International Journal of Electronics Engineering (ISSN: 0973-7383)
Volume 11 • Issue 1 pp. 860-871 Jan 2019-June 2019 www.csjournals.com

System Reliability Analysis and Optimization of Soft Drink Plant: A Case Study

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Abstract: In the current scenario, the production system availability places at top level to meet the market demand. Availability is function of maintainability and reliability. In the current article, we perform the availability analysis of serial procedures in the soft drink plant. The mathematical modeling is used to analyze the performance of the system and these models are being developed in terms of differential equation with mnemonic rule. The failure and repair rate parameters of each component follow the exponential distribution. The steady state availability derived with probabilistic approach using normalizing condition. The availability of the system is then optimized with the help of genetic algorithm (GA) technique. MATLAB 7.4 is used for the analysis of the system.

Introduction

In the present period of mechanization and modernization, the task for setting up of production plants includes a terrific capital cost particularly for the industry like paper mills, food production industry; coal-fired thermal plants, butter oil processing plant, and textile factories, etc.

To meet the increasing customer demand industries needs to run continuously without any failure. Therefore, the reliability and availability are the main parameters during planning, designing and operation of industrial systems. The reliability and availability analysis is most desirable for longer working duration of industries to reduce the production cost. The present analysis can benefit industry in terms of lower maintenance and higher production rate. The need and application of reliability technology has been addressed by various researchers in the past.

Abuelmaatti *et al.* (2000) demonstrated simulated program with integrated circuit emphasis for the calculation of reliability, SSA and MTFR, of redundant systems. Rajiv *et al*. (2008) proposed a DSS for washing unit of a paper industry. (Garg *et al.* 2009) proposed a mathematical model based on Markovian approach for a cattle feed plant were presented. The Particle Swarm Optimization (PSO) approach was used (Kumar and Tewari 2017) to optimize the performance of Carbonated Soft Drink Glass Bottle (CSDGB) filling system of a beverage plant. Analysis and performance modeling of

Leaf Spring Manufacturing Industry has been discussed by Sharma et al. (2017).. Singh *et al.* (1999) evaluated the steady state availability of a utensils making industry taking exponential failure and repair rates for different machines. Goel *et al.* (2001) **(**investigated different reliability parameters viz availability function and MTFR of a butter manufacturing system in a dairy plant taking constant distributed failure rates of its different subunits using Markov approach. Kras *et al.* (2006) presented a markovian approach to develop a reliability model of the redundant system. Garg *et al.* (2009) described the state transition diagram for availability analysis of cattle feed plant using Markov Process. Garg *et al.* (2010) proposed a DSS for a tab fabrication plant. The differential equations were solved by Markovian approach is used to develop the decision tables for steady state availability**.** Kumar *et al.* (2011) used genetic algorithm for performance optimization and mathematical modelling in CO_2 cooling system of fertilizer plant.

Vikas Modgil et al. (2013) analyzed the manufacturing industry perfor-mance by using two parameters i.e. time-dependent system availability and long-term availability in the shoe manufacturing unit. Elegbede *et al.* (2003) allocated availability level to some repairable industrial system using GA. Fleming *et al*. (2004) proposed a technology for forecasting the piping reliability with the help of new methods and database by using Markov piping reliability model. Ram *et al.* (2017) reported the assumption of failure of different parts of gas turbine such as compressor, combustor and human failure and determined the reliability characteristics by using the supplementary variable technique and markov process. Garg *et al*. (2013) analyzed the system behavior by utilizing the rough and imperfect data of the complex repairable system.Snipas *et al.*,2018 presented the large state solution is helpful for the solution of markov chain reliability models by using previously proposed methodology based upon the Stochastic Automata Networks formalism..

System Description

Filling soft drinks in bottles is the system of vital importance in the concerned industry. This system comprises of Six subsystems namely uncaser machine, electronic bottle inspection station, filling machine, coding machine, and case packer. The functions performed by these machines are as follows:-

Uncaser machine (One No.): it separates the empty bottles from crates and fed them to the next machine i .e bottle washer.

Bottle Washer (One No.): Manually bottles are being fed in this machine and washing of the bottles are being done here.

