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Performance Analysis of Carded Silver System: A Case Study

Mukesh Kumar*

Ph.D., Mechanical Engineering, UIET, MDU, Rohtak

Abstract – Reliability/Availability engineering is the vital upcoming field taken up by industries, engineers and research aspirants in today's scenario.It affects all state of our life directly or indirectly. A performance model has been developed by considering the exponential distribution of probable failure and repair rate using Markovian approach. The differential difference equations for various state probabilities have been derived from state transition diagram and solved by applying differential equations to obtain the steady state system availability. In the current article, we perform the availability analysis of serial procedures on the carded silver production systemthe 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. The findings of the paper might be helpful for maintenance planning and identification of criticalsubsystem of the system.

Keywords: Reliability and Availability, Genetic Algorithm, MATLAB.

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1. INTRODUCTION

In worldwide competitive scenario, the industrialists are adopting new technologies to run the industries round the clock for reaching their targets and fulfillment of user's needs. The products should be available to consumers to their satisfaction at reasonable cost. To meet the increasing customer demand industries needs to run continuously without any failure. So the products should be available to consumers to their satisfaction at reasonable cost. 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. Elegbede*et al.*[1] solved a multi-objective combinatorial optimization problem using GA and experiments plan methodology. Castro *et al.* [2] presented a methodology using GA for solving the engineering design problems. Khanduja et al. [3,4] proposed a mathematical modeling in distinct process plants using reliability and availability analysis technique.Azaron*et al.* [5] suggested a method for optimization reliability and evaluationby redundant systems for non-repairable dissimilar component cold stand system.Garg et al. [6] presented the availability of combed sliver yarn production system, an important functionary unit of yarn production plant. Kumar et al. [7] used genetic algorithm for performance optimization and mathematical modelling in CO2 cooling system of fertilizer plant. Garg et al. [8] analyzed the system behavior by utilizing the rough and imperfect data of the complex repairable system.Sharma *et al*. [9] described the GA approach for the availability optimization of refining unit of a sugar industry. A reliability mode using Markov approach proposed by Gowid et al [10] in LNG production plant for computation of time dependent system availability. Hou*et al.* [11] discussed the availability evaluation of systems by means of random set theory. Kumar et al.[12]. Implemented the PSO technique to improve the availability of a repairable system in lectogen milk powder system plant and to optimize the availability of various sub-systems. Kumar et al.,[13] analyze the behaviour of multi-state repairable system of Towel Manufacturing System using G.A. Malik et. al. [14] had examined performance modeling for water flow system.

2. SYSTEM DESCRIPTION

Carded silver production system comprises of three subsystems namely blow room, Carding machine, and Draw Frames. Cotton arrives in the mill in the form of hard pressed bales which consists of lot of impurities. After doing some manual operation of this hard pressed bales material with the purpose of improve the quality of yarn. After that this conditioned material is fed manually in to blow room where opening and cleaning of cotton takes place. next from the blow room small cotton tufts transfer to the all cards where cards individualize and clean cotton fiber remove neaps, tiny lumps and fused fiber end and deliver silver continuously which is collected in cans. in between some small operation is done for improving the luster and strength of carded silver .After that it is passed through draw frames for improving silver uniformity which after drawing operation goes for spinning operation.

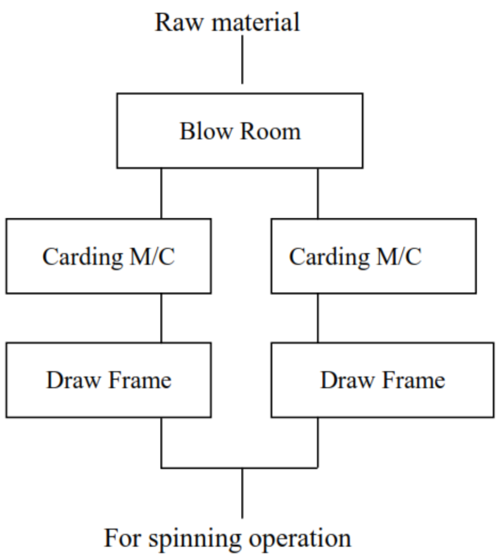

Figure1. Schematic flow diagram of Carded Silver System

2.1 Assumption

- Failure/repair rates for every subsystem are exponentially distributed i.e. constant.
- No simultaneous failures occur between subsystems/system.
- The execution for a predetermined duration of a repaired unit is in the same class as new.
- No further failure can occur when system is in failure state.
- The capacity and nature of standby subsystems are same as the working subsystems.
- All the subsystems are initially in good working state.
- At any given time each subsystem has three states viz. working, reduced or failed.
- System may operate in reduced capacity.

