Availability Optimization of a Cylinder Block in Cast Iron Manufacturing Plant using Markov Birth-Death Process

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Abstract

In the current work, a cylinder block in cast iron plant has been beneath neath attention for its accessibility and optimization. The goal of the present paper is to optimize contribution variables of the cylinder block in cast iron plant, to maximize framework availability. Cast iron plant includes mainly, five subsystems linked in series configuration. For analysis, Repair & failure rates, and Transition rates of every subsystem is occupied from upkeep record sheets. Steady state availability is achieved by expending standardising condition. The optimization of framework availability is performed by Markov Process.

Keywords: Availability, Markov Birth-Death Process, Repair Rate, Failure Rate

1. Introduction:

Reliability and availability are well-organized performance procedures of any structure, to achieve high-profit, productivity, and optimum use of human resources, it is vital to keep system presentation measures at optimum level and to avoid loss of goodwill of organizations.Throughout the planning, development, and production of machine elements, continues to be a big problem. Even as number of entities as well as the complexity of mining equipment continue to grow, the implications of hardware failures become increasingly crucial. An unanticipated breakdown might result in much greater repair expenses than planned servicing. Improving the dependability and accessibility of the elements is one technique for mitigating the impact of failures. The evaluation method of total component conditions includes dependability as well as accessibility. The gathering and analysis of proper data would be a first step in improving dependability and availability.The behavior of a bread plant was examined by Kumar et al. in [2018]. In order to do a sensitivity analysis on a cold standby framework made up of two identical units with server failure and prioritized for preventative maintenance, Kumar et al. [2019] used RPGT. Two halves make up the current paper, one of which is in use and the other of which is in cold standby mode. The good and fully failed modes are the only differences between online and cold standby equipment. PSO was used by Kumari et al. [2021] to research limited situations. Using a heuristic approach, Rajbala et al. [2022] investigated the redundancy allocation problem in the cylinder manufacturing plant.A

case study of an EAEP manufacturing facility was examined by Rajbala et al. [2019] in their work on system modeling and analysis in 2019. In a paper mill washing unit, Kumar et al. [2019] investigated mathematical formulation and behavior study. Using RPGT, Agrawal et al. [2021] looked at the Reverse Osmosis Water Treatment Plant. In their study, Kumar et al. [2018] investigated a 3:4:: outstanding system plant's sensitivity analysis. A study of the urea fertilizer industry's behavior was conducted by Kumar et al. [2017]. The scientific formulation and profit function of an edible oil refinery facility were investigated by Kumar et al.[2017].Kumari et al. [2022] studied on the PSO for constrained cost reliability of rubberPlant.Singla et al. [2022] studied on the mathematical model for finding the availability under the reduced capacity has been proposed using the Chapman Kolmogorov approach with the help of transition diagrams associated with various possible combinations of probabilities.Sinla et al. [2022] studied on the Mathematical analysis of regenerative point graphical technique. Malik et al. [2022] present paper talks over perform ability evaluation for a steam generation system of a Coal Fired Thermal Power Plant (CFTPP) using the concept of the Markov method. Cast Iron is a manufacturing plant in which cylinder block are formed. Cast Iron manufacturing plant consisting of five subsystems namely Sand mixing unit, Sand core making unit, Moulding line, Sand extractor machine and Fettling Machine. All the machines are organized in series. Disappointment and repair rates of every machine are expected to be constant. These differential equations are solved for time dependent and steady state availability analysis and availability optimization.

1.1 System Description:

Cylinder block production facility with five connected in series subsystems. The following is a description of the subsystems:

- **Sand mixing machine:**cylinder blocks are mainly done using sand mixing unit. Resin and harder mix in silicon and to make Sand unable for core making.
- **Sand core making machine:** In sand core making machine, mix sand and pour in cold box core making machine to make the Sand core.
- **Moulding line machine:** In moulding line machine, Sand core fix in moulding line and molten cast iron metal pour in sand mould line. It makes cast iron casting.
- **Sand extractor machine:** In sand extractor machine, Sand extract from casting by Sand extractor machine.
- **Fettling Machine:** In fettling machine, extra parts remove from casting, after fettling casting dispatch to customer.

