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Assessing the Impact of Number of Repair Persons on Availability of an Industrial System: A Case Study

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Abstract

The main aim of the research study is to accessing the impact of failure and repair rate along with the number of repair persons on the availability of system. The various factors affecting the production rate and minimize the input labor cost for the maintenance of the mixing section of a paint industry as well as ensuring the elongated availability of the selected system. In view of above statement, A behavioral model has been developed and mathematical formulation has been performed considering constant feseable failure and repair rates. The difference-differential equations for various state probabilities have been generated using the state transition state diagram and further, solved using Lagrange method to obtain the steady state long-term system availability. It helps in find out the optimum man power required for maintenance activities, so that utilization of resources should be maximum. It has been observed from the analysis that only three number of maintenance personal are required, if the number of repair persons increases it does not affect the system availability, it remains constant. The results of the paper are discussed with representatives of plant management and these may be beneficial for them from view point of maintenance activities.

Keywords: Availability, Markov Process, Paint Industry, Repairmen, Lagrange Method.

INTRODUCTION

In today's scenario, these industries are becoming more complex, sophisticated and automated, so that they may run continuously without any failure to meet the increasing customer demand. 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. The mechanical systems have involved the personal attention of so many people involved in research in the area of reliability engineering. System's performance analysis is done to pin point the primary factors. The unit under present research comprises of specialized single purpose machines.

In paper industry, the availability and MTBF estimation for washing systems was evaluated (Kumar *et al.,* 1989) using simple probability considerations. For maximizing the system's availability, a multiple objective formulation has been suggested by Coit *et al*.(2004). Todinav et al.(2007) proposed the total cost of the system can be reduced based on reliability allocation by a new method of optimization in engineering system. (Garg *et al.* 2009) proposed a mathematical model based on Markovian approach for a cattle feed plant were presented. A methodology was proposed by Akaron *et al.* (2009) to evaluate system reliability and carried out an optimization study on irreparable dissimilar components made by redundant systems. The availability of combed sliver yarn production system was presented by Garg *et al.*(2010) and found out the optimum number of repair persons for the system concerned. A reliability model (Garg *et al.* 2010), using steady state and time dependent availability in manufacturing unit (block-board) of a plywood industry under faulty and ideal preventive maintenance, has been developed.Kumar et al. (2011) used genetic algorithm for performance optimization and mathematical modelling in CO_2 cooling system of fertilizer plant The simulation model for determining the availability of electric power generation system in a power plant (Ravinder *et al*. 2012). Modgil *et al.* (2013) presented an availability of shoe manufacturing unit by using Markov process and calculating TDSA and SSA of a system. A reliability mode using Markov approach proposed by Gowid et al(2014) in LNG production plant for computation of time dependent system availability. A performance model was developed (Kajal and Tewari,2014) to optimize the availability of multistage industrial system with redundancy by using Markovian approach and then further optimizing water feed system of thermal power plant with the help of Genetic Algorithm. Barabadi et al. (2014) proposed an application of reliability models with covariates using spare parts requirements as reliability performance indicator and presented a case study of repairable system. Hou *et al.* (2015) discussed the availability evaluation of systems by means of random set theory. Cekyay *et al.* (2015) presented the Reliability, MTTF and Long Term Availability Analysis of systems with constant failure.Joint modelling involving quality improvement and preventive maintenance for deteriorating single-machine manufacturing system discussed by Biao Lu et al. (2016). A stochastic process based on Markov theory presented by Yi Wan et al.(2016) to evaluate the reliability of electronic systems in terms of heat and temperature.

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). Three states of various components are considered by author as good, reduced and failed. This model helped in making different maintenance decision and preventive activities

The available literature reveals that many of the researchers have used complicated methodology to calculate long-term based availability of the selected system and limited their research work in developing and analyzing the theoretical models of sugar plant, chemical industries, paper plant, thermal power plant etc, only. But hardly any work related to effect of repairmen on system availability of a paint industry has been reported in literature. In the present work, an attempt has been made to address the problem related to mixing section of a paint industry.