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Electronic bottle inspection station (Two Nos. Working in parallel): After washing the left out impurities are checked on this machine. The bottle is free from impurities than it is sent to the next machine otherwise it is sent back to the bottle washer.

Filling machine (one no.): Here predetermined quantity of liquid cold drink is filled in to the bottle and carbon dioxide gas in adequate quantity is added to the mixture.

Coding machine (one no.): stamping regarding the price, expiry date etc is being done here.

Case packer (one no.): This machine packs the bottles in to crates.

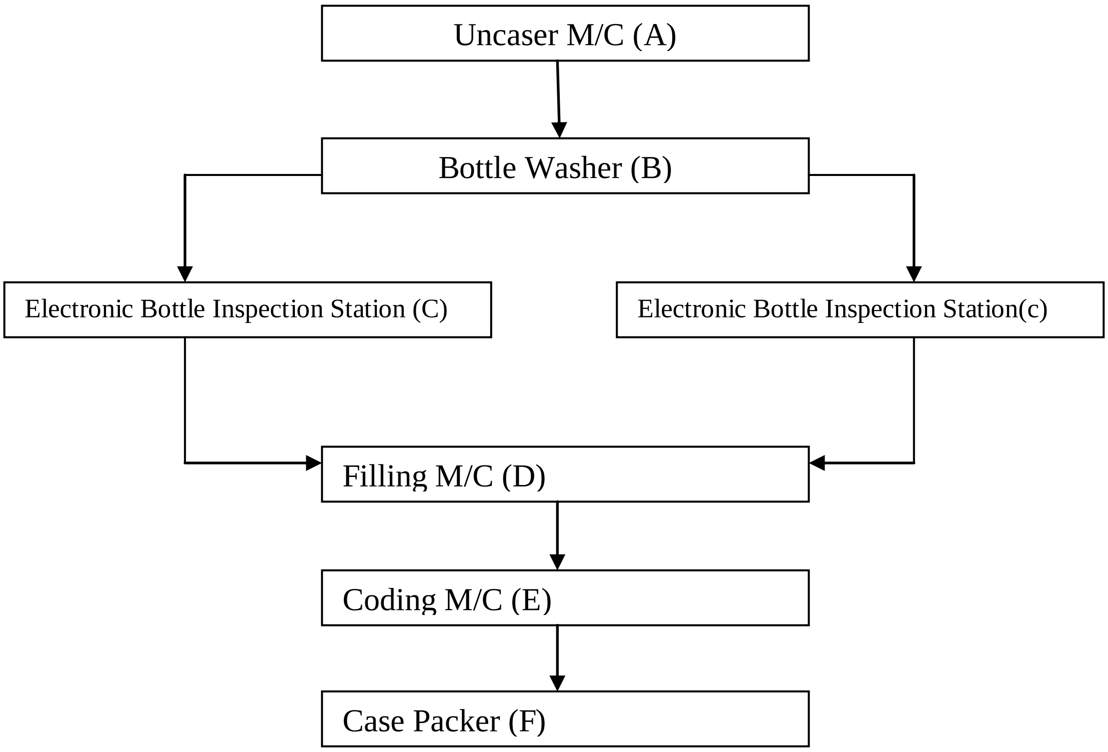

Figure1. Schematic flow diagram of soft drink Plant

Assumption

1. Failure/repair rates for every subsystem are exponentially distributed i.e. constant.
2. No simultaneous failures occur between subsystems/system.
3. The system after repair has same performance level as new one.

International Journal of Electronics Engineering (ISSN: 0973-7383)
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4. The capacity and nature of standby subsystems are same as the working subsystems.
5. All the subsystems are initially in good working state.
6. At any given time each subsystem has three states viz. working, reduced or failed.
7. System may operate in reduced capacity.