1.2 AssumptionsandNotations:

- A, B, D, E, F: represents good states.
- A, b, c, d, e: indicates unsuccessful states.
- m_1, m_2, m_3, m_4,m_5 : indicates the failure rates.
- h_1, h_2, h_3, h_4,h_5 : indicates the failure rates.
- Failure and repair rates are constant.

- If the server is free, repair of the unsuccessful unit will begin immediately. Else, the failed unit is queued for repair.

1.3 State Transition Diagram (STD):

STD is used to signify finite state machines. This is used to model an object that has a finite number of conceivable states and whose interaction by the outside world can be defined by changes in states depending on the number of events. The transition diagram of cast iron manufacturing plant described below Figure 1:
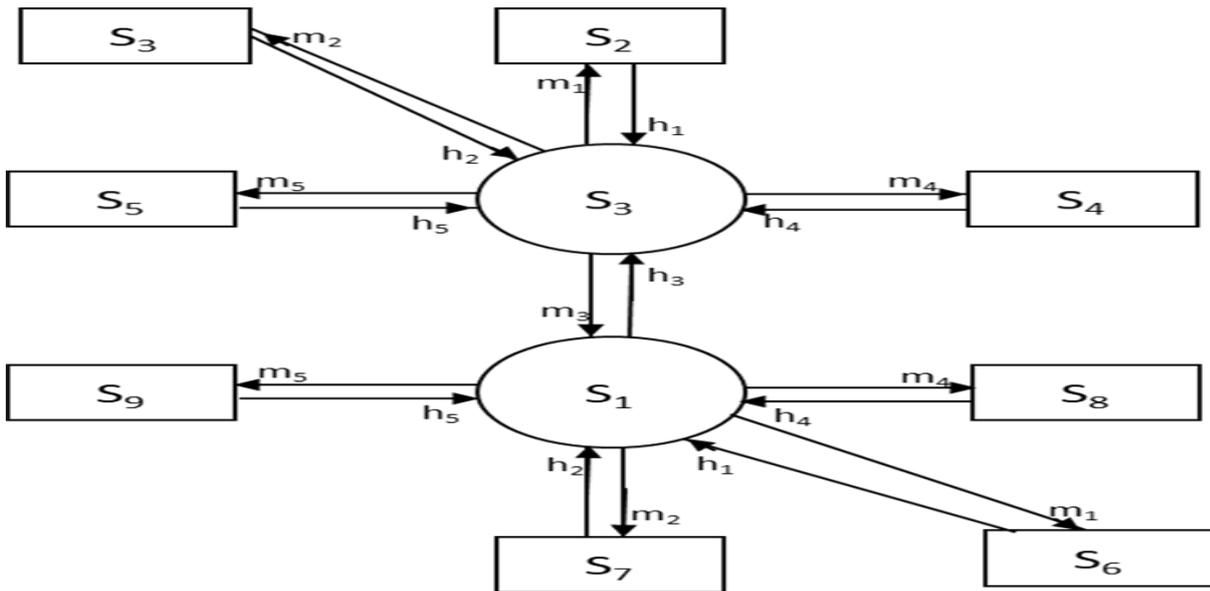

Figure 1: Transition Diagram

S_0 = ABDEF,　　　S_1 = aBDEF,　　　S_2 = ABDeF,　　　S_3 = ABDEf,

S_4 = AbDEF,　　　S_5 = ABdEF,　　　S_6 = a′BDeF,　　　S_7 = a′BDEf,

S_8 = a′bDEf,　　　S_9 = a′BdEF

2. Mathematical Modelling:

$$p_0' (t) + (m_1 + m_2 + m_3 + m_4 + m_5)p_0(t) = h_1 p_2(t) + h_2 p_2(t) + h_3 p_1(t) + h_4 p_4(t) + h_5 p_5(t) \quad (1)$$

$$p_1' (t) + (m_1 + m_2 + m_3 + m_4 + m_5)p_1(t) = h_1 p_6(t) + h_2 p_7(t) + h_3 p_0(t) + h_4 p_8(t) + h_5 p_9(t) \quad (2)$$

