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RELIABILITY OPTIMIZATION USING HYBRID GENETIC AND PARTICLE SWARM OPTIMIZATION ALGORITHM

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Abstract: Redundancy-allocation problem i.e. RAP is among the reliability optimization problems which make use of non-linear programming method to improve the reliability of complex system. The objective of this research paper is reliability optimization through the application of Genetic Algorithm i.e. GA and Hybrid Genetic & Particle Swarm Optimization (H-GAPSO) on a RAP. Certain shortcomings have been seen when results are obtained by application of single algorithms. In order to get rid of these shortcomings, HGA-PSO is introduced where attractive properties of GA and PSO are combined. This hybrid method makes use of iterative process of GA after obtaining initial best population from PSO. Comparative Analysis of results of GA and H-GAPSO is done with respect to reliability and computation (CPU) time and it is observed that H-GAPSO improved system reliability up to maximum by 63.10%. MATLAB programming has been used for computation of results from GA and HGA-PSO algorithms.

Keywords: Redundancy allocation problem, reliability optimization, GA, PSO, H-GAPSO.

MSC: 90B25, 90C30, 68T20.

1. INTRODUCTION

Due to rapid industrialization and modernization, there has been massive innovation in the new technology/manufacturing techniques which has subsequently led to the growth in the complexity in the systems. In aiming to ensure requisite quality of products there is a requirement of more reliable units/machines in the manufacturing process and mechanical framework of the industries. The requirement of reliability-optimization is primarily because of market pressure, safety matters, obsolescence of technology, competition between industries manufacturing similar kind of products, research and development risks, management emphasis, etc. In addition to above mentioned requirements for reliability optimization, certain constraints like cost, weight, volume, distance, etc are also required to be taken into the considerations. It can be noted that constraint optimization plays a crucial role in the modern-day industries and engineering. These constrained-optimization problems are relatively difficult to be solved vis-à-vis non-constrained optimization problems by the virtue of existence of numerous constraints and their relationship with the objective function. Constrained problems may be continuous, discrete or mixed with non-linear objective functions and constraints. Solution of these problems are generally found with the help of general methods like mathematical programming (linear, homogeneous linear, integer, dynamic or non-linear) and meta-heuristic methods. In the last decade, diversity in meta-heuristic algorithms have been formulated and implemented on constrained-optimization problems. Gradient methods are used to explore solution space nearby initial point as these converge faster and solution with higher accuracy are obtained in comparison to stochastic approaches which use local search tasks. Pre-requisites for successful implementation and execution of these methods are availability of good starting points and continuous cost variable functions.

Now a day, the nature based meta-heuristic algorithms are getting popular as they are flexible in nature to solve optimization and other kinds of problems very easily as compared to classical methods. It is proved by various researches that nature based algorithms like GA (genetic algorithm), ACO (ant colony optimization), PSO i.e. particle swarm optimization, ES (evolution strategy) etc. attracts researchers because these algorithms do not require any mathematical presumptions for the optimization problem and carries remarkable global search capabilities. These meta-heuristic algorithms are applied in wide areas of research fields for redundancy allocation problems (RAP) like, engineering problems, reliability optimization, decision making etc.