Notations

A,B,C,D,E F	Represents working state of uncaser,bottle washer, electronic bottle inspection station, filling machine, coding machine, case packer.
a,b,c,d,e,f	Represents failed state of uncaser,bottle washer, electronic bottle inspection station, filling machine, coding machine, case packer.
$\phi_{11}, \phi_{12}, \phi_{13}, \phi_{14}$	Represents failure rate of A,B,C,and D,
ϕ_{13}	Represents failure rate of C^1 in reduced capacity state
$\mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}$	Represents repair rate of A,B,C,D and E
μ_{13}	Represents repair rate of C^1 in reduced capacity state
Pi(t)	Represents that probability of system in i^{th} state at time ‘t’.
,	Represents Derivatives w.r.t. ‘t’
Av_1	Steady State/Long Term Availability

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Volume 11 • Issue 1 pp. 860-871 Jan 2019-June 2019 www.csjournals.com

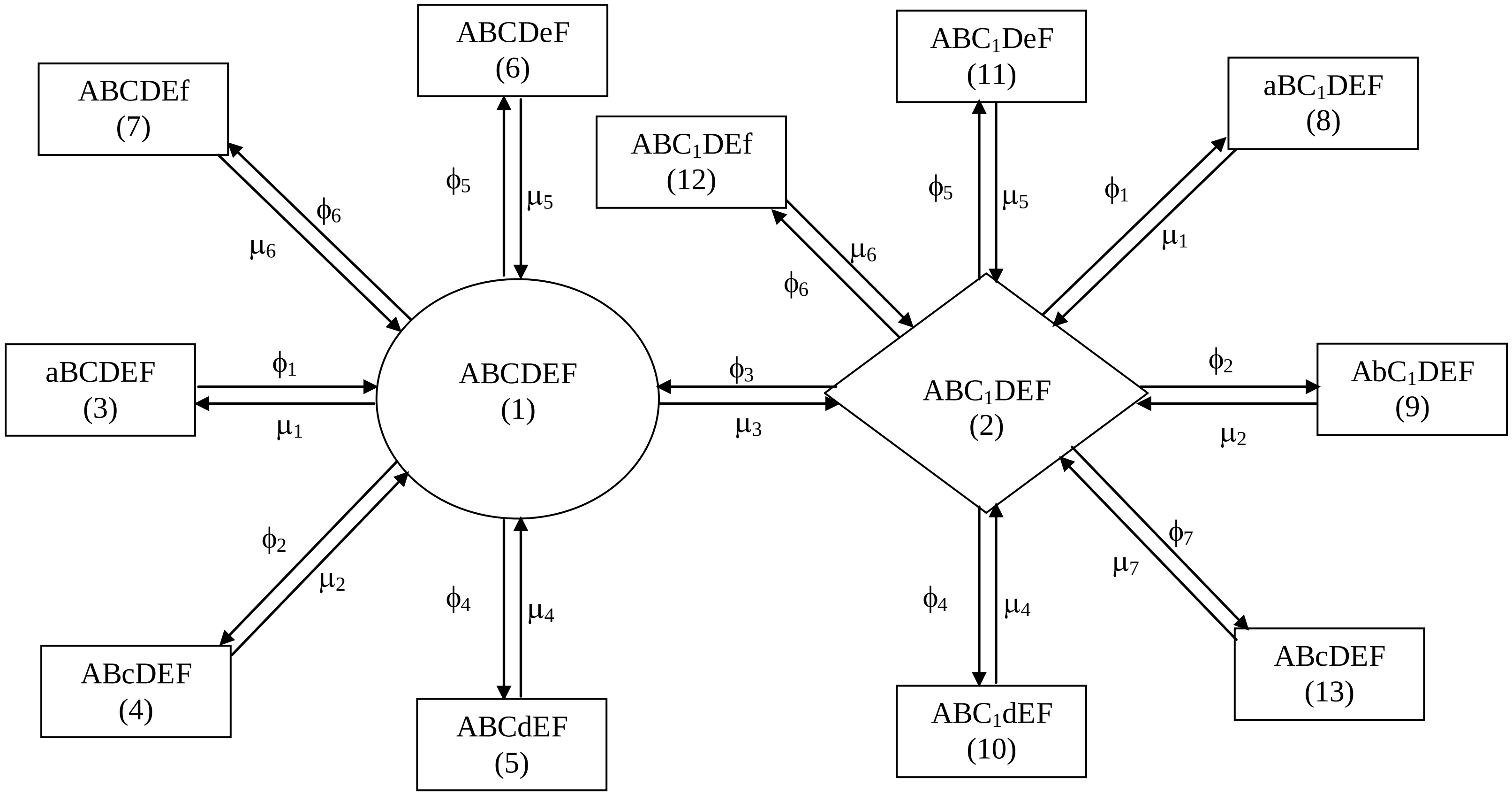

Fig. 4.2: State Transition Diagram of soft drink filling station

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Volume 11 • Issue 1 pp. 860-871 Jan 2019-June 2019 www.csjournals.com

Performance modeling of the soft drinks Manufacturing System.

