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Reliability Optimization of Redundancy Allocation Problem of a Series-parallel System using NAQPSO Algorithm in Triangular Neutrosophic Environment

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Abstract
In the literature, reliability optimization of a redundancy allocation problem is a significant field of study. The major goal of this kind of issue is to increase the system's reliability. Our goal in this study is to increase the reliability of a redundancy allocation problem with time-dependent component reliabilities while taking single valued triangular neutrosophic numbers into account for the control parameters. An innovative attractor quantum particle swarm optimization is utilized to softly compute the maximum of the n stage series-parallel system. To further illustrate how sensitive the suggested algorithm is to the neutrosophic atmosphere, a numerical problem is solved.
Keywords: Redundancy Allocation Problem (RAP), NAQPSO Algorithm, Single Valued Triangular Neutrosophic Number (SVTNN), Average Beta-uniform Distribution Method of Crispification, Series-parallel System

1. Introduction

The term reliability is very often used in our daily life. From the family of human beings to the industrial sectors or managements are deeply influenced by reliability. Reliability is a chance or probability of a system that happens continuously as the operation time of the system moves. After the Second World War, it becomes a challenge for the society that how to improve the reliability of a system in addition to different obstacles.

It is seen that the researchers consider the components of a reliable system as constant in their corresponding researches. But it is not always good to take the reliability components as constants because reliability is time dependent in our existing systems. Very few works are done considering the time dependent component reliabilities of a system under redundancy in each subsystem in the literature. In redundancy allocation problem (RAP), the decision variables are considered as redundancies.

Obtaining maximum system reliability in a redundancy allocation problem means to find the solution as redundant vector of the whole reliable system subject to time dependent variable in each of the subsystem [11, 22, 24, 27, 39, 41]. several evolutionary algorithms and modified versions of these algorithms [36, 37] are employed to solve such kind of problems.

For optimizing a reliable system heuristic method [32], reduced gradient method [15], surrogate constraints algorithm [31] were implemented for different allocating models. Different optimizing techniques are reported in the literature by Chern and Jan [7] and Misra [29].

Kim et al. and Misra et al. [18, 29] used their heuristic algorithms to obtain the solution of reliability optimization problems. A series system is used by Huang [14] to solve a multi-objective decision-making reliability optimization issue. Sung and Cho's [40] reliability optimization incorporates many options as well as certain financial limitations. Mahapatra and Roy [23] use the fuzzy multi-objective mathematical programming technique to solve reliability optimization challenges. To tackle the redundancy allocation problem, Gupta et al. [11] used the penalty technique in an interval context. The stochastic reliability optimization in interval context was described by Bhunia et al. [5]. Sahoo et al. [38] took the risk of presenting an application of GA in tackling reliability optimization problems. The generalized fuzzy number is used to determine the optimal redundancy of a series-parallel system [22]. Several researchers [8, 9, 25, 26, 46, 47, 48] have considered interval environments for obtaining optimal solution in their proposed reliable systems. Besides, many of them [6, 10, 39] have employed their soft

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computing techniques (PSO, GA) using fuzzy atmospheres to solve reliability optimization problems.

A multi-objective redundancy allocation problem was solved using particle swarm optimization by Khalili-Damghani et al. [17]. PSO and intuitionistic fuzzy environments were employed by Garg and Rani [10] in finding reliability of an industrial system. Sahoo et al. [37] used a GA to solve a reliable series system in fuzzy atmosphere. Jia et al., Kumar et al. and Xi et al. [16, 19, 20, 21, 42] developed novel QPSO algorithms to solve nonlinear optimization problems.

Recently, consideration of intuitionistic fuzzy environments for solving differently designed reliable systems such as series, series-parallel, bridge etc. are found in the study of various researchers [3, 4, 8, 33, 34].