In order to enhance global search capability and to deal with exploration-exploitation tradeoff, two or more nature based algorithms are combined. Several hybridization algorithms with genetic algorithms are applied attain more computationally efficient results. [1] solved a RRAP with the help of heuristic algorithm to enhance the system reliability. [2] Introduced hybrid algorithm which combined neural network with genetic algorithm to solve RRAP (reliability redundancy allocation (RRAP) problem) aiming to enhance reliability of the complex systems. [3] proposed MOWFA (multi-objective water flow) algorithm to find solution for the redundancy allocation problem to increase the reliability and reduce cost of the system, further comparative analysis of MOWFA is done with NSGA-II and NRGA to evaluate the performance of proposed MOWFA. [4] proposed hybrid convolutional neural network i.e. CNN with genetic and particle swarm optimization to overcome the incorrectness in wind power forecasting system. [5] applied hybrid algorithm of cuckoo search algorithm and genetic algorithm to solve the reliability redundancy allocation (RRAP) problem in an effort to attain highest system reliability, hybrid algorithm performed well to make balance in the exploration-exploitation trade off which improved the convergence in the search space. [6] proposed improved particle swarm optimization to improve global search ability, avoid premature convergence and enhance the optimization process while solving reliability redundancy allocation (RRAP) problem of simple and complex systems in an effort to enhance reliability of the system under different kinds of subject to constraints like cost, weight, volume etc. [7] Introduced the hybrid genetic & particle swarm optimization aiming to find solution for the redundancy allocation problems (RAP) for series, series-parallel and bridge systems in an effort to enhance the reliability of system and to improve computational efficiency under subject to constraints like cost, volume, system weight etc. [8] used genetic algorithm (GA) to find the solution of redundancy allocation problem (RAP) of single objective function with several constraints, also called non-linear programming problem for complex system. [9] proposed optimal redundancy strategy based reliability redundancy allocation (RAP) problem, further parallel genetic algorithm (GA) is introduced to find solutions for such problems in an effort to increase reliability of the system. [10] proposed general reliability-redundancy allocation problem (GRRAP) for more general network systems, further proposed BAT-SSOA3 algorithm which is combination of binary-addition-tree (BAT) algorithm, SSO (simplified swarm optimization) and (A3) small-sampling tri-objective orthogonal array to solve GRRAP. [11] introduced effective oriented genetic algorithm that is improved version of genetic algorithm (GA) to find solution for reliability redundancy allocation (RRAP) problems of series & parallel multistate systems in an efforts to improve reliability of the system by increasing the reliability of subsystems. [12] used genetic algorithm, penalty function based cuckoo optimization algorithm & stochastic fractal search guided by penalty to find solution of reliability redundancy allocation (RRAP) problems, further comparison has been made to showcase the differences in methods. [13] proposed general redundancy allocation problem (GRAP) for more general network systems, further proposed hybrid swarm optimization (HSO) algorithm which is combination of simplified swarm optimization & particle swarm optimization (PSO) to solve GRAP. [14] used non-dominating sorting and non-dominating ranked genetic algorithms to find solution for multi-objective redundancy allocation problems under the cost constraint of the weighted-k-out-of-n system. [15] used penalty function approach and hybrid algorithm to enhance reliability of the system reliability of reliability redundancy allocation (RRAP) problem subject to cost constraint. Hybrid algorithm used is combination of genetic algorithm and self organizing migrating algorithm. [16] applied improved PSO (particle swarm optimization) to reliability redundancy allocation (RRAP) problem with heterogeneous components in an effort to increase system reliability by using mixed redundancy strategy. [17] proposed two-phase linear programming technique to solve non-linear redundancy allocation problems with multiple constraints. [18] proposed intelligent particle swarm optimization (PSO-IM) which have better search ability as compared to basic PSO in an effort to obtain highest reliability for reliability redundancy allocation (RRAP) problem of complex systems. [19] applied hybrid meta-heuristic algorithm that is combination of genetic algorithm (GA), GVNS (general variable-neighborhood search) algorithm and VND (variable-neighborhood descent) algorithm to find solution of multi-vehicle-covering tour problem. [20] applied NSGA-II that is a multi-objective genetic algorithm on reliability redundancy allocation (RRAP) problem in an effort to increase reliability of system and decrease the cost, volume, weight etc. [21] applied hybrid genetic simulating annealing (HGSA) algorithm on redundancy allocation problem in an effort to attain highest reliability for the system under cost constraint, further comparative analysis of HGSAA is done with heuristic algorithm, constraint optimization genetic (COGA) algorithm, hybrid particle swarm optimization & constraint optimization genetic (HPSOCOGA) algorithm. [22] used HGAPSO algorithm for feature selection in complex computations in order to minimize computation time and data size. [23] used HGAPSO algorithm to improve the correctness of routes planning for shipping in maritime traffic networks. [24] applied H-PSOCOGA algorithm to solve redundancy allocation problem in an effort to attain highest reliability of the system subject to cost constraint, further comparative analysis of results of H-PSOCOGA, heuristic algorithm and constraint genetic algorithm is done. Literature demonstrates that aforementioned algorithms successfully applied to different kinds of constrained reliability redundancy allocation problems for complex systems. Hybridized genetic algorithms and particle swarm optimization algorithms are performing well in variety of redundancy allocation problems and other kinds of problems.

