Reliability–Redundancy Allocation of Pharmaceutical Plant Using Cuckoo Search and Hybrid of GWO-CS

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Abstract

The Reliability-Redundancy Allocation Problem (RRAP) is a non-linear mixed-integer programming problem. It is essential to the design of any system and the enhancement of reliability. In this article, two metaheuristic techniques: Cuckoo-Search (CS) and a Hybrid of Grey-Wolf Optimization (GWO) and CS (HGWOCS) are proposed to address the reliability optimization of pharmaceutical plant. This plant illustrates RRAP to optimize reliability under designed constraints such as weight, cost, and volume. The GWO exploration ability and the CS exploitation ability are merged in this hybrid technique. These approaches are compared in terms of optimal solution and accuracy with each other results and previous literature. The statistical outcomes and convergence rate show the expected approach's excellent performance. The final conclusion revealed that the proposed optimization algorithm can accurately enhance the reliability of the pharmaceutical plant.

Keywords: RRAP, HGWOCS, CS, pharmaceutical plant, reliability.

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1 Introduction

Reliability is a key factor of world industrial development, industry must prioritize it to achieve high levels of productivity, safety, and efficiency. By employing strategies such as maintenance, repair programs, quality control measures, and backup systems industrial organizations can help to ensure that their systems are reliable and effective over the long term. Many authors have worked continuously to improve the system's reliability, such as Kumar et al. (2019) enhanced the safety of nuclear power plants. They also optimized the reliability and cost of the power plant with the GWO technique. Ram et al. (2022) evaluated reliability measures and the cost of solar road studs by utilizing the Markov process and Particle Swarm Optimization (PSO). To evaluate reliability measures and the cost of the complex system, Kumar et al. (2022) introduced a multi-objective particle swarm optimization technique. Pant et al. (2017) introduced a modified PSO algorithm for both constrained and unconstrained nonlinear optimization.

The demand for medications has increased significantly due to changes in lifestyle and an increase in chronic diseases such as diabetes, heart disease, and cancer. As a result, pharmaceutical plants are under increasing pressure to produce medications at a high rate and maintain high levels of reliability to meet this demand. The pharmaceutical plants should therefore be as trustworthy as possible. To increase the system's reliability three main techniques can be used: redundancy allocation, reliability allocation, and reliability-redundancy allocation (Aqel and Mellal, 2023). One of these reliability design techniques has been introduced over the last two decades to help organizations improve the reliability of their products/systems/processes and to reduce the risk of failure and downtime to RRAP.

RRAP is a mathematical optimization problem that aims to distribute redundant parts to a system in a way that optimizes overall system reliability. The issue arises during the design of systems in which multiple components must work together to achieve a certain level of reliability. The goal of RRAP is to find the most efficient way to allocate redundant parts to a system's various constraints, including volume, weight, and cost. The main objective is to assess the right amount and redundant components to add to the system to increase reliability while reducing costs and other constraints. By optimizing the allocation of redundant components, the reliability of these systems can be significantly improved, reducing the probability of failures and improving overall performance and safety. Many researchers have been working on RRAP for the past few years to solve optimization problems. Chern (1992) demonstrated that RRAP is organized as a non-deterministic polynomial-time hardness class even in a regular structure such as a series system. Chen (2006) examined nonlinear mixed-integer reliability design issues where the number of redundancy elements and the corresponding component reliability in each sub-system can be decided upon concurrently to optimize the system's performance. To address the reliability-redundancy optimization issues, Coelho (2009) introduced an effective PSO algorithm created on the chaotic sequence and Gaussian distribution (PSO-GC). A brand-new algorithm Hybrid Salp-Swarm Algorithm with Teaching Learning Based Optimization (HSSATLBO) introduced by Kundu and Jain (2022) to solve RRAP with non-linear resource constraints. Zavieh (2022) developed a K-mixed strategy for an innovative model for the RRAP by proper genetic algorithm. A new hybrid GWO-PSO (HPSGWO) algorithm based on PSO and Grey Wolf Optimizer (GWO) is presented by Bhandari et al. (2022), to solve the cold-standby reliability redundancy allocation problem (RRAP). Bhandari et al. (2023) used the recently developed metaheuristic hybrid particle swarm grey wolf optimizer to maximize the reliability of a proposed system i.e., Fire Extinguisher Drones (FED), while taking into account the system's limited resources, including volume, cost, and weight.