Notations

B,C,D.	Represents working state of Blow Room, Carding Machine, and Draw Frame.
b,c,d.	Represents failed state of Blow Room, Carding Machine, and Draw Frame.
ϕ_1, ϕ_2, ϕ_3	Represents failure rate of B,C and D
ϕ_2, ϕ_3	Represents failure rate of $C^1$and D^1 in reduced capacity state
μ_1, μ_2, μ_3	Represents repair rate of B,C and D
μ_2, μ_3	Represents repair rate ofC^1 and D^1in 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

2.2 Performance modeling

$$P_1'(t) + (\phi_1 + \phi_2 + \phi_3)\, P_1(t) = \mu_1 P_5(t) + \mu_2 P_3(t) + \mu_3 P_2(t) \quad — \quad (1)$$
$$P_2'(t) + (\phi_1 + \phi_2 + \phi_3)\, P_2(t) = \mu_1 P_6(t) + \lambda_3 P_1(t) + \mu_2 P_4 \quad — \quad (2)$$
$$P_3'(t) + (\phi_1 + \phi_3 + \phi_2)\, P_3(t) = \mu_1 P_7(t) + \mu_3 P_4(t) + \mu_2 P_1(t) \quad — \quad (3)$$
$$P_4'(t) + (\phi_1 + \mu_3 + \mu_2 + \phi_4 + \phi_5)\, P_4(t) = \mu_4 P_9(t) + \mu_1 P_8(t) + \mu_5 P_{10}(t) + \phi_3 P_3(t) + \phi_2 P_2(t) \quad (4)$$
$$P_5'(t) + \mu_1 P_5(t) + \phi_1 P_1(t) \quad — \quad (5)$$
$$P_6'(t) + \mu_1 P_6(t) + \phi_1 P_2(t) \quad — \quad (6)$$
$$P_7'(t) + \mu_1 P_7(t) + \phi_1 P_3(t) \quad — \quad (7)$$
$$P_8'(t) + \mu_1 P_8(t) + \phi_1 P_4(t) \quad — \quad (8)$$
$$P_9'(t) + \mu_4 P_9(t) + \phi_4 P_4(t) \quad — \quad (9)$$
$$P_{10}'(t) + \mu_5 P_{10}(t) + \phi_5 P_4(t) \quad — \quad (10)$$

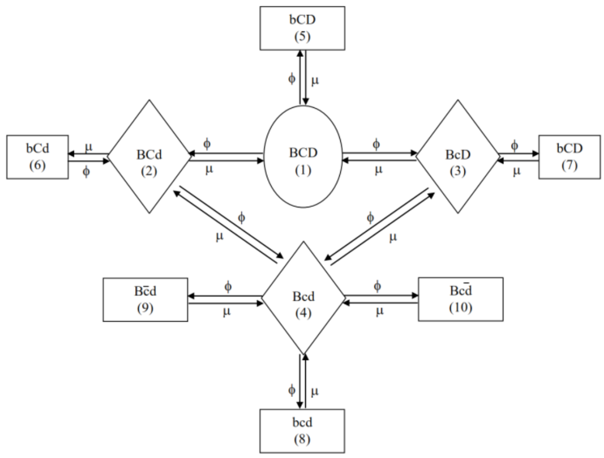

Fig. 4.2: State Transition Diagram of carded silver system

2.3 Steady State Behaviour

Steady state availability of the system is essential to be analysed by putting $t \rightarrow \infty$ and d/dt= 0 on equations (1) to (4) we get:

$$(\phi_1 + \phi_2 + \phi_3)\, P_2 = \mu_1 P_6 + \lambda_3 P_1 + \mu_2 P_4$$
$$(\phi_1 + \phi_3 + \phi_2)\, P_3 = \mu_1 P_7 + \mu_3 P_4 + \phi_2 P_1$$
$$\lambda_1\, (\mu_3 + \mu_2 + \phi_4 + \phi_5)\, P_4 = \mu_4 P_9 + \mu_1 P_8 + \mu_5 P_{10} + \lambda_3 P_3 + \lambda_2 P_2$$

$$\mu_1 P_5 = \phi_1 P_1$$
$$\mu_1 P_6 = \phi_1 P_2$$
$$\mu_1 P_7 = \phi_1 P_3$$
$$\mu_1 P_8 = \phi_1 P_4$$
$$\mu_4 P_9 = \phi_4 P_4$$
$$\mu_5 P_{10} = \phi_5 P_4$$
$$P_6 = \frac{\phi_1}{\mu_1} P_2$$
$$P_7 = \frac{\phi_1}{\mu_1} P_3$$
$$P_8 = \frac{\phi_1}{\mu_1} P_4$$
$$P_9 = \frac{\phi_4}{\mu_4} P_4$$
$$P_{10} = \frac{\phi_5}{\mu_5} P_4$$

$$(\mu_3 + \mu_2) P_4 = \phi_3 P_3 + \phi_2 P_2 \quad — \quad (11)$$
$$(\phi_2 + \mu_3) P_2 = \phi_3 P_1 + \mu_2 P_4 \quad — \quad (12)$$
$$(\phi_3 + \mu_2) P_3 = \mu_3 P_4 + \phi_2 P_1 \quad — \quad (13)$$
$$P_2 = \left(\frac{\phi_3}{\phi_2 + \mu_3}\right) P_1 + \left(\frac{\mu_2}{\phi_2 + \mu_3}\right) P_4 \quad — \quad (14)$$
$$P_3 = \left(\frac{\mu_3}{\phi_3 + \mu_2}\right) P_4 + \left(\frac{\phi_2}{\phi_3 + \mu_2}\right) P_1 \quad — \quad (15)$$
$$P_4 = \left(\frac{\phi_3}{\mu_2 + \mu_2}\right) P_3 + \left(\frac{\phi_2}{\mu_3 + \mu_2}\right) P_2 \quad — \quad (16)$$
$$P_2 = B_1 P_1 + B_2 P_4 \quad — \quad (17)$$
$$P_3 = B_3 P_4 + B_4 P_1 \quad — \quad (18)$$
$$P_4 = B_5 P_3 + B_6 P_2 \quad — \quad (19)$$

$$P_4 = B_5 [B_3 P_4 + B_4 P_1] + B_6 [B_1 P_1 + B_2 P_4]$$
$$P_4 = B_5 B_3 P_4 + B_5 B_4 P_1 + B_6 B_1 P_1 + B_6 B_2 P_4$$
$$P_4 [1 - B_3 B_5 - B_6 B_2] = [B_5 B_4 + B_2 B_1] P_1$$

$$P_4 = \left[\frac{B_4 B_5 + B_1 B_6}{1 - B_3 B_5 + B_2 B_6}\right] P_1 = B_7 P_1$$
$$P_2 = B_1 P_1 + B_2 B_7 P_1 = P_1 [B_1 + B_2 B_7] \quad — \quad (20)$$
$$P_3 = B_3 P_4 + B_4 P_1 = B_3 B_7 P_1 + B_4 P_1 = P_1 [B_4 + B_3 + B_7] \quad — \quad (21)$$
$$Z_i = \frac{\phi_i}{\mu_i} \quad i = 1, 4, 5$$

$$P_5 = Z_1 P_1$$
$$P_6 = Z_1 P_2$$
$$P_7 = Z_1 P_3$$
$$P_8 = Z_1 P_4$$
$$P_9 = Z_4 P_4$$
$$P_{10} = Z_5 P_4$$

$$P_1 + P_2 \ldots\ldots P_{10} = 1$$

$$P_1 \left[\frac{1}{1 + B_8 + B_9 + B_7 + Z_1 + Z_1 B_8 + Z_1 B_9 + Z_1 B_7 + Z_4 B_7 + Z_5 B_7}\right] = 1$$
$$A_v = P_1 + P_2 + P_3 + P_4 = P_1 [1 + B_8 + B_9 + B_7] \quad —(22)$$