SYSTEM DESCRIPTION

The production process of paint mixing system has been described in this section. The paint mixing system of a paint industry consists of three sub-systems namely Grinding Machine (G), Mixing Machine (M) and Conveyor System(C) all working in series. The grinder machine is used to grind the various ingredients of paint and turned them into the powdered from so that it fed to the mixer machine. The mixer machine mixes all ingredients such as water, titanium dioxide, calcium carbonate, latex, paint solution and other additives. The conveyor is used to carry these ingredients to the filling machine. The sub-system M is a 4-out-of-9: G system i.e. nine (09) numbers off mixer are working in parallel. Mixing system fails either when there are remaining only three mixer in operating position, or sub-system G or C gets failed. While there are only three mixer in good working state, the system considered as under breakdown and the combined repair of all the mixers has been performed. Generally, seven or eight units always remain in working. The nine mixer repaired with the help of ‘r’ number of repairmen then (r < 9). To find out the optimum value of ‘r’ which is calculated with respect to long run availability of the system operating with seven or eight mixers. It is considered that if at least seven mixers remain in operative state the production requirement can be fulfilled easily. With this consideration, the performance of the system is being investigated in the present research work.

The figure no.1 shows the schematic block diagram of paint mixing system of paint industry. It comprises of three subsystems as described under:

Grinder (G): This sub-system is used to grind the various ingredients of paint and turned them into the powdered from so that they may fed to the mixer machine. This machine is subjected to failure.

Mixer (M): It is used to make the mix raw material coming as output from the grinder machine with the specific paint solution. These are nine in numbers and subjected to failure.

Conveyor (C): This sub-system is used to carry these ingredients to the filling machine. It is also subjected to failure.

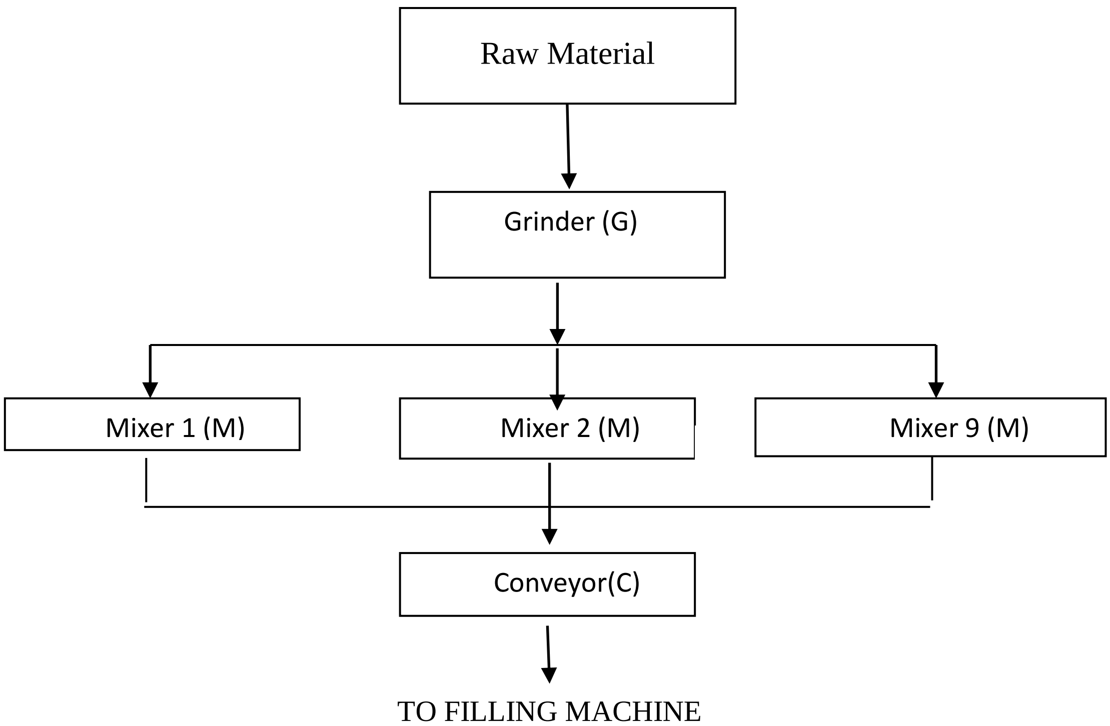

Figure 1: Process Flow Diagram of Mixing Section of Paint industry Situated in Haryana

