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Optimization of Availability of Towel Manufacturing System: A Case Study

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Abstract

The main objective of this paper is to analyze the behavior of multi-state repairable system of Towel Manufacturing System. In current article we evaluate the critical component and optimizing availability parameters for the Towel Manufacturing System through Genetic Algorithm (GA). This system consists of four vital components arranged in hybrid combination. The availability/performance modeling is carried out by taking into consideration exponential distribution for possible failures and repairs. A mathematical model based on the Markov method is used to develop differential equations. These equations are then resolved using boundary and normalizing conditions to evaluate the long term availability of the towel manufacturing system. Genetic Algorithm has also been used to optimize the performance of subsystems in the towel manufacturing industry. Therefore, findings of this study can facilitate appropriate maintenance decisions and enhance system performance.

Keywords: Towel Manufacturing System, Long term availability, Markov process, Genetic Algorithm, GA

INTRODUCTION

In today's worldwide competitive era, industries have to run their system 365 days in a year to fulfill the customer's demand without any failure for their survival. But the failure is an inevitable phenomenon and it may occur due to various reasons. The failure of system in industry may result in various losses to the industrialist in terms money, low production, loss of human lives etc. Therefore, the system reliability /availability analysis for industrial system emerges as a thrust area in current scenario. The analysis helps to find the critical subsystem/component in the whole system and accordingly the maintenance strategy can be designed. Further the various factors /variables affect the availability of the system can be optimized for the maximum availability using optimization technique.

Several scientists and researchers contribute in the availability analysis of various systems. Some of them are discussed here; Garg et al. [1] presented the availability of combed sliver yarn production system, an important functionary unit of yarn production plant. Adhikarya et al. [2] applied RAM technique for improving availability in coal based thermal power plant by deciding maintenance schedule and finding critical subsystems of the plant concerned. Coit et al. [3] projected a manifold objective formulation for attaining highest availability. Kumar et al. [4] evaluated the availability of CO_2 carbon dioxide cooling system of a fertilizer plant using Markovian approach. Goyal et al. [5] evaluated the steady-state availability of a repairable system through the Markov modeling and Lagrange's method. Guilani et al. [6] presented the GA approach in redundancy allocation problem considering the three performance rate for each sub-system. Gupta et al. [7] computed the long-run availability of a manufacturing plant and presented the numerical results for identifying the criticality of various sub-systems to improve the overall performance of the plant. Kumar et al. [8] applied the PSO technique to improve the performance of a repairable system in brewery plant. Ram et al. [9] performed the sensitivity analysis in order to measure the system performance with respect to the variation of failure rates of different sub-systems. Zhang et al. [10] proposed a simplified method for offshore oil production system which is a hybrid approach i.e. combination of continuous-time and discrete time. Rabbani et al. [11] employed the GA and PSO algorithms to obtain the optimum value of designed parameters of a CCHP system.

Ying-Shen et al. [12] proposed a GA based optimization model to optimize availability of a series-parallel system. Gupta et al. [13] explains the present paper discusses the performance modeling and decision support system for a feed water unit of a thermal power plant using the concept of performance analysis and modeling..Khanduja et al. [14] developed the performance model in a paper plant and presented the GA technique for the optimization of system performance. Modgil *et al*. [15] derived a model for performance evaluation and it used Markov process for the shoe upper manufacturing unit. Kumar et al. [16]. 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. Gupta et al. [17] developed a performance model of power generation system of a thermal plant using Markov technique and probabilistic approach

In the present work availability analysis of Towel Manufacturing System has been carried out with an aim to find the critical component and optimizing the various parameters affecting the availability of the system. The Towel Manufacturing System has four components namely weaving machine, dryer machine, length cutting machine and stitching machine arranged in series and parallel combinations as shown in figure 1. After performing weaving operations the towel are being dried. After the drying action different sizes of towels are cut in the length cutting machines. Finally all the corners of towels are stitched.

SYSTEM DESCRIPTION

1. Sub-system W: It includes two sets of weaving machines which are arranged in parallel. The failure of one machine reduces the production the subsystem fall under the reduced capacity.

2. Sub-system D: After performing weaving operation the towels are fed in to the dryer where its moisture evaporates. It is the single component failure of this component leads to complete failure of system.

3. Sub-system C: In this sub-system towels are cut in to different sizes. It is the single component failure of this component leads to complete failure of system.

4. Sub-system D: In this sub-system all the corners of towels are stitched. It includes two sets of machines which are arranged in parallel. The failure of one unit reduces the production capacity.

