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Research Article

Optimization the Availability of a System with Short Circuit and Common Cause Failures

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Abstract

Redundancy allocation problem is one of the most important problems in *reliability* field. In this problem, the reliability and availability of the systems are maximized via allocating redundant components to subsystems. Many different assumptions are considered to draw this problem near to real conditions. In this paper, we work on a system with k-out-o-n subsystems as well as considering short circuit and common cause failures for the components in each subs in addition to ordinary components failures. Obviously, the components are repairable. We present a Markov model to show the effects of these two failures on system availability. For solving the presented model, we used Biographic Based Optimization (BBO) algorithm and minimize the system cost to achieve the predetermined system availability. We used the BBO algorithm for calculating the availability of the system, and response surface methodology for tuning the algorithm parameters.

Keywords : Availability; Short circuit; Common cause failure; K-out-of-n; repairable; Biographic based optimization algorithm

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1 Introduction

REliability is one of the most important features of each system. Many researchers have tried to maximize system reliability by increasing components failure rates and adding redundant components to the system. RAP (Redundancy Allocation Problem) is a problem that increases system reliability via adding some redundant components to each subs. This problem has some constraints like system weight, cost, etc. In this paper we work on a system with s serially connected k-out-of-n subs. The components in each subs are repairable and have constant failure rate. In addition to ordinary failures, the components have two other failure modes: short circuit failure and common cause failure. The major studies that have been conducted so far are summarized in Table 1.

Short circuit failure for an electrical system happened when a trouble happened and lets electric current goes on an unwelcomed direction. CCF (Common Cause Failure) happens for more than one component at a moment. The causes of CCF are environmental factors like changing electrical current. Moore and Shannon was first stud-

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Table 1: Major studies on systems with standby redundancy.

Paper	Redundancy strategy			Failure rate distribution
	Strategy	Switching	Component	
Albright and Soni [?]	Standby	Perfect	Homogenous	Exponential
Robinson and Neuts [?]	Standby	Perfect	Homogenous	PH-type
Gurov and Utkin [?]	Standby	Imperfect	Homogenous	Arbitrary
Coit [?]	Active or Standby	Imperfect	Homogenous	Erlang
Azaron et al. [?]	Standby	Perfect	Heterogeneous	Erlang
Sayeghi et al. [?]	Active or Standby	Imperfect	Homogenous	Exponential

ied CCF for three state components; two failure modes and one workings state [?]. Price [?] studied the reliability of the three state components in a series-parallel systems and tried to optimize the system redundant components. Jenney and Sherwin [?] studied a system with series-parallel and parallel-series configuration with identical components and determined the relations between open failure and short circuit failure of components. They showed that if one of the components in a parallel system fails for a short circuit failure, the system stops working. Hagan [?] made a brief study on CCF and the some similar terms like “common disaster,” “systematic failures,” and “cross-linked failure.” In this decade, all the other terms have referred to CCF. In 1977, Dhillon [?] investigated CCF reasons in a system with two non-identical redundant components and determined the availability equations of the system. He considered that if one of the redundant components fails, this component will be repaired and added to system. He defined three types of failures for the components.

Dhillon [?] presented a model with three kinds of failures: short circuit, open failure, and CCF. When the system is active the failure is considered a repair state. He solved the system equations using Laplace transform and expanded these equations. Chung [?] presented a model with three kinds of failures and the components of repair and replacement possibility.

Table 2 contains a number of recent studies on reliability area, along with a summary of the model behaviors.

In this paper, we solved an RAP with k-out-of-n subs and repairable components. Also in addition to ordinary failure of components, CCF and short circuit failures are considered for components. For solving the presented model, BBO (Biographic Based Optimization) algorithm has been used. The paper comprises five sections. In the second section, we discuss Markov model. In the third section, the model definition is presented and section four deals with BBO algorithm. A numerical example is presented in section five and the last part is devoted to conclusion and further studies.

2 Markov model

Markov process is a process in which the future probabilities only depend on the process situation in the present. If the time is divided into past, present and future, the future of the process only depends on the present and not the past. Three principles of Markov process are being stationary of the process states, identifiable and memorylessness of system states. Because the components in this paper have constant failure rate, all the Markov model necessaries are established. Figure ?? illustrates the states of a k-out-of-n system with CCF and short circuit failures (Dhillon) [?].