In present research, Genetic algorithm i.e. GA & Hybrid genetic & particle swarm optimization algorithm (HGA-PSO) is applied on reliability redundancy allocation (RRAP) problem of tablet medicine manufacturing system in an effort to increase reliability of the tablet manufacturing system of Yaris pharmaceuticals under given cost constraint. Further, performances of algorithms are compared to see the effectiveness of applied algorithms. Rest of research paper is sorted like this: section 2 introduces the details of system and formulated reliability redundancy allocation problem. Section 3 describes the genetic algorithms (GA) and hybrid genetic - particle swarm optimization algorithm (HGA-PSO) used in the paper. Computational results obtained for the redundancy allocation (RAP) problem are discussed and compared in section 4. In the end, drawn conclusion is discussed in section 5.

2. PROBLEM FORMULATION

Yaris Pharmaceuticals is Goods Manufacturing Practice certified pharmaceutical company situated in Himachal Pradesh. Yaris Pharmaceuticals have all the manufacturing sections like capsules, tablets, liquid medicines, ointments, dry syrup and sachets. In this paper, tablet medicine manufacturing section is considered as system.

2.1. System description

Tablet medicine manufacturing system of Yaris Pharmaceuticals consists of seven units named as weighing machine, mixing equipment, granulator, drying equipment, tableting machine, evaluation/quality control equipment and coating-packing machine are connected in series. Process for manufacturing tablet medicine undergoes following steps:

Raw powders, drugs and excipients are weighted using weighing machine as per the dosage required for making tablet. Raw powders, drugs and excipients are then mixed with the help of mixing equipments to obtain the homogenous powdered mixture, which is then taken in the granulation process by collecting them into layers and aggregated to deliver them in free flowing form. Screened wet granules are then dried at controlled temperature under 550^0C for particular time period in fluid bed dryer, after drying proper mesh screen is used to screen the dried granules. Granules are taken in tablet compression process, in which compression of granules is done in required shapes, scored or unscored and coded using tablet press. Finally tablets are coated and packed by coating solutions in order to deal with the irritating taste/odour, to control the loosening of drug material from tablet and to increase the appealing look.

2.2. Notations

n_i	i^{th} component
a_i	Number of components with i^{th} component
$R_i(n_i)$	Reliability of component- n_i
$Q_i(n_i)$	Unreliability of component-n_i
$R_s(n)$	System reliability
$H_j(n_i)$	j^{th} resource used by ith component
$t = 7$	Total number of subsystems
C	Maximum cost
$\propto$	Rate at which individuals affected by GA are decreasing
γ	Rate of increasing of GA maximum iterations
GA_{PS}	Particle's population size in GA
GA_{Min}	Minimum iteration inside GA
GA_{Max}	Maximum iteration inside GA
GA_{Cur}	GA affected current individuals
GA_{Curmin}	GA affected minimum individuals
GA_{Curmax}	GA affected maximum individuals
GA_{FPS}	Initial population size inside GA
GA_{LPS}	Ending population size inside GA
PSO_i	Current iteration in PSO
PSO_{max}	Maximum iterations in PSO

2.3. Problem Description

In present research paper, a tablet medicine manufacturing system comprised of seven subsystems in Yaris pharmaceuticals is considered. The system works in sequence only if all seven subsystems work accurately. Objective of the problem is to minimize the cost and maximize the reliability of the system in the manufacturing process of liquid medicine. Redundancy-allocation problem for the tablet medicine manufacturing system is described as follows:

Maximize

$$R_s(n) = \prod_{i=1}^{7} R_i(n_i) \tag{1}$$

Subject to cost constraint:

$$\sum_{i=1}^{7} f^1(n_i) * a_i \leq 31450000 \tag{2}$$

$$R_i(n_i) = (1 - (Q_i(n_i))^{a_i}) \tag{3}$$

Here, considered cost constraint i.e. C = Rs. 31450000.
Reliability and cost of subsystems of tablet manufacturing system of Yaris pharmaceuticals is given in Table 1.

