Availability Analysis of Carded Sliver Yarn Production System Using Numerical Technique

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Abstract

This research work focuses on analysis of Long Term Availability (LTA) And Transient Availability (TA) of the complex system namely Carded Sliver yarn Production System of a Textile Industry with the application of Markov Method (MM). The mathematical model for the system concerned has been developed on the basis of actual working conditions. The model developed is being solved using numerical method namely Runge-Kutta (RK) to compute TA i.e. Time dependent. Further LTA has been computed by applying normalizing condition, and recursive method. On the basis of LTA and TA analysis the most critical subsystem has been identified. Here, component D i.e. Draw Frame is most critical component in the present case. Further, repair priorities have been proposed on the basis of impact of Repair Rate (RR) on LTA and TA of the system chosen. The proposed repair priority for component D, B and C are I, II and III respectively.

Keywords: Markov method (MM), carded sliver yarn, runge-kutta, repair priority.

1. Introduction

Due to technological improvements, the industrial components are becoming more productive and more reliable but highly complicated. The word reliability originates from failure itself. Frequent failures of an industrial system make it unreliable for the use. The cost of unreliable system is so much high in terms of economy and safety. It is thus required in industries to use the Reliability, Availability and Maintainability (RAM) approach forenhancing the production of industrial system. To have this, the overall reliability and availability of the different systems/subsystems used may be maintained at the highest working level. It is not possible to have fault free operation because the failure can never be avoided rather the efforts can be exerted to minimize it to an extent using various kind's reliable components, proper preventive maintenance of the components or subsystem and by deciding repair priorities different subsystems of the system. To analyse the system performance in various industries few measures are used regarding reliability and maintainability. The availability is one of the index to measure the system performance because availability is the function of both reliability and maintainability. In the present work Long Term Availability (LTA) and Transient Availability (TA) are considered as an important factor for the performance measures of the industrial system and deciding repair priorities of the carded sliver yarn production system in textile industry. The various subsystems of the yarn production system are arranged in mixed layout as shown in figure 1.The various applications of MM have been described in the literature such as Singh I.P. (1989) proposed the availability estimation model of a system includes four types of components follows pre-emptive main concerns repairs. Dayal (1991) developed the one out of N: G system considering common cause failures. Kumar et. al. (2009) presented a performance model of ammonia synthesis system for availability analysis and evaluation using MM. Kumar & Tewari (2011) done the LTA analysis of carbon dioxide (CO_2) cooling system in a fertilizer industry taking normalizing conditions. Modgil et al., (2013) dealt with Steady State Availability (SSA) model using MM applied to shoe manufacturing industry and evaluated the time based system availability. Usubamatov et al., (2013) suggested a mathematical model for automated production lines considering machine availability as an important parameter. Aggarwal et al., (2014) evaluate the performance of butter oil making system in a dairy plant by using MM and computed the MTBF using Runge-Kutta approach has been applied. Li & Peng, (2014) computed the system availability and cost of operation for hybrid industrial system and Genetic Algorithm (GA) has been used as a optimizing tool. Aggarwal et al. (2015) dealt SSA analysis of a fertilizer plant by applying MA considering the exponential distribution for governing parameters and propose the suitable maintenance plan to improve the system. Kumar &Tewari, (2016) analyzed the SSA of bottle filling system of a bottling plant and optimize the SSA using PSO. Malik et. al. (2018) discussed the maintenance priority decision for water flow system in coal fired power plant. Malik & tewari (2021) presented the Performability and maintenance priority decision of coal ash handling plant in thermal power plant.

Literature review shows that most of the work had been confined to areas like fertilizer, sugar, chemical and other related industries. The earlier work was more conserve towards theoretical models and SSA only, very few research works found related to TA. In the present research work LTA and TA (for a period of one year) has been applied to carded sliver production system of textile industry for identification of most critical component along with repair priorities for all units involved in the system concerned.