$$P_1 = \frac{1}{1 + \phi_8 + \phi_9 + \phi_7 + Z_1 + Z_1 \phi_8 + Z_1 \phi_9 + Z_1 \phi_7 + Z_4 \phi_7 + Z_5 \phi_7}$$
$$A_v = [1 + Y_8 + Y_9 + Y_7] = P_1$$

2.4 Performance Analysis

Table 4.1 Decision Matrix of Blow Room machine (B) ofCarded Silver Production System.

μ_1 \ ϕ_1	0.006	0.003	0.005	0.009	Other Constant Parameters
0.1	0.9431	0.9343	0.9256	0.9171	$\phi_2 = 0.005$, $\mu_2 = 0.01$, $\phi_3 = 0.007$, $\mu_3 = 0.4$,
0.2	0.9705	0.9658	0.9612	0.9566	
0.3	0.9800	0.9768	0.9737	0.9705	
0.4	**0.9849**	0.9824	0.9800	0.9776	

Table 4.2 Decision Matrix of Carding Machine (C) of Carded Silver Production System.

μ_2 \ ϕ_2	0.005	0.004	0.006	0.008	Other Constant Parameters
0.01	0.9431	0.9380	0.9300	0.9250	$\phi_1 = 0.006$, $\mu_1 = 0.1$, $\phi_3 = 0.007$, $\mu_3 = 0.4$,
0.03	0.9588	0.9430	0.9301	0.9256	
0.05	0.9691	0.9566	0.9491	0.9391	
0.07	**0.9760**	0.9500	0.9420	0.9291	

Table 4.3 Decision Matrix of Draw Frame Machine(D) ofCarded Silver Production System.

μ_3 \ ϕ_3	0.007	0.008	0.009	1.000	Other Constant Parameters
0.4	0.9431	0.9381	0.9291	0.9201	$\phi_1 = 0.006$, $\mu_1 = 0.1$, $\phi_2 = 0.005$, $\mu_2 = 0.01$,
0.5	0.9560	0.9400	0.9331	0.9222	
0.6	0.9660	0.9490	0.9301	0.9242	
0.7	**0.9783**	0.9690	0.9598	0.9387	

3. RESULTS AND DISCUSSION

Table 4.1 represents the decision matrix for subsystem Blow Room machine (B).as failure rate varies of subsystem (B) from 0.006 to 0.0009(keeping other parameters constant) the availability drops by 2.75% & it gets improved by 4.24% with repair rate varies from 0.1 to 0.4.

Table 4.2 represents the decision matrix for subsystem Carding machine (C).as failure rate varies of subsystem (D) from 0.002to 0.008 (keeping other parameters constant) the availability decreases by 1.91% & it gets improved by 3.37% with repair rate varies from 0.01 to 0.07.

Table 4.3 represents the decision matrix for subsystem Draw frame machine(D) as failure rate varies of subsystem (S) from 0.005 to 0.008 (keeping other parameters constant) the availability decreases by 2.43% & it gets improved by 2.37% with repair rate varies from 0.1 to 0.4.

Table 4.4: Suggested Repair Priorities for Carded Silver Production System

Subsystem	Failure Rates	Percentage Reduction in Availability	Repair Rates	Percentage Improvement in Availability	Repair Priority
Blow Room machine (B)	0.006 to 0.009	2.75%	0.1 to 0.4	4.24%	I
Carding Machine (C)	0.005 to 0.008	1.91%	0.01 to 0.07	3.37%	III
Draw Frame Machine(D)	0.007 to 1.00	2.43%	0.4 to 0.7	2.37%	II

The subsystem priorities have been decided on the basis of their effect on overall system availability .It is clear from table 4.4 Blow Room machine (B) is most critical subcomponent and assigned top priorities from view point of repair. Similarly Draw Frame Machine (D) second lastly Carding Machine (C) has minimum effect on system availability hence assigned last priority.

