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Particle swarm optimization of a wheel production facility to address a reliability issue

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Abstract:. The use of nature-inspired algorithms is one of the most used strategies for resolving practical optimization problems. It has become one of the most popular and successful ways of optimization as a result. The use of particle swarm optimization in a wheel manufacturing factory to address reliability issues is covered in this research. Four distinct experimental designs were used to test the analysis of PSO on limited problems. The objective function and limits that were applied in each experiment are described in the sections that follow along with an overview of each experiment. Each of these problems has a suggested solution, illustrating the broad variety of PSO's potential uses.

Keywords: Particle swarm Optimization, Reliability

1. Introduction

The terms "local optimization" and "global optimization" are used to refer to various elements of the optimization problem. Local optimization searches for the highest or lowest value by narrowing its attention to a specific region of the role value space. Finding the best or worse value across the entire function value space is the aim of global optimization. A single-objective optimization problem is expressed as shadows when there is no loss of simplification:

$$minx\epsilon sf(x), x = Li \leq xi \leq Ui$$
$$s.t.\, g_i(x) \leq 0, j = 1,2, \ldots, J$$
$$h_k(x) = 0, k = 1,2 \ldots., K$$

To solve the current issue, algorithms are used in conjunction with optimization techniques. This method considers all equality, inequality, and side limitations and finds an optimal design variable value. Numerous local or relative optimum conditions, also known as optimal conditions, may exist for a variety of problems.

2. Particle Swarm Optimization (PSO)

2.1 Velocity updates equation:

In a multidimensional search space, a swarm of particles moves in pursuit of the optimum. Each particle in a swarm is influenced by its immediate surroundings and personal perception. The following equation gives the particle's rate of movement from one location to another:

vt+1x=vtx+C1*r and Pbest-xt+C2*r and Gbest-xt

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:

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

These two equations will continuously updating the solution until a predefined termination condition is satisfied. PSO, which is a population-based process, takes into account more than one potential solution. The global and local bests of the search space are utilized as a guide for each solution. As a result, it offers an algorithm that is reliable and discovers the ideal ratio between exploration and exploitation. Some of the most significant PSO traits include the ones listed below:

1. To start, PSO is a reasonably simple algorithm to understand and is therefore more suited for implementation in practical settings.
2. Its underlying principle is swarm intelligence. This method can be used in both engineering and science.
3. It does not overlap and does not do such mutation computations, in contrast to GA.

The paper is arranged in a system as shadows: The overview of optimization and its many strategies is provided in Section 1. Different nature-inspired algorithms are provided in Section 2. This section provides the mathematics for many algorithms, such as the Genetic Algorithm and PSO approaches. The mathematics of the dependability issues employing these strategies are described in Section 3. The numerical analysis of the solution is presented in Section 4. presents the conclusion and makes some recommendations for the future. The consequences of pollution and climate change are the most urgent global issues. This article talks about the wheel manufacturing sector, which on a daily basis serves a lot of our needs and wants. The gravity die casting machine, gate cutting machine, heat treatment machine, and turning machine are some of the subsystems of the wheel manufacturing facility. Eriesons (2014) conducted an analysis of an EGR-structure's mean value. The accessibility analysis and dependability modelling of combined cycle power plants were granted by Abbasour et al. (2016). Assuming any necessary to complete the superior of the complex mechanical systems, Komal et al. (2009) presented the dependability, accessibility, and maintainability analysis prompts specific strategy to carryout structure change. The accessibility, consistency, and downtime of an organisation using a repairable device are examined by Kiureghian et al. in 2007. Reifarth (2014) investigated the efficacy and mixing of EGR capacity. Mathematical analysis of the regeneration point graphical approach was addressed by Sinla et al. in 2022. Jieong et al. (2009) used the GA/PSO half-and-half calculation to solve multi-objective streamlining problems. The Markov approach is a perform ability evaluation technique used in Malik et al.'s (2022) study to discuss the steam generating system of a coal-fired thermal power plant (CFTPP).

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2.3 The System

This article talks about the wheel manufacturing sector, which on a daily basis serves a lot of our needs and wants. The gravity die casting machine, gate cutting machine, heat treatment machine, and turning machine are some of the subsystems of the wheel manufacturing facility. Because each subsystem is crucial to the success of the plant, each one in this system serves a particular function in the operation of the overall system. Each subsystem is sequentially connected to the others. This paper describes the heat treatment machine, a component of the wheel production facility. Any component of the system's operation or failure has some impact on the system's performance.

2.4 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 utilized aimed at Drilling, Milling, and Threading. HM involves of unique unit. The complete procedure fails after HM not be positive.