ASSUMPTIONS AND NOTATIONS

Assumptions:

The given assumptions are considered during analysis of the system.

All the units are in operative condition initially and can be taken as in good health.

i. Every unit normally experiences two primary states; namely failed or good.

ii. A failed system behaves like a new system; whose failure rates are taken exponentially distributed and repair time for the sub-systems is randomly distributed.

iii. Statistical independence is accorded to all the given transition rates.

iv. A sub-system has 'r' repair facilities for doing repair action of the sub-system M.While for all other sub-systems, separate repair facilities exist and their repair starts after the failure of these sub-systems.

v. When there are three mixing machines in the working state; in that case system is taken as to be under breakdown and the collective repair of all the nine mixing machines starts on immediate basis.

vi. Simultaneous failure does not exist among the sub-systems.

Notations:

Grinder (A) : Having one unit subjected to failure.

Mixer (B) : comprises of nine identical units working in parallel arrangement

The system remains in working condition till at least four units of (B) remain in working order.

Conveyor (C) : Having one unit arranged in series with Mixer.

'o' indicates that machine/subsystem is operational

'g' indicates machine/subsystem is operative

'r' indicates machine/subsystem is under repair action

A^k: (A = A, C) represents the operational state of grinder and conveyor w.r.t. k, (k = o, g, r)

C^k_j: the operational states of the Mixer w.r.t. k, (k = o, g, r) where 'j' indicates its remaining working mixers. (j = 4,5, 6, . . . , 9)

γ: failure rate of a mixer

δ: failure rate of grinder

Φ: failure rate of conveyor

θ (x): rate of repair of mixer

τ(x) rate of repair of sub-system Grinder,

ζ (x) rate of repair of sub-system conveyor ,

P_9 (t): Probability of full capacity working state at time t

P_k (t) probability of system to be in 'k^{th}'state at time t (k =4, 5, 6. . . 9)

The figure no. 2 shows the states transition diagram, the probable transition states of the system concerned.