In all the above-mentioned existing studies of literature, it was not seen to consider the reliability optimization problems with time dependent reliability components with variable failure rates. Very few researchers indulged their researches considering the reliability components as time dependent as well as random failure rates. Some of these works were done by various renowned researchers [12, 13, 28, 30, 35, 43, 44]. Ardakan et al. [1] and Ahmadivala et al. [2] considered time depending reliability components in their chosen reliability optimization problems. Transfer learning is implemented by Zafar and Wang [43] taking reliability optimization problem with time dependent reliability components. Recently,

In this paper, we want to find the system reliability considering the time dependent components. The reliability of each component has to be diminished exponentially with respect to time. A new imprecise environment is taken under consideration to make the problem more realistic and for handling the diverse situations. The crisp and neutrosophic models are formulated separately. In this study, a series-parallel system with n stages is taken subject some restrictions. To clarify the effectiveness of the proposed algorithm as well as the imprecise environment, a numerical problem is illustrated via tableau and graphs.

The rest of this paper is organized as follows: In section 2, the necessary assumptions and symbols are kept. The definitions of neutrosophic set along with its different variants are included in section 3. Section 4 provides the crispification techniques for the considered single valued triangular neutrosophic number. The nonlinear integer programming problem is formulated in section 5. The solution methodology such as the integration handling technique, constrained handling technique and soft computing technique are included in section 6. For the clarification of our proposed environments and algorithms, a numerical example is taken and sensitivities are drawn graphically in section 7. Outcomes associated with this study are analyzed with the inclusion of section 8. Section 9 concludes the whole work done in this paper with some future scopes.

2. Assumptions and Notation

2.1 Assumptions: In this paper, the following assumptions are considered.

i. Series-parallel reliability system is chosen.
ii. All the redundant components are active and non-repairable.
iii. Identical components are considered for each subsystem.
iv. Reliability components are taken as time dependent.
v. The failure rate of each component is constant.
vi. System reliability is independent of the failure of subsystem's components.
vii. Reliability components follows exponential distribution which diminishes as time goes.

2.2 Notation: The following notations are used throughout this paper.

Symbols	Meanings
$\hat{P}$	*Single valued triangular neutrosophic number*
$T_{\hat{P}}(x), I_{\hat{P}}(x), F_{\hat{P}}(x)$	*Truth membership, Indeterminacy membership and False membership functions w.r.t* $\hat{P}$
x_i	*Number of active redundant components in i-th subsystem* $(i = 1,2,\dots,m)$
$x = (x_1, x_2, \dots, x_m)$	*Redundancy vector*
$R_s(x,k,t)$, $\hat{R}_s(x,k,t)$	*System reliability functions in crisp and neutrosophic environments*
$a_j(x, x_2, \dots, x_n)$, $\hat{a}_j(x_1, x_2, \dots, x_n)$	*Crisp, neutrosophic constraint's usability functions*

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$a_j(x,x_2,\ldots,x_n)$, $\hat{a}_j(x_1,x_2,\ldots,x_n)$	*Crisp, neutrosophic constraint's usability functions*
q_j, $\hat{q}_j$	*Crisp and neutrosophic availability of resources of j-th constraint*
l_i, u_i	*Lower and upper bounds of z_i*
M	*Particle' size in NAQPSO algorithm*
$f(p_{ibest})$	*Best fitness value of i-th particle*
m_{best}	*Mean best position vector at τ -th iteration*
$Y^{\tau}{}_{iD}$	*The i-th particle in the D-th swarm at τ-th iteration*

3. Some Definitions

3.1 Neutrosophic Set (NS)

A neutrosophic set, $\tilde{P}$ in a universe of discourse Y is defined with respect to three functions, namely truth-membership function $T_{\tilde{P}}(y)$, indeterminacy-membership function $I_{\tilde{P}}(y)$ and falsity-membership function $F_{\tilde{P}}(y)$ such that $T_{\tilde{P}}(y): Y \to (0-,\ 1+)$, $I_{\tilde{P}}(y): Y \to (0-,\ 1+)$ and $F_{\tilde{P}}(y): Y \to (0-,\ 1+)$. Here, $0- \le SupT_{\tilde{P}}(y) \le SupI_{\tilde{P}}(y) \le SupF_{\tilde{P}}(y) \le 3+$, as there is no restriction on the sum of $T_{\tilde{P}}(y)$, $I_{\tilde{P}}(y)$ and $F_{\tilde{P}}(y)$.