3 System definition

3.1 Parameters of the model

i : Subsystem component index, $i = 1, 2, ..., n$,

Table 2: Some recent studies on reliability area

Authors	Published year	State	Elements type	Algorithm	Objective setting	Failure rate
Sharifi et al. [?]	2005	Binary	Homogeneous	Markov model	Single	Constant
Lins and Droguett [?]	2008	Binary	Heterogeneous	ACO	Multiple	Constant
Ouzineb et al. [?]	2008	Multistate	Homogeneous	TS	Single	Constant
Sharma and Agarwal [?]	2009	Multistate	Heterogeneous	ACO	Single	Constant
Lins and Droguett [?]	2009	Binary	Heterogeneous	GA	Multiple	Constant
Ouzineb et al. [?]	2011	Multistate	Heterogeneous	GA	Single	Constant
Ebrahimipour and Sheikhalishahi [?]	2011	Binary	Heterogeneous	PSO	Multiple	Constant
Lins and Droguett [?]	2011	Multistate	Heterogeneous	GA	Multiple	Constant
Garg and Sharma [?]	2012	Binary	Heterogeneous	GA	Multiple	Constant
Garg et al. [?]	2013	Binary	Heterogeneous	Bee colony	Single	Constant
Levitin et al. [?]	2013	Multistate	Heterogeneous	GA	Single	Constant
Maatouk et al. [?]	2013	Multistate	Heterogeneous	GA	Single	Constant
Chambari et al. [?]	2013	Binary	Heterogeneous	SA	Single	Constant
Gago et al. [?]	2013	Binary	Heterogeneous	Greedy, Walk back	Single	Constant
Ebrahimipour et al. [?]	2013	Binary	Heterogeneous	Fuzzy inference system (FIS)	Single	Constant
Liu et al. [?]	2013	Multistate	Heterogeneous	Imperfect repair model	Single	Constant
Khalili-Damghani	2014	Binary	Heterogeneous	e-constraint	Multiple	Constant
et al. [?]						
Guilani et al. [?]	2014	Multistate	Homogeneous	Markov model	Single	Constant
Sharifi et al. [?]	2015	Binary	Heterogeneous	GA, MA	Single	Time Number
Mousavi et al. [?]	2015	Multistate	Homogeneous	CE-NRGA	Multiple	Constant
Zaretalab et al. [?]	2015	Multistate	Homogeneous	MOSA	Multiple	Constant
Miriha et al. [?]	2017	Binary	Heterogeneous	NSGAII-MOEA/D	Multiple	Time

Table 3: Lower and upper bound of BBO algorithm parameter

	Lower value	Upper value
$N\ Pop$	24	50
$M - Max$	0.05	0.2
I	1	2
E	1	2

Table 4: Best solution of BBO algorithm parameter

	Best
$Npop$	46
$M - Max$	0.07515
I	1.4352
E	1.5037

Table 5: Failure rates of all kinds of components failures

i	Choice 1			Choice 2			Choice 3			Choice 4		
	λ_{i1}	α_{i1}	γ_{i1}	λ_{i2}	α_{i2}	γ_{i2}	λ_{i3}	α_{i3}	γ_{i3}	λ_{i4}	α_{i4}	γ_{i4}
1	0.0011	0.4216	0.0005	0.0007	0.2904	0.0004	0.0009	0.3772	0.0005	0.0005	0.2052	0.0003
2	0.0005	0.2052	0.0003	0.0006	0.2476	0.0003	0.0007	0.2904	0.0004	-	-	-
3	0.0016	0.6500	0.0008	0.0011	0.4216	0.0005	0.0014	0.5572	0.0007	0.0008	0.3336	0.0004
4	0.0019	0.7452	0.0009	0.0014	0.5572	0.0007	0.0016	0.6500	0.0008	-	-	-
5	0.0006	0.2476	0.0003	0.0007	0.2904	0.0004	0.0005	0.2052	0.0003	-	-	-
6	0.0001	0.0404	0.0001	0.0002	0.0808	0.0001	0.0003	0.1220	0.0002	0.0004	0.1632	0.0002
7	0.0009	0.3772	0.0005	0.0008	0.3336	0.0004	0.0006	0.2476	0.0003	-	-	-
8	0.0021	0.8428	0.0011	0.0011	0.4216	0.0005	0.0009	0.3772	0.0005	-	-	-
9	0.0003	0.1220	0.0002	0.0001	0.0404	0.0001	0.0004	0.1632	0.0002	0.0009	0.3772	0.0005
10	0.0019	0.7452	0.0009	0.0016	0.6500	0.0008	0.0011	0.4216	0.0005	-	-	-
11	0.0006	0.2476	0.0003	0.0005	0.2052	0.0003	0.0004	0.1632	0.0002	-	-	-
12	0.0024	0.9428	0.0012	0.0020	0.7940	0.0010	0.0016	0.6500	0.0008	0.0011	0.4216	0.0005
13	0.0002	0.0808	0.0001	0.0001	0.0404	0.0001	0.0003	0.1220	0.0002	-	-	-
14	0.0011	0.4216	0.0005	0.0008	0.3336	0.0004	0.0005	0.2052	0.0003	0.0001	0.0404	0.0001