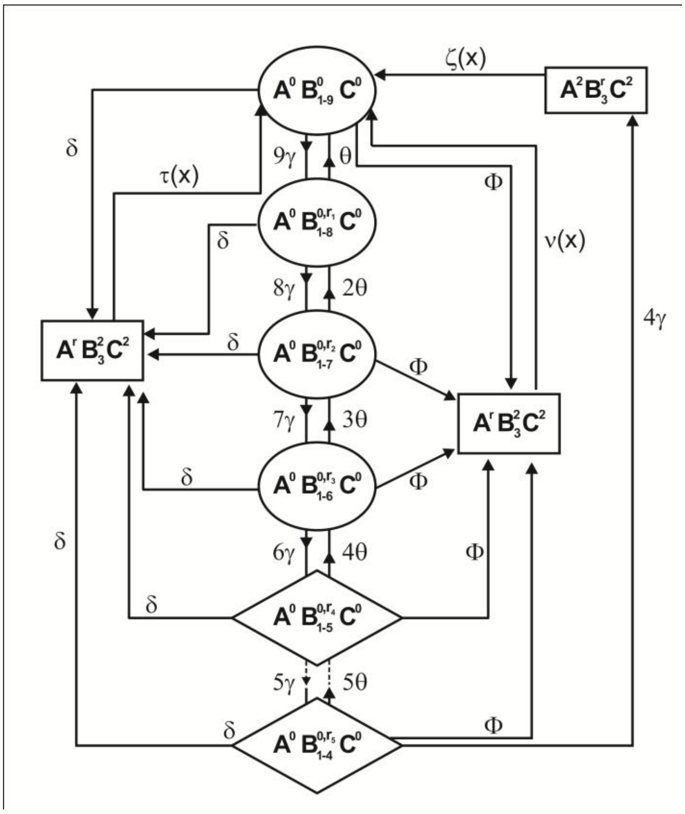

Figure 2: State Transition Diagram of Mixing Section of Paint Industry

MATHEMATICAL MODELING OF THE SYSTEM

The various probabilities consideration generates the following differential equations based on Markovian approach for the transition diagram as shown in figure no.2:

$$\left[\frac{d}{dt}+\ \Phi_9\right] P_9\ (t)=R_9(t) \tag{1}$$

$$\left[\frac{d}{dt}+\Phi_i\right]P_i(t)=(i+1)\gamma\ P_{i+1}(t)+\theta\ M_i\ P_{(i-1)}(t)$$
$$(i=4,5,..,..,9) \tag{2}$$

$$\left[\frac{d}{dt}+\ (\delta+\Phi+4\gamma+5)\right] P_4(t) =5\gamma P_5(t) \tag{3}$$

$$\left[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\zeta(x)\right] P_3(x,t) =4\gamma P_4(t) \tag{4}$$

$$\left[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\nu(x)\right] P_2(x,t)=\Phi\sum_{i=4}^{9} Pi(t) \tag{5}$$

$$\left[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\tau(x)\right] P_1(x,t)=\delta\sum_{i=4}^{a} Pi(t) \tag{6}$$

Where,

$\Phi_9=(\delta+\Phi+9\gamma)$,

$\Phi_i=(\delta+\Phi+i\gamma+\theta L_i)$ where i=4,5,..,..,9

$\theta_i=L_i+N$

$L_i=\begin{cases} 9-\text{i and N}=1 \text{ if i} \leq 9-\text{i} \leq \text{r}-1 \\ r \; and N=0 \; if \; r \leq 9-\text{i} \leq 4 \end{cases}$

$S=\begin{cases} 4 & \text{if r}=4 \\ r & if \; r \leq 3 \end{cases}$

R_9 (t) $=\theta P_8$ (t) $+\int \zeta(x) P_3$(x, t) dx $+ \int \nu(x) P_1(x, t\nu 12)$dx $+ \int \tau(x) \; P_2(x,t)dx$ (7)

The applied Initial and boundary conditions, we get:

$P_9(t)=1$,

$P_k(t)=0$,

$P_k(x,0)=0$

$P_3(0,t)=4\gamma \; P_4(t)$

$P_2(0,t)= \Phi \sum_{i=4}^{9} Pi(t)$

$P_1(0,t)= \delta \sum_{i=4}^{9} Pi(t)$ (8)

Solution of equation

The equation are solved by applying initial and boundary conditions to equations (1) to (3) which are first order differential equations and (4) to (6) which are first order partial differential equations what we get is as below:

$P_9(t)=e^{-\Phi_9 t}(1+\int R_9(t) \, e^{\Phi_9 t}$dt (9)

$P_i(t)=e^{-\Phi_i t} \int\{((i+1) \; \gamma \; P_{i+1}(t)+\theta M_i P_{i-1}(t)\} \; e^{\Phi_1(t)} dt$,(i=5,6,…..9) (10)

$P_4(t)= e^{-(\delta+\Phi+5\gamma+5\theta)t} 5\gamma \int P_5(t) \, e^{+(\delta+\Phi+5\gamma+5\theta)t} dt$, (s=r) (11)

$P_3(x,t)=(e^{-\int \zeta(x)dx}(4\gamma P_4(t-x)+5\gamma \int P_4(t) \int_e^{\zeta(x)dx} dx$ (12)

$P_2(x,t)=e^{-\int \nu(x)dx}(\Phi \sum_{i=4}^{9} p_i(t-x)+ \Phi \int \sum_{i=4}^{9} p_i(t) \, e^{\int^{\nu(x)dx}}$ dx) (13)

