fails.

iv. Cutting Machine (CM): CM is used to dress all undesirable casting parts such as the runner (the area where the material is fed into the cavity) and the separation line. CM only has one entity. When CM fails to act successfully, the system fails.

v. Horizontal Machine (HM): HM is utilizedaimed atDrilling, Milling, and Threading. HMinvolves of unique unit. The completeprocedure fails after HM not be positive.

3.3 Indicative and Notations

a) The presence of restored entity is high quality.

b) Switch - over devices are perfect.

α_i: Specify the corresponding mean failure rates of SCMM, GDCM, VM, CM,and HM, i=1,2,3,4,5,6.

B_i: Specifies the individual repair rates of SCMM, GDCM, VM, CM, and HM.

$p_i{}'(t)$: Denote the differential of probability function $p_1(t)$.

$p_i(t)$: Probability of the plant is in i^{th}states at time t.

3.4 Mathematical Modelling

$$p_1'(t) + (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6)p_1(t) = \beta_1 p_2(t) + \beta_3 p_6(t) + \beta_4 p_7(t) + \beta_5 p_8(t) + \beta_6 p_9(t)$$

$$p_2'(t) + (\alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \beta_1)p_2(t) = \beta_2 p_3(t) + \beta_3 p_4(t) + \beta_4 p_5(t) + \beta_5 p_{10}(t) + \beta_6 p_{11}(t) + \alpha_1 p_1(t)$$

3.5 Steady state availability analysis

The wheelplant is executedaimed at a long run purpose. Consequently the steady state probability of organization can be producedthrough using variables aimed at$\frac{d}{dt} \to 0$ and $p_1(t) \to p_1$as $t \to \infty$ in the upstairs equation. These values must been reserved in terms of p_1 as shadow:

$$p_2 = T_0 p_1 p_3 = T_1 p_1 p_4 = T_2 T_0 p_1$$
$$p_5 = T_3 T_0 p_1 p_6 = T_2 p_1 p_7 = T_3 p_1$$
$$p_8 = T_4 p_1 p_9 = T_5 p_1 p_{10} = T_4 T_0 p_{11} = T_5 T_0 p_1$$

Where $T_0 = \frac{\alpha_1}{\beta_1}$,$T_1 = \frac{\alpha_2}{\beta_2}$,$T_2 = \frac{\alpha_3}{\beta_3}$

$$T_3 = \frac{\alpha_4}{\beta_4}, T_0 = \frac{\alpha_5}{\beta_5}, T_0 = \frac{\alpha_6}{\beta_6}$$

The probability p_i is deteremined by using the normalizing condition

$$\sum_{l=1}^{11} p_l = 1 = p_1 + p_2 + p_3 + p_4 + p_5 + p_6 + p_7 + p_8 + p_9 + p_{10} + p_{11}$$
$$= p_1 + T_0 p_1 + T_1 T_0 p_1 + T_2 T_0 p_1 + T_3 T_0 p_1 + T_2 p_1 + T_3 p_1 + T_4 p_1 + T_5 p_1 + T_4 T_0 p_1 + T_5 T_0 p_1$$
$$= p_1(1 + T_0 + T_1 T_0 + T_2 T_0 + T_3 T_0 + T_2 + T_3 + T_4 + T_5 + T_4 T_0 + T_5 T_0)$$
$$p_1 * U = 1$$
$$p_1 = \frac{1}{U}$$