2. System Description

The carded sliver yarn production system consists of three subsystems namely blow room (single unit), carding system (multi units) and draw frame (multi unit). The process flow diagram shows the arrangement of various components of carded sliver production system as shown in figure 1.

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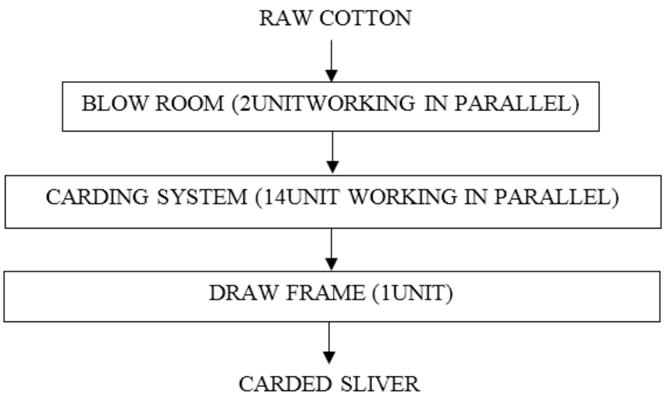

Figure 1; Process Flow Diagram of Carded Sliver Production System

The Raw cotton received in the textile mill in hard pressed material form; it is conditioned at 55-60% Relative Humidity (RH) for about 24 hours with the purpose to improve the quality of the yarn. Then the conditioned material fed manually into the blow room where opening and cleaning of cotton takes place. Subsequently small tufts of clean and opened cotton transferred to Carding system. Cards individualizes and cleans the cotton fibers, remove neaps, tiny lumps and fused fiber ends and deliver slivers continuously, which further moved to the Draw Frames. Draw Frames provide strength to these slivers and finally strengthen slivers are collected in cans.

Sub-system B (Blow Room): Consists of 2 Units working in parallel.

Sub-system C (Carding System): Consists of 14 Units working in parallel. The system works in reduced state when 1^{st} and 2^{nd} failure occurs and thereafter unit considered in failed state.

Sub-system D (Draw Frame): Having one number and on failure the whole system goes into breakdown state.

2.1. Assumptions and Notations

The assumptions taken for mathematical modeling of the chosen system are as follows:

1. Failure/repair parameters are considered to be exponentially distributed.
2. Every system works as new after repair.
3. The system works in reduced state.
4. The repair works starts immediately after failure occurs.

'o': System is in operative state
'g': System is in good condition
'r': System is under repair
'qr': System is waiting for repair

: Represents Good operational condition.

: Represents reduced state.

: Represents failed state.

The figure 2 shows the Transition Diagram (TD) of carded sliver production system with different probable states. Based on TD the availability model has been developed.