3.2 Single Valued Triangular Neutrosophic Number (SVTNN)

A single-valued triangular neutrosophic number (SVTNN) $\hat{P}$ with the set of parameters $n_{11} \le m_{11} \le l_{11} \le n_{21} \le m_{21} \le l_{21} \le l_{31} \le m_{31} \le n_{31}$ is defined as given below.

$\hat{P} =< (l_{11}, l_{21}, l_{31}), (m_{11}, m_{21}, m_{31}), (n_{11}, n_{21}, n_{31}) >$ in the set of real numbers R.

The truth membership, indeterminacy membership and falsity membership degree of $\hat{P}$ are defined by the equations (1), (2) and (3) respectively.

$$T_{\hat{P}}(y) = \begin{cases} \dfrac{y - l_{11}}{l_{21} - l_{11}}, & l_{11} \le y \le l_{21} \\ \dfrac{l_{31} - y}{l_{31} - l_{21}}, & l_{21} \le y \le l_{31} \\ 0, & \text{elsewhere} \end{cases} \qquad (1)$$

$$I_{\hat{P}}(y) = \begin{cases} \dfrac{y - m_{11}}{m_{21} - m_{11}}, & m_{11} \le y \le m_{21} \\ \dfrac{m_{31} - y}{m_{31} - m_{21}}, & m_{21} \le y \le m_{31} \\ 0, & \text{elsewhere} \end{cases} \qquad (2)$$

$$F_{\hat{P}}(y) = \begin{cases} \dfrac{y - n_{11}}{n_{21} - n_{11}}, & n_{11} \le y \le n_{21} \\ \dfrac{n_{31} - y}{n_{31} - n_{21}}, & n_{21} \le y \le n_{31} \\ 0, & \text{elsewhere} \end{cases} \qquad (3)$$

4. Beta and Uniform Distribution Method of Crispification

According to Rahmani et al. [45], the crispification of the triangular fuzzy number $\breve{A} = (a_1, a_2, a_3)$ is given by the following formula.

$$(Beta)_{\breve{A}} = \frac{(a_1 + a_2 + a_3)}{3}.$$

Thus, the crispification formulae for the truth membership, indeterminacy membership and falsity membership degree of single valued triangular neutrosophic number $\hat{P}$ are given as below.

$$(Beta)_{T_{\hat{P}}} = \frac{(l_{11} + l_{21} + l_{31})}{3},$$

$$(Beta)_{I_{\hat{P}}} = \frac{(m_{11} + m_{21} + m_{31})}{3},$$

$$(Beta)_{F_{\hat{P}}} = \frac{(n_{11} + n_{21} + n_{31})}{3}.$$

Now, taking the average of these three types of memberships, the corresponding modified Beta-uniform distribution method becomes as follows:

$$(Ave_{Beta})_{T_{\hat{P}}} = \frac{(n_{11} + m_{11} + l_{11} + n_{21} + m_{21} + l_{21} + l_{31} + m_{31} + n_{31})}{9}.$$

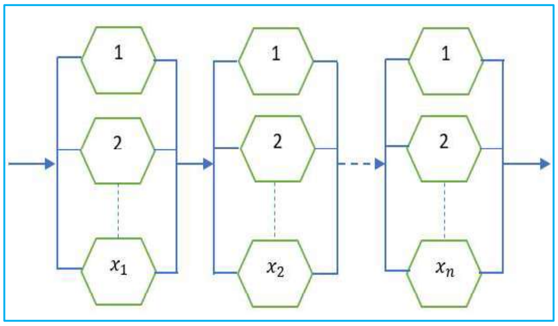
5. Problem Formulation

A series-parallel system (Fig.1) with n number of subsystems is considered. All the components connected to the system as well as subsystems are time dependent. The problem thus formulated, represents a redundancy allocation problem. Our main purpose is to find the maximum value of the system reliability under some restrictions. The redundant components of the respective subsystems construct the required solution vector to the redundancy allocation problem.