Table 6: Repair rates of components

i	Choice 1			Choice 2			Choice 3			Choice 4		
	μ_{0i1}	μ_{ci1}	μ_{shi1}	μ_{0i2}	μ_{ci2}	μ_{shi2}	μ_{0i3}	μ_{ci3}	μ_{shi3}	μ_{0i4}	μ_{ci4}	μ_{shi4}
1	0.0042	0.0032	0.0021	0.0029	0.0022	0.0015	0.0038	0.0028	0.0019	0.0021	0.0015	0.0010
2	0.0021	0.0015	0.0010	0.0025	0.0019	0.0012	0.0029	0.0022	0.0015	-	-	-
3	0.0065	0.0049	0.0032	0.0042	0.0032	0.0021	0.0056	0.0042	0.0028	0.0033	0.0025	0.0017
4	0.0075	0.0056	0.0037	0.0056	0.0042	0.0028	0.0065	0.0049	0.0032	-	-	-
5	0.0025	0.0019	0.0012	0.0029	0.0022	0.0015	0.0021	0.0015	0.0010	-	-	-
6	0.0004	0.0003	0.0002	0.0008	0.0006	0.0004	0.0012	0.0009	0.0006	0.0016	0.0012	0.0008
7	0.0038	0.0028	0.0019	0.0033	0.0025	0.0017	0.0025	0.0019	0.0012	-	-	-
8	0.0084	0.0063	0.0042	0.0042	0.0032	0.0021	0.0038	0.0028	0.0019	-	-	-
9	0.0012	0.0009	0.0006	0.0004	0.0003	0.0002	0.0016	0.0012	0.0008	0.0038	0.0028	0.0019
10	0.0075	0.0056	0.0037	0.0065	0.0049	0.0032	0.0042	0.0032	0.0021	-	-	-
11	0.0025	0.0019	0.0012	0.0021	0.0015	0.0010	0.0016	0.0012	0.0008	-	-	-
12	0.0094	0.0071	0.0047	0.0079	0.0060	0.0040	0.0065	0.0049	0.0032	0.0042	0.0032	0.0021
13	0.0008	0.0006	0.0004	0.0004	0.0003	0.0002	0.0012	0.0009	0.0006	-	-	-
14	0.0042	0.0032	0.0021	0.0033	0.0025	0.0017	0.0021	0.0015	0.0010	0.0004	0.0003	0.0002

Table 7: Weight and cost of components.

i	k	Choice 1		Choice 2		Choice 3		Choice 4	
		C_{i1}	W_{i1}	C_{i2}	W_{i2}	C_{i3}	W_{i3}	C_{i4}	W_{i4}
1	1	1	3	1	4	2	2	2	5
2	2	2	8	1	10	1	9	-	-
3	1	2	7	3	5	1	6	4	4
4	2	3	5	4	6	5	4	-	-
5	1	2	4	2	3	3	5	-	-
6	2	3	5	3	4	2	5	2	4
7	1	4	7	4	8	5	9	-	-
8	2	3	4	5	7	6	6	-	-
9	3	2	8	3	9	4	7	3	8
10	3	4	6	4	5	5	6	-	-
11	3	3	5	4	6	5	6	-	-
12	1	2	4	3	5	4	6	5	7
13	2	2	5	3	5	2	6	-	-
14	3	4	6	4	7	5	6	6	9