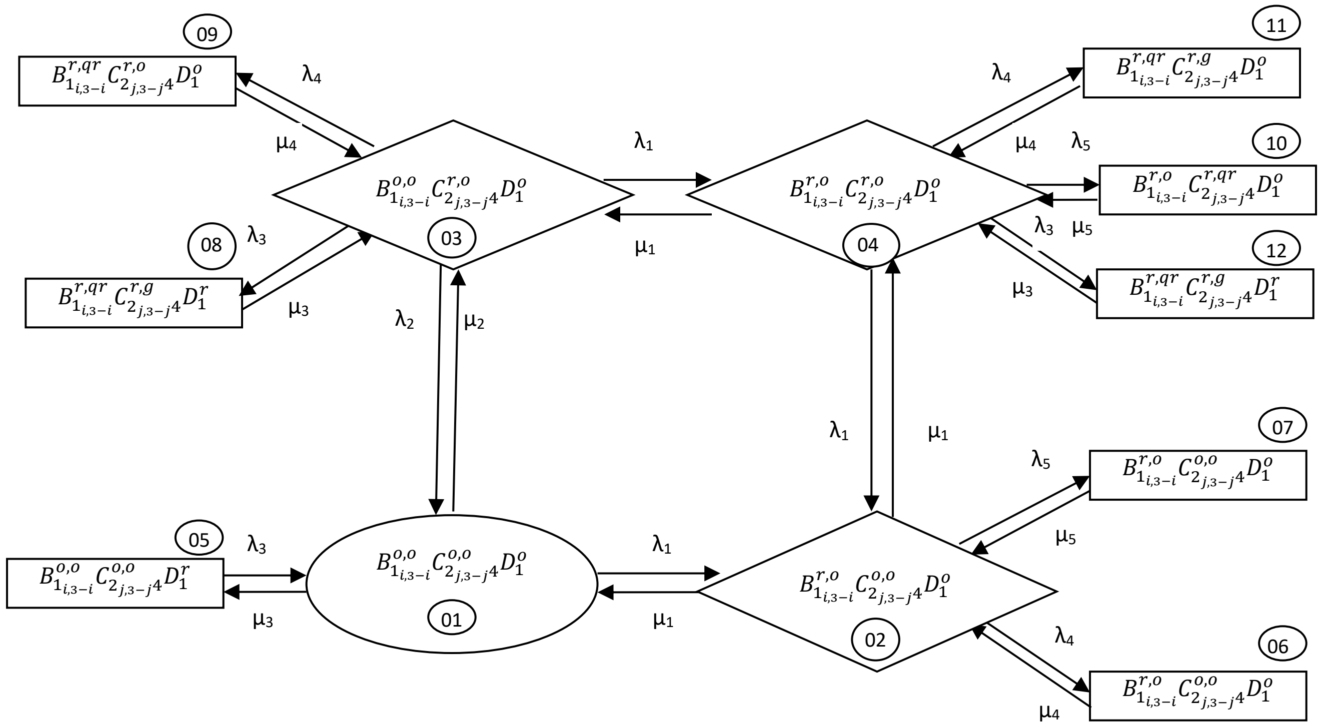

Figure 2; State Transition Diagram of Carded Sliver Production System

3. Mathematical Modeling

The various probability considerations obtained from TD the various differential equations of first order of carded sliver yarn production system are as under:

$$P_1'(t) + K_1P_1(t) = \mu_1P_2(t) + \mu_2P_3(t) + \mu_3P_5(t) \quad (1)$$
$$P_2'(t) + K_2P_2(t) = \mu_2P_4(t) + \mu_3P_6(t) + \mu_4P_7(t) + \lambda_1P_1(t) \quad (2)$$
$$P_3'(t) + K_3P_3(t) = \mu_3P_8(t) + \mu_2P_9(t) + \mu_1P_4(t) + \lambda_2P_1(t) \quad (3)$$
$$P_4'(t) + K_4P_4(t) = \mu_5P_{10}(t) + \mu_3P_{11}(t) + \mu_4P_{12}(t) + \lambda_1P_3(t) + \lambda_2P_2(t) \quad (4)$$
$$P_5'(t) + \mu_3P_5(t) = \lambda_3P_1(t) \quad (5)$$
$$P_6'(t) + \mu_3P_6(t) = \lambda_3P_2(t) \quad (6)$$
$$P_7'(t) + \mu_4P_7(t) = \lambda_4P_2(t) \quad (7)$$
$$P_8'(t) + \mu_3P_8(t) = \lambda_3P_3(t) \quad (8)$$
$$P_9'(t) + \mu_2P_9(t) = \lambda_2P_3(t) \quad (9)$$
$$P_{10}'(t) + \mu_5P_{10}(t) = \lambda_5P_4(t) \quad (10)$$
$$P_{11}'(t) + \mu_3P_{11}(t) = \lambda_5P_4(t) \quad (11)$$
$$P_{12}'(t) + \mu_4P_{12}(t) = \lambda_3P_4(t) \quad (12)$$

Where

$$K_1 = (\lambda_1 + \lambda_2 + \lambda_3)K_2 = (\lambda_3 + \lambda_2 + \mu_1 + \lambda_4)K_3 = (\lambda_1 + \lambda_2 + \mu_2 + \lambda_3)$$
$$K_4 = (\lambda_3 + \lambda_4 + \mu_2 + \mu_1 + \lambda_3)$$

On solving above states equations (1 to 12) by applying initial condition i.e $t = 0, P_i(t) = 1$ for $i=1$and $P_i(t) = 0$ for $i \neq 0$using numerical method i.e. RK fourth order method. Here the time taken for TA is one year for different FR and RR parameters.