3.1 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.

Performance optimization: (Table 1 and 2)

POP SIZE	10	20	30	40	**50**	60	70	80
A_V	0.9819	0.9849	0.9850	0.9851	**0.9853**	0.9852	0.9848	0.9847
ϕ_1	0.00608	0.00601	0.00605	0.00602	**0.00606**	0.006	0.00612	0.00617
ϕ_2	0.00514	0.00696	0.00531	0.00504	**0.00517**	0.00545	0.00516	0.00523
ϕ_3	0.00652	0.00606	0.00622	0.00611	**0.00620**	0.00614	0.00616	0.00615
ϕ_4	0.00541	0.00604	0.00617	0.00521	**0.00522**	0.00521	0.00603	0.00557
ϕ_5	0.00737	0.00715	0.00717	0.00617	**0.00609**	0.00612	0.00631	0.00771
μ_1	0.33214	0.39633	0.39998	0.399999	**0.39999**	0.4	0.39997	0.39999
μ_2	0.03081	0.03999	0.03953	0.03684	**0.03894**	0.03999	0.03995	0.039792
μ_3	0.69616	0.69924	0.69757	0.69999	**0.69443**	0.67951	0.69591	0.69958
μ_4	0.29949	0.38516	0.38060	0.39999	**0.39999**	0.4	0.39986	0.39703
μ_5	0.68260	0.79804	0.79739	0.79372	**0.79825**	0.79220	0.79862	0.79934

Simulation is done for utmost population size those changes from 10 to 80**.** Here the Generation size is kept constant as 100. The most favorable value of system's availability is 98.53%, for which the finest probable combination of failure and repair parameters is **ϕ_1=0.00606,μ_1=0.39999, ϕ_2 =0.00517, μ_2=0.03894, ϕ_3=0.00620, μ_3=0.69443, ϕ_4=0.00522, μ_4=0.39999, ϕ_5=0.00609, μ_5=0.79825, at population size 50** as given in table 1.

GEN SIZE	50	100	150	200	250	300	350	400
A_V	**0.9846**	**0.9851**	**0.9852**	**0.9851**	**0.9850**	**0.9850**	**0.9846**	**0.9840**
ϕ_1	0.00621	0.00601	**0.006**	0.00601	0.006007	0.00601	0.00160	0.00110
ϕ_2	0.00527	0.00504	**0.005**	0.00502	0.005002	0.005	0.00202	0.00200
ϕ_3	0.00608	0.00603	**0.006**	0.00633	0.00600	0.00605	0.000054	0.000039
ϕ_4	0.00519	0.00549	**0.005**	0.00514	0.00500	0.00502	0.00534	0.00501
ϕ_5	0.00617	0.006	**0.00630**	0.00600	0.00611	0.00603	0.00506	0.00505
μ_1	0.39875	0.39999	**0.4**	0.39999	0.39999	0.4	0.399999	0.399999
μ_2	0.03998	0.04	**0.03998**	0.39999	0.03999	0.03999	0.7999999	0.7999999
μ_3	0.69143	0.69999	**0.69996**	0.69996	0.69999	0.69999	0.899999	0.899999
μ_4	0.39146	0.39829	**0.03996**	0.39999	0.39999	0.39999	0.399999	0.399999
μ_5	0.79699	0.78484	**0.79989**	0.79989	0.79999	0.39999	0.899999	0.899999

Again, the simulation is made for maximum number of generation, varies from 50 to 400 with a step size of 50. Here, the population size is kept constant at 100. The optimum value of system's performance is 98.52%, for which the finest combination of failure and repair variable is ϕ_1 =**0.006**, μ_1=0.4, ϕ_2 =0.005, μ_2 =**0.03998**, ϕ_3=0.006, μ_3 =**0.69996**, ϕ_4 =0.005, μ_4 =**0.03996**,ϕ_5=0.00630, μ_5=0.79989 at generation rate 150as given in table 2.

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Corresponding Author

Mukesh Kumar*

Ph.D., Mechanical Engineering, UIET, MDU, Rohtak

mannmukesh2006@gmail.com