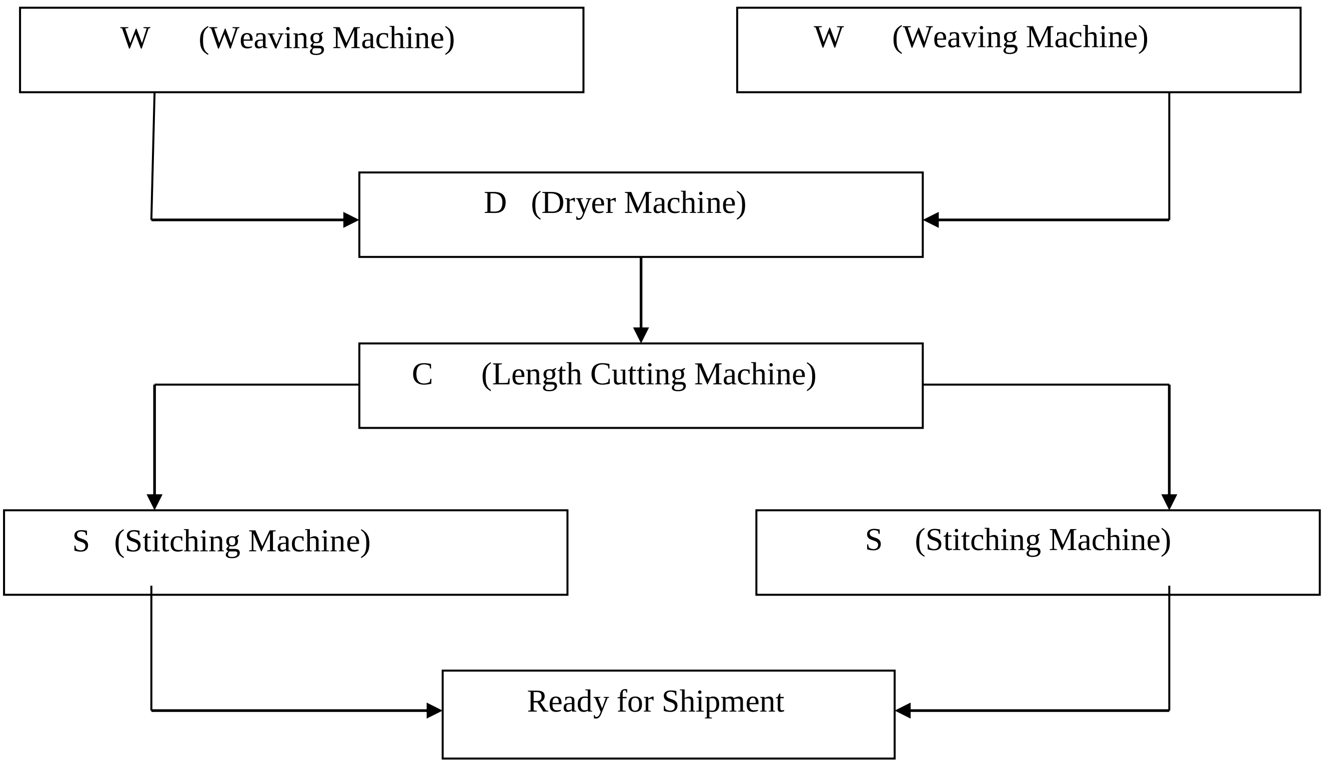

Figure 1. Schematic flow diagram of Towel Manufacturing System.

The following assumptions and notations are being used for availability modeling

Assumptions

1. The failure as well as repair rates of the components is taken as constant under exponential distribution
2. The performance of a repaired unit is as good as new, for a specified duration.
3. Adequate repair amenities are provided,
4. Redundant units (if any) given of the same capacity as the active units.

Notations

Component-W	:	Consists of two weaving machines working in parallel can work with reduced capacity and breakdown state.
Component –D	:	One dryer machine can work with breakdown state.
Component -C	:	One length cutting machine can work with breakdown state.
Component –S	:	Two stitching machines working in parallel subjected to minor as well as major failure only.
$\tau_1, \tau_2, \tau_3, \tau_4$	:	Failure rates of W,D,C,S.
τ_5, τ_6	:	Failure rates of W and S in reduced capacity.
$\eta_1, \eta_2, \eta_3, \eta_4$	:	Repair rates of W,D,C,S.
η_5, η_6	:	Repair rates of D and C in reduced state.

$P_i(t)$	:	Initially all the components are in working capacity.
'	:	Derivatives w.r.t.'t'
W,D,C,S	:	Full capacity working state
W_1,S_1	:	Reduced capacity working state
W,d,c.s	:	Failed state

Based on above assumptions and notations the availability model/state transition diagram of Towel Manufacturing System has been build up as shown in figure 2.