Many meta-heuristics techniques have been developed to solve RRAP (non-linear optimization problems). To find the best solutions for these, extensive computational work is needed. Some of the developments of metaheuristic algorithms are: PSO (Eberhart and Kennedy, 1995; Kennedy and Eberhart, 1997; Hu and Eberhart, 2002), Honey Bee Swarm (HBS) (Karaboga, 2005), Genetic Algorithms (GA) (Ardakan and Hamadani, 2014), GWO (Mirjalili, 2014; Pahuja, 2020), Cuckoo Search (CS) (Valian and Valian, 2013; Yang and Deb, 2009), Artificial Bee Colony Algorithm (ABC) (Yeh and Hsieh, 2011), Simulated Annealing Algorithm (SAA) (Kim et al., 2006), Hybrid of Grey Wolf Optimizer and Cuckoo Search (HGWOCS) (Long, 2020), Shuffled Frog Leaping Algorithm (SFLA) (Gandhi and Bhattacharjya, 2020), Hybrid PSO-GWO (Bhandari et al., 2023), these are a few meta-heuristics approaches used in RRAP. These previous investigations formed a basis for some more recent research into the fields of hybrid-metaheuristic algorithms, meta-heuristic algorithms, and their applications. Here, the RRAP is reorganized to accommodate the pharmaceutical plant. Setting reliability goals for components to conform to resource consumption constraints, such as overall cost, is part of the RRAP.

Recently researchers have become interested in the hybrid of two meta-heuristics because it achieves the objective of finding the best global solution with outcomes that are much better than the individual meta-heuristics as such in terms of quality, time, and best convergence rate. Some of the hybrid approaches successfully employed by authors thus far are as follows: To resolve the reliability-redundancy allocation, Kanagaraj et al. (2013) introduced a recently developed nature-based optimization approach called a hybrid of CS and GA (CS-GA), which combines the familiar CS and GA. Ab Rashid (2017) proposed a hybrid technique based on Ant-Colony Optimization (ACO) and GWO to optimize the assembly-sequence planning problem. The Hybrid Ant Wolf-Algorithm (HAWA) that has been proposed is intended to prevent premature convergence in ACO. Pieprzycki and Filipowicz (2023) examined the use of two swarm intelligence algorithms (CS and Firefly Algorithm ((FA)) to assess and increase the reliability of two complex systems. Thymianis et al. (2023) focused on RRAP and employed hybrid schemes made up of individual nature-inspired algorithms, exploring whether hybridization is a useful approach for solving problems with multiple objectives. To predict students' outcomes by enhancing faculty and students' educational opportunities. The HGWOCS, which has proven to be the best meta-heuristic method for solving all types of optimization problems, serves as the inspiration for the research presented in this paper. Additionally, some techniques have been researched while taking into account numerical examples of the series system (Hikita et al., 1992; Kuo et al., 2007). The main aim of the work is to maximize the proposed plant's overall reliability. The number of redundant components and the reliability of each component in the subsystems are decision variables that need to be optimized for this. The component specifications, which have taken into account factors like cost, weight, and volume, define the limits of the system.

The article is structured as follows: In segment 2, a brief explanation of the suggested strategies is given. The development of optimization strategies is covered in Segment 3. Segment 4 describes the mathematical model of the plant. A comparative analysis of numerical results taking into consideration the different techniques discussed in this article is presented in Segment 5. Finally, a conclusion is reached in segment 6 using the findings.

The following is the paper's contributions:

(1) This paper proposes CS and HGWOCS algorithms to update the search process. (2) The proposed optimization algorithm is used to resolve the RRAP instances, and their performance is compared with the PSO algorithm, and each other technique results under the same conditions. (3) The performance of the CS and HGWOCS algorithm is analyzed.

2 Optimization Methods

2.1 Grey Wolf Optimization (GWO)

The GWO algorithm, developed most recently by Mirjalili et al. (2014), addresses practical optimization issues in the study of grey wolves' social intelligence, which favors living in packs of five to twelve people. The wolves in it are divided into four subgroups: alpha, beta, delta, and omega wolves. There is a distinct role for each wolf category. The alpha's main duty, whether male or female, is to make decisions (such as regarding hunting, where to sleep, and when to rise). It is rumored that beta works with alpha to train delta to act as a scouts, caretakers, elders, and hunters. By following alpha and beta wolves, delta can control omega wolves. Omega wolves must accept all other wolves, which requires that they update their positions with the assistance of all alpha, beta, and delta wolves. These four are initially the solution candidates, and they gradually get better in subsequent iterations. The hierarchical dominant order is given in Figure 1.

In the GWO, wolves follow the hunters and direct the hunt. The updated wolf position is computed as:

$$X_1 = X_\alpha - (D_\alpha) \cdot A_1. \tag{1}$$

$$X_2 = X_\beta - (D_\beta) \cdot A_2. \tag{2}$$

$$X_3 = X_\delta - (D_\delta) \cdot A_3. \tag{3}$$

$$X(t+1) = \frac{X_1 + X_2 + X_3}{3}. \tag{4}$$

Where $X(t+1)$ is an offspring influenced equally by the three wolf pack leaders $(X_\alpha, X_\beta, X_\delta)$, t presents the current iteration, A and C are the