The various state probabilities in the form of differential equations based on transition diagram is as under:-

$P_1^{1\prime}(t) + (K_1) P_1(t) = \mu_1 P_3(t) + \mu_2 P_4(t) + \mu_3 P_2(t) + \mu_4 P_5(t) + \mu_5 P_6(t) + \mu_6 P_7(t)$ …….1

$P_2^{1\prime}(t) + (K_2) P_2(t) = \phi_3 P_1(t) + \mu_4 P_{10}(t) + \mu_5 P_{11}(t) + \mu_6 P_{12}(t) + \mu_7 P_{13}(t) + \mu_2 P_9(t) + \mu_5 P_{11}(t)$……2

$P_3^{1\prime}(t) + \mu_1 P_3(t) = \phi_1 P_1(t)$ 3

$P_4^{1\prime}(t) + \mu_2 P_4(t) = \phi_2 P_1(t)$ 4

$P_5^{1\prime}(t) + \mu_4 P_5(t) = \phi_4 P_1(t)$ 5

$P_6^{1\prime}(t) + \mu_5 P_6(t) = \phi_5 P_1(t)$

$P_7^{1\prime}(t) + \mu_6 P_7(t) = \phi_6 P_1(t)$ 6

$P_8^{1\prime}(t) + \mu_1 P_8(t) = \phi_1 P_2(t)$ 7

$P_9^{1\prime}(t) + \mu_2 P_9(t) = \phi_2 P_2(t)$ 8

$P_{10}^{1\prime}(t) + \mu_4 P_{10}(t) = \phi_4 P_2(t)$ 9

$P_{11}^{1\prime}(t) + \mu_5 P_{11}(t) = \phi_5 P_2(t)$ 10

$P_{12}^{1\prime}(t) + \mu_6 P_{12}(t) = \phi_6 P_2(t)$ 11

$P_{13}^{1\prime}(t) + \mu_7 P_{13}(t) = \phi_7 P_2(t)$ 12

Where

$K_1=(\phi_1 + \phi_2 + \phi_3 + \phi_4 + \phi_5 + \phi_6)$

$K_2=(\mu_3 + \phi_4 + \phi_1 + \phi_2 + \phi_7 + \phi_5 + \phi_6)$

With initial conditions at time t = 0

$P_i(t) = 1$ for i=1, 13

$P_i(t) = 0$ for $i \neq 1$

Steady State Behavior:

Industrialist desire that their system should be run for maximum duration of time therefore steady state availability of the system is essential to be analysed by putting $t\rightarrow\infty$ and d/dt= 0 on equations (1) and (2) we get:

$(K_1) P_1 = \mu_1 P_3 + \mu_2 P_4 + \mu_3 P_2 + \mu_4 P_5 + \mu_5 P_6 + \mu_6 P_7$ — 14

$(K_2) P_2 = \phi_3 P_1 + \mu_4 P_{10} + \mu_5 P_{11} + \mu_6 P_{12} + \mu_7 P_{13} + \mu_2 P_9 + \mu_1 P_8$ — 15