The LTA of the system concerned is given by equation 13 as follows

$$A(t) = P_1(t) + P_2(t) + P_3(t) + P_4(t) \qquad (13)$$

4. Transient Availability Analysis

Both the availabilities i.e. LTA and TA of the system have been computed for different values of the failure rates (FR) and repair rates (RR). Taking suitable range of FR and RR from components repair history sheet and their effect on system performance have been evaluated and presented in tables 1 to 6.

Table 1. TA of Blow Room with change in its FR

Days \ λ_1	**0.001**	**0.0011**	**0.0012**	**0.0013**
30	0.974178	0.973171	0.972362	0.971234
60	0.963120	0.962137	0.961357	0.960237
90	0.956092	0.955293	0.954651	0.953723
120	0.952811	0.952219	0.951746	0.951018
150	0.951329	0.950339	0.949975	0.949383
180	0.950777	0.949728	0.948600	0.948292
210	0.949286	0.948831	0.948516	0.948167
240	0.949079	0.948735	0.948472	0.948097
270	0.948464	0.946683	0.948371	0.948072
300	0.948901	0.948678	0.948369	0.948072
330	0.948879	0.948675	0.948272	0.948072
360	0.948873	0.948574	0.948272	0.948072

Table 1 reveals that TA of the system reduced by 0.302% as FR (λ_1) of Blow Room varies from 0.001 to 0.0013 keeping FR and RR of other components constant.

Table 2. TA of Carding System with Change in its FR

Days \ λ_2	**0.001**	**0.002**	**0.003**	**0.004**
30	0.974178	0.971509	0.969609	0.968287
60	0.963120	0.962376	0.959269	0.956419
90	0.956092	0.954177	0.952768	0.952515
120	0.952811	0.951932	0.949742	0.948712
150	0.951329	0.950066	0.947097	0.945042

180	0.950777	0.948582	0.944903	0.941760
210	0.949286	0.947408	0.943136	0.941760
240	0.949079	0.946501	0.941726	0.938977
270	0.948464	0.945822	0.940629	0.936714
300	0.948901	0.945032	0.939800	0.934887
330	0.948879	0.944741	0.938835	0.931535
360	0.948873	0.944683	0.928609	0.930460

Similarly, table 2 shows that TA of the system reduces marginally by 0.604% for a period of 30 days as FR of Carding System changes from 0.001 to 0.004 keeping FR and RR of other components constant.

Table 3. TA of Draw Frame with Change in its FR

Days \ λ_3	**0.001**	**0.002**	**0.003**	**0.004**
30	0.974178	0.954556	0.932274	0.910279
60	0.963120	0.934119	0.896951	0.865888
90	0.956092	0.917233	0.880597	0.846191
120	0.952811	0.911855	0.873759	0.838348
150	0.951329	0.910031	0.869778	0.833556
180	0.950777	0.907622	0.868549	0.831698
210	0.949286	0.906437	0.867204	0.830898
240	0.949079	0.906163	0.866914	0.830752
270	0.948464	0.906014	0.866759	0.830679
300	0.948901	0.905934	0.866679	0.830665
330	0.948879	0.905911	0.866660	0.830016
360	0.948873	0.905211	0.866651	0.830005

The table 3 demonstrates that TA of the system decreases significantly by 6.4% for a period of 30 days as FR (λ_3) of Draw Frame changes from 0.001 to 0.004 keeping FR and RR of other components constant.