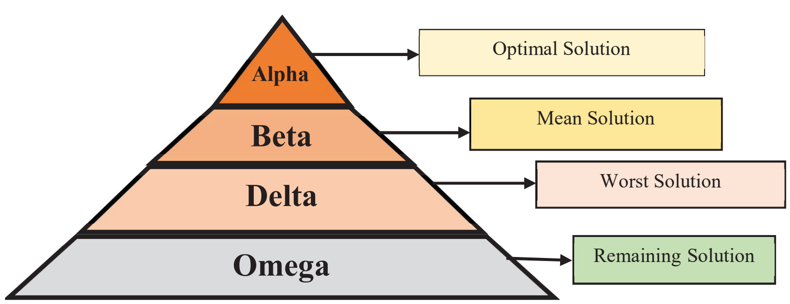

Figure 1 Hierarchy of grey wolf dominance in pack.

coefficient vectors, and *X* – position vector of the grey wolf. The following equations can be used to determine the values of *A* and *C*:

$$\begin{aligned} A &= r_1 \cdot 2a - a. \\ C &= 2 \cdot r_2. \end{aligned} \tag{5}$$

Here, $D_\alpha, D_\beta, D_\delta$, the calculations look like this:

$$\begin{aligned} D_\alpha &= |X_\alpha \cdot C_1 - X|. \\ D_\beta &= |X_\beta \cdot C_2 - X|. \\ D_\delta &= |X_\delta \cdot C_3 - X|. \end{aligned} \tag{6}$$

r_1 and r_2 are random vectors belonging to the range [0,1]. Over the course of iterations, the components of the vector are linearly decreased from 2 to 0. Because the expression contains random variables, the value of *A* ranges from -2 to 2.

2.2 Cuckoo Search (CS)

Cuckoo Search (CS) is a nature-based optimization technique that is used to resolve optimization problems. In 2009, Xin-She Yang and Suash Deb first put forward the concept of cuckoo-search. This algorithm is inspired by cuckoo birds' reproductive behavior. A set of solutions known as host nests are generated at random to begin the search process. Each cuckoo bird lays an egg in a host nest that is chosen at random while searching and then leaves the nest. The quality of the new egg is evaluated, and if it is better than the quality of the egg in the host nest, the new egg replaces the original egg in the nest. The cuckoo bird then either flies to another nest and lays another egg or generates a new egg and repeats the process until a stopping criterion is met. This process is repeated until a satisfactory solution is found or a predetermined maximum number of iterations is reached. The CS algorithm has several advantages, such as its simplicity, easy implementation, and ability to handle optimization problems. However, it may not be suitable for all optimization problems and may require fine-tuning of its parameters to achieve optimal performance. The CS can be mathematically described as follows:

i. Initialization: Randomly generate a set of solutions (host nests) X_i, $i = 1, 2 \ldots, n$.
ii. Fitness evaluation: Evaluate the fitness value $f(X_i)$ of each solution X_i.

iii. Egg laying: For each cuckoo bird *j*, generate a new egg u_j by randomly modifying a randomly selected host nest X_i through the following equation:

$$u_j = X_i + \alpha * levy\_flight$$

iv. where α is a step size and *levy_flight* are the Levy flight step size that is produced using the following equation

$$levy\_flight = \sigma * (u - \mu)$$

v. where σ and μ stand for the Levy distribution's scale and location parameters, respectively, and *u* is a random number produced from a uniform distribution.

vi. Egg selection: Replace the egg in the nest with the new egg u_j with a certain probability *pa*. If the egg in the nest has a better fitness value than the new egg, then the new egg is discarded.

vii. Local search: Execute a local search using the best answer so far.

viii. Termination: Stop the search process when a satisfactory solution is found.

CS technique can be modified to incorporate various enhancements such as elitism, dynamic step size adjustment, and hybridization with other optimization algorithms to improve its performance. Here are several specific applications of the CS Algorithm in reliability optimization:

- **System Reliability Design:** CS can be used to optimize the design parameters of complex systems to improve overall reliability. This includes optimizing component configurations, redundancy strategies, and maintenance schedules to maximize system reliability while reducing cost or resource consumption.
- **Component Placement Optimisation:** In electronic systems and circuits, CS can improve system reliability by optimizing component placement. CS can improve overall system performance and reliability by optimizing component placement, reducing interference and signal distortion.
- **Fault Tolerance Optimisation:** CS can improve fault-tolerant mechanisms in systems, ensuring reliable operation even in the presence of faults or failures. This includes improving fault detection algorithms, fault isolation strategies, and fault recovery mechanisms to reduce downtime and increase system reliability.
- **Software Reliability Optimisation:** CS can help to improve the reliability of software systems and applications. This includes optimizing

code structure, error handling mechanisms, and software testing strategies to reduce the number of software failures and increase overall system reliability.

- **Maintenance Optimisation:** CS can optimize maintenance schedules for industrial equipment and systems to increase reliability and reduce downtime. By optimizing maintenance intervals, CS can ensure that maintenance activities are performed at the most optimal times, preventing unexpected failures and extending asset operational lives.
- **Engineering Optimisation:** CS can be used to optimize structural, mechanical, and electrical circuit designs. It aids in the determination of optimal parameters that satisfy specific constraints and objectives, thereby improving system efficiency and performance.