$\mu_1 P_3 = \phi_1 P_1$ $\Rightarrow P_3 = \frac{\phi_1}{\mu_1} P_1$

$\mu_2 P_4 = \phi_2 P_1 \quad \Rightarrow P_4 = \frac{\phi_2}{\mu_2} P_1$

$\mu_4 P_5 = \phi_4 P_1 \quad \Rightarrow P_5 = \frac{\phi_4}{\mu_4} P_1$

$\mu_5 P_6 = \phi_5 P_1 \quad \Rightarrow P_6 = \frac{\phi_5}{\mu_5} P_1$

$\mu_6 P_7 = \phi_6 P_1 \quad \Rightarrow P_7 = \frac{\phi_6}{\mu_6} P_1$

$\mu_1 P_8 = \phi_1 P_2 \quad \Rightarrow P_8 = \frac{\phi_1}{\mu_1} P_2$

$\mu_2 P_9 = \phi_2 P_2 \quad \Rightarrow P_9 = \frac{\phi_2}{\mu_2} P_2$

$\mu_4 P_{10} = \phi_4 P_2 \quad \Rightarrow P_{10} = \frac{\phi_4}{\mu_4} P_2$

$\mu_5 P_{11} = \phi_5 P_2 \quad \Rightarrow P_{11} = \frac{\phi_5}{\mu_5} P_2$

$\mu_6 P_{12} = \phi_6 P_2 \quad \Rightarrow P_{12} = \frac{\phi_6}{\mu_6} P_2$

$\mu_7 P_{13} = \phi_7 P_2 \quad \Rightarrow P_{13} = \frac{\phi_7}{\mu_7} P_2$

$P_2 = \frac{\phi_3}{\mu_3} P_1 \qquad P_2 = Z_3 P_1 \qquad Z_i = \frac{\phi_i}{\mu i}$

The probability of initially all good working condition is determine by initial and normalizing condition, i.e

$P_i(t) = 1$ for i=1 and $P_i(t) = 0$ for $i \neq 1$, we get:

The probability of full capacity working state P1 is obtained by using normalizing condition i.e . All state prob =1

i.e $\sum_{i=1}^{13} P_i = 1$

$P_1 + P_2 + P_3 + \ldots\ldots\ldots\ldots P_{13} = 1$

$P_1 [1 + Z_3 + Z_1 + Z_2 + Z_4 + Z_5 + Z_6 + Z_1Z_3 + Z_2Z_3 + Z_4Z_3 + Z_5Z_3 + Z_6Z_3 + Z_7Z_3 = 1$

$P_1 = 1/[1 + Z_3 + Z_1 + Z_2 + Z_4 + Z_5 + Z_6 + Z_1Z_3 + Z_2Z_3 + Z_4Z_3 + Z_5Z_3 + Z_6Z_3 + Z_7Z_3]$

$A_{v1} = P_1 + P_2 = [1 + Z_3]P_1$

PERFORMANCE/ BEHAVIOURal analysis:

The behavior analysis is being carried out by captivating appropriate failure and repair parameters of all components from maintenance record of soft drinks Manufacturing System and detailed discussion with the maintenance personnel. The simulation results are presented in table 1 to 4**.**

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Table 4.1 Decision Matrix of Uncaser machine (A) of Soft drinks Manufacturing System

Table 4.1 represents the decision matrix for subsystem (A) Uncaser machine. On increasing the failure rate of subsystem (A) from 0.001 to 0.004 (keeping other parameters constant) the availability declines by 2.65% & it gets increased by 0.77% with an increase in repair rate from 0.1 to 0.7.

μ_1 \ ϕ_1	**0.001**	**0.002**	**0.003**	**0.004**	**Other Constant Parameters**
0.1	0.9089	0.9007	0.8927	0.8848	$\phi_2 = 0.002$, $\mu_2 = 0.1$, $\phi_3 = 0.003$, $\mu_3 = 0.04$, $\phi_4 = 0.003$, $\mu_4 = 0.1$,
0.3	0.9144	0.9117	0.9089	0.9062	
0.5	0.9156	0.9139	0.9122	0.9106	
0.7	**0.9160**	0.9148	0.9137	0.9125	

Table 4.2 The Decision Matrix of Bottle Washer machine (B) of Soft drinks Manufacturing System.

Table 4.2 Represents the decision matrix for subsystem (B) bottle washer machine. On increasing the failure rate of subsystem (B) from 0.002 to 0.008 (keeping other parameters constant) the availability declines by 5.17% & it gets increased by 1.36% with an increase in repair rate from 0.1 to 0.4.