Currently the steady state accessibility of the wheel plant is particular by

$$A_v = p_1 + p_2$$

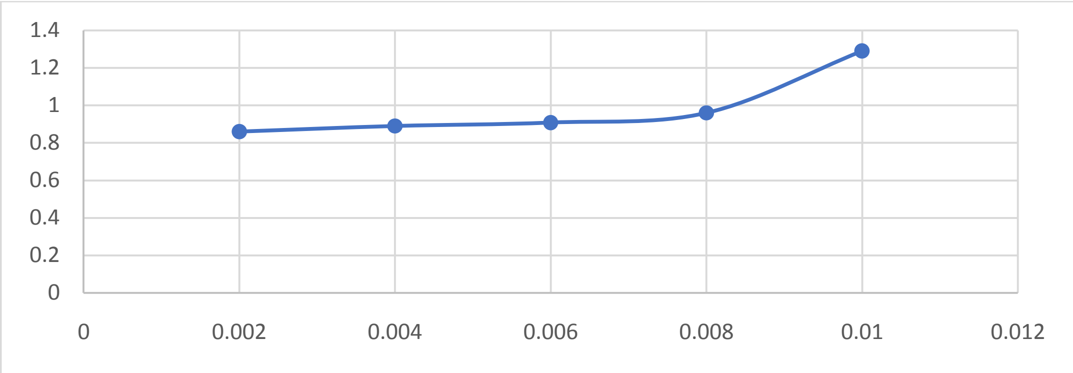
4. Numerical Results

Table 1, 2, 3 and Figure 1, 2 3, and 4 represents the availability aimed atnumeroussystems of the wheel plant. Various values of availability for dissimilarmixture of repair/disappointment rates are intended. The greatestfavourableconsequence of disappointment/repair rates might be appreciated as per completelysystem of the wheel plant.

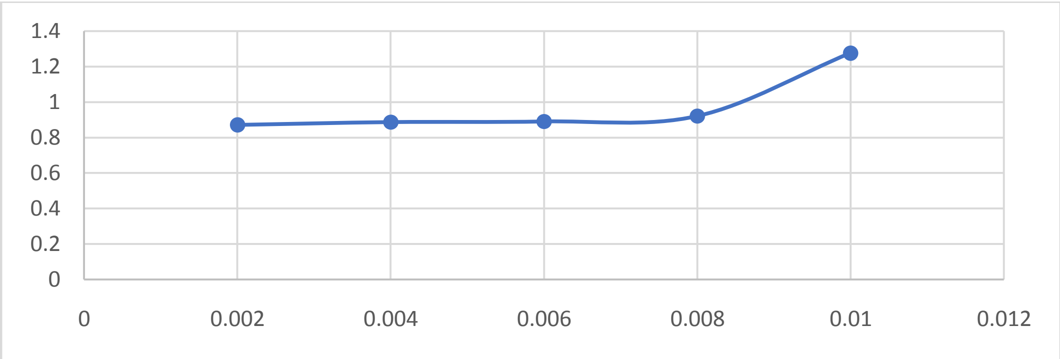
Table 1: Value of Availability aimed atvarious values of Failure/Repair Rates of SCMM

B_1 α_1	**0.02**	**0.04**	**0.06**	**0.08**	**0.10**
0.002	0.8709	0.8603	0.8587	0.8456	0.8345

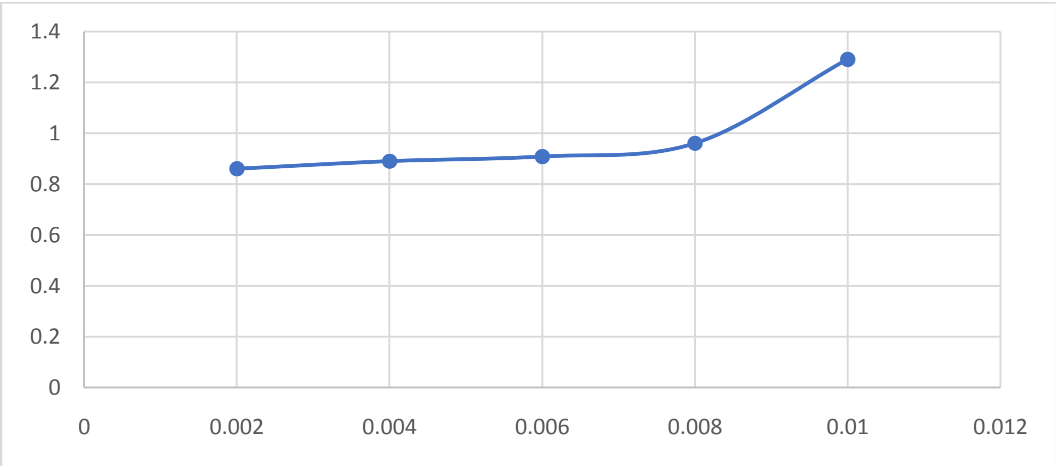
0.004	0.8867	0.8902	0.8935	0.8993	0.9081
0.006	0.8902	0.9085	0.9632	0.9829	0.9948
0.008	0.9208	0.9604	0.9741	0.9892	0.9987
0.010	1.2760	1.2909	1.3872	1.4902	1.5722