Table 4. TA of Blow Room with Change in its RR

Days \ μ_1	**0.020**	**0.021**	**0.022**	**0.023**
30	0.974178	0.975509	0.977911	0.980971
60	0.963120	0.964256	0.969625	0.970215
90	0.956092	0.959154	0.961405	0.967343
120	0.952811	0.953204	0.954758	0.955194
150	0.951329	0.951877	0.953112	0.953493
180	0.950777	0.950850	0.951835	0.952156

210	0.949286	0.950067	0.951622	0.951133
240	0.949079	0.949487	0.950087	0.950315
270	0.948464	0.949072	0.949133	0.949295
300	0.948901	0.949027	0.949079	0.949017
330	0.948879	0.948597	0.948631	0.948709
360	0.948873	0.948739	0.948799	0.948801

On the same pattern table 4 depicts that TA of the system improves slightly by 0.697% for a period of 30 days as FR (μ_1) of Blow Room changes from 0.025 to 0.055 keeping FR and RR of other components constant.

Table 5. TA of Carding System with Change in its RR

μ_2 / Days	**0.025**	**0.035**	**0.045**	**0.055**
30	0.974178	0.976847	0.976935	0.977713
60	0.963120	0.963144	0.966474	0.967576
90	0.956092	0.956165	0.957416	0.958479
120	0.952811	0.952913	0.954038	0.955133
150	0.951329	0.951772	0.954030	0.953852
180	0.950777	0.950886	0.950976	0.951462
210	0.949286	0.949726	0.950575	0.950657
240	0.949079	0.949400	0.950322	0.950427
270	0.948464	0.949198	0.950153	0.950215
300	0.948901	0.949018	0.950056	0.950174
330	0.948879	0.948994	0.950004	0.950174
360	0.948873	0.948992	0.949990	0.950174

Similarly, on increasing the RR (μ_2) from 0.020 to 0.055of Carding System the TA of the system improves by 0.362% within 30 days period keeping FR and RR of other components constant as shown in table 5.

Table 6. TA of Draw Frame its Change in its RR

μ_3 / Days	**0.2**	**0.3**	**0.4**	**0.5**
30	0.974178	0.977564	0.979660	0.982504
60	0.963120	0.969929	0.975241	0.979502
90	0.956092	0.967292	0.974095	0.978750
120	0.952811	0.965848	0.973703	0.978448
150	0.951329	0.965699	0.973485	0.978257
180	0.950777	0.965528	0.973361	0.978188
210	0.949286	0.965486	0.973322	0.978092

240	0.949079	0.965445	0.973297	0.978063
270	0.948464	0.965445	0.973280	0.978032
300	0.948901	0.965439	0.973270	0.978028
330	0.948879	0.965439	0.973269	0.978028
360	0.948873	0.965439	0.973269	0.978028

Consequently, table 6 exhibits that TA of the system improves slightly by 0.85% as RR (μ_3) of Carding components varies from 0.020 to 0.050 within a period of 30 days keeping FR and RR of other components constant.

The above TA Analysis helps in identifying the critical component and deciding repair priorities of all the components of the system concerned. On the basis of above analysis the most critical component comes out to be draw frame which affects the system TA most. The table 7 shows the effect of FR and RR of various components on TA. Also the repair priorities of different components have been proposed.

Table 7. Repair Priorities for Carded Sliver Production System (Transient State)

Subsystem	**Failure Rate (FR)**	**Percentage Decrease in (TDSA)**	**Increase in Repair Rate (RR)**	**Percentage Increase in (TA)**	**Proposed Repair Priorities**
Blow Room	0.001 to 0.0013	0.302%	0.02 to 0.023	0.697%	II
Carding Units	0.001 to 0.004	0.604%	0.0205to 0.055	0.362%	III
Draw Frames	0.001 to 0.004	6.4%	0.02 to 0.05	0.85%	I

5. Long Term Availability (LTA) Analysis

The industrial systems are expected to run for a long period of time, therefore LTA has been computed for the same system as above. On solving the equations 1 to 12 taking $\frac{d}{dt}=0, \frac{\partial}{\partial t}=0$

The LTA of the system concerned , expressed by equation no. 13.