2.3 Hybrid of GWO-CS (HGWOCS)

The primary objective of the hybrid CS-GWO approach is to combine the benefits of cuckoo search optimization with traditional grey wolf algorithms to solve the static problem in GWO. The traditional GWO method involves selecting control elements r_1 and r_2 at random. Static controlling elements can cause local minimal issues. Cuckoo search is used in this case to choose the best control elements for GWO. Listed below are the segments of the suggested algorithm:

Parameter	Settings
No. of iterations	350
Lower boundary limit	0.50
Upper boundary limit	0.99
No of variables	10

Start $>$ Initialization of population $>$ Evaluate fitness of each individual $>$ Set the best solution as the current global best $>$ Repeat until convergence:

- For each Grey Wolf Pack member:
  - Modify the position of the wolf using GWO
  - Evaluate the objective function
  - Compare with the previous best solution and update if necessary
- For each Cuckoo Population member:
  - Update the position of the cuckoo using CS
  - Evaluate the objective function
  - Compare with the previous best solution and update if necessary

- Combine the new solutions obtained from GWO and CS
- Evaluate the objective function of the combined solutions
- Compare with the previous best solution and update if necessary
- Update the global best solution

End > Return the global best solution

CS combines the two algorithms by running them concurrently and combining the resulting solutions at each iteration. The algorithm starts with the initialization of the population and the evaluation of the fitness of each individual. The optimum solution found so far is set as the current global best. The algorithm then repeats the following steps until it converges: for each Grey Wolf Pack member, the position is updated using GWO, and for each Cuckoo population member, the position is updated using CS. The new solutions obtained from both algorithms are then combined, and their fitness is evaluated. If the new result is better than the previous optimum result, it becomes the new global best result. Finally, the algorithm returns the global best solution found. The hybridization of the GWO algorithm and the CS Algorithm can be a potent approach for reliability optimization. By combining the strengths of both algorithms, it's possible to leverage their complementary features to tackle reliability optimization problems effectively. Here are the applications of the HGWOCS algorithm:

- **Enhanced Exploration and Exploitation:** GWO is renowned for its effective exploratory skills, whereas CS is superior at exploitation. Combining these elements allows the hybrid algorithm to effectively search the solution space for promising regions (GWO), which it can then use to refine solutions for improved performance (CS).
- **Dynamic Parameter Adjustment:** The properties of the optimization problem and the development of solutions allow the HGWOCS to dynamically modify its parameters. Because of its flexibility, the algorithm can balance exploitation and exploration, which is important for reliability optimization tasks in that achieving the ideal ratio of reliability, cost, as well as efficiency is critical.
- **Multi-Objective Optimization:** Many times, reliability optimization entails achieving multiple different objectives at once, like optimizing system performance or reliability while reducing costs. Decision-makers can choose from a set of trade-off solutions because the hybrid algorithm can handle multi-objective optimization by utilizing techniques like Pareto optimization or weighted aggregation of objectives.
- **Constraint Handling:** System requirements, resource constraints, and operational considerations are some of the constraints that are

commonly present in reliability optimization problems. To guarantee that solutions fulfill all constraints while maximizing reliability goals, the hybrid algorithm can incorporate constraint handling mechanisms.
- **Adaptive Search Strategies:** The HGWOCS algorithm can use adaptive search strategies, which dynamically modify the search behavior according to how the optimization process is going. This flexibility keeps the algorithm from prematurely converging to less-than-ideal solutions and enables it to concentrate its search efforts on promising areas of the solution space.
- **Integration with Reliability Models:** Reliability models and simulation tools can be easily integrated with this hybrid algorithm to assess candidate solutions' reliability performance. This integration makes it possible to evaluate reliability metrics in real-time and makes it easier to find the best solutions that satisfy reliability requirements.
- **Application in Complex Systems:** Applications for the HGWOCS algorithm include manufacturing processes, transportation networks, critical infrastructure, and power grid reliability optimization. This is capable of efficiently identifying robust and resilient solutions by taking into account the interdependencies and uncertainties present in these systems.

In general, the fusion of GWO and CS algorithm exhibits considerable potential for tackling reliability optimization issues in various fields, providing an adaptable and versatile method for identifying ideal solutions that strike a balance between dependability, expenses, and efficiency factors. Figure 2. represents the flow chart of HGWOCS (Mahmoud et al., 2022).

3 Mathematical Model

3.1 System Description of Pharmaceutical Plant

Ten subsystems are connected in series in the pharmaceutical plant described by Garg and Sharma (Garg and Sharma, 2013; see Figure 3). The working of a pharmaceutical plant can vary depending on the specific products being manufactured and the equipment and processes used. However, some general steps are involved in the operation of the plant:

(i) Raw Material Preparation: Raw material preparation involves the collection, identification, and testing of raw materials that are required for the production process. The raw materials are then stored in a warehouse until required.