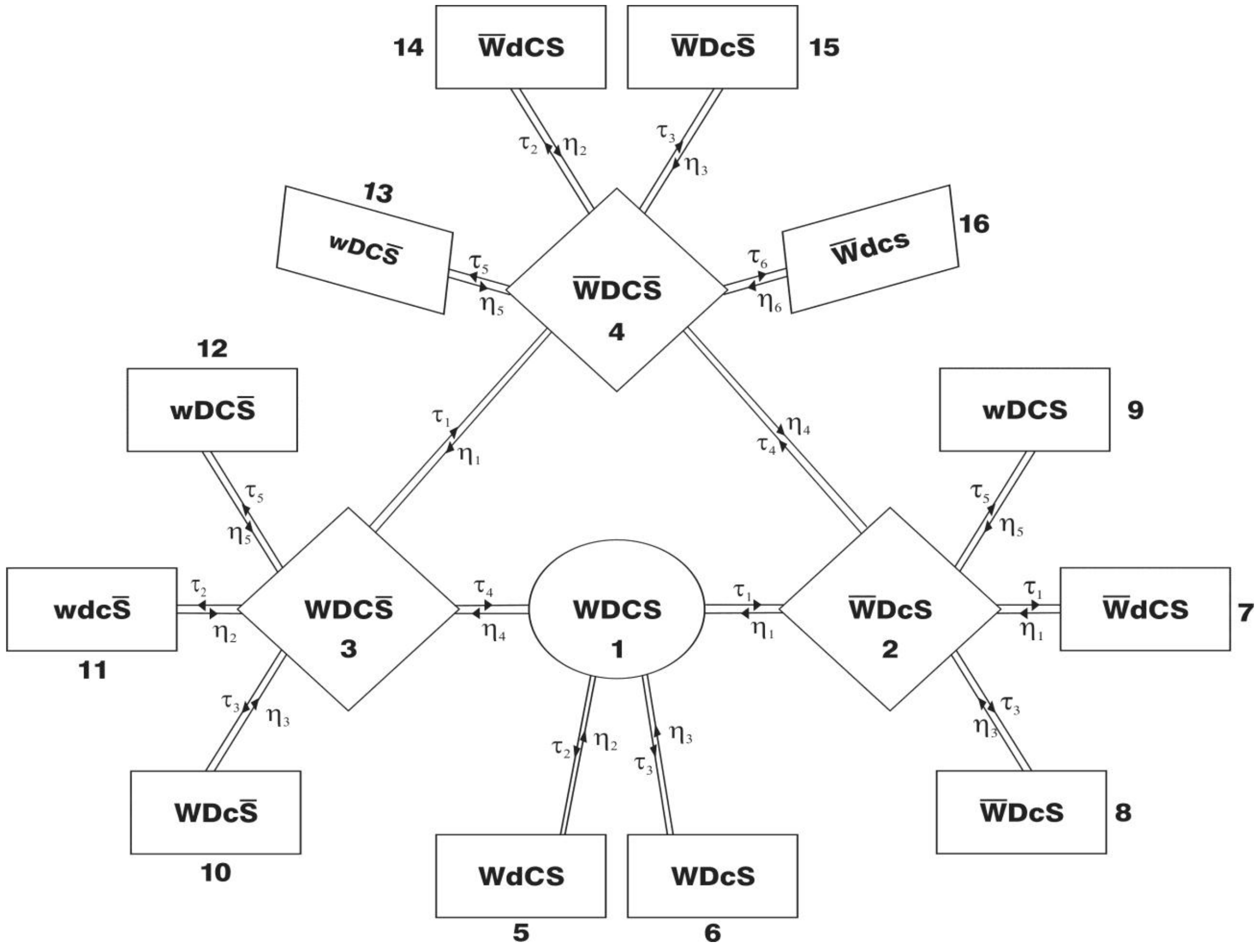

Figure 2. Transition diagram of Towel Making System.

Availability modeling of the system: Pertaining to the real environment of the industry availability modeling has been done as shown in figure 2. Two of the system components are subjected to major failure and two are subjected to minor failure only. The major failure takes the system to breakdown state while the minor failures can be repaired during the reduced capacity state. The state transition diagram of the towel manufacturing system is revealed in figure 2. State 1 represents the full working state, the state 2, 3 represents the reduced capacity working state and others from 4 to 16 represents the failed state.

Probability consideration provides the subsequent differential equations associated with the availability model/transition diagram.