$$p_2' (t) + h_1 p_2(t) = m_1 p_0(t) \quad (3)$$

$$p_3' (t) + h_2 p_3(t) = m_2 p_0(t) \quad (4)$$

$$p_4' (t) + h_4 p_4(t) = m_4 p_0(t) \quad (5)$$

$$p_5' (t) + h_5 p_5(t) = m_5 p_0(t) \quad (6)$$

$$p_6' (t) + h_1 p_6(t) = m_1 p_1(t) \quad (7)$$

$$p_7' (t) + h_2 p_7(t) = m_2 p_1(t) \quad (8)$$

$$p_8' (t) + h_4 p_8(t) = m_4 p_1(t) \quad (9)$$

$$p_9'(t) + h_5 p_9(t) = m_5 p_1(t) \quad (10)$$

The manufacturing plant must be available for a long period of time. Therefore, steady state probability of the structure can be obtained by taking $\frac{d}{dt} \to 0$ and $p_l(t) \to p_l$ as $t \to \infty$ in above equations (1 to10). The system's steady state probabilities are attained in terms of P_0 as follow:

$$p_1 = \alpha\, p_0, where\ \alpha = h_3 / (1 - m_1 - m_2 - m_4 - m_5)$$
$$p_2 = \beta_1\, p_0, where\ \beta_1 = m_1 / h_1$$
$$p_3 = \beta_2\, p_0, where\ \beta_2 = m_2 / h_2$$
$$p_4 = \beta_3\, p_0, where\ \beta_3 = m_4 / h_4$$
$$p_5 = \beta_4\, p_0, where\ \beta_4 = m_5 / h_5$$
$$p_6 = \alpha\, \beta_1\, p_0, where\ \beta_1 = m_1 / h_1$$
$$p_7 = \alpha\, \beta_2\, p_0, where\ \beta_2 = m_2 / h_2$$
$$p_8 = \alpha\, \beta_3\, p_0, where\ \beta_3 = m_4 / h_4$$
$$p_9 = \alpha\, \beta_4\, p_0, where\ \beta_4 = m_5 / h_5$$

The Probability $P_i(t)$ is evaluated using normalizing condition

$$\sum_{i=0}^{9} P_i = 1$$

$$1 = p_0 + p_1 + p_2 + p_3 + p_4 + p_5 + p_6 + p_7 + p_8 + p_9$$
$$1 = p_0 + \alpha\, p_0 + \beta_1\, p_0 + \beta_2\, p_0 + \beta_3\, p_0 + \beta_4\, p_0 + \alpha\, \beta_1\, p_0 + \alpha\, \beta_2\, p_0 + \alpha\, \beta_3\, p_0 + \alpha\, \beta_4\, p_0$$
$$1 = p_0(1 + \alpha + \beta_1 + \beta_2 + \beta_3 + \beta_4 + \alpha\, \beta_1 + \alpha\, \beta_2 + \alpha\, \beta_3 + \alpha\, \beta_4)$$
$$1 = p_0 * K, where\ K = (1 + \alpha + \beta_1 + \beta_2 + \beta_3 + \beta_4 + \alpha\, \beta_1 + \alpha\, \beta_2 + \alpha\, \beta_3 + \alpha\, \beta_4)$$
$$p_0 = 1/K$$

Currently steady state availability of the cast iron manufacturing plant is specified by

$$A_v = p_0$$

3. Results and Discussion:

The results and discussions of the time-dependent availability and steady-state availability of the system are defined below:

3.1 Time-dependent Availability:

The findings of the system's time-dependent availability are computed using a MATLAB software. The findings are presented as a table and graph.