In crisp environment the time dependent RAP for series-parallel system is given by the equation (4).

where, $x = (x_1, x_2, \dots, x_n)$ represents the vector of redundancy and $x_i\ (\geq 0)$ is an integer and $t \in (0, 100]$. Here, $r_i(t) = e^{-kt}$ is the reliability of the i-th component of the reliable system and k is the failure rate of the same component.

Fig. 1: Series-parallel system with n stages



The corresponding neutrosophic model is formulated as given below.

$$Maximize\ R_S(t) = \prod_{i=1}^{n}[1 - (1 - e^{-kt})^{x_i}] \quad (5)$$

subject to

$$\hat{a}_j(x_1, x_2, \dots, x_n) \leq \hat{q}_j, j = 1,2, \dots, m$$

$$l_i \leq x_i \leq u_i, i = 1,2, \dots, n\ .$$

where, $x = (x_1, x_2, \dots, x_n)$ represents the vector of redundancy and $x_i\ (\geq 0)$ is an integer and $t \in (0, 100]$. Here '^' is used to represent the neutrosophic values of the parameters involved in the constraints.

6. Solution Procedure

The considered reliability optimization problem is an integer nonlinear programing problem with some constraints. In this study, the main objective is to maximize the system reliability $\mathcal{R}_s(x, \mu, t)$ subject the redundancy lying in each subsystem. Simpson's 1/3rd method is employed to integrate the reliability function in the range (0, 100] to overcome the difficulty in classical technique to obtain the exact value of integration. Besides, Big-M penalty technique is implemented as a tool for handling the constraints involved in the optimization problems. After that the unconstrained optimization problem is solved using a novel attractor based PSO algorithm.

6.1 Novel Attractor Particle Swarm Optimization (NAQPSO)

The computational procedure of NAQPSO algorithm is given as follows:

Step 1: Introduce Y as initialized particle and put $Y_{iD} = P_{iD}$.

Step 2: Generate P_{iD} and P_{gD} using the function of fitness and the best position of the particles respectively.

Step 3: Calculate the average optimal position of all the particles using the equation

$mbest =$
$\frac{1}{M}\sum_i^M pbest_i =$
1MiMpbesti,1,1MiMpbesti,2,..., 1MiMpbesti,d.

Step 4: obtain the value of R_{iD} (Novel attractor) using the equation, $R_{iD} = \frac{L_c - C_c}{L_c}\beta P_{iD} + \frac{C_c}{L_c}(1-\beta)P_{gD}$, $\beta \sim U(0,1)$; where, L_c is the total number of iterations and C_c is the current number of iterations.

Step 5: Employ the equation, $Y_{iD} = R_{iD} \pm \alpha|mbest_D - Y_{iD}| \times \log(1/u)$, $u \sim U(0,1)$ to get the new position Y_{iD}; where, α is called the contraction-expansion coefficient.

Step 6: Reiterate the steps 2–5 unless the convergency criterion of the algorithm is met.

6.2 Integration Handling Technique

Due to the complexity of integrands, implementation of traditional analytical method for finding the integrations associated to the proposed problems, becomes a tedious work. To overcome this situation, we are interested to employ numerical technique. Simpson's 1/3rd rule is being used to find the integrations related to our considered problem. This integration formula is given by equation (6).

$$\int_p^q F(y)dy = \frac{l}{3}\left((v_0 + v_m) + 4(v_1 + v_3 + \dots + v_{m-1}) + 2(v_2 + v_4 + \dots + v_{m-2})\right) \quad (6)$$

Here, $y_0, y_1, \dots, y_m$ are the points at which the interval $[p, q]$ is divided into m equal parts where m is a multiple of three and $v_0, v_1, \dots, v_m$ represents the corresponding ordinates, l represents the subintervals length and $l \geq 0$. There are 24 subintervals of equal length in the present exertion.