μ_2 \ ϕ_2	**0.002**	**0.004**	**0.006**	**0.008**	**Other Constant Parameters**
0.1	0.9089	0.8927	0.8770	0.8619	$\phi_1 = 0.001$, $\mu_1 = 0.1$, $\phi_3 = 0.003$, $\mu_3 = 0.04$, $\phi_4 = 0.003$, $\mu_4 = 0.1$,
0.2	0.9172	0.9089	0.9007	0.8927	
0.3	0.9207	0.9144	0.9089	0.9034	
0.4	**0.9215**	0.9172	0.9138	0.9089	

Table 4.3 **The Decision Matrix of Electronic Bottle Inspection Station (C) of Soft drinks Manufacturing System.**

Table 4.3 Represents the decision matrix for subsystem (C) bottle washer machine. On increasing the failure rate of subsystem (B) from 0.003 to 0.009 (keeping other parameters constant) the availability declines by 1.12 % & it gets marginally increased by 0.52 % with an increase in repair rate from 0.4 to 0.7.

μ_3 \ ϕ_3	**0.003**	**0.005**	**0.007**	**0.007**	**Other Constant Parameters**
0.4	0.9089	0.9068	0.9028	0.8987	$\phi_1 = 0.001$, $\mu_1 = 0.1$, $\Phi_2 = 0.002$, $\mu_2 = 0.1$, $\Phi_4 = 0.003$, $\mu_4 = 0.1$,
0.5	0.9122	0.9089	0.9056	0.9023	
0.6	0.9131	0.9103	0.9075	0.9048	
0.7	**0.9137**	0.9113	0.9089	0.9066	

Table 4.4 **The Decision Matrix of Filling machine (D) of Soft drinks Manufacturing System.**

Table 4.4Represents the decision matrix for subsystem (D) bottle washer machine. On increasing the failure rate of subsystem (D) from 0.003 to 0.009 (keeping other parameters constant) the availability declines by 5.17 % & it gets marginally increased by 2.34 % with an increase in repair rate from 0.1 to 0.7.

μ_4 \ ϕ_4	**0.003**	**0.005**	**0.007**	**0.009**	**Other Constant Parameters**
0.1	0.9089	0.8927	0.8770	0.8619	$\phi_1 = 0.001$, $\mu_1 = 0.1$, $\Phi_2 = 0.002$, $\mu_2 = 0.1$, $\Phi_3 = 0.003$, $\mu_3 = 0.04$,
0.3	0.9257	0.9201	0.9144	0.9089	
0.5	0.9292	0.9257	0.9223	0.9189	
0.7	**0.9307**	0.9282	0.9257	0.9233	

Genetic algorithm

Genetic algorithm techniques have efficiently been used to achieve the quality solution for both constrained and unconstrained optimization programme.GA begins with set of solutions (represented by Chromosomes) called population. solutions from one population are taken and used to form new population. This is motivated by hope that new population will be better than previous one. solutions which are than selected to form new solution (offspring)are selected according to their fitness (the more suitable they are the more chances to reproduce).this is repeated until some conditions are satisfied.

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Performance optimization: (Table 1 and 2)

POP SIZE	10	20	30	40	50	60	**70**	80	90	100
A_V	0.9660	0.9682	0.9683	0.9689	0.9697	0.9696	0.9698	**0.9701**	0.9699	0.9699
ϕ_1	0.001	0.00100	0.00123	0.00120	0.00110	0.00110	0.00104	**0.00105**	0.001	0.00100
ϕ_2	0.002	0.00200	0.00219	0.00200	0.00205	0.00205	0.00207	**0.00210**	0.00206	0.002086
ϕ_3	0.0003	0.00005	0.00003	0.00004	0.00004	0.00004	0.00004	**0.00004.**	0.00003	0.00003
ϕ_4	0.0050	0.00505	0.00512	0.005258	0.00506	0.00506	0.00508	**0.005008**	0.005004	0.00505
ϕ_5	0.0050	0.00507	0.00501	0.00511	0.00502	0.005021	0.005068	**0.00508**	0.00503	0.00500
ϕ_6	0.00310	0.00325	0.00338	0.00306	0.00305	0.00305	0.003078	**0.00303**	0.003040	0.00305
ϕ_7	0.00758	0.00340	0.00419	0.00330	0.00308	0.00308	0.00302	**0.00300**	0.00304	0.00340
μ_1	0.39948	0.33628	0.39999	0.39999	0.39999	0.399999	0.399999	**0.39999**	0.399999	0.39999
μ_2	0.74393	0.603641	0.78963	0.799999	0.799999	0.799999	0.799999	**0.799999**	0.799999	0.799999
μ_3	0.65321	0.89035	0.89987	0.89999	0.83893	0.83893	0.89999	**0.89999**	0.89999	0.89999
μ_4	0.32788	0.39987	0.399999	0.399999	0.399999	0.399999	0.399999	**0.399999**	0.399999	0.399999
μ_5	0.84141	0.89045	0.899999	0.899999	0.899999	0.899999	0.899999	**0.899999**	0.899999	0.899999
μ_6	0.4	0.39999986	0.39999802	0.39999999	0.39999999	0.39999999	0.39999999	**0.39999999**	0.399999996	0.39999998
μ_7	0.354132	0.3879854	0.3999763	0.3999999	0.38796340	0.3879634	0.39999994	**0.39999999**	0.39999999	0.3999999