$P_1(x,t)=e^{-\int \tau(x)dx}(\delta \sum_{i=4}^{9} p_i(t-x)+ \delta \int \sum_{i=4}^{9} p_i(t) \, e^{\int^{\tau(x)dx}}$ dx) (14)

System Reliability indices*:*

i) Reliability function $R_1(t)$ for the system concerned if all the mixer remain in operative condition is represented by:

$R_1(t) = P_9(t)=e^{- \;\; 9t}[1+\int\{\tau(x)P_2(x,t)+\nu(x)P_1(x,t)+\zeta(x)P_3(x,t)dx+\theta P_8(t)\}e^{\Phi_9 t}$dt] (15)

Reliability function(RF) R_7 (t*)*

ii) **RF** $R_7(t)$ of the system if seven or more mixer are being operative, is represented by:

$R_7(t)=\sum_{i=7}^{9} Pi(t)=\sum_{i=7}^{9} e^{-\Phi_i t}\{\int((i+1)\zeta P_{i+1}(t)+\theta M_i \, P_{(i-1)}(t) \; e^{\Phi_i t}$dt}+[1+$\int\{\int(\tau(x) \; P_2(x,t)+\nu(x)P_1(x,t)+\zeta(x)P_3(x,t)dx+\theta P_8(t)\} \; e^{\Phi_9 t}$dt] (16)

The failure frequency of mixing system as system goes to failed state, on failure of subsystem G and C.

iii) $F(t)=5\gamma P_5(t)+(\delta+\Phi)P_9(t)$
$=25\gamma^2 e^{-(\delta+\Phi+5\gamma+5\theta)t} \int P_5(t) e^{(\delta+\Phi+5\gamma+5\theta)t}dt+(\delta+\Phi)e^{-\Phi_9 t}$[1+ $\int\{\int(\tau(x)P_2(x,t)+\nu(x)P_1(x,t)+\zeta(x)P_3(x,t)dx+\theta P_{11}(t)\}e^{\Phi_9 t}dt]$ (17)

Steady State Availability of the system

The SSA of the system concerned can also be as special case with constant transition rates by taking **t=∞** and **d/dt=→ 0**, then various state probabilities can be represented as below:

$\Phi_9 P_9(t) = \theta P_8+ \tau P_2+\zeta P_3+\nu P_1$

$\Phi_i P_i = (i+1) \, \gamma \, P_{i+1} + \theta M_1 P_{i+1}$

$\Phi_4 P_4 = 5\gamma \, P_5$

$\zeta P_3 = 4P_4$

$\Phi P_2 = \phi \sum_{i=4}^{9} P_i$

$\tau P_1 = \delta \sum_{i=4}^{9} P_i$ (18)

Where,

$K_1 = \frac{5\gamma}{\delta+\Phi+4\gamma+5\theta}$ (S =r, 5)

$K_{i-3} = K_{i-3} = \frac{(i+1)\gamma}{\delta\,+\,\Phi\,+i\gamma\,+\,\theta L_i - \,\Phi M_i Z_i - \,4}$

$K_2 = K_2 K_4$

$K_3 = K_2 \, K_3 \, K_4$

$K_4 = K_1{*}K_2 \, K_3 \, K_4$

$K_5 = K_1 \, K_1{*} \, K_2 \, K_3 \, K_4$

$K_6 = \frac{4\gamma}{\zeta} K_1 \, K_1{*} \, K_2 \, K_3 \, K_4$

$\sum_{i=1}^{9} P_i = 1$

We get,

$P_9 = \frac{1}{(1+\,Z_4 +\,\sum_{i=1}^{5} K_i)\left(1+\frac{\delta}{\tau}+\frac{\Phi}{\nu}\right)+\,K_6}$ (19)

The steady state availability(A_1) of the paint mixing system if all the mixer are in working state.