7. Numerical Example

$$Maximize\ R_S(t) = \prod_{i=1}^{4}[1 - (1 - e^{-kt})^{x_i}]$$

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subject to

$$\sum_{j=1}^{4} C_j\, x_j \le C_s\,,$$

$$\sum_{j=1}^{4} W_j x_j \le W_s,$$

where, $x_i \in \mathbb{N},\ r_i(t) = e^{-kt}, i = 1,2,3,4; t \in (0,100]$.

Table 1: Fixed parameters

j	C_j	W_j
1	1.2	5
2	2.3	4
3	3.4	8
4	4.5	7
$C_s = 56;$	$W_s = 120$	

Table 2: Representation of SVTNNs

j	$\widehat{C}_j$	$\widehat{W}_j$
1	<(1.1, 1.2, 1.3), (1.0, 1.12, 1.32), (0.85,1.11,1.34)>	<(4.5, 5, 5.2), (4.4, 4.8, 5.3), (4.2, 4.7, 4.9)>
2	<(2.2, 2.3, 2.4), (2.1, 2.21, 2.42), (1.98,2.0, 2.45)>	<(3.5, 4, 4.2), (3.4, 3.8, 4.3), (3.2, 3.6, 4.6)>
3	<(3.3, 3.4, 3.5), (3.1, 3.38, 3.6), (2.9, 3.35, 3.7)>	<(7.8, 8, 8.2), (7.6, 7.92, 8.3), (7.5, 7.9, 8.4)>
4	<(4.4, 4.5, 4.6), (4.3, 4.4, 4.7), (4.1, 4.3, 4.9)>	<(6.8, 7, 7.2), (6.6, 6.9, 7.4), (6.5, 6.7, 7.5)>
$\widehat{C}_S =< (50, 56, 58), (48, 55, 59), (46, 53, 61) >$ $\widehat{W}_S =< (117, 120, 124), (113, 118, 125\ ), (111, 117.5, 127) >$		

Table 3: Crispified values of SVTNNs

j	$\mathbf{Ave}_{\mathbf{Beta}}(\widehat{C}_j)$	$\mathbf{Ave}_{\mathbf{Beta}}(\widehat{W}_j)$
1	1.148889	4.777778
2	2.228889	3.844444
3	3.358889	7.957778
4	4.466667	6.955556
$\mathbf{Ave}_{\mathbf{Beta}(\widehat{C}_j)} = \mathbf{54}$ $\mathbf{Ave}_{\mathbf{Beta}(\widehat{W}_j)} = \mathbf{119.1667}$		

8. Result Analysis

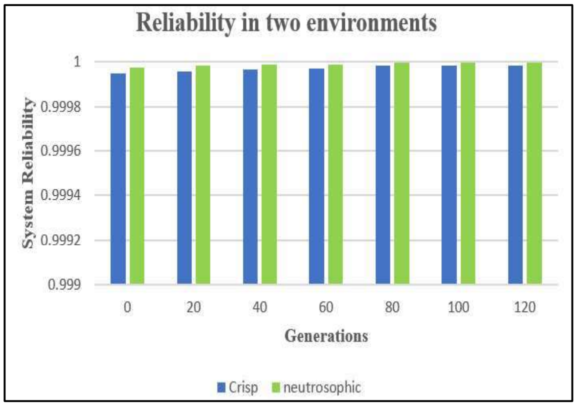
In this paper, a numerical problem is considered for testing the efficiency of the employed method to maximize the system reliability with respect to the redundant components. For solving the considered numerical problem with the help of NAQPSO algorithm, 30 runs are taken independently. Here the proposed NAQPSO algorithm is coded in C++ in a personal computer with Intel(R) Core (TM) i3-1005G1 CPU @ 1.20GHz 1.19 GHz processor, 4GB RAM in Linux operating system. In this NAQPSO, for solving the chosen example, the population size and the maximum number of generations are taken as 70 and 100 respectively. It is clear from the Table 4 that the maximum system reliability is obtained when the components failure rates are quadratic function of time.