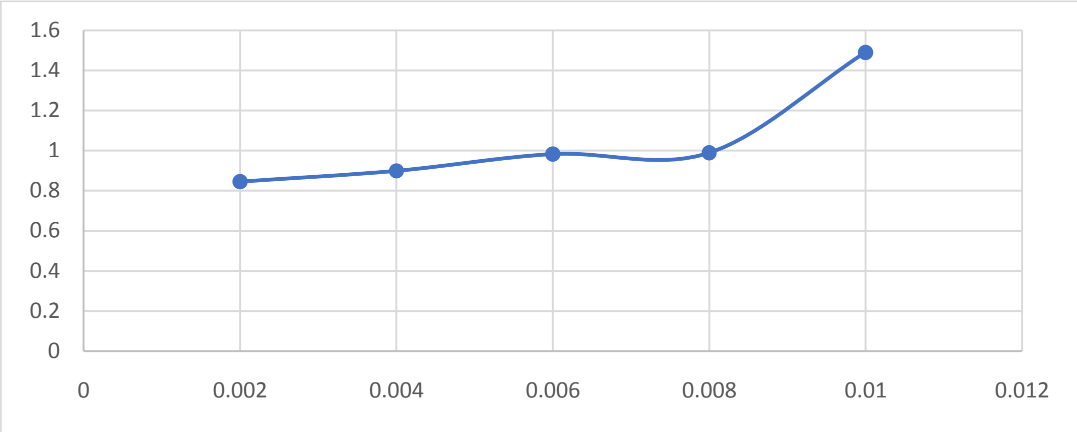
The Different Availability at Different Time for alpha=0.02



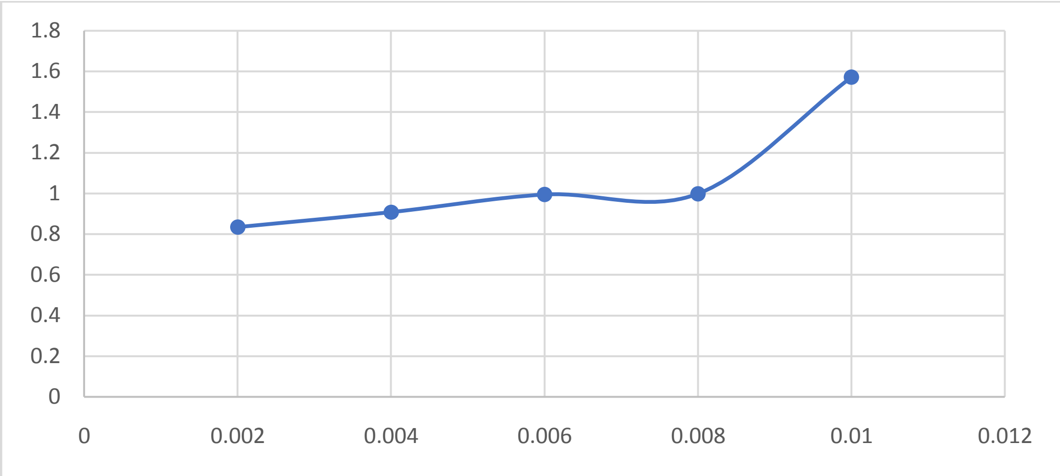
The Different Availability at Different Time for alpha=0.04