Table 8: The results of algorithm

No.	Parameters	BBO Solution		
	$W_{\max}$	A	W	C
1	0.9144	180	112	180
2	0.9140	179	111	179
3	0.9135	178	112	178
4	0.9129	177	111	177
5	0.9122	176	108	176
6	0.9118	175	112	175
7	0.9102	171	109	174
8	0.9102	173	108	173
9	0.9076	172	108	172
10	0.9089	171	107	171
11	0.9078	170	108	170
12	0.9082	169	108	169
13	0.9049	167	111	168
14	0.9038	167	108	167
15	0.9031	166	110	166
16	0.9024	165	111	165
17	0.9018	164	111	164
18	0.8983	163	104	163
19	0.8981	162	106	162
20	0.8963	161	106	161

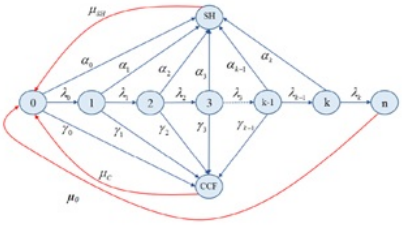

Figure 1: State space diagram of the system [?]

λ_i : Open failure rate of the subsystem components, $i = 1, 2, ..., k$,

α_i : Short circuit failure rate of subsystem components, $i = 1, 2, ..., k$,

γ_i : Common cause failure rate of subsystem components, $i = 0, 1, 2, ..., (k - 1)$,

$n_{Max,i}$: Upper limit of n_i,

μ_o : Open (failure) repair rate of subsystem components,

μ_{sh} : Short circuit (failure) repair rate of subsystem components,

μ_c : Common cause (failure) repair rate of subsystem components,

$P_i\,(t)$: The probability that the subsystem is in state i at the time t,

$P_{sh}\,(t)$: The probability that the subsystem is in short circuit failure mode at the time t,

$P_c\,(t)$: The probability that the subsystem is in CCF mode at the time t,

N : Total components number of the subsystem,

$A\,(t)$: System availability at the time t,

C : Upper limit of in hand budget,

n_i : Number of components in subsystem i,

z_i : Component type index for subsystem i, $z_i \in \{1, 2, ..., m_i\}$,

m_i : Maximum of component types for subsystem i,

k_i : Minimum number of components needed to be work in order to run subsystem i,

c_{ij} : The cost of j th component in subsystem i,

w_{ij} : The weight of j th component in subsystem i,

W : Upper limit of system acceptable weight,

t : Mission time of system,

3.2 System assumptions

The system assumptions are as follows:

- The system is series-parallel,
- The subsystems are k-out-of-n,
- Redundancy strategy of subsystem components are active,
- The components of each subsystem are identical,
- A subsystem is considered as repairable due to open failure, short circuit failure, and CCF,
- CCF may happens when at least two components working in a subsystem,
- Only one kind of failure may happen at a time,

3.3 Mathematical model

The equations of the subsystem states are as follows (Dhillon, 1978):

$$\begin{aligned}
p_0^{'}(t) &= -\left(\lambda_0+\alpha_0+\gamma_0\right)p_0(t)+p_{sh}(t)\,\mu_{sh}\\
&\quad + p_c(t)\,\mu_c + p_0(t)\,\mu_0\\
p_1^{'}(t) &= -\left(\lambda_1+\alpha_1+\gamma_1\right)p_1(t)+p_0(t)\,\lambda_0\\
p_2^{'}(t) &= -\left(\lambda_2+\alpha_2+\gamma_2\right)p_2(t)+p_1(t)\lambda_1\\
&\vdots\\
p_{k-1}^{'}(\mathrm{t}) &=- \left(\lambda_{\mathrm{k}-1}+\alpha_{\mathrm{k}-1}+\gamma_{\mathrm{k}-1}\right)p_{k-1}(t)\\
&\quad + p_{k-2}(t)\ \lambda_{k-2}2,3,4,\ldots,n-1\\
p_k^{'}(t) &= \left(\lambda_{\mathrm{k}}+\alpha_{\mathrm{k}}\right)p_k(t)+p_{\mathrm{k}-1}(t)\,\lambda_{\mathrm{k}-1}\\
\mathrm{k} &= (\mathrm{n}-1)\\
&\vdots\\
p_n^{'}(t) &= -\ \mu_0 p_n(t)+p_k(t)\lambda_k
\end{aligned}$$