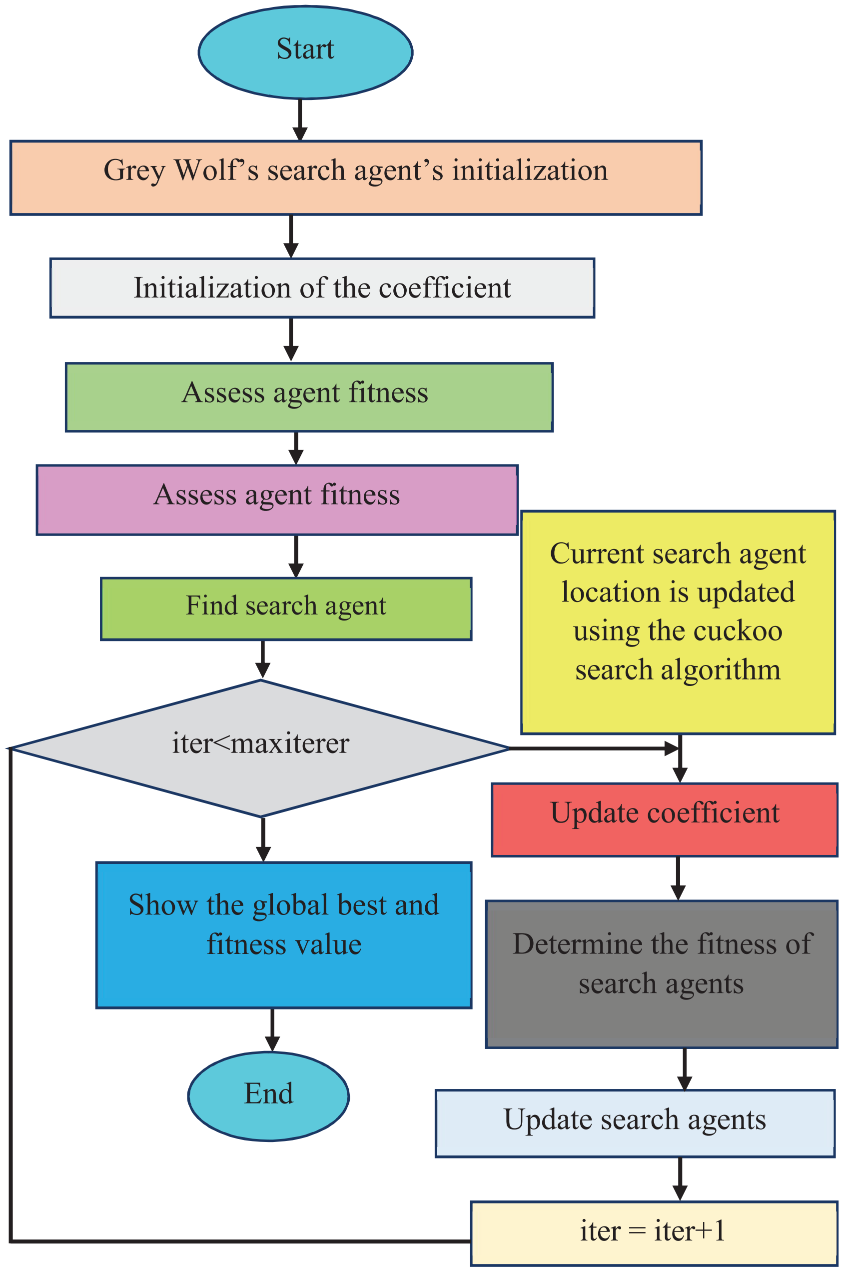

Figure 2 Process flowchart of HGWOCS algorithm.

