Performance modeling and availability analysis of sole lasting unit in shoe making industry

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ABSTRACT: In the present work, time dependent availability of sole lasting unit in a shoe making plant is estimated. Here, Performance modelling has been developed on the basis of Markov birth-death process using probabilistic approach. The first order governing equations thus formulated using the mnemonic rule are solved to estimate the availability of the system. The failure rates and the repair rates of the subsystems are taken constant and are statistically independent .The solution of these equations is carried out using more sensitive and advance numerical technique, known as adaptive step-size control Runge-Kutta method to find the time reliant availability. This performance model deals with quantitative study of all aspects which influence all maintenance decisions associated with sole lasting unit system. The results obtained in the present work are considered to be very useful for devising the best possible maintenance strategies

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Key Words: Performance Modelling; Reliability; Availability; Runge-Kutta; Sole lasting.

I. INTRODUCTION

To achieve high production goals, the systems should be available (i.e. run failure free) for maximum possible duration. But practically these systems are subjected to random failures due to poor design, wrong manufacturing techniques, lack of operative skills, poor maintenance, overload, delay in starting maintenance and human error etc. These causes lead to non-availability of an industrial system resulting into improper utilization of resources (man, machine, material, money and time). So, to achieve high production and good quality, there should be highest system availability. Several researchers have discussed the reliability and availability of industrial system using different techniques and conditions to solve the governing equations. Zuo et al. [1] report an application of the k-out of-n: F and the consecutive – k-out-of-n: G system reliability models in evaluation of the life distribution of furnaces used in a petro-chemical company. Singh I.P. [2] studied the reliability analysis of a complex system having four types of components with pre-emptive priority repairs. Singh and Dayal [3] also discussed the reliability analysis of a repairable system in a fluctuating environment. Dhillon and Natesan [4] discussed the power system in fluctuating environment.S. Garg et al. [5,6] computed availability of crank-case manufacturing in a 2-wheeler automobile industry and block board system under pre-emptive priority discipline. Zhang [7] discussed the stochastic behaviour of an (n+1) unit standby system under pre-emptive priority rule and finds the expression for steady as well as time dependent state of the system.

II. SYSTEM DESCRIPTION

After final stitching of the shoe upper, it comes in the sole lasting section, where it is fixed on the last. The sole lasting unit of the shoe making plant consists of six subsystems (As shown in flow diagram in Figure no.-1). The insole is pasted to the shoe upper manually with the help of adhesives.

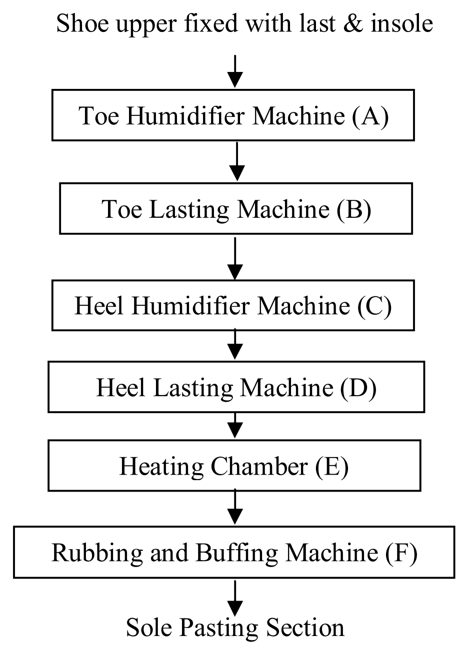

Figure-1: Flow diagram of Sole Lasting Section

1. *Toe Humidifier (A) (One in number): To get the* desired shape of the toe, the toe of the shoe upper is humidified with steam on this machine. The humidification softens the shoe leather so that it gets desired shape. The time and temperature of the steam supply depends upon the quality of leather.
2. Toe-Lasting machine (B) (Two in number): Toe-lasting is a process in which the leather of the shoe is stretched over the insole on the toe side.

After shoe lasting, a nail is pierced in to the shoe so that the height of heel is maintained. After that, Side lasting of the shoe is done manually with the help of simple tools such as pliers etc.; the leather of the shoe upper is stretched over the insole from all sides of shoe.