The effect of FR and RR of various components of the system has been computed and results are presented in tables8 to10 keeping the same FR and RR parameters as considered in TA analysis above.

Table 8. Effect of FR and RR of Blow Room on LTA

μ_1 / λ_1	**0.02**	**0.021**	**0.022**	**0.023**
0.001	0.9483	0.9484	0.9486	0.9497
0.0011	0.9481	0.9482	0.9483	0.9484

0.0012	0.9479	0.9480	0.9481	0.9482
0.0013	0.9476	0.9478	0.9479	0.9480

Table 8 shows the LTA of the system reduced by 0.738% as the FR of the blow room changes from 0.001 to 0.0013 and LTA improves marginally by 0.14% with change of RR from 0.020 to 0.023 keeping FR and RR of other components constant.

Table 9. Effect of FR and RR of Carding System on LTA

μ_2 / λ_2	**0.025**	**0.035**	**0.045**	**0.055**
0.001	0.9483	0.9491	0.9495	0.9487
0.002	0.9439	0.9467	0.9479	0.9485
0.003	0.9375	0.9430	0.9455	0.9468
0.004	0.9293	0.9384	0.9425	0.9447

Table 9 demonstrates that the LTA of the system significantly reduced by 2% as the FR of the Carding system changes from 0.001 to 0.0013 and LTA improves marginally by 0.042% with change of RR from 0.025 to 0.055 keeping FR and RR of other components constant.

Table 10. Effect of FR and RR of Draw Frame on LTA

μ_3 / λ_3	**0.02**	**0.03**	**0.04**	**0.05**
0.001	0.9483	0.9439	0.9514	0.9560
0.002	0.8881	0.9151	0.9293	0.9380
0.003	0.8503	0.8881	0.9082	0.9208
0.004	0.8156	0.8625	0.8881	0.9041

Table 10 displays that the LTA of the system significantly reduced by 1.3% as the FR of the Draw Frame changes from 0.001 to 0.0013 and LTA improves marginally by 0.085% with change of RR from 0.025 to 0.055 keeping FR and RR of other components constant.

The above LTA Analysis also identifies the same critical component and helps in deciding repair priorities of all the components of the system concerned. The table 11 shows the effect of FR and RR of various components on LTA. Also the repair priorities of different components have been proposed.

Table 11. Repair Priorities for Carded Sliver Production System (LTA)

Subsystem	**FR**	**% age reduce in LTA**	**rise in (RR)**	**% age Increase in LTA**	**Proposed Repair Priorities**
Blow Room	0.001 to 0.0013	0.738%	0.02 to 0.023	0.14%	II
Carding Units	0.001 to 0.004	2.0%	0.0205to 0.055	0.042%	III
Draw Frame	0.001 to 0.004	1.3%	0.02 to 0.05	0.81%	I

6. Conclusion

The impact of the FR and RR on LTA and TA of the system has been analyzed and presented in tables 1 to 6 and 8 to 9 respectively. The table 7 and 11 clearly shows that the component D i.e. Draw Frame has highest impact on the TA and LTA of the whole system. With increase in RR of Draw frame the TA improves by 0.85% and LTA improves by 0.81%. So, Draw Frame is the most critical component of the above said system, hence proposed top repair priority. On the same basis, repair priority of component B i.e. Blow Room and component C i.e. Carding unit are proposed II and III accordingly. The outcome of the present research work was discussed with management and found beneficial for improvement of LTA and TA of the whole system. Further, LTA and TA modeling of system concerned of a textile industry can also be addressed by applying different modeling techniques like FMEA, Monte Carlo Simulation, RBD, FTA and Petri Nets. The proposed methodology may be used to model other industrial systems.

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