$P'_1(t) + (\tau_1 + \tau_2 + \tau_3 + \tau_4) P_1(t) = \eta_1 P_2(t) + \eta_2 P_5(t) + \eta_3 P_6(t) + \eta_4 P_3(t)$ (1)

$P'_2(t) + (\tau_1 + \tau_3 + \tau_5 + \mu_1) P_2(t) = \tau_1 P_1 + \eta_4 P_4 + \eta_5 P_9 + \eta_1 P_7 + \eta_3 P_8$ (2)

$P'_3(t) + (\tau_4 + \tau_3 + \tau_2 + \tau_5 + \tau_1) P_3(t) = \eta_1 P_4 + \tau_4 P_1 + \eta_5 P_{12} + \eta_2 P_{11} + \eta_3 P_{10}$ (3)

$P'_4(t) + (\tau_5 + \tau_2 + \tau_3 + \tau_6 + \eta_1 + \eta_4) P_4(t) = \tau_4 P_2 + \tau_1 P_3 + {}_5P_{13} + \eta_2 P_{14} + \eta_3 P_{15} + \eta_6 P_{16}$ (4)

$P'_5(t) + \eta_2 P_5 = \tau_2 P_1$ (5)

$P'_6(t) + \eta_3 P_6 = \tau_3 P_1$ (6)

$P'_7(t) + \eta_1 P_7 = \tau_1 P_2$.(7)

$P'_8(t) + \eta_3 P_8 = \tau_3 P_2$ (8)

$P'_9(t) + \eta_5 P_9 = \tau_5 P_2$ (9)

$P'_{10}(t) + \eta_3 P_{10} = \tau_3 P_3$ (10)

$P'_{11}(t) + \eta_2 P_{11} = \tau_2 P_3$ (11)

$P'_{12}(t) + \eta_5 P_{12} = \tau_5 P_3$ (12)

$P'_{13}(t) + \eta_5 P_{13} = \tau_5 P_4$ (13)

$P'_{14}(t) + \eta_2 P_{14} = \tau_2 P_4$ (14)

$P'_{15}(t) + \eta_3 P_{15} = \tau_3 P_4$ (15)

$P'_{16}(t) + \eta_6 P_{16} = \tau_6 P_4$ (16)

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System availability: All the components must be operative for the long duration of time to achieve higher system performance. So, system availability for lengthy duration is calculated by substituting steady state conditions i.e. by putting $t \to \infty$ and $d/dt = 0$ on equations 2 to 16 we get:

Now $P_2 = P_1 S_9$ $P_3 = P_1(S_4 + S_3 S_4)$

$P_4 = S_8 P_1$ $P_5 = Z_2 P_1,$

$P_6 = Z_3 P_2,$ $P_7 = Z_1 P_2$

$P_8 = Z_3 P_2,$ $P_9 = Z_5 P_2,$

$P_{10} = Z_5 P_3$ $P_{11} = Z_2 P_3,$

$P_{12} = Z_5 P_3,$ $P_{13} = Z_5 P_4$

$P_{14} = Z_2 P_4,$ $P_{15} = Z_3 P_4,$

$P_{16} = Z_6 P_4$

$P_7 = Z_1 S_9 P_1,$ $P_8 = Z_3 S_9 P_1,$ $P_{10} = Z_5 S_8 P_1$

$P_{11} = Z_2 S_8 P_1,$ $P_{12} = Z_5 S_8 P_1,$ $P_{13} = Z_5 S_7 P_1$

$P_{14} = Z_2 S_7 P_1,$ $P_{15} = Z_2 S_7 P_1,$ $P_{16} = Z_6 S_7 P_1$

where

$S_1 = \tau_1/(\tau_4+\eta_1),$

$S_2 = \eta_4/(\tau_4+\eta_1),$

$S_3 = \tau_1/(\eta_4+\tau_1),$

$S_4 = \tau_4/(\eta_4+\tau_1),$

$S_5 = \tau_4/(\eta_1+\eta_4),$

$S_6 = \tau_1/(\eta_1+\eta_4),$

$S_7 = (S_1 S_1 + S_1 S_1)/(1 - S_1 S_1 - S_1 S_1),$

$S_8 = (S_4 + S_3 S_7),$

$S_9 = (S_1 + S_7)$,

$Z_i = \lambda_i/\mu_i$, for i =1, 2, 3, 4, 5, 6 and 7

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 $\sum_{i=1}^{16} P_i = 1$

$P_1 + P_1 S_9 + P_1(S_4 + S_3 S_4) + S_8 P_1 + Z_2 P_1 + Z_3 P_2 + Z_1 P_2 + Z_3 P_2 + Z_5 P_2 + Z_5 P_3 + Z_2 P_3 + Z_5 P_3 + Z_5 P_4 + Z_2 P_4 + Z_3 P_4 + Z_6 P_4 = 1$

$P_2 = P_1 S_9$

Now substituting the value of P_2 in above equation

$\mathbf{P_1+}\ P_1S_9 + P_1(S_4+S_3S_4) + S_8P_1 + Z_2P_1 + Z_3P_1S_9 + Z_1P_1S_9 + Z_3P_1S_9 + Z_5P_1S_9 + Z_5P_1(S_4 + S_3S_4) + Z_2P_1(S_4 + S_3S_4) + Z_5P_1(S_4 + S_3S_4) + Z_5S_8P_1Z_2S_8P_1 + Z_3S_8P_1 + Z_6S_8P_1 = 1$