The Different Availability at Different Time for alpha=0.06



The Different Availability at Different Time for alpha=0.08

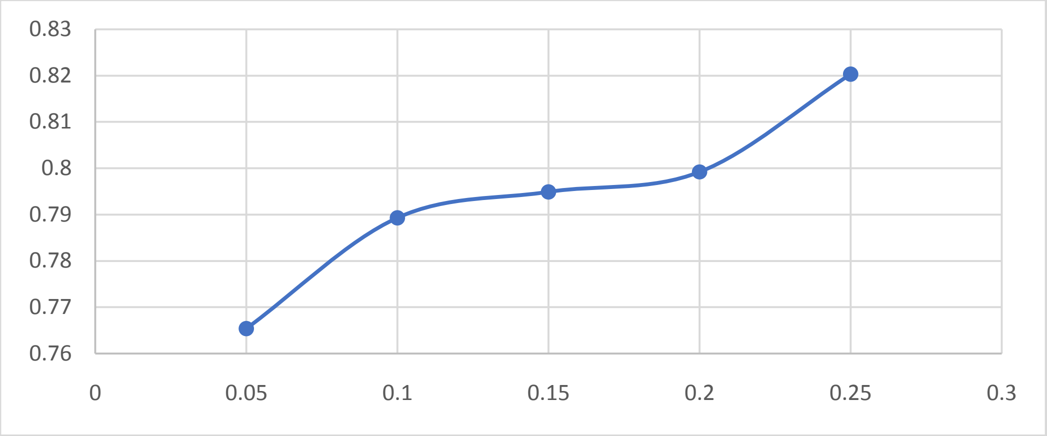


The Different Availability at Different Time for alpha=0.10

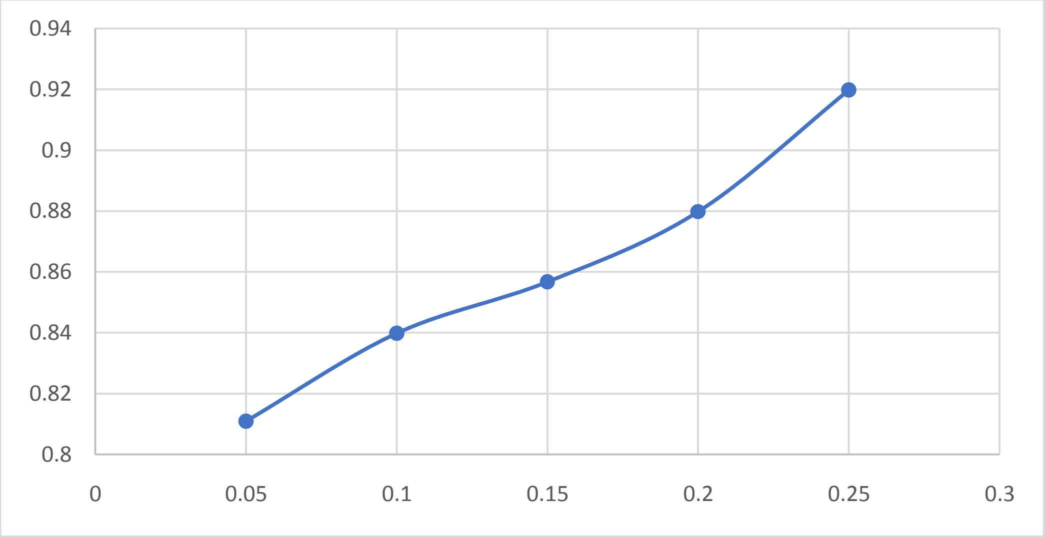
Figure 1: Value of Availability aimed atvarious values of Failure/Repair Rates of SCMM

Table 2: Value of Availability aimed atvarious values of Failure/Repair Rates of GDCM