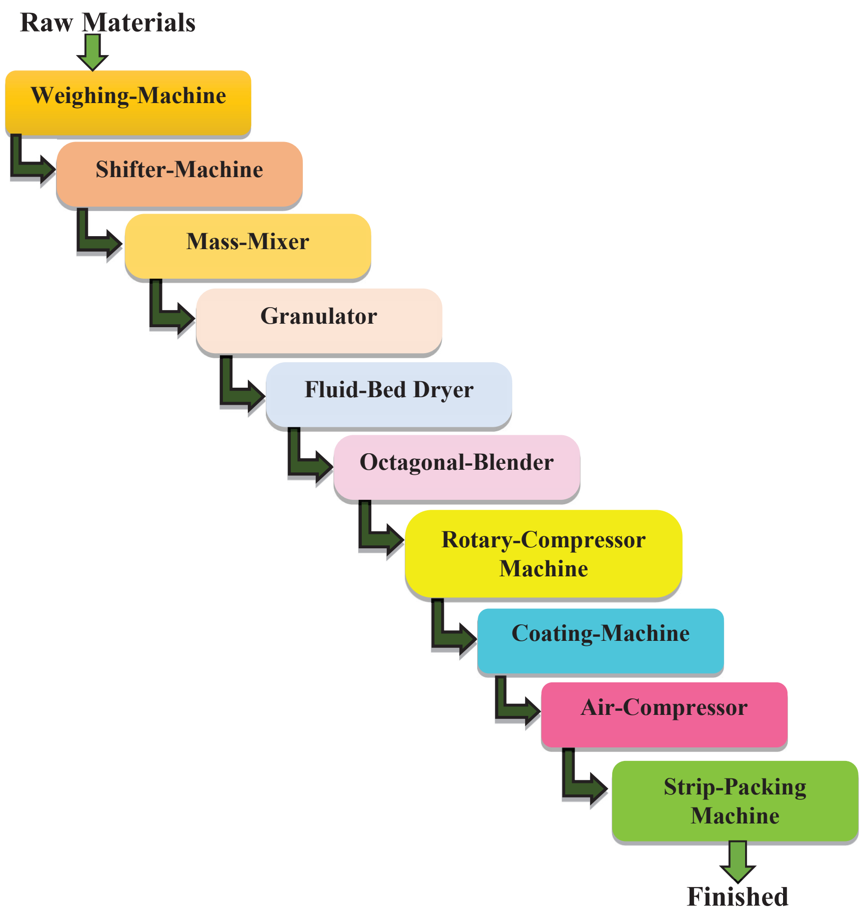

Figure 3 Process of pharmaceutical plant.

(ii) Weighing Machine: Weighing machines are used to accurately measure the quantity of raw materials required for each batch of production. Sifter machines are then used to remove any impurities or foreign particles from the raw materials.

(iii) Sifter Machine: The Weighing machine's mixture is put inside the Shifter. Raw material is sieved using a shifter. The raw material is transferred to a mass mixer after sieving.

(iv) Mass Mixer: The mass mixer is then used to blend the raw materials and create a homogeneous mixture. Granulators are used to compress and shape the mixture into granules.

Table 1 Pharmaceutical-plant's data (Garg and Sharma, 2013)

Components	$10^5\ \alpha_i$	β_i	w_i	$w_i \cdot v_i^2$	*V*	*C*	*W*	*T*(hrs.)
1	0.611360	1.5	4	9				
2	4.032464	1.5	5	7				
3	3.578225	1.5	3	5				
4	3.654303	1.5	2	9	289	553	483	1000
5	1.163718	1.5	3	9				
6	2.966955	1.5	4	10				
7	2.045865	1.5	1	6				
8	2.649522	1.5	1	5				
9	1.982908	1.5	4	8				
10	3.516724	1.5	4	6				

- **(v) Granulator:** Granulators are used to compress and shape the mixture into granules.
- **(vi) Fluid Bed:** Fluid bed dryers are then used to dry the granules to the desired moisture content.
- **(vii) Octagonal Blender:** It is used to blend the dried granules with other ingredients, such as lubricants and disintegrants.
- **(viii) Rotary Compression Machine:** Rotary compression machines are used to compress the blended granules into tablets.
- **(ix) Coating Machine:** It is used to apply a coating to the tablets to protect them and make them easier to swallow.
- **(x) Air Compressor:** It is used to power production equipment and provide compressed air for various applications.
- **(xi) Strip Packing Machine:** It is used to package tablets into strips or blister packs for distribution. Finally, this procedure is complete.

Overall, these machines and processes are essential for the production of high-quality pharmaceutical products that meet strict regulatory requirements and ensure the safety and efficacy of the products it produces. Table 1 includes the input parametric values for the earlier-mentioned system.

3.2 Mathematical Modeling

The general system RRAP can be expressed as follows:

$$\begin{aligned} &\text{Maximize} && R_s(r, n). \\ &\text{Subjected to} && h_j(r, n) \leq 0, \quad j = 1, 2, \ldots, M, \\ & && 0 \leq r_j \leq 1, \quad r_j \in [0, 1], \quad n_j \in \mathbb{Z}^+. \end{aligned}$$

Where,

h – the collection of constraint functions typically connected to system volume, weight, and cost'
R_s – system's reliability,
$r = (r_1, r_2, \ldots, r_m)$ – vectors of the system's component reliability; i^{th}subsystem's,
reliability and component number are denoted by the variables r_i and n_i, respectively. The objective is to increase overall system reliability while taking volume, cost, and weight as constraints.