$P_1(1+S_9+(S_4+S_3S_4)+S_8+Z_2+Z_3S_9+Z_1S_9+Z_3S_9+Z_5S_9+Z_5(S_4+S_3S_4)+Z_2(S_4+S_3S_4)+Z_5(S_4+S_3S_4)+Z_5S_8+Z_2S_8+Z_3S_8+Z_6S_8)=1$

Where
$K=1+S_9+(S_4+S_3S_4)+S_8+Z_2+Z_3S_9+Z_1S_9+Z_3S_9+Z_5S_9+Z_5(S_4+S_3S_4)+Z_2(S_4+S_3S_4)+Z_5(S_4+S_3S_4)+Z_5S_8+Z_2S_8+Z_3S_8+Z_6S_8$

$\mathbf{P_1 = 1/(}1+S_9+(S_4+S_3S_4)+S_8+Z_2+Z_3S_9+Z_1S_9+Z_3S_9+Z_5S_9+Z_5(S_4+S_3S_4)+Z_2(S_4+S_3S_4)+Z_5(S_4+S_3S_4)+Z_5S_8+Z_2S_8+Z_3S_8+Z_6S_8))$

The system availability in the long run is given by

$$Av = P_1 + P_2 + P_3 + P_4$$

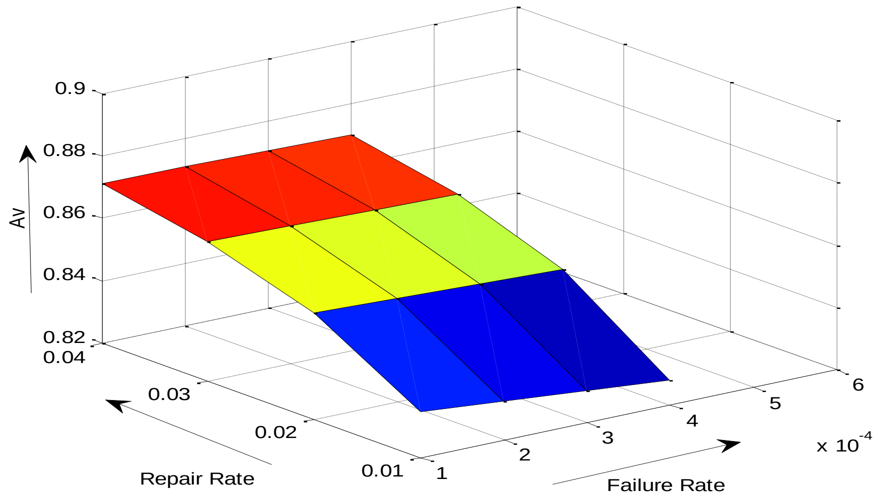
Behavior analysis:

The behavior analysis is being carried out by captivating appropriate failure and repair parameters of all components from maintenance record of towel making system and detailed discussion with the maintenance personnel. The simulation results are presented in table 1 to 4. The effect of various components on system availability with different combinations of failure and repair parameters has been shown in table 1 to 4. It also reveals the effect of failure and repair parameters of all subsystems on towel making system performance. On the basis of analysis we can select the best possible combination of failure and repair rate (τ_i, η_i) to increase the system's availability. Table 1 to 4 also reflects the maximum availability level for all the subsystems (for Weaving 0.8712, Dryer 0.8376, Cutting machine 0.8368, Stitching 0.8401.

Table 1: Impact of Failure and Repair Parameters of Weaving Machine (W) on System's Availability

η_1 \ τ_1	0.0001	0.0002	0.0003	0.0004	**Other Constant Parameters**
0.01	0.8345	0.8324	0.8302	0.8280	τ_2=0.0002 η_2=0.02
0.02	0.8542	0.8532	0.8523	0.8514	τ_3=0.0003 η_3=0.004 τ_4=0.003
0.03	0.8646	0.8641	0.8635	0.8630	η_4=0.01 τ_5=0.05
0.04	**0.8712**	0.8709	0.8705	0.8701	η_5=0.3 τ_6=0.003 η_6=0.01

Table 1 and its graph (shown below) reveal the impact of weaving machine failure and repair parameters on Towel Manufacturing System availability. It has been observe that on increasing the failure rate from 0.0001 to 0.0004 the system availability decreases by 0.76%. However on increasing the repair rate from 0.01 to 0.04 the system availability improves by 4.39%.