2.5 **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. Mathematical Modelling

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

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

3.1 Steady state availability analysis

The wheel plant is executed aimed at a long run purpose. Consequently the steady state probability of organization can be produced through 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:

$$p_2 = T_0 p_1 \qquad p_3 = T_1 p_1 \qquad p_4 = T_2 T_0 p_1$$

$$p_5 = T_3 T_0 p_1 \qquad p_6 = T_2 p_1 \qquad p_7 = T_3 p_1$$

$$p_8 = T_4 p_1 \qquad p_9 = T_5 p_1 \qquad p_{10} = T_4 T_0 \qquad p_{11} = T_5 T_0 p_1$$

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 Figures 1, 2, 3, and 4 show the availability aimed at various wheel plant systems. Different availability levels are meant for different combinations of repair and disappointment rates. The most positive effect of disappointment/repair rates can be fully understood in accordance with the wheel plant's system.

Table 1: Value of Availability aimed at various 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

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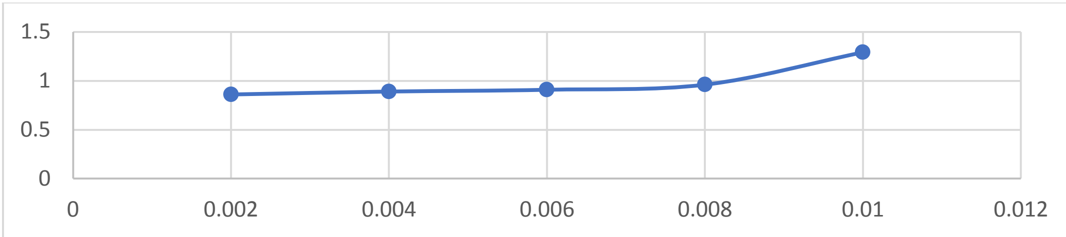
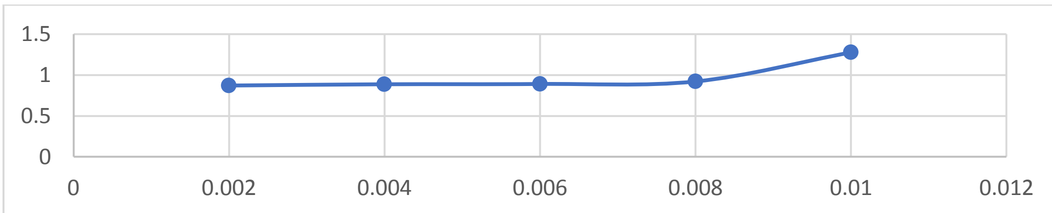
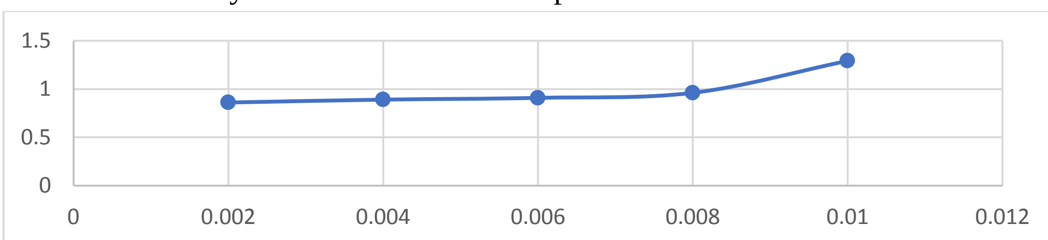


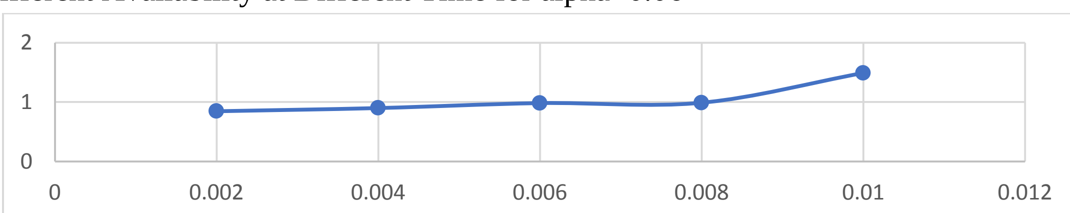
The Different Availability at Different Time for alpha=0.02



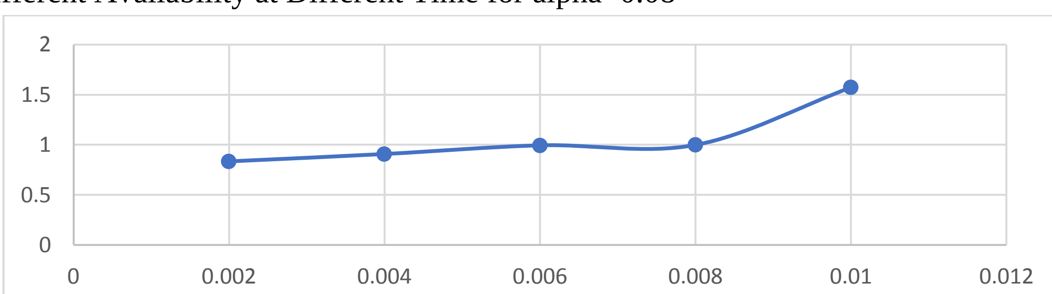
The Different Availability at Different Time for alpha=0.04