Table 1: Reliability & cost of subsystem

Subsystems	n_1	n_2	n_3	n_4	n_5	n_6	n_7
Reliability of subsystem	0.979	0.95	0.90	0.83	0.86	0.911	0.95
Cost of subsystem	1169000	941000	2,599000	1029000	10500000	961000	261000

3. METHODOLOGY

In machine learning several techniques has been developed, among them nature based techniques are popular to deal with complex problems. This section describes genetic algorithm and its hybridization with particle swarm optimization in detail along with their flowcharts.

3.1. Genetic Algorithm

Genetic Algorithm (i.e. GA) is a adaptive meta-heuristic search algorithm inspired by Charles Darwin's theory of natural evolution. These algorithms make use of search-based optimization techniques and are employ ideas of natural selection and genetics. High quality solutions for both optimization and search problems are generated through random search within a well-defined search space. GA was initially invented by John Holland & his collaborators in 1960s. Holland was most likely the first individual to make use of crossover, selection, recombination, mutation and learning of adaptive & artificial systems. Since then, GA has been grossly calculated, experimented and even implemented in many engineering disciplines. In GA, there is population of possible solutions of given problem. Available solutions repetitively go through recombination and mutation to produce new offspring. Each individual is allocated with a fitness value on the basis of value of its objective function, further healthy individuals get higher opportunity to mate and give "fitter" individuals. Therefore, we are able to evolve better individuals (solutions) over generation to come to a stopping criterion as shown in Figure 1.