Behaviour of sub-system W with their combinations of failure and repair rate parameters

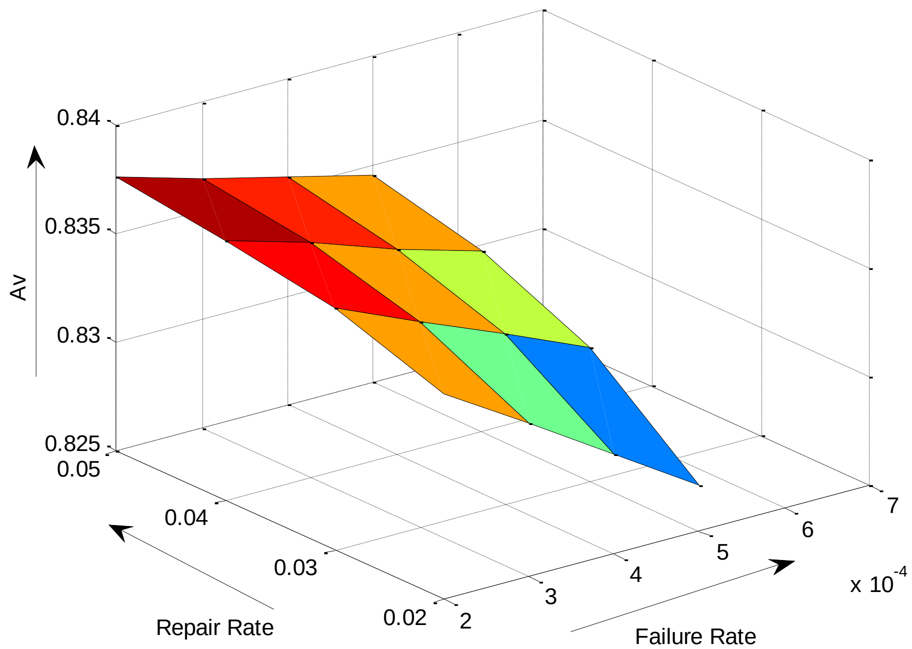
Sub-system W Availablity-0.8712

Failure rate 0.0004,Repair rate 0.04

Table 2: Impact of Failure and Repair Parameters of Dryer Machine on System's Availability

η_2 \ τ_2	0.0002	0.0003	0.0004	0.0005	Other Constant Parameters
0.02	0.8345	0.8321	0.8296	0.8271	τ_1=0.0001 η_1=0.01
0.03	0.8362	0.8345	0.8329	0.8312	τ_3=0.0005 η_3=0.008
0.04	0.8370	0.8358	0.8345	0.8333	τ_4=0.0035 η_4=0.035
0.05	**0.8376**	0.8365	0.8355	0.8345	τ_5=0.05 η_5=0.3

Table 2 and its graph (shown below) explained that failure and repair rates of dryer machine have marginal effect on the system's availability. On raising the failure rate from 0.0002 to 0.0005 the availability is reduced by 0.0.88%. However on increasing the repair rate from 0.02 to 0.05 the system availability increases by 0.37%.



Behaviour of sub-system (D) with their combinations of failure and repair rate parameters

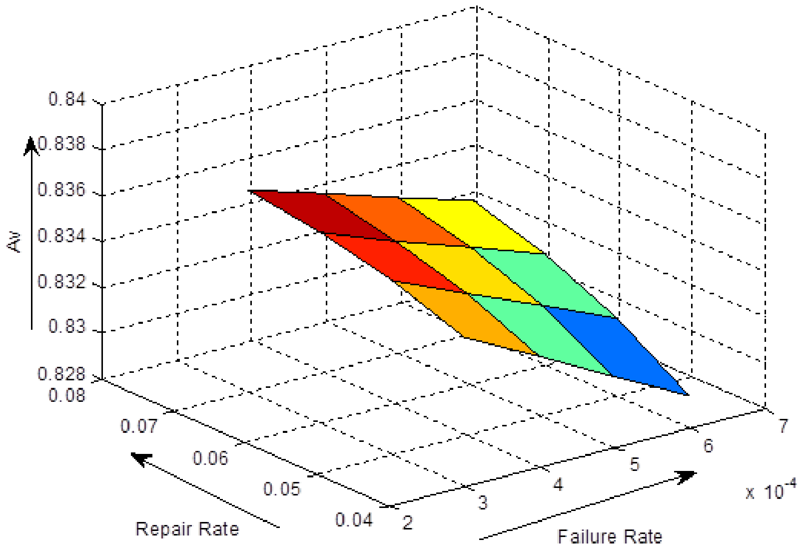
Sub-system D Availablity-0.8376

Failure rate 0.0005,Repair rate 0.05

Table 3: Impact of Failure and Repair Parameters of Cutting Machine on System's Availability

τ_3 / η_3	0.0003	0.0004	0.0005	0.0006	Other Constant Parameters
0.04	0.8345	0.8328	0.8311	0.8294	τ_1=0.0001 η_1=0.01 τ_2=0.0002 η_2=0.02 τ_4=0.003 η_4=0.01 τ_5=0.05 η_5=0.3 τ_6=0.003 η_6=0.01
0.05	0.8356	0.8342	0.8328	0.8314	
0.06	0.8363	0.8351	0.8340	0.8328	
0.07	**0.8368**	0.8358	0.8348	0.8338	

Table 3 and its graph (shown below) depict that the failure and repair rate of cutting machine also have marginal effect on system availability. On increasing the failure rate from 0.0003 to 0.0006 the system availability decreases by 0.61%. However on raising the repair rate from 0.04 to 0.07 the system availability improves by 0.27%.