Table1: Effect of availability w.r.t. time

Time (months)	Availability
0	1
15	0.96
30	0.93
45	0.87
60	0.82

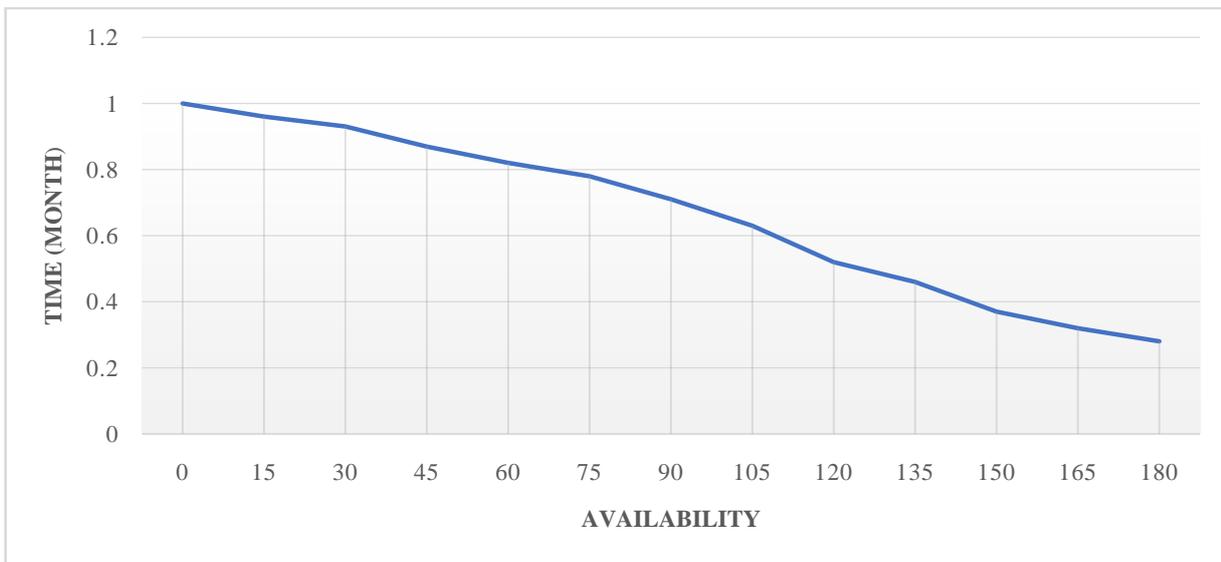| 75	0.78
90	0.71
105	0.63
120	0.52
135	0.46
150	0.37
165	0.32
180	0.28

Fig. 2: Variation of availability w.r.t. time

3.2 Steady-state Availability of the system:

The results of steady-state availability are described in form of tables and graphs.The table 2 is developed by fixed the($h_2 = 0.02$, $m_2= 0.002$, $h_3 = 0.03$, $m_3= 0.003$, $h_4= 0.04$, $m_4 = 0.004$,$h_5 = 0.05$, $m_5 = 0.005$) as a constant and varying the value of (h_i, m_i), where i run from 1 to 5.

Table 2: Effect of availability w.r.t. failure and repair rates of Sand Mixing machine

$h_1 \rightarrow$ $m_1 \downarrow$	0.01	0.03	0.05	0.07	0.09	Constant Value
0.001	0.7781	0.7615	0.7536	0.7478	0.7303	$h_2 = 0.02$, $m_2= 0.002$,
0.003	0.8370	0.7780	0.7650	0.7540	0.7472	$h_3 = 0.03$, $m_3= 0.003$,
0.005	0.8960	0.7820	0.7770	0.7610	0.7511	$h_4= 0.04$, $m_4 =$
0.007	0.9470	0.8305	0.7816	0.7706	0.7648	0.004,$h_5= 0.05$, $m_5 =$
0.009	0.9530	0.8621	0.8140	0.7790	0.7750	0.005