Considering two types of short circuit and CCF (the system of Figure **??**, the equations are as follows (Dhillon, 1978):

$$p_{sh}^{'}(t) = -\mu_{sh}p_{sh}(t)+\sum_{i=0}^{k}\alpha_i p_i(t)$$

$$p_c^{'}(t) = -\mu_c p_c(t)+\sum_{i=0}^{k-1}\gamma_i p_i(t)$$

For both equations, $k = n-1$. Because the redundancy strategy of the subsystems is active, we have:

$$\begin{aligned}
&n = N \quad ; \quad N \geq 2\\
&\lambda_i = (\mathrm{N}\ -\ \mathrm{i})\,\lambda; \qquad \mathrm{i}\ = 1,2,\ldots,N
\end{aligned}$$

After solving the above equations, the probability of each state in each subsystem is determined. The mathematical model is as follows:

$$\begin{aligned}
&\max \mathrm{A(t)}\\
&\ \mathrm{St}:\\
&\qquad \sum_{i=1}^{N} c_{i.z_i}.n_i \leq C\\
&\qquad \sum_{i=1}^{N} w_{i.z_i}.n_i \leq W\\
&\qquad K_i \leq n_i \leq n_{\max,i}\\
&\qquad 1 \leq Z_i \leq m_i\\
&\qquad n_i, z_i \in N
\end{aligned}$$

4 Solving method

As RAP belongs to Np-hard problems, the metaheuristic algorithms are suitable for solving this problem. In this paper, we used BBO algorithm. This algorithm is inspired by the nature of biographic for searching in solution region. Simon [**?**] established the principle of this algorithm. This algorithm is a population based algorithm like GA. It means that this algorithm uses the single solutions for achieving the better solutions. In BBO, each environmental region is known as a particular member and has its own HSI[1] and the greater values for HSI defines the better solution. The regions with less HSI try to attract the properties of the region with higher HSI to improve themselves and be more similar to these regions. Two patterns are available for these emigrations: external immigration and internal immigration. The external immigration is proposed for the solutions with high HIS that share their properties and the internal immigrations are for the regions with less HIS that attract these properties. The external immigration rate is μ_i and the internal immigration rate is λ_i. The pseudo-code of BBO algorithm is as follows:

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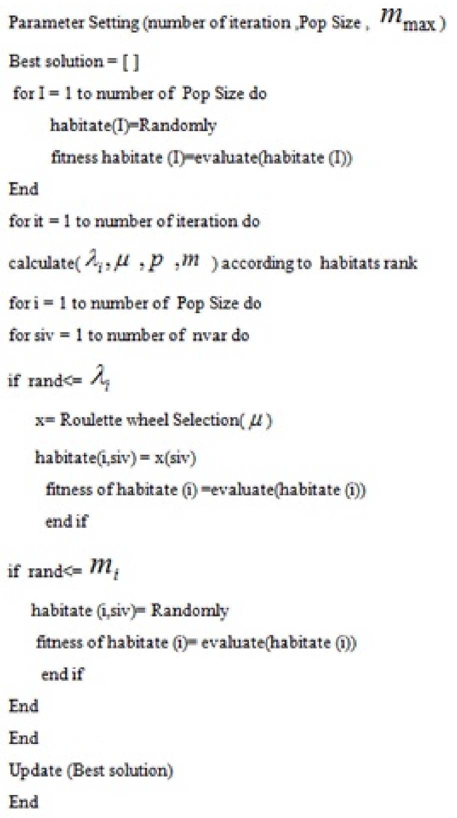
[1] Habitat Suitability Index



```
Parameter Setting (number of iteration ,Pop Size , $m_{max}$ )
Best solution = [ ]
 for I = 1 to number of  Pop Size do
        habitate(I)=Randomly
        fitness habitate (I)=evaluate(habitate (I))
End
for it = 1 to number of iteration do
calculate( $\lambda_i$ , $\mu$  , $p$  , $m$  ) according to  habitats rank
for i = 1 to number of  Pop Size do
for siv  = 1 to number of  nvar do
if  rand<=  $\lambda_i$
     x= Roulette wheel Selection( $\mu$ )
     habitate(i,siv) = x(siv)
       fitness of habitate (i) =evaluate(habitate (i))
       end if
if  rand<=  $m_i$
     habitate (i,siv)= Randomly
      fitness of habitate (i)= evaluate(habitate (i))
       end if
End
End
Update (Best solution)
End
```

Figure 2: Pseudo cod of BBO algorithm

5 Parameter tuning

The result of metaheuristic algorithms depends on the parameter values. We used RSM[2] presented by Montgomery [?]. BBO algorithm parameters are population size ($Npop$), mutation rate ($M-Max$), maximum internal immigration rate (I) and the maximum external immigration rate (E). The algorithm stop condition is 50 algorithm iterations. The lower and upper bond of these parameters are presented in Table 3 and the best solution of these parameters using RSM are presented in Table 4.