i) $A_1 = P_9 = \frac{1}{(1+\,Z_4 +\,\sum_{i=1}^{5} K_i)\left(1+\frac{\delta}{\tau}+\frac{\phi}{\nu}\right)+\,K_6}$ (20)

The steady state availability(A_7) of the system, if seven or more mixer are operative , then

$A_7 = \sum_{i=7}^{9} P_i = \frac{1+\,Z_4 +\,K_6}{1+\,Z_4 +\,\sum_{i=1}^{5} K_i)\;(1+\left(1+\frac{\delta}{\tau}+\frac{\phi}{\nu}\right)+\,K_6}$ (21)

ii) The frequency of failure(F) of paint mixing system represented by equation 22

$$F = (\delta + \Phi)\, P_9 + 4\, P_4 = \frac{\delta + \Phi + 4\; K_1}{(1 + Z_5 + \sum_{i=1}^{5} K_i)\left(1 + \frac{\delta}{\tau} + \frac{\Phi}{v}\right) + K_6} \qquad (22)$$

Performance Analysis

Reliability indices (m) of the mixing section can be obtained from equations (19)–(22),by above said data and and ‘r = 7’ is reflected in Table 1.

Table 1: Steady state availability (A_7) v/s number of repairmen (r)

R	1	2	3	4	5	6	7
A_7	0.9655	0.97850	0.9791	0.9791	0.9791	0.9791	0.9791

Table 2: Influence of failure rates of A (grinding) and C (conveyor) of Asian paint mixing section on availability

Φ_1 \ γ_1	0.001	0.0015	0.002	0.0025	Other Parameters
0.025	0.9961	0.9957	0.9952	0.9948	ζ =0.001, θ = 0.1, ν = 0.2, r = 2.0
0.035	0.9949	0.9943	0.9937	0 .9931	
0.045	0.9937	0 .9930	0.9923	0.9915	
0.055	0.9927	0.9919	0.9910	0.9901	

Table 3: Influence of repair rates of A (grinding) and C (conveyor) of Asian paint mixing section on availability

μ \ ν	0.2	.25	.35	.40	Other Parameters
0.1	0.9961	.9963	.9966	.9966	γ = 0.0025, Φ= ζ=0.001, r = 2.0
0.2	0.9979	.9980	.9981	.9982	
0.3	0.9986	.9986	.9987	.9988	
0.4	0.9989	.9990	.9990	.9991	

RESULTS AND DISCUSSION

Table 1 shows that system availability is 0.9655 when there is only one repairman, availability of the system increases as number of repairmen increases from 1 to 3 and after that there is no improvement in system availability as the number of repairmen increased. It has been observed from table 2 that the availability of the system concerned declines marginally by 0.0013% as failure rate of grinding machine enhanced from 0.001 to 0.0025 simultaneously the failure rate of conveyor is 0.025. Also, the system availability decreases slightly by 0.0034% as the failure rate of conveyor increases from 0.025 to 0.055 keeping failure rate mixing machine constant i.e. 0.001. The table 4.3 revels that system availability increases by 0.05% and 0.28% with an increase in repair rate of Grinding machine from 0.2 (once in 10 hour) to 0.4 (once in 2.5 hour) and conveyor from 0.1 to .4 respectively.

CONCLUSIONS

The primary result or inference from the analysis is that it is proposed that the repairmen needed are minimum in order to keep seven or more, out of nine, mixing machines in proper working states, when the system availability 0.9791. Three is the value which appears to be correct and optimum for least number of repairmen in the present case. After this value of ‘r’ minimum number of repairmen has been fixed, the impact of repair and failure rates of different subsystems constituting the system is analyzed. It is also seen that failure and repair rates of Grinding machines has effect on the system availability by 0.0013% (it is decrease) and 0.05% (it is increase) respectively. On the same lines, the failure and repair rates of Conveyor machines also affect the availability of the system by 0.0034% (it is decrease) and 0.28% (it is increase) respectively. This information is very crucial for the officials of the management and it shall help them in developing a complete schedule plan for making use of suitable repair facility for achieving the optimum availability.

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