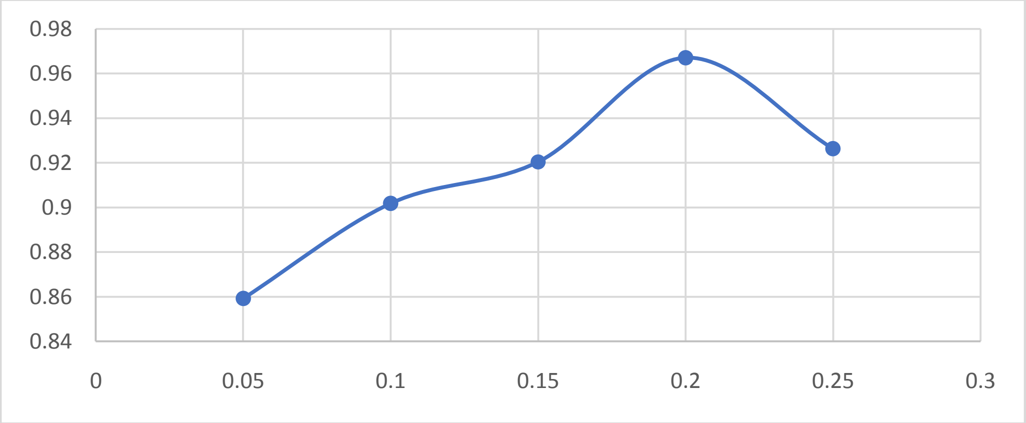
β_3 α_3	**0.05**	**1**	**0.15**	**0.2**	**0.25**
0.05	0.7654	0.7893	0.7949	0.7992	0.8203
0.01	0.8109	0.8398	0.8567	0.8798	0.9198
0.015	0.8592	0.9018	0.9204	0.9671	0.9263
0.02	0.8829	0.8946	0.9283	0.9937	0.9983
0.025	0.8921	0.9016	0.9187	0.9289	0.9387



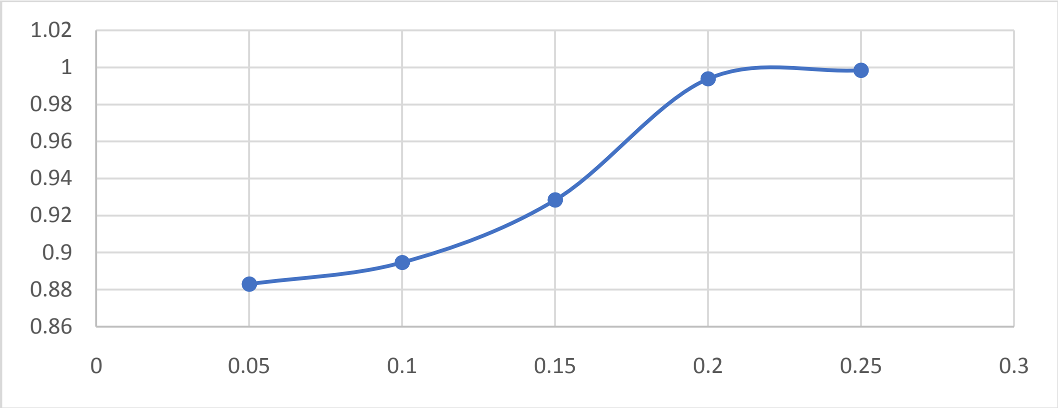
Availability aimed atvarious values of Failure/Repair Rates of GDCMfor $\alpha_3 = 0.05$



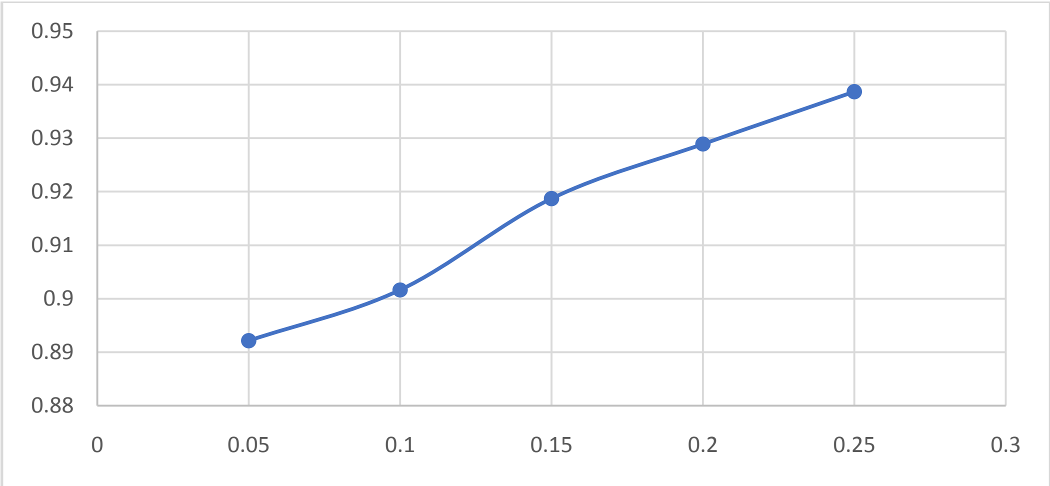
Availability aimed atvarious values of Failure/Repair Rates of GDCMfor $\alpha_3 = 0.1$