The Different Availability at Different Time for alpha=0.06



The Different Availability at Different Time for alpha=0.08

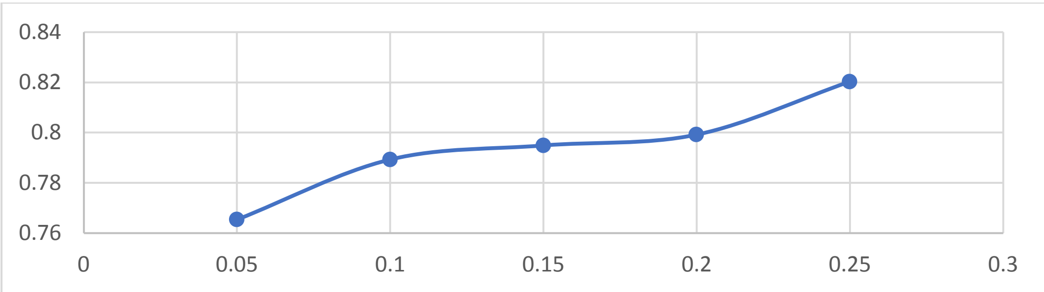


The Different Availability at Different Time for alpha=0.10

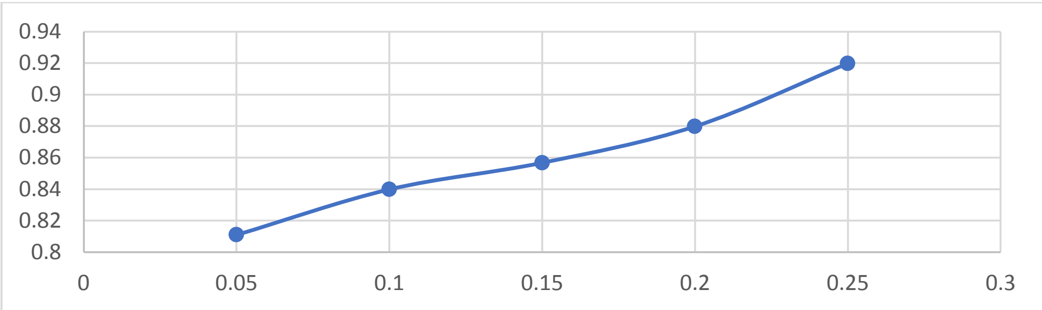
Figure 1: Value of Availability aimed at various values of Failure/Repair Rates of SCMM

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

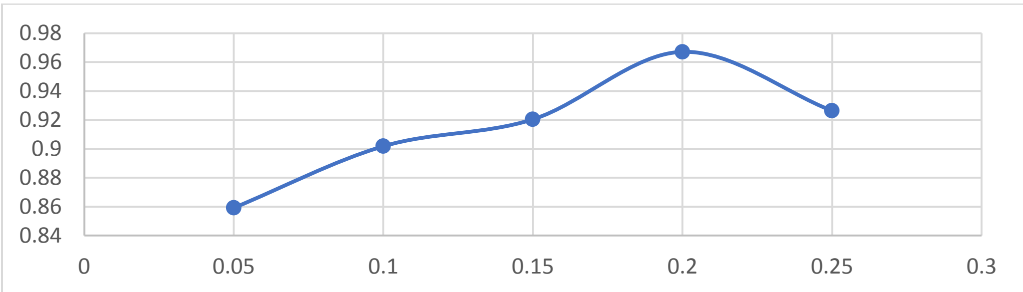
β_3 / α_3	**0.05**	**1**	**0.15**	**0.2**	**0.25**
0.05	0.7654	0.7893	0.7949	0.7992	0.8203
0.01	0.8109	0.8398	0.8567	0.8798	0.9198
0.015	0.8592	0.9018	0.9204	0.9671	0.9263
0.02	0.8829	0.8946	0.9283	0.9937	0.9983
0.025	0.8921	0.9016	0.9187	0.9289	0.9387



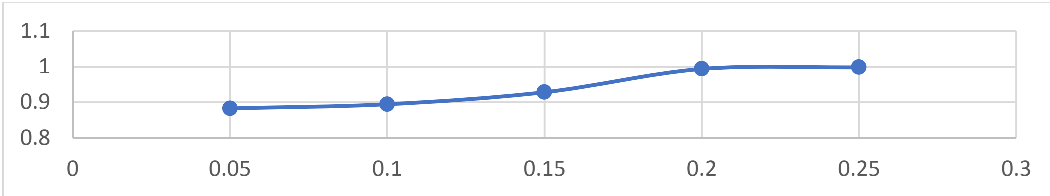
Availability aimed at various values of Failure/Repair Rates of GDCM for $\alpha_3 = 0.05$