Following is the pharmaceutical plant's RRAP formulation. (Aquel and Mellal, 2023):

$$\text{Maximize} \qquad R_s = \prod_{i=1}^{10} [1 - (1 - r_1)^{n_i}].$$

$$\text{Subjected to} \qquad h_1(r, n) = \sum_{i=1}^{10} v_i^2 \cdot w_i \cdot n_i^2 leV,$$

$$h_2(r, n) = \sum_{i=1}^{10} [n_i + e^{(n_i/4)}] \cdot \alpha_i \cdot \left(-\frac{1000}{\ln r_i}\right)^{\beta_i} \leq C,$$

$$h_3(r, n) = \sum_{i=1}^{10} w_i \cdot e^{(n_i/4)} \cdot n_i \leq W,$$

$$0.5 \leq r_i \leq 1 - 10^{-6}, \quad r_i \in [0, 1],$$

$$1 \leq n_i \leq 10, \quad n_i \in \mathbb{Z}^+.$$

The system's volume, cost, and weight restrictions are denoted as $h_{1,2}$, and $3(\cdot)$. T is the mission time. v_i, w_i, represents each component's volume and weight at stage i, respectively. The interconnecting hardware is taken into account by the factor $e^{(n_i/4)}$, β_i, α_i-cost-reliability curve's shape and scaling factor for each component in stage i respectively,

V – upper-limit on the sum of the volume,
C – upper-limit on the system's cost,
W – upper-limit on the system's weight.

4 Results

In this paragraph, the authors examine the effectiveness of the suggested techniques for RRAP of the pharmaceutical plant using a number of constraints

Table 2 The parameter settings for all examined algorithms

Algorithms	Parameters	Value
PSO	w_1	0.9
	w_2	0.4
	No of particles	10
	c_1	2.05
	c_2	2.05
	upper bound	0.99
	lower bound	0.50
CS	p_a	0.25
	beta	3/2
	No of iteration	350
	No of particles	10
	No of search agent	25
	upper bound	0.99
	lower bound	0.050
HGWOCS	upper bound	0.99
	lower bound	0.50
	No of iteration	350
	No of particles	10
	No of particles	10

e.g., cost, volume, and weight. The maximum reliability of the proposed plant obtained by HGWOCS and CS was examined and compared with previous literature. The exploration range for each parameter is tabulated in Table 2. The authors evaluated the problem in the following range as each algorithm has a maximum population size of 300 and the allocated number of iterations is 350. To avoid duplication, at least ten independent runs were also conducted.

4.1 Comparative Study

The previously discussed problem is solved using the metaheuristic algorithms such as HGWOCS and CS algorithm. The number of redundant components (n) and the corresponding reliability (r) of each component in all the subsystems with various constraints must be determined concurrently in such a pharmaceutical plant. Results obtained after using optimization techniques (see Table 3) have been compared with the PSO (Garg and Sharma, 2013). The HGWOCS has maximum reliability ($R_S - 0.958809593551719$) in comparison to other algorithms. Figure 4 shows that the HGWOCS is more

Table 3 Analyzing and comparing the results

Algorithm	PSO (Garg and Sharma, 2013)	CS	HGWOCS
R_s	0.956021	0.957356262646423	**0.958809593551719**
r_1	0.871922	0.872960313913417	0.884493712796683
r_2	0.827480	0.842015406066221	0.821201811727072
r_3	0.835569	0.824088985591777	0.826197971187502
r_4	0.800000	0.821952104305154	0.826951240800421
r_5	0.865663	0.842337837555759	0.866007816108885
r_6	0.831345	0.824890256466994	0.838790683178984
r_7	0.864687	0.833370374118274	0.846422085457948
r_8	0.800000	0.840382786418284	0.836415203328232
r_9	0.858897	0.841596178009797	0.849155365653882
r_{10}	0.832932	0.835612779396000	0.828370367306616
n_1	3	3	3
n_2	3	3	3
n_3	3	3	3
n_4	3	3	3
n_5	3	3	3
n_6	3	3	3
n_7	3	3	3
n_8	3	3	3
n_9	3	3	3
n_{10}	3	3	3
slack (g_1)	0.0532050	1.023950964796768	0.08560.26587451200
slack (g_2)	13.025996	13.025996311986262	13.026025698741252
slack (g_3)	10.000000	10.000000000000000	10.000000000000000

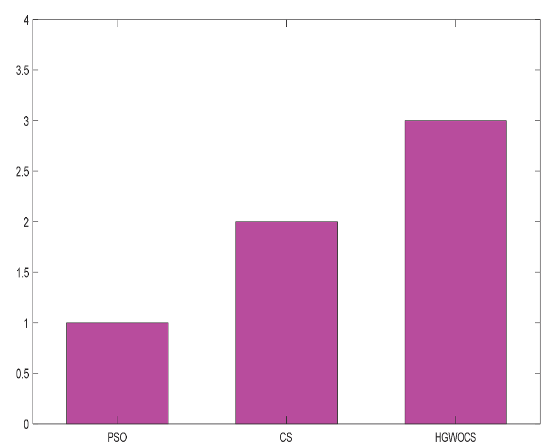

Figure 4 Algorithms' bar graph.