Availability aimed atvarious values of Failure/Repair Rates of GDCM For $\alpha_3 = 0.15$



Availability aimed atvarious values of Failure/Repair Rates of GDCM**for $\boldsymbol{\alpha_3 = 0.2}$**



Availability aimed atvarious values of Failure/Repair Rates of GDCMfor $\alpha_3 = 0.25$

Figure 2: Value of Availability aimed atvarious values of Failure/Repair Rates of GDCM

Table 3: Variation of Failure/Repair Rates of DCM

β_4 α_4	0.07	0.014	0.21	0.28	0.35
0.007	0.7893	0.7901	0.8038	0.8305	0.8982
0.011	0.8102	0.8301	0.8494	0.8590	0.8926
0.015	0.8385	0.8532	0.8945	0.8967	0.9021
0.019	0.9806	0.9821	0.9926	1.0236	1.1343
0.023	1.052	1.1244	1.3532	1.4842	1.4908

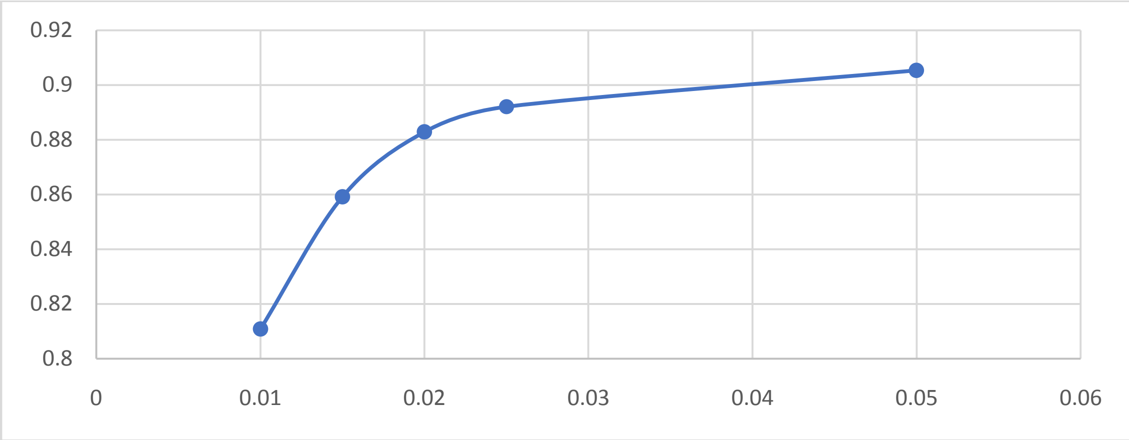


Figure 3: Variation of Failure/Repair Rates of DCM

4.1 Convergence graph

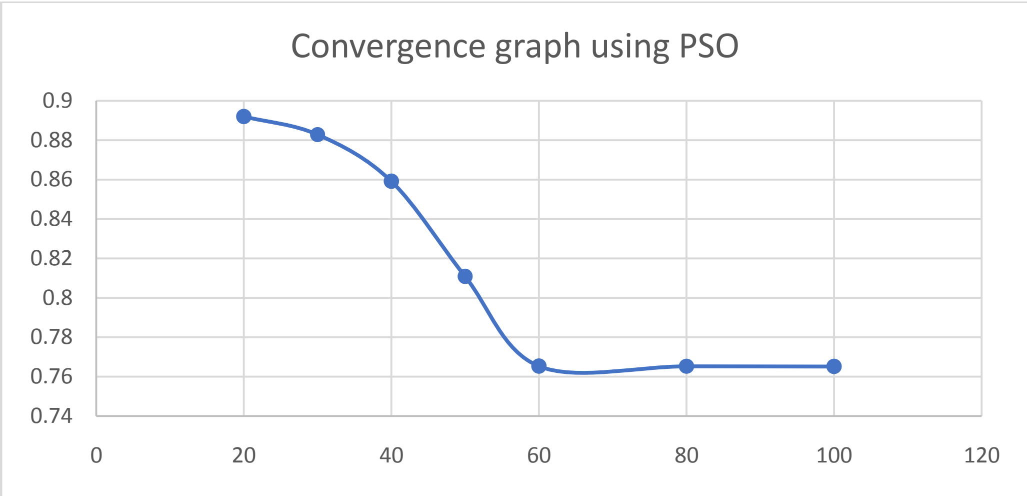


Figure 4: Convergence graph using PSO

5. Conclusion:

In this paper, we have used PSO algorithm to solve reliability problemwhich is based on testing and evaluating Different Values of Failure and Repair Rates due to faults in the system. PSO is powerful tool which is used to solve many optimization problems over the years. This problem is used to testify the working of PSO. The results obtained are encouraging in order to find the restored solution in the contrast behavior of the problem.

References:

1) Ericson, C. (2014). Mean value modelling of a poppet valve EGR-system. *Vehicular Systems, Dept. of Electrical Engineering at Linkopingsuniversitet*, 1-54.

2) Kiureghian, A. D.,Ditlevsen, O., and Song, J. (2007). Availability, reliability and downtime of systems with repairable components. Reliability Engineering & System Safety, 231-242.
3) Reifarth, S. (2014). Efficiency and Mixing Analysis of EGR-Systems for Diesel Engines. *Ph.D thesis, Department of Machine Design, Royal Institute of Technology, Stockholm,* 1-85.