3. Heel humidifier (C) (One in number): To get the desired shape of the heel, the heel of the shoe upper is humidified with steam on this machine. The humidification softens the shoe lather so that it gets desired shape. The time and temperature of the steam supply depends upon the quality of leather.
4. Heel Lasting machine (D) (Two in number): It is a process in which the leather of the shoe is stretched over the insole on the heel side.

After that the nail is removed before it enters the heating chamber machine.

5. Heating cum wrinkle free Machine (E) (One in number): Before entering the heating chamber the hot air is passed on the shoe so that any wrinkle present may be removed. After that shoe enter in heating chamber where any kind of moisture, wrinkle, burr etc. present may be removed.
6. Rubbing and Buffing machine (F) (One in number): The iron brush wheel mounted on the machine is rubbed /rolled against the shoe so that proper rubbing according to shape of sole may be done. Reg marg wheel is rolled over the shoe for buffing operation.

After that the shoe is moved to sole pasting section.

III ASSUMPTIONS

i. Failure and repair rates for each subsystem are constant and statistically independent.
ii. Not more than one failure occurs at a time.
iii. Performance wise a repaired unit is as good as new.
iv. The standby units are of the same nature and capacity as the active units.
v. All the units are initially operating and are in good state.
vi. Each unit has three states viz. good, degraded and failed.
vii. There is only one repair facility

IV NOTATIONS

The notations associated with the transition diagram (Figure 2) are as follows:

: System working In Full Capacity.
:System working In Reduced Capacity.
:System working In the Fail/Breakdown state.

Superscript 'O': Subsystems in operating state.
Superscript 'g' Subsystems in good but not in operating state.
Superscript 'r': Subsystems in under repair.
Superscript 'qr': Subsystems in queuing for repair.
λ_i, λ_{3-i} : Failure rates Toe Lasting Machines ($B_1$and B_2)
λ_j, λ_{3-j} : Failure rates Heel Lasting Machines ($D_1$and D_2)
$\lambda_1, \lambda_2, \lambda_3, \lambda_4$: Failure rates of A,C,E and F.
λ_7, λ_8 : Failure rates of B & D from in reduced state
μ_i, μ_{3-i} : Repair rates of ($B_1$and B_2)
μ_j, μ_{3-j} : Repair rates of ($D_1$and D_2)
$\mu_1, \mu_2, \mu_3, \mu_4$: Repair rates of A,C,E and F.
μ_7, μ_8 : Repair rates of B & D In reduced State.
$P_i(t)$: Probability that at time't' all units are good and the system is in i^{th} state.
' : Derivatives w.r.t. 't'

IV PERFORMANCE MODELING OF THE SYSTEM

Probability considerations give the following differential equations associated with the Transition Diagram (Figure 2):

$$P_1'(t)+T_1P_1(t)=\mu_1P_5(t)+\mu_3P_6(t)+\mu_5P_7(t)+\mu_6P_8(t)+\mu_2P_2(t)+\mu_4P_3(t)+\mu_7P_{13}(t)+\mu_8P_{18}(t) \quad (1)$$

$$P_2'(t)+T_2P_2(t)=\lambda_2P_1(t)+\mu_1P_9(t)+\mu_3P_{10}(t)+\mu_5P_{11}(t)+\mu_6P_{12}(t)+\mu_7P_{23}(t) \quad (2)$$

$$P_3'(t)+T_3P_3(t)=\lambda_4P_1(t)+\mu_1P_{14}(t)+\mu_3P_{15}(t)+\mu_6P_{17}(t)+\mu_8P_{24}(t)+\mu_5P_{16}(t) \quad (3)$$

$$P_4'(t)+T_4P_4(t)=\lambda_2P_3(t)+\mu_1P_{19}(t)+\mu_3P_{20}(t)+\mu_5P_{21}(t)+\mu_6P_{22}(t)+\lambda_4P_2(t) \quad (4)$$

$$P_i'(t)+\mu_jP_i(t)=\lambda_jP_k(t) \quad (5)$$

(For k=1, j=1, 3, 5, 6; i=5, 6, 7, 8 respectively)
(For k=2, j=1, 3, 5, 6, 7; i=9, 10, 11, 12, 13 respectively)
(For k=3, j=1, 3, 5, 6, 8; i=14, 15, 16, 17, 18 respectively)
(For k=4, j=1, 3, 5, 6, 7, 8; i=19, 20, 21, 22, 23, 24 respectively)