Table 4: Comparison of the obtained results

Environments	Best found Rs	% of occurrence of best Rs	Worst found Rs	% of occurrence of worst Rs	Average Rs	Standard deviation of Rs	Average CPU time (sec)	Number of runs
Crisp	0.99952457	45	0.9991654	21	0.9993123	0.00000521	0.00879	30
Neutrosophic	**0.9998967**	50.33	0.9996716	11	0.999526586	0.00007120	0.056	30

The optimal value of the objective function in neutrosophic environment exceeds the optimal value in crisp environment. In case of crisp environment, the maximum system reliability is 0.99952457 and in case of neutrosophic environment, it is 0.9998967. Figure 2 shows the

Fig. 2: Reliability w.r.t Generations of NAQPSO Algorithm



From Fig. 2, it is clear that crispified data for the single valued triangular neutrosophic environment yields better output than the fixed parameters involved in the considered example for the proposed NAQPSO algorithm.

9. Concluding Remarks

We investigated a more realistic and practical form of the redundancy allocation problem in this paper, which addresses time-dependent component reliabilities. The soft computing technique of NAQPSO has been used to solve the numerical problem in crisp and neutrosophic environment. We are able to find significant results on maximizing the system reliability in comparison to the works done previously. Throughout this work we have seen that neutrosophic environment produces a remarkable result for the proposed problem. Besides, our proposed soft computing technique plays an important role in obtaining better result than the existing soft computing techniques.

For future study, researchers have a scope to consider the uncertain environments as type-2 fuzzy, nonlinear intuitionistic fuzzy etc. for the optimization of reliability redundancy allocation problems. Furthermore, other heuristic or metaheuristic algorithms like ABC, GA can be applied for solving the considered optimization problem.

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References

[1]. M Ahmadivala, C Mattrand, N Gayton, A Dumasa, T Yalamas, and A Orcesi, Application of AK-SYS method for time-dependent reliability analysis, 24e`me Congre`s Franc¸ais de Me´canique Brest, 26 au 30 Aou^t. (2019).

[2]. MA Ardakan, Z Mirzaei, AZ Hamadani, and EA Elsayed, Reliability optimization by considering time dependent reliability for components, John Wiley & Sons Ltd, Qual Reliab Engng Int, 33, 1641–1654 (2017).

[3]. E Baloui Jamkhaneh, System reliability using generalized intuitionistic fuzzy exponential lifetime distribution, Int J Soft Comput Eng, 7, 2231–2307 (2017).

[4]. N Bhattacharyee, R Paramanik, and SK Mahato, Optimal redundancy allocation for the problem with chance constraints in fuzzy and intuitionistic fuzzy environments using soft computing technique, Annals Opt Theor Prac, 3(2), 25-47 (2020).

[5]. AK Bhunia, L Sahoo, and D Roy, Reliability stochastic optimization for a series system with interval component reliability via genetic algorithm, Appl Math Comput, 216, 929–939 (2010).

[6]. DX Chen, Fuzzy reliability of the bridge circuit system, Syst Eng-Theory Pract, 11, 109–112 (1977).

[7]. MS Chern and RH Jan, Reliability optimization problems with multiple constraints, IEEE Trans Reliab, 35(4), 431–436 (1986).

[8]. H Garg, A novel approach for analyzing the reliability of series-parallel system using credibility theory and different types of intuitionistic fuzzy numbers, J Braz Soc Mech Sci Eng, 38(3), 1021–1035 (2016).

[9]. H Garg, Performance analysis of an industrial system using soft computing based hybridized technique, J Braz Soc Mech Sci Eng, 39(4), 1441–1451 (2017).

[10]. H Garg and M Rani, An approach for reliability analysis of industrial systems using PSO and IFS technique, ISA Trans Elsevier, 52(6), 701–710 (2013).