4) Sabouhi, H., Abbaspour, A. and Firuzabad, M. F. (2016). Reliability modeling and availability analysis of combined cycle power plants. *International Journal of Electrical Power & Energy Systems*, 79, 108-119
5) Jieong, S., Hasegawa, S., Shimoyama, and Obayashi, S. (2009). Development and investigation of efficient GA/PSO-hybrid algorithm applicable to real-world design optimization. *IEEE Computational Intelligence Magzine,* 4, 36-44.
6) Komal, S., P. and Kumar, D. (2009). RAM analysis of the press unit in a paper plant using genetic algorithm and lambda-tau methodology. *In Proceeding of the 13th online International Conference (WSC '08), (Springer Book Series),* 127–137.
7) Kumari S, Khurana P, Singla S (2021) Behavior and profit analysis of a thresher plant under steady state. *International Journal of System Assurance Engineering and Man*., 1-12.
8) Kumar, A., Goel, P., Garg, D., and Sahu A. (2017). System behavior analysis in the urea fertilizer industry. Book: Data and Analysis communications in computer and information Science, 1: 3-12.
9) Rajbala, Kumar, A. and Khurana, P. (2022). Redundancy allocation problem: Jayfe cylinder Manufacturing Plant. *International Journal of Engineering, Science & Mathematic*, 11, 1-7.
10) Kumari, S., Singla, S. and Khurana, P. (2022) Particle swarm optimization for constrained cost reliability of rubber Plant. *Life Cycle Reliability and Safety Engineering*, 1-5.
11) Singla, S. and Dhawan, P. (2022). Mathematical analysis of regenerative point graphical technique (RPGT). *Mathematical Analysis and its Contemporary Applications,* 49-56.
12) Singla, Shakuntla et al. (2022). Mathematical Model for Analysing Availability of Threshing Combine Machine Under Reduced Capacity. *Yugoslav Journal of Operations Research*, 425–437.
13) Malik, S. et al. (2022) Performability evaluation, validation and optimization for the steam generation system of a coal-fired thermal power plant, *Elsevir,* 1-9.