6 Numerical example

In this paper, we considered a system with 14 subsystems. For each subs, four different kind of component are available at most. Also three kinds of failures may happen: open failure, short circuit failure and CCF. By changing the maximum acceptable weight of the system we create 20 different problems and the entire problem was solved using BBO. The failure rates of the parameters are presented in Table 5 and the repair rates are in Table **??**. Other components parameters are presented in Table **??**. The result for 20 solved problems are presented in Table **??**.

7 Conclusion and further studies

Short circuit and CCF are the two important factors that need to tend to. In short circuit failure, K subsystems are used out of N subsystems. Since it is impossible for a component to fail in both short circuit and common cause, failure in each component of a system is regarded independent from the other components of that system. The simultaneous effect of these three failures in a k out of n system is very important. Due to the nature of common cause failure, if one component of the system fails, the whole subsystem will fail since the same kind of component is used in each subsystem. One of the objectives of reliability is designing systems with high reliability. Therefore, the reliability of the system has been improved using BBO.

In this paper, we work on a RAP with three kinds of failures. The subs are considered as k-out-of-n and the components are repairable. For calculating the availability of the system we used BBO algorithm and for tuning the algorithm parameters RSM has been used. It seems that this model works close to real world.

For further studies one can work on the same system with multistate components. Also this problem may be solved using different algorithms.

References

[1] S. C. Albright, A. Soni, Evaluation of costs of ordering policies in large machine repair problems, *Naval Research Logistics (NRL)* 31 (1984) 387-398.

[2] A. Azaron, Reliability evaluation of multicomponent cold-standby redundant systems, *Applied Mathematics and Computation* 173 (2006) 137-149.

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[2] Response Surface Methodology

[3] A. Chambari, An efficient simulated annealing algorithm for the redundancy allocation problem with a choice of redundancy strategies, *Reliability Engineering & System Safety* 119 (2013) 158-164.

[4] W. K. Chung, A k-out-of-n: G three-state unit redundant system with common-cause failures and replacements, *Microelectronics Reliability* 21 (1981) 589-591.

[5] D. W. Coit, Maximization of system reliability with a choice of redundancy strategies, *Iie Transactions* 35 (2003) 535-543.

[6] B. S. Dhillon, A common cause failure availability model, *Microelectronics Reliability* 17 (1978) 583-584.

[7] B. S. Dhillon, A k-out-of-N three-state devices system with common-cause failures, *Microelectronics Reliability* 18 (1978) 447-448.

[8] V. Ebrahimipour, M. Sheikhalishahi, Application of multi-objective particle swarm optimization to solve a fuzzy multi-objective reliability redundancy allocation problem, *in Systems Conference (SysCon), 2011 IEEE International* (2011).

[9] V. Ebrahimipour, S. Asadzadeh, A. Azadeh, An emotional learning-based fuzzy inference system for improvement of system reliability evaluation in redundancy allocation problem, *The International Journal of Advanced Manufacturing Technology* 11 (2013) 1-16.

[10] J. Gago, Exact cost minimization of a series-parallel reliable system with multiple component choices using an algebraic method, *Computers & Operations Research* 40 (2013) 2752-2759.

[11] H. Garg, S. Sharma, Multi-objective reliability-redundancy allocation problem using particle swarm optimization, *Computers & Industrial Engineering* 64 (2013) 247-255.

[12] H. Garg, M. Rani, S. Sharma, An efficient two phase approach for solving reliability redundancy allocation problem using artificial bee colony technique, *Computers & Operations Research* 40 (2013) 2961-2969.

[13] P. P. Guilani, Reliability evaluation of non-reparable three-state systems using Markov model and its comparison with the UGF and the recursive methods, *Reliability Engineering & System Safety* 129 (2014) 29-35.

[14] S. V. Gurov, L. V. Utkin, Cold standby systems with imperfect and noninstantaneous switch-over mechanism, *Microelectronics Reliability* 36 (1996) 1425-1438.

[15] E. W. Hagan, Common- Mode / Common - Cause Failure: A Review and Bibliography, *Nuclear safety information Center*, (1979).

[16] B. Jenney, D. Sherwin, Open & short circuit reliability of systems of identical items, *IEEE Transactions on Reliability* 35 (1986) 532-538.