With initial conditions at time t = 0:

$P_i(0)=1$ When $i=0$; $P_i(0)=0$ When $i\neq 0$

Where

$$T_1=(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6)$$

$$T_2 = (\lambda_1 + \lambda_3 + \lambda_5 + \lambda_6 + \lambda_4 + \lambda_7 + \mu_2)$$
$$T_3 = (\lambda_1 + \lambda_3 + \lambda_5 + \lambda_6 + \lambda_8 + \lambda_2 + \mu_4)$$
$$T_4 = (\lambda_1 + \lambda_3 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8)$$

V PERFORMANCE ANALYSIS

The failure and repair rates of various subsystems of sole lasting unit are collected on monthly basis from the plant personals of a shoe making Plant. The performance analysis with different combinations of failures and repair rates, for the whole year is calculated shown in tables 1-12,which deals with the quantitative analysis of all the factors viz. courses of action and states of nature, which influence the maintenance decisions associated with the sole lasting unit.

The failure and repair rate of the Sub-system B and D almost remains same throughout the year and taken as λ_2=0.02, λ_4=0.001, μ_2=1.7, μ_4=2.5 respectively.

Table 1: Availability for the Month of January

Failure Rate λ_1=0.004, λ_3 =0.009, λ_5=0.001, λ_6=0.01, λ_7=λ_8=0.004

Repair Rate μ_1 =1.5, μ_3=1.2, μ_5=1.14, μ_6 =1, μ_7= μ_8=0.2

Month Time(In days)	January Availability(A_V)
5	0.979283
10	0.979182
15	0.979160
20	0.979152
25	0.979147
30	0.979145

Table 2: Availability for the Month of February

Failure Rate λ_1=0.015, λ_3 =0.012, λ_5=0.0015, λ_6=0.01, λ_7= λ_8=0.003

Repair Rate μ_1 =2.5, μ_3=1.5, μ_5=1.1, μ_6 =1.9, μ_7= μ_8=0.9

Time(In days)	Availability(A_V)
5	0.976975
10	0.976961
15	0.976960
20	0.976960
25	0.976959
30	0.976959

Table 3: Availability for the Month of March

Failure Rate λ_1=0.0072, λ_3 =0.0019, λ_5=0.015, λ_6=0.09, λ_7= λ_8=0.001

Repair rate μ_1=1.55,μ_3=1.25,μ_5=0.85,μ_6 =1.2,μ_7= μ_8=1

Time(In days)	Availability (A_V)
5	0.898886
10	0.898772
15	0.898770
20	0.898769
25	0.898768
30	0.898767

Table 4: Availability for the Month of April

Failure Rate λ_1=0.05, λ_3 =0.09, λ_5=0.011, λ_6=0.01, λ_7= λ_8=0.01

Repair rate μ_1 =2, μ_3=1.75, μ_5=1.4, μ_6 =1, μ_7= μ_8=0.9

Time(In days)	Availability(A_V)
5	0.913746
10	0.913710
15	0.913709
20	0.913707
25	0.913706
30	0.913705

Table 5: Availability for the Month of May

Failure Rate λ_1=0.0076, λ_3 =0.015, λ_5=0.005, λ_6=0.09, λ_7= λ_8=0.0015

Repair rate μ_1 =0.76, μ_3=0.95, μ_5=1, μ_6 =0.9, μ_7= μ_8=1

Time(In days)	Availability(A_V)
5	0.884441
10	0.884177
15	0.884175
20	0.884174
25	0.884173
30	0.884172