[11]. R Gupta, AK Bhunia, and D Roy, A GA based penalty function technique

technique, ISA Trans Elsevier, 52(6), 701–710 (2013).
[11]. R Gupta, AK Bhunia, and D Roy, A GA based penalty function technique for solving constrained redundancy allocation problem of series system with interval valued reliabilities of components, J Comput Appl Math, 232(2), 275–284 (2009).
[12]. AZ Hamadani and HA Khorshidi, System reliability optimization using time value of money, Int J Adv Manuf Technol, 66(14), 97–106 (2013).
[13]. Z Hu, and S Mahadevan, Time-dependent system reliability analysis using random field discretization, ASME J Mech Des, 137(10), 101-404 (2015).
[14]. H Huang, Fuzzy multi-objective optimization decision-making of reliability of series system, Microelectron Reliab, 37(3), 447–449 (1996).
[15]. Hwang CL, Tillman FA, Kuo W (1979) Reliability optimization by generalized Lagrangian-function based and reduced-gradient methods. IEEE Trans Reliab 28:316–319
[16]. Jia P, Duan S, Yan J (2015), An Enhanced Quantum-Behaved Particle Swarm Optimization Based on a Novel Computing Way of Local Attractor. Information, 6, 633-649; doi:10.3390/info6040633
[17]. Khalili-Damghani K, Abtahi AR, Tavana M (2013) A new multi objective particle swarm optimization method for solving reliability redundancy allocation problems. Reliab Eng Syst Saf 111:58–75
[18]. Kim JH, Yum BJ (1993) A heuristic method for solving redundancy optimization problems in complex systems. IEEE Trans Reliab 42(4):572–578
[19]. Kumar N, Mahato SK, Bhunia AK (2020) A new QPSO based hybrid algorithm for constrained optimization problems via tournamenting process. Soft Comput 24:11365–11379. https://doi.org/ 10.1007/s00500-019-04601-3
[20]. Kumar N, Shaikh AA, Mahato SK, Bhunia AK (2021a) Applications of new hybrid algorithm based on advanced cuckoo search and adaptive Gaussian quantum behaved particle swarm optimization in solving ordinary differential equations. Expert Syst Appl 172:114646
[21]. Kumar N, Shaikh AA, Mahato SK, Bhunia AK (2021b) Development of some techniques for solving system of linear and nonlinear equations via hybrid algorithm. Expert Syst e12669
[22]. Mahapatra GS, Roy TK (2011) Optimal redundancy allocation in series-parallel system using generalized fuzzy number. Tamsui Oxford J Inform Math Sci 27(1):1–20
[23]. Mahapatra GS, Roy TK (2012) Reliability evaluation of bridge system with fuzzy reliability of components using interval nonlinear programming. Electron J Appl Stat Anal 5(2):151–163
[24]. Mahato SK, Bhattacharyee N, Paramanik R (2020) Fuzzy reliability redundancy optimization with signed distance method for defuzzification using genetic algorithm. Int J Oper Res (IJOR) 37(3):307–323
[25]. Mahato SK, Bhunia AK (2016) Reliability optimization in fuzzy and interval environments: applications of genetic algorithm in reliability optimization in crisp, stochastic, fuzzy & interval environments. LAP LAMBERT Academic Publishing
[26]. Mahato SK, Sahoo L, Bhunia AK (2012) Reliability-redundancy optimization problem with interval valued reliabilities of components via genetic algorithm J. Inf Comput Sci (UK) 7(4):284–295
[27]. Mahato SK, Sahoo L, Bhunia AK (2013) Effects of defuzzification methods in redundancy allocation problem with fuzzy valued reliabilities via genetic algorithm. Int J Inf Comput Sci 2(6):106–115
[28]. Matteo F, Carlo G, Federico P, Enrico Z (2021) Time-dependent reliability analysis of the reactor building of a nuclear power plant for accounting of its aging and degradation. Reliab Eng Syst Safety 205:107173
[29]. Misra B, Sharma U (1991) An efficient algorithm to solve integer