[17] K. Khalili Damghani, A. R. Abtahi, M. Tavana, A Decision Support System for Solving Multi Objective Redundancy Allocation Problems, *Quality and Reliability Engineering International* 30 (2014) 1249-1262.

[18] G. Levitin, Reliability of series-parallel systems with random failure propagation time, *IEEE Transactions on Reliability* 62 (2013) 637-647.

[19] I. Lins, E. Droguett. Multiobjective optimization of redundancy allocation problems in systems with imperfect repairs via ant colony and discrete event simulation, *in Proceedings of the European Safety & Reliability Conference (ESREL). Valencia, Spain*, (2008).

[20] I. D. Lins, E. L. Droguett, Multiobjective optimization of availability and cost in repairable systems design via genetic algorithms and discrete event simulation, *Pesquisa Operacional* 29 (2009) 43-66.

[21] I. D. Lins, E. L. Droguett, Redundancy allocation problems considering systems with imperfect repairs using multi-objective genetic algorithms and discrete event simulation, *Simulation Modelling Practice and Theory* 19 (2011) 362-381.

[22] Y. Liu, A joint redundancy and imperfect maintenance strategy optimization for multi-state systems, *IEEE Transactions on Reliability* 62 (2013) 368-378.

[23] I. Maatouk, E. Chtelet, N. Chebbo, Availability maximization and cost study in multi-state systems, *in Reliability and Maintainability Symposium (RAMS), 2013 Proceedings-Annual*, IEEE.

[24] M. Miriha, Bi-objective Reliability Optimization of Switch-Mode k-out-of-n Series Parallel Systems with Active and Cold Standby Components Having Failure Rates Dependent on the Number of Components, *Arabian Journal for Science and Engineering* 42 (2017) 5305-5320.

[25] D. C. Montgomery, Design and Analysis of Experiments 6th Edition with Design Expert Software, (2004), John Wiley & Sons.

[26] E. F. Moore, C. E. Shannon, Reliable circuits using less reliable relays, *Journal of the Franklin Institute* 262 (1956) 191-208.

[27] S. M. Mousavi, Two tuned multi-objective meta-heuristic algorithms for solving a fuzzy multi-state redundancy allocation problem under discount strategies, *Applied Mathematical Modelling* 39 (2015) 6968-6989.

[28] M. Ouzineb, M. Nourelfath, M. Gendreau, Tabu search for the redundancy allocation problem of homogenous series parallel multi-state systems, *Reliability Engineering & System Safety* 93 (2008) 1257-1272.

[29] M. Ouzineb, M. Nourelfath, M. Gendreau, A heuristic method for non-homogeneous redundancy optimization of series-parallel multi-state systems, *Journal of Heuristics* 17 (2011) 1-22.

[30] H. W. Price, Reliability of parallel electronic components, *IRE Transactions on Reliability and Quality Control* 11 (1960) 35-39.

[31] D. G. Robinson, M. F. Neuts, An algorithmic approach to increased reliability through standby redundancy, *IEEE Transactions on Reliability* 38 (1989) 430-435.

[32] M. Sharifi, M. Ganjian, H. Ghajar. Expansion of Reliability Models based on Markov Chain with Consideration of Fuzzy Failure Rates: System with two Parallel and Identical Elements with Constant Failure Rates, *in Computational Intelligence for Modelling, Control and Automation*, 2005 and International Conference on Intelligent Agents, Web Technologies and Internet Commerce, International Conference on (2005). IEEE.

[33] M. Sharifi, Reliability optinization of a series-parallel k-out–of-N system with failure pate depends on working components of system, *International Journal of Industrial Engineering* 22 (2015) 4-14.

[34] V. K. Sharma, M. Agarwal. Ant colony optimization approach to heterogeneous redundancy in multi-state systems with multi-state components. in Reliability, Maintainability and Safety, *ICRMS 2009.* 8th International Conference on 2009. IEEE.

[35] H. Shayeghi, Reliability Optimization of Series-Parallels Systems Using PSO Technique, *in IC-AI* 2008.

[36] D. Simon, Biogeography-based optimization, *IEEE transactions on evolutionary computation* 12 (2008) 702-713.

[37] A. Zaretalab, A knowledge-based archive multi-objective simulated annealing algorithm to optimize series parallel system with choice of redundancy strategies, *Computers & Industrial Engineering* 80 (2015) 33-44.

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