Psuedocode for Genetic Algorithm

```
Objective function
Define Fitness (for maximization)
Initialize population
Introductory probabilities p_b and p_d of crossover and mutation respectively
Do
Create fresh solution by mutation and crossover
If p_b > rand, then crossover; end if.
If p_d > rand, then mutation; end if.
Consent to fresh solution only if its fitness rise
Choose the present best for upcoming generation
While minimum error or maximum iterations standard is not attained
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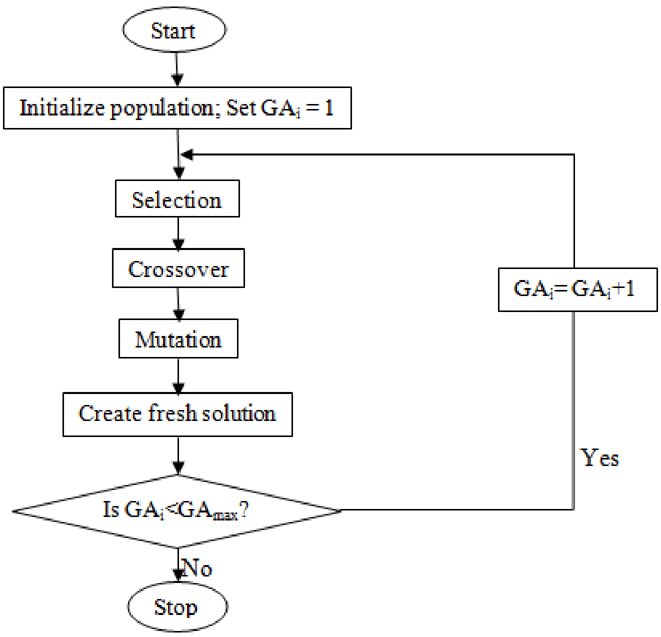

Figure 1: Flow chart for genetic algorithm

3.2. Hybrid PSO-GA

PSO is a stochastic optimization technique to find solution for complex global optimization problems. Performance of PSO greatly relies on appropriate strategies of parameter selection for parameter's fine-tuning behaviour. In PSO particles are initialized randomly with their own position and velocity in the multidimensional searching space. Particle's velocity forces them to move and update their previous position to next position in search of optimal solution. The mathematical equations lead particle's updating process are velocity and position update equations. Updating process simultaneously includes the storage of particle's personal best (P_p) position and global best (P_g) position. The process of finding optimal solution stops when there is no update in position of all particles. PSO is a population dependent algorithm which has the capability of social thinking whereas GA is also a population based algorithm. However, it makes use of local search. Combination of these algorithms gives birth to PSO-GA approach and leads to finding a global solution, refer Figure 2.

1. Let n_0^i represent the starting position of i^{th} particle that is taken on random basis by uniform distribution in bounds of $U(n_{min}, n_{max})$; where n_{min} represents lower bound and n_{max} represents upper bound of design variables.
2. Position of every particle in swarm is tuned by self and neighbor's experience. Particle's position is named as personal best (P_p) position and that of its neighbor is named as P_g position. Position of every particle is updated by the velocity vector grounded on both memory obtained by every particle and understanding gained by swarm as whole.
3. Update the position of particle as per the following equation:

$$n_{k+1}^i = n_k^i + u_{k+1}^i$$

4. GA is applied separately to each of the selected particles which have been generated after PSO iterations. However, GA is not implemented on whole population in aiming to save time. Out of the swarm size, the number is defined by GA_{Cur} and is generated by following equation:

$$GA_{Cur} = GA_{CurMax} - \left(\frac{PSO_i}{PSO_{Max}}\right)^{\propto} \times (GA_{CurMax} - GA_{CurMin})$$

5. Succeeding selection, crossover & mutation, a kind of elitism is carried out to preserve best solution in population by using following equation:

$$n_{i+1} = \begin{cases} r_i & if\ z(r_i) < z(n_i) \\ n_i & otherwise \quad i = 1, 2, \ldots, GA_{PS} \end{cases}$$

6. Succeeding evaluation of fresh population, size of population is defined as following:-

$$GA_{PS} = GA_{FPS} - \left(\frac{PSO_i}{PSO_{Max}}\right)^{\propto} \times (GA_{LPS} - GA_{FPS})$$

7. Maximum iterations for GA changes w.r.t. iteration of PSO; is defined as following:-

$$GA_{Max} = GA_{Min} - \left(\frac{PSO_i}{PSO_{Max}}\right)^{\gamma} \times (GA_{Max} - GA_{Min})$$

8. After successive reproduction process, population escort towards global optimum.

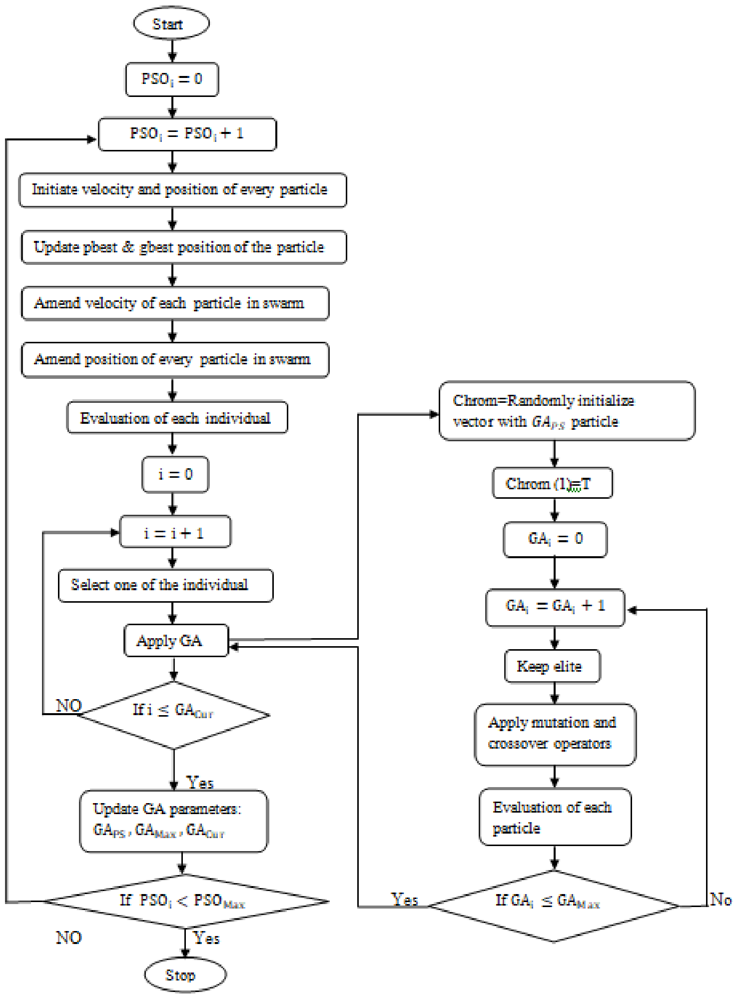

Figure 2: Flow chart for genetic algorithm

4. RESULTS & DISCUSSION

A redundancy allocation problem of a system of seven subsystems is taken. Two algorithms named as genetic algorithm GA & Hybrid genetic-particle swarm optimization (HGA-PSO) are applied to find solution of the proposed redundancy allocation problem of Yaris Pharmaceuticals. Results of redundancy allocation problem (RAP) obtained from genetic algorithm GA & hybrid genetic-particle swarm optimization (HGA-PSO) is described in Table 2 and Table 3 respectively.
Since the genetic algorithm i.e. GA is used to find solutions of the constrained optimization problem, results obtained under given cost constraint are in the form of redundancy allocation. Obtained results from Table 2, improved system reliabil-

Table 2: Result of GA

Subsystem	n_1	n_2	n_3	n_4	n_5	n_6	n_7
No. Of components used by subsystem	3	5	2	5	1	4	4

Table 3: Result of HGA-PSO

Subsystem	n_1	n_2	n_3	n_4	n_5	n_6	n_7
No. Of components used by subsystem	2	4	4	3	1	3	4

ity to some extent but not at best level. To overcome the shortcomings of genetic algorithm i.e. GA, Hybrid genetic & particle swarm optimization i.e. HGA-PSO is applied to maximize the system reliability up to a remarkable level. Further, Comparative analysis of genetic algorithm i.e. GA & Hybrid genetic & particle swarm optimization i.e. HGA-PSO is done in terms of redundancy allocation, increase in system reliability and computation time in Table 4. Genetic algorithm (GA) also performed well in terms of improvement in system reliability, but hybrid genetic-particle swarm optimization (HGA-PSO) gave remarkable results. Genetic