programming problems arising in system-reliability design. IEEE Trans Reliab 40(1):81–91
[30]. Mori Y, Ellingwood BR (1993) Time-dependent system reliability analysis by adaptive importance sampling 12(1): 59–73
[31]. Nakagawa Y, Miyazaki S (1981) Surrogate constraints algorithm for reliability optimization problems with two constraints. IEEE Trans Reliab 30(2):181–184
[32]. Nakagawa Y, Nakashima K (1977) A heuristic method for determining optimal reliability allocation. IEEE Trans Reliab 26(3):156–161
[33]. Paramanik R, Kumar N, Mahato SK. Solution for the optimality of an intuitionistic fuzzy redundancy allocation problem for complex system using Yager's ranking method of defuzzification with soft computation. International Journal of System Assurance Engineering and Management 2022; 13(2); 615-624.
[34]. Paramanik R, Mahato SK, Bhattacharyee N, Supakar P, Sarkar B (2020) Multiple Constrained Reliability-Redundancy Optimization under Triangular Intuitionistic Fuzziness Using a Genetic Algorithm. In Reliability Management and Engineering (pp. 205-232), CRC Press
[35]. Ruigang Y, Wenzhao L, Guangli Z, Yuzhen L, Weichen J (2021) Interval non-probabilistic time-dependent reliability analysis of boom crane structures. J Mech Sci Tech 35(2):535–544
[36]. L Sahoo, AK Bhunia, and PK Kapur, Genetic algorithm based multi-objective reliability optimization in interval environment, Comput Ind Eng, 62(1), 152–160 (2012).
[37]. L Sahoo, AK Bhunia, and SK Mahato, Optimization of system reliability for series system with fuzzy component reliabilities by genetic algorithm, J Uncertain Syst, 8(2), 136–148 (2014).
[38]. L Sahoo, AK Bhunia, and D Roy, A genetic algorithm-based reliability redundancy optimization for interval valued reliabilities of components, J Appl Quant Methods, 5(2), 270–287 (2010).
[39]. L Sahoo, AK Bhunia, and D Roy, Reliability optimization with high and low-level redundancies in interval environment via genetic algorithm, Int J Syst Assur Eng Manage, (2013). https://doi.org/ 10.1007/s13198-013-0199-9
[40]. CS Sung and YK Cho, Reliability optimization of a series system with multiple choice and budget constraints, Eur J Oper Res, 127(1), 159–171 (2000).
[41]. FA Tillman, CL Hwang, and W Kuo, Optimization of system reliability, Marcel Dekker, New York (1980).
[42]. M Xi, J Sun, and Xu Wenbo, An improved quantum-behaved particle swarm optimization algorithm with weighted mean best position, Appl Math Comput, 205,751–759 (2008).
[43]. T Zafar and Z Wang, Time-dependent reliability prediction using transfer learning, Struct Multidiscip Optim, 62, 147–158 (2020). https://doi.org/10.1007/s00158-019-02475-5
[44]. Zhu and Zhifu, Efficient time-dependent system reliability analysis, Doctoral Dissertations 2552 (2016). https://scholarsmine.mst.edu/doctoral_dissertations/2552
[45]. A Rahmani, F Hosseinzadeh Lotfi, M Rostamy-Malkhalifeh, and T Allahviranloo, A New Method for Defuzzification and Ranking of Fuzzy Numbers Based on the Statistical Beta Distribution, Hindawi Publishing Corporation Advances in Fuzzy Systems, (2016). http://dx.doi.org/10.1155/2016/6945184
[46]. R Paramanik, N Kumar, N Bhattacharyee, and SK Mahato, Optimization of imprecise redundancy allocation problems for a complicated system using soft computing technique, Journal of Scientific Enquiry, 2(9), 58-67 (2022).
[47]. R Paramanik, SK Mahato, Reliability optimization of fully fuzzy redundancy allocation problem in uncertain environment via soft

computing technique, Journal of Scientific Enquiry, 2(8), 48-57 (2022)
[48]. R Paramanik, SK Mahato, N Kumar, N Bhattacharyee, and R Gupta, Optimization of system reliability for multi-level RAPs in intuitionistic fuzzy atmosphere using genetic algorithm, Results in Control and Optimization, 9(2), (2022).