The simulation is done for utmost population size that changes from 10 to 100**.** Here the Generation size is kept constant as 500. The most favorable value of system's availability is 97.01%, for which the finest probable combination of failure and repair parameters is **ϕ_1=0.00105,μ_1=0.39999, ϕ_2 =0.00210, μ_2=0.79999, ϕ_3=0.00004, μ_3=0.89999, ϕ_4=0.00500, μ_4=0.39999, ϕ_5=0.00508, μ_5=0.89999, ϕ_6=0.00303, μ_6=0.399999, ϕ_7=0.00300, μ_7=0.39999 at population size 80** as given in table 1.

GEN SIZE	50	100	150	200	250	300	350	400	**450**	500
A_V	0.9675	0.9683	0.9686	0.9691	0.9694	0.9695	0.9697	0.9697	**0.9701**	0.9699
ϕ_1	0.00116	0.00108	0.001119	0.001012	0.00111	0.00110	0.00160	0.00110	**0.00105**	0.00105
ϕ_2	0.00273	0.00249	0.00232	0.00213	0.00219	0.00214	0.00202	0.00200	**0.00105**	0.00200
ϕ_3	0.000068	0.000061	0.000035	0.000049	0.000039	0.000036	0.000054	0.000039	**0.000036**	0.000036
ϕ_4	0.00504	0.00522	0.00500	0.00506	0.00501	0.00506	0.00534	0.00501	**0.00501**	0.00501
ϕ_5	0.00545	0.00506	0.00527	0.00536	0.00522	0.00501	0.00506	0.00505	**0.005012**	0.00501
ϕ_6	0.00317	0.00324	0.00332	0.00320	0.00305	0.003109	0.003174	0.003108	**0.00300**	0.003007
ϕ_7	0.003595	0.00326	0.004434	0.00313	0.00430	0.003085	0.003433	0.003070	**0.003074**	0.003074

μ_1	0.37826	0.399999	0.39868	0.39999	0.399999	0.399999	0.399999	0.399999	**0.399999**	0.399999
μ_2	0.791325	0.799985	0.799832	0.799999	0.799997	0.799999	0.7999999	0.7999999	**0.7999999**	0.7999999
μ_3	0.88358	0.88335	0.89303	0.89125	0.89826	0.86783	0.899999	0.899999	**0.898169**	0.898169
μ_4	0.39522	0.39823	0.399995	0.399999	0.399998	0.399999	0.399999	0.399999	**0.399999**	0.399999
μ_5	0.875187	0.897297	0.899991	0.899998	0.899999	0.899999	0.899999	0.899999	**0.899999**	0.899999
μ_6	0.398173	0.399968	0.399990	0.399999	0.399999	0.399999	0.399999	0.399999	**0.399999**	0.399999
μ_7	0.386242	0.4	0.396209	0.399999	0.3984274	0.3999999	0.3999999	0.3999999	**0.3999999**	0.3999999

Again, the simulation is made for maximum number of generation, varies from 50 to 500 with a step size of 50. Here, the population size is kept constant at 100. The optimum value of system's performance is 97.01%, for which the finest combination of failure and repair variable is **ϕ_1 =0.00105, μ_1=0.399999, ϕ_2 =0.00105, μ_1 =0.7999999, ϕ_3=0.000036, μ_1 =0.898169, ϕ_4 =0.00501, μ_1 =0.399999, ϕ_5 =0.005012, μ_1=0.899999,ϕ_6=0.00300, μ_6 =0.399999, ϕ_7 =0.003074, μ_7 =0.399999at generation rate 450** as given in table 2.