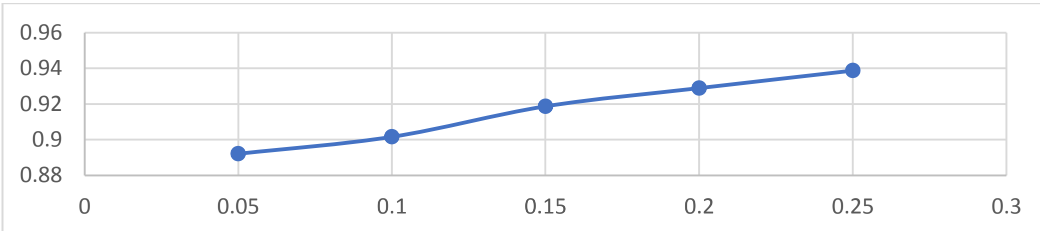
Availability aimed at various values of Failure/Repair Rates of GDCM for $\alpha_3 = 0.1$



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



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



Availability aimed at various values of Failure/Repair Rates of GDCM for $\alpha_3 = 0.25$

Figure 2: Value of Availability aimed at various 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

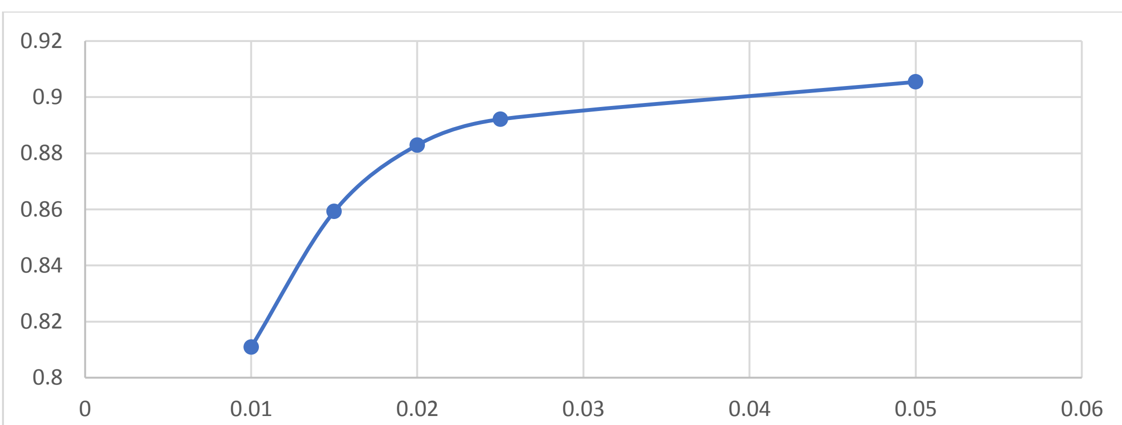


Figure 3: Variation of Failure/Repair Rates of DCM

4.1 Convergence graph

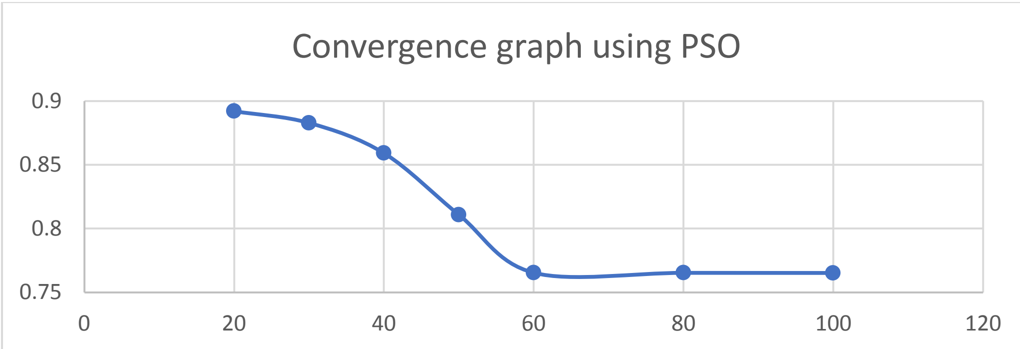


Figure 4: Convergence graph using PSO

5. Conclusion:

In this study, the reliability problem, which is based on testing and assessing various values of failure and repair rates because of system flaws, is solved using the PSO algorithm. PSO is a potent tool that has been utilized for many years to tackle optimization issues. This issue serves as evidence for the effectiveness of PSO. The outcomes are encouraging in terms of locating the restored answer in the problem's divergent behavior.

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