Behaviour of sub-system (C) with their combinations of failure and repair rate parameters

Sub-system D Availablity-0.8368

Failure rate 0.0006,Repair rate 0.006

Table 4: Effect of failure and repair rates of stitching machine on long term System Availability

η_4 \ τ_4	0.03	0.04	0.05	0.06	Other Constant Parameters
0.01	0.8345	0.8302	0.8279	0.8265	τ_1=0.0001 η_1=0.01 τ_2=0.0002 η_2=0.02 τ_3=0.0003 η_3=0.004 τ_5=0.05
0.02	0.8350	0.8310	0.8298	0.8278	
0.03	0.8387	0.8327	0.8309	0.8298	
0.04	**0.8401**	0.8344	0.8319	0.8309	

Table 4 and its graph (shown below) illustrate the effect of failure and repair rates of stitching machine on towel making system availability.

On enhancing the failure rate from 0.03 to 0.06 the system availability decreases by 0.76%. However on raising the repair rate from 0.01 to 0.04 the system availability improves by 0.66%.

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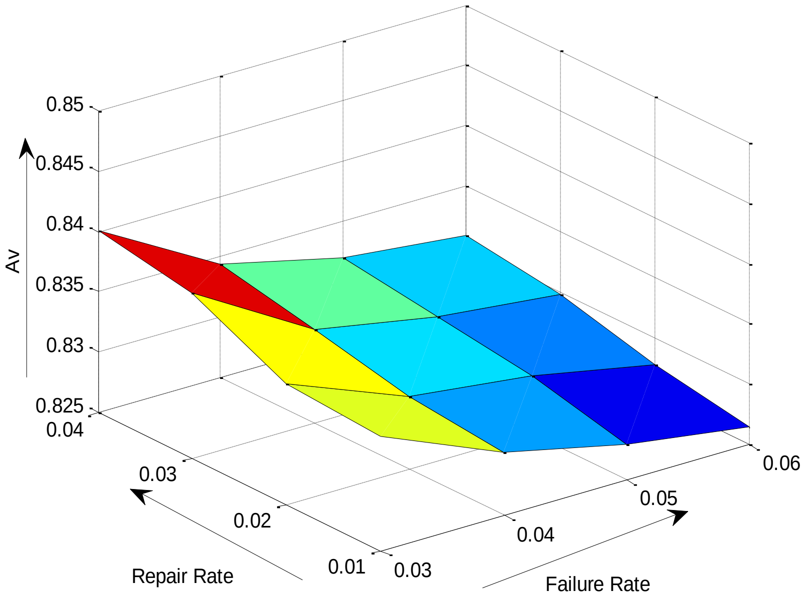

Behaviour of sub-system (S) with their combinations of failure and repair rate parameters

Sub-system D Availablity-0.8401

Failure rate 0.06, Repair rate 0.04

Genetic algorithm

Genetic algorithm techniques have efficiently been used to achieve the quality solution for both constrained and unconstrained optimization programme.GA recognized the initial population randomly and fittest chromosome represents the best solution. The chromosomes are evaluated for fit value and best individuals are selected to become the parents of next generation. Crossover operator combines the best solution. Individuals to yield better chromosomes.it propagate good features of current population into the next generation, which will have better fitness value than the previous generation. The mutation operator is used to rearranging the structure of chromosomes to avoid the possibility of new solution very similar to the previous solution after several generations. The whole process is repeated until either the best fitness level of population has been achieved or the maximum number of generation has been produced.