Table 4: Comparison of GA and HGA-PSO Results

4*Alogrithm	Result of Redundancy Allocation Problem							4* Increase in System Reliability (%)	4* CPU time (s)
	n_1	n_2	n_3	n_4	n_5	n_6	n_7		
GA	3	5	2	5	1	4	4	48.25	0.21
HGA-PSO	2	4	4	3	1	3	4	63.10	3.07

algorithm (GA) improved system reliability by 48.25 % whereas Hybrid genetic & particle swarm optimization i.e. HGA-PSO improved it by 63.10% as shown in Figure 3, it proves that hybrid genetic & particle swarm optimization i.e. HGA-PSO overcome the shortcomings of genetic algorithm.

Hybrid genetic & particle swarm optimization (HGA-PSO) has performed well as compared to genetic algorithm i.e. GA in terms of increasing system reliability but lacking in providing fast results as shown in Figure 4. HGA-PSO is taking much more computation time i.e. 3.07 seconds, whereas GA is taking very less computation time i.e. 0.21 seconds.

Results demonstrates that Hybrid genetic & particle swarm optimization (i.e. HGA-PSO) is providing fine results as compared to genetic algorithm i.e. GA for the proposed redundancy allocation (RAP) problem (see Figure 5) but takes longer computation time.

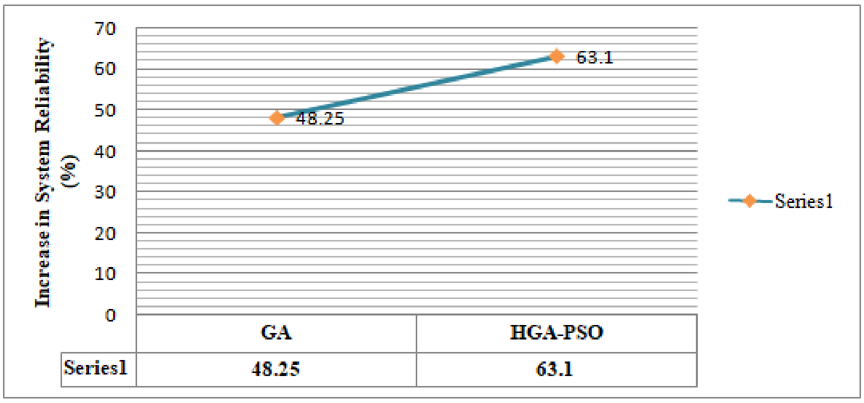

Figure 3: Flow chart for genetic algorithm

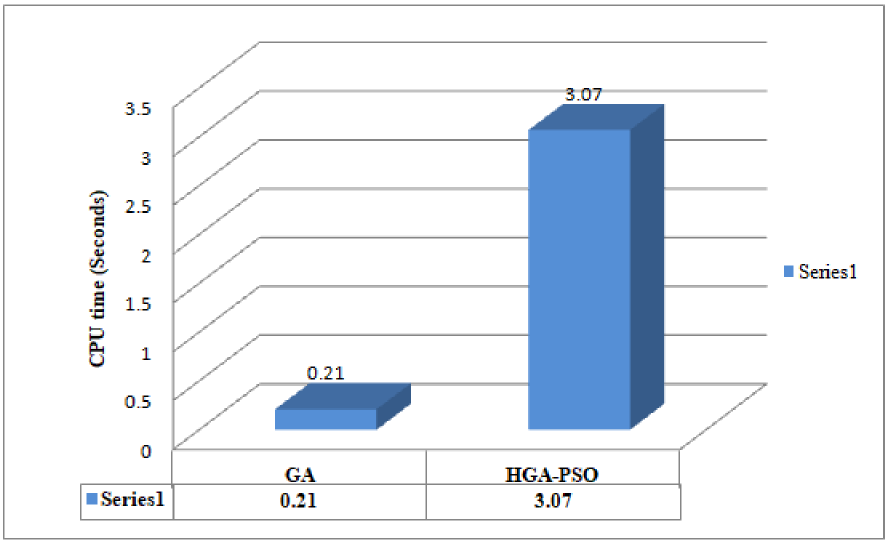

Figure 4: Flow chart for genetic algorithm

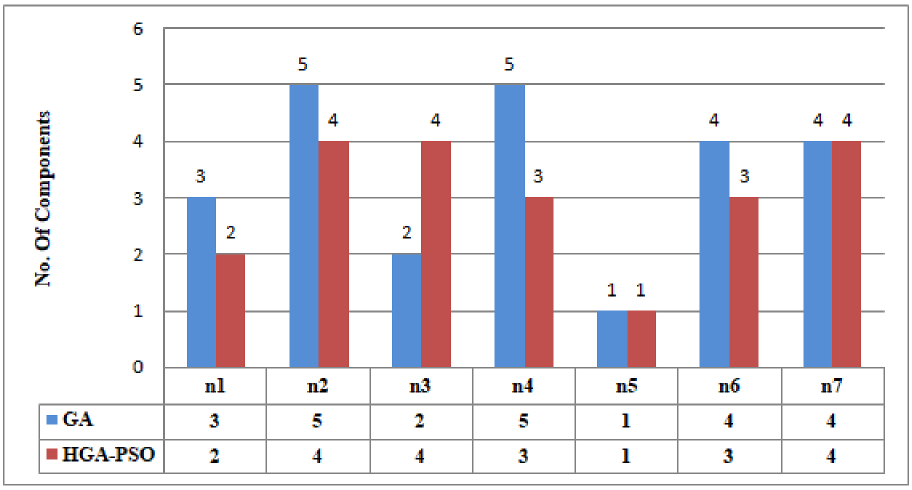

Figure 5: Flow chart for genetic algorithm

5. CONCLUSION

Now a day there is massive use of complex systems due to rapid industrialization, which demands the much more reliable subsystems or machines for the longevity of system and qualitative production. In this paper, two algorithms namely Genetic algorithm i.e. GA and Hybrid genetic & particle swarm optimization (HGA-PSO) are applied on redundancy allocation (RAP) problem of tablet medicine manufacturing system in Yaris Pharmaceuticals in an effort to enhance the reliability of system under given cost constraint. The main aim of present research is to maximize the reliability of system is satisfied by HGA-PSO which is illustrated in table 4. Comparative analysis of performance of both the algorithms is done and it is observed that proposed HGA-PSO is performing better than GA in terms of reliability but the computation time (CPU time) is 3.07 seconds which is higher than GA's CPU time. CPU time depends on different algorithms; if hybrid algorithm is implemented then it extracts solution in high CPU time as compared to single algorithm. The system reliability is enhanced by 63.10% after applying the combination of two algorithms i.e. HGA-PSO (table 4).

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