References

1. Abuelmaatti, M.T. and Qamber, I.S. 1. Abuelmaatti,M.T and Qamber,I.S (2000), "Using Spice Circuit Simulation Program in Reliability Analysis of Redundant Systems with Non-Repairable Units and Common-Cause Failures", Active and Passive Elec. Comp., Vol. 22, No.4, pp. 235-255.
2. Rajiv K, Tewari P C, Chauhan R.S, (2008), "Performance Analysis of Screening Unit in a Paper Plant Using Genetic Algorithm", Journal of Industrial and Systems Engineering, Vol. 3, No. 2, pp 140-151.
3. Garg, D., Kumar, K. and Singh, J. (2009), "Availability Analysis of a Cattle Feed Plant Using Matrix Method", International Journal of Engineering, Vol. 3, No.2, pp. 201-209.
4. Kumar, P. and Tewari, P.C. (2017), "Performance analysis and optimization for CSDGB filling system of a beverage plant using particle swarm optimization" *International Journal of Industrial Engineering Computations*, Vol. 8, pp. 303-314.
5. Sharma, D., Kumar, A., Kumar, V. and Modgil, V. (2017), "Performance modeling and availability analysis of leaf spring manufacturing industry, *International Journal of Mechanical and Production Engineering*, Vol. 5, pp. 1-5.
6. Singh, J. and Mahajan, P. (1999), "Reliability of Utensils Manufacturing Plant-A Case Study", Opsearch, Vol. 36, No.3, pp. 260-269.
7. Goel P and Singh J.(2001), "Availability Analysis of Butter Manufacturing System in a Dairy Plant", Proceedings- Recent Developments in Operation Research.
8. Kraš, B. Sviličić: Predictive reliability analysis of redundant ship navigational...Pomorstvo, god. 20, br. 2 (2006), str. 119-126
9. Garg, D., Kumar, K. and Singh, J. (2009), "Availability Analysis of a Cattle Feed Plant Using Matrix Method", International Journal of Engineering, Vol. 3, No.2, pp. 201-209.
10. Garg, D., Kumar, K. and Singh, J. (2010), "Decision Support System of a Tab Manufacturing Plant", Journal of Mechanical Engineering, Vol. 41, Issue 1, pp. 71-79. 93.
11. Kumar S and Tewari P C (2011), "Mathematical Modeling and Performance Optimization of Co2 Cooling System of a Fertilizer Plant", International Journal of Industrial Engineering Computation, Vol. 2, pp 689-695.

12. Modgil,V., Sharma, S.K. and Singh, J. (2013), “Performance modeling and availability analysis of shoe upper manufacturing unit” *International Journal of Quality andReliability Management*, Vol. 30 No. 8, pp. 816-831.
13. Elegbede, C. and Adjallah, K. (2003), “Availability allocation to repairable systems with genetic algorithms: a multi-objective formulation”, Reliability Engineering and System Safety, Vol. 82, pp. 319–330
14. Fleming, K.N. (2004), “Markov Models for Evaluating Risk-Informed In-Service Inspection Strategies for Nuclear Power Plant Piping Systems”, Reliability Engineering and System Safety, Vol. 83, Issue 1, pp. 27-45.
15. Ram, M., and Nagiya, K. (2017), “Gas turbine power plant performance evaluation under key failures”, Journal of Engineering Science and Technology, Vol. 12, No. 7, pp. 1871-1886.
16. Snipas, M. Radziukynas, V. and Valakevicius, E. (2018), “Numerical solution of reliability models described by stochastic automata networks”, Reliability Engineering and System Safety, Vol. 169: 570–578.