POP SIZE	50	100	150	200	250	300	**350**	400	450
A_V	0.93918	0.94277	0.94378	0.94429	0.94436	0.9449	**0.9459**	0.9452	0.94388
λ_1	0.0001	0.000104	0.000172	0.000162	0.000153	0.000145	**0.000104**	0.000108	0.000113
λ_2	0.000252	0.000208	0.000201	0.000206	0.000209	0.000204	**0.0002**	0.000228	0.000209
λ_3	0.000361	0.000304	0.000311	0.000317	0.000335	0.000304	**0.000301**	0.000303	0.000339
λ_4	0.031043	0.030962	0.030113	0.030086	0.030007	0.030031	**0.03**	0.030008	0.030259
λ_5	0.005147	0.005098	0.005203	0.005001	0.005097	0.005009	**0.005002**	0.005013	0.00503
λ_6	0.003182	0.003123	0.003056	0.003133	0.003025	0.003035	**0.003**	0.003016	0.003016
μ_1	0.038668	0.039991	0.039995	0.039983	0.03994	0.039998	**0.04**	0.039998	0.038775
μ_2	0.049995	0.049999	0.04701	0.04996	0.048731	0.049989	**0.049999**	0.048992	0.049893
μ_3	0.069997	0.065989	0.069985	0.069992	0.069847	0.069998	**0.069999**	0.069999	0.069997
μ_4	0.039992	0.039994	0.039994	0.038764	0.039997	0.038868	**0.04**	0.039999	0.038962
μ_5	0.07551	0.078462	0.079986	0.08	0.079997	0.079999	**0.08**	0.08	0.079998
μ_6	0.039992	0.039956	0.039998	0.03999	0.039996	0.03997	**0.04**	0.04	0.04

τ_1 η

The simulation is executed for utmost population size that varies from 50 to 450**.** Here the Generation size is kept constant as 100. The most favorable value of system's availability is 94.59%, for which the finest probable combination of failure and repair parameters is τ_1**=0.000104,** η_1 **=0.04,** τ_2 **=0.0002,** η_2**=0.049999,** τ_3**=0.000301,** η_3**=0.069999,** τ_4**=0.03,** η_4**=0.04,** τ_5**=0.00502,** η_5**=0.08,** τ_6**=0.003,** η_6**=0.04 at population size 350** as given in table 2.

Again, the simulation is made for maximum number of generation, varies from 100 to 550 with a step size of 50. Here, the population size is kept constant at 100. The optimum value of system's performance is 94.56%, for which the finest combination of failure and repair variable is

τ_1 =0.00012, η_1=0.04, τ_2 =0.000209, η_2 =0.05,τ_3=0.000308,η_3 =0.07,τ_4 =0.030006, η_4 =0.04, τ_5 =0.005006, η_5 =0.08,τ_6 =0.003008,η_6 =0.04 at generation rate 500 as given in table 3.

Gen. Size	100	150	200	250	300	350	400	450	**500**	550
Availability	0.9421	0.94372	0.94495	0.94497	0.94528	0.94528	0.94534	0.94534	**0.94561**	0.9451
λ_1	0.000103	0.000103	0.000103	0.000103	0.000103	0.000103	0.000102	0.000102	**0.00012**	0.0001
λ_2	0.000223	0.000223	0.000223	0.000222	0.000222	0.000222	0.000218	0.000218	**0.000209**	0.00024
λ_3	0.000312	0.000312	0.000312	0.000311	0.000311	0.000311	0.000311	0.000311	**0.000308**	0.000309
λ_4	0.03128	0.030304	0.03128	0.030301	0.030056	0.030056	0.030056	0.030056	**0.030006**	0.03
λ_5	0.005066	0.005005	0.005066	0.005005	0.005005	0.005005	0.005005	0.005005	**0.005006**	0.005023
λ_6	0.003118	0.003118	0.003118	0.003053	0.003038	0.003038	0.003037	0.003037	**0.003008**	0.003
μ_1	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	**0.04**	0.04
μ_2	0.04755	0.049999	0.04755	0.05	0.05	0.05	0.05	0.05	**0.05**	0.05
μ_3	0.069958	0.069998	0.069958	0.07	0.07	0.07	0.07	0.07	**0.07**	0.07
μ_4	0.038117	0.038117	0.038117	0.04	0.04	0.04	0.04	0.04	0.04	0.04
μ_5	0.079995	0.079999	0.079995	0.08	0.08	0.08	0.08	0.08	0.08	0.08
μ_6	0.039995	0.04	0.039995	0.04	0.04	0.04	0.04	0.04	0.04	0.04

CONCLUSIONS

In this paper, the behavior analysis has been conducted by utilizing the crisp data of system under consideration and traced out the best system performance for towel making system. In the proposed methodology, a Markov Process based performance model has been constructed to analyze the effect of failure and repair parameters of different components, more closely, on system performance. In order to enhance the system efficiency and to obtain the the optimal combinations of failure and repair rate parameters for various components, the performance model has been solved through GA.The following observation can be made from availability results.

1. It can be easily identified that sub-system weaving machine is more critical than other sub-system in terms of the effect on system availability.
2. The behavior of the system can be predicted with more reality using the proposed methodology.
3. The maintenance priorities can be setting up using the behavior analysis of the system
4. The system availability has been increased from 83.45% to 94.59% using GA.
5. The major conclusion of this study is that GA based approach performs well in determining the optimal combination of failure and repair parameters to enhance the system performance..

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