Table 6: Availability for the Month of June

Failure Rate λ_1=0.004, λ_3 =0.02, λ_5=0.0045, λ_6=0.001, λ_7= λ_8=0.0025

Repair rate μ_1 =2.1, μ_3=1.4,μ_5=1.5,μ_6 =1.55,μ_7=μ_8=0.7

Time(In days)	Availability(A_V)
5	0.963959
10	0.963938
15	0.963934
20	0.963931
25	0.963929
30	0.963928

Table 7: Availability for the Month of July

Failure Rate λ_1=0.015, λ_3 =0.05, λ_5=0.009, λ_6=0.025, λ_7= λ_8=0.003

Repair rate μ_1 =0.9, μ_3=0.8, μ_5=1.7, μ_6 =1, μ_7= μ_8=1.2

Time(In days)	Availability(A_V)
5	0.901428
10	0.901095
15	0.901092
20	0.901090
25	0.901089
30	0.901089

Table 8: Availability for the Month of August

Failure Rate λ_1=0.014, λ_3 =0.014, λ_5=0.019, λ_6=0.03, λ_7= λ_8=0.045

Repair rate μ_1 =1.5, μ_3=1, μ_5=0.75, μ_6 =1.2,μ_7=μ_8=1.6

Time(In days)	Availability(A_V)
5	0.931467
10	0.931101
15	0.931094
20	0.931094
25	0.931093
30	0.931093

Table 9: Availability for the Month of September

Failure Rate λ_1=0.0035, λ_3 =0.006, λ_5=0.005, λ_6=0.005, λ_7= λ_8=0.0054

Repair rate μ_1 =2, μ_3=1.2, μ_5=0.9, μ_6 =2, μ_7= μ_8=1.3

Time(In days)	Availability(A_V)
5	0.985379
10	0.985361
15	0.985360
20	0.985359
25	0.985359
30	0.985358

Table 10: Availability for the Month of October

Failure Rate λ_1=0.01, λ_3 =0.05, λ_5=0.01, λ_6=0.01, λ_7= λ_8=0.04

Repair rate μ_1 =1.7, μ_3=1.5, μ_5=1, μ_6 =1.4, μ_7= μ_8=1.2

Time(In days)	Availability(A_V)
5	0.946651
10	0.946612
15	0.946611
20	0.946611
25	0.946610
30	0.946610

Table 11: Availability for the Month of November

Failure Rate λ_1=0.0055, λ_3 =0.012, λ_5=0.0051, λ_6=0.044, λ_7= λ_8=0.0025

Repair rate μ_1=1.08,μ_3=0.98, μ_5=1,μ_6 =0.47,μ_7=μ_8=0.1

Time(In days)	Availability(A_V)
5	0.899704
10	0.896714
15	0.895944
20	0.895927
25	0.895919
30	0.895917

Table 12: Availability for the Month of December

Failure Rate λ_1=0.02, λ_3 =0.05, λ_5=0.045, λ_6=0.0015, λ_7= λ_8=0.0025

Repair rate μ_1 =2.1, μ_3=1.35, μ_5=0.95, μ_6 =1, μ_7= μ_8=0.2

Time(In days)	Availability(A_V)
5	0.912947
10	0.912772
15	0..912759
20	0.912755
25	0.912752
30	0.912751

VI CONCLUSION

Here, the performance analysis of sole lasting unit of a shoe making industry has been done for the whole year on monthly basis failure and repair rates with the help of performance modeling. It is concluded that the availability of three state model is higher than the two state system model, having same constant failure and repair rates. Therefore it is essential to apply maintenance to the subsystems on reaching the reduced-failed state to enhance the availability of the industrial system.

The critical subsystems which are being identified in the performance analysis should be given more attention and due consideration as far as the maintenance is concerned. The proper maintenance planning and scheduling of critical systems will help the management to reduce the failure rates and hence will improve the overall availability of plant concerned. The results of this paper will be highly beneficial to the management for futuristic maintenance planning and control of the system concerned in shoe making industry.

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Annexure-1

State Transition Diagram (Fig. No. 2)

: System working in full capacity

: System working in reduced capacity

: System working in Failed State