Table 4 Result obtained by HGWOCS and CS

Algorithms	CS	HGWOCS
Maximum	0.957356262646423	0.958809593551719
Minimum	0.804445088137627	0.916351913450014
Mean	0.935400401417543	0.944026274991235
SD	0.033430839858395	0.002536895425481

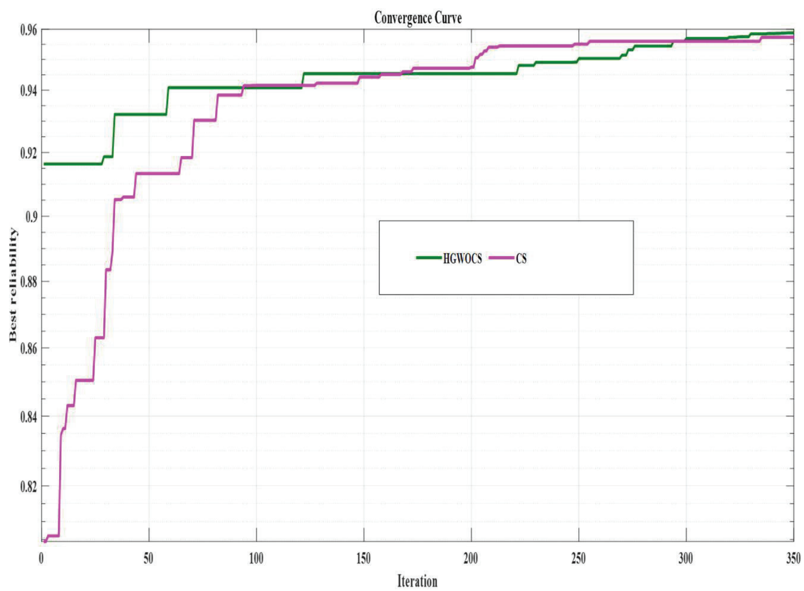

Figure 5 Convergence plot of HGWOCS and CS.

reliable than the PSO and CS. The slack (unused resource) and redundancy are also reported in the table. The bold type represents the best solution for system reliability.

4.2 Statistical Analysis

The mean, maximum, minimum, and Standard Deviation (SD) of pharmaceutical plants is statistically analyzed in this segment for both developed strategies. Table 4 summarizes the accuracy comparison of both algorithms over ten runs. The statistical data shown that the HGWOCS is the most accurate and reliable algorithm. The findings also indicate that the developed HGWOCS, which has a low standard deviation, is the most specific and efficient method in the CS domain.

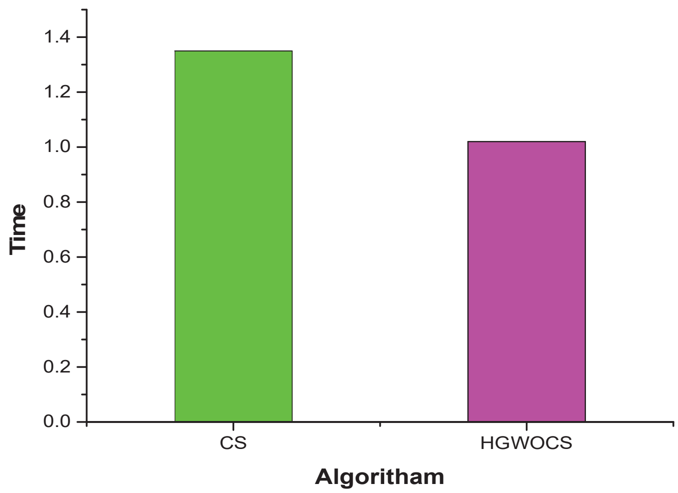

Figure 6 Graph of CPU timing for both techniques.

4.3 Convergence Analysis

This subsegment describes the convergence curve used in pharmaceutical plants to assess the computational capacity of the HGWOCS and CS techniques. According to the convergence rate study, the HGWOCS algorithm is more accurate than the CS algorithm because it gave the optimum reliability i.e., 0.957356262646423 the CS (See Figure 5) with minimum CPU time as shown in Figure 6. The HGWOCS algorithm substantially outperformed the CS algorithm in terms of convergence speed and generates an achievable solution for the same number of function iterations (i.e., 350).

5 Conclusion

This study used two meta-heuristic techniques, HGWOCS and CS, to formulate and optimize a non-linear mixed integer programming problem with the objective of improving the reliability of pharmaceutical plants. The outputs of these techniques are contrasted with those of other approaches and previous research. The obtained solutions showed that the suggested strategies provide better system reliability than the literature, and the best value of reliability was obtained by the HGWOCS rather than CS. The maximum reliability obtained by the HGWOCS is -0.958809593551719, which is better than the CS and PSO. The statistical study demonstrates the robustness of the implemented HGWOCS technique on pharmaceutical plants, which has a lower SD than the CS algorithm. The best outcomes may be used by plant system experts to allocate the reliability of the system and then improve system productivity.

As for future work, other metaheuristic algorithms can be considered to further enhance solutions or be used to solve other numerical examples. In addition, multi-objective optimization RRAP can be analyzed and studied.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

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Human and Animal Rights

There is no humans and animals related research are involved in this work.

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The current research totally belongs to the contributors and related works are properly cited in the article.

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