Table no. 2 shows the values of the availability for different values of failure and repair rates. The values of availability vary from 0.7303 to 0.9530. The values of table are expressed in form of graph as shown figure 3:
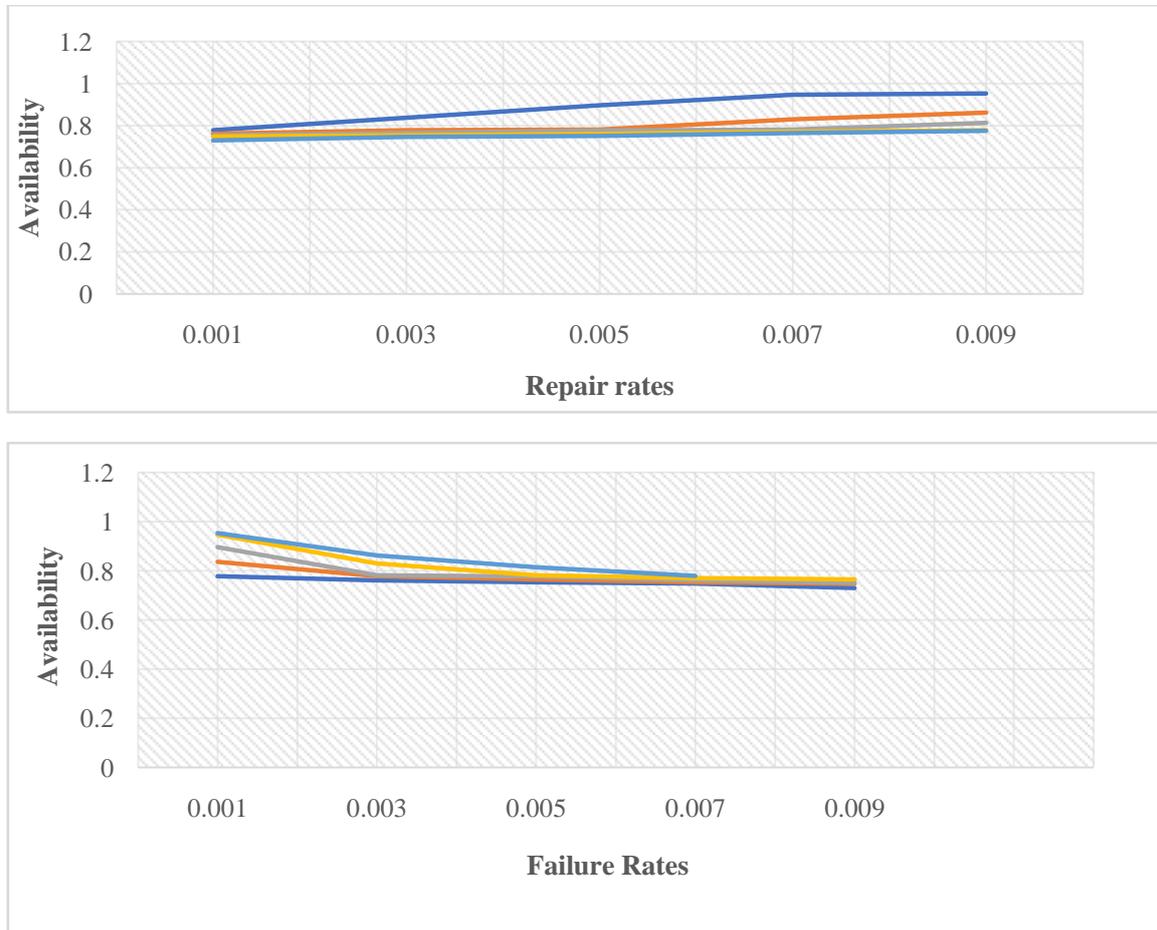

Figure 3: Variation of availability w.r.t. failure and repair rates of Sand Mixing machine

The table 3 is developed by fixed the ($h_1 = 0.01$, $m_1 = 0.001$, $h_3 = 0.03$, $m_3 = 0.003$, $h_4 = 0.04$, $m_4 = 0.004$, $h_5 = 0.05$, $m_5 = 0.005$) as a constant and varying the value of (h_i, m_i), where i run from 1 to 5.

Table 3: Effect of availability w.r.t. failure and repair rates of Sand Core MakingMachine

h_2 $\rightarrow m_2$ $\downarrow$	0.02	0.04	0.06	0.08	0.10	Constant Value
0.002	0.7816	0.7540	0.7306	0.7260	0.7101	$h_1 = 0.01$, $m_1 = 0.001$,
0.004	0.8081	0.7608	0.7550	0.7401	0.7270	$h_3 = 0.03$, $m_3 = 0.003$,
0.006	0.8470	0.7705	0.7780	0.7503	0.7311	$h_4 = 0.04$, $m_4 =$
0.008	0.8667	0.7990	0.7911	0.7660	0.7508	$0.004, h_5 = 0.05$,
0.010	0.9082	0.8740	0.8440	0.7718	0.7620	$m_5 = 0.005$

Table no. 3, shows the values of the availability for various values of failure and repair rates. The values of availability vary from 0.7101 to 0.9082. The values of table are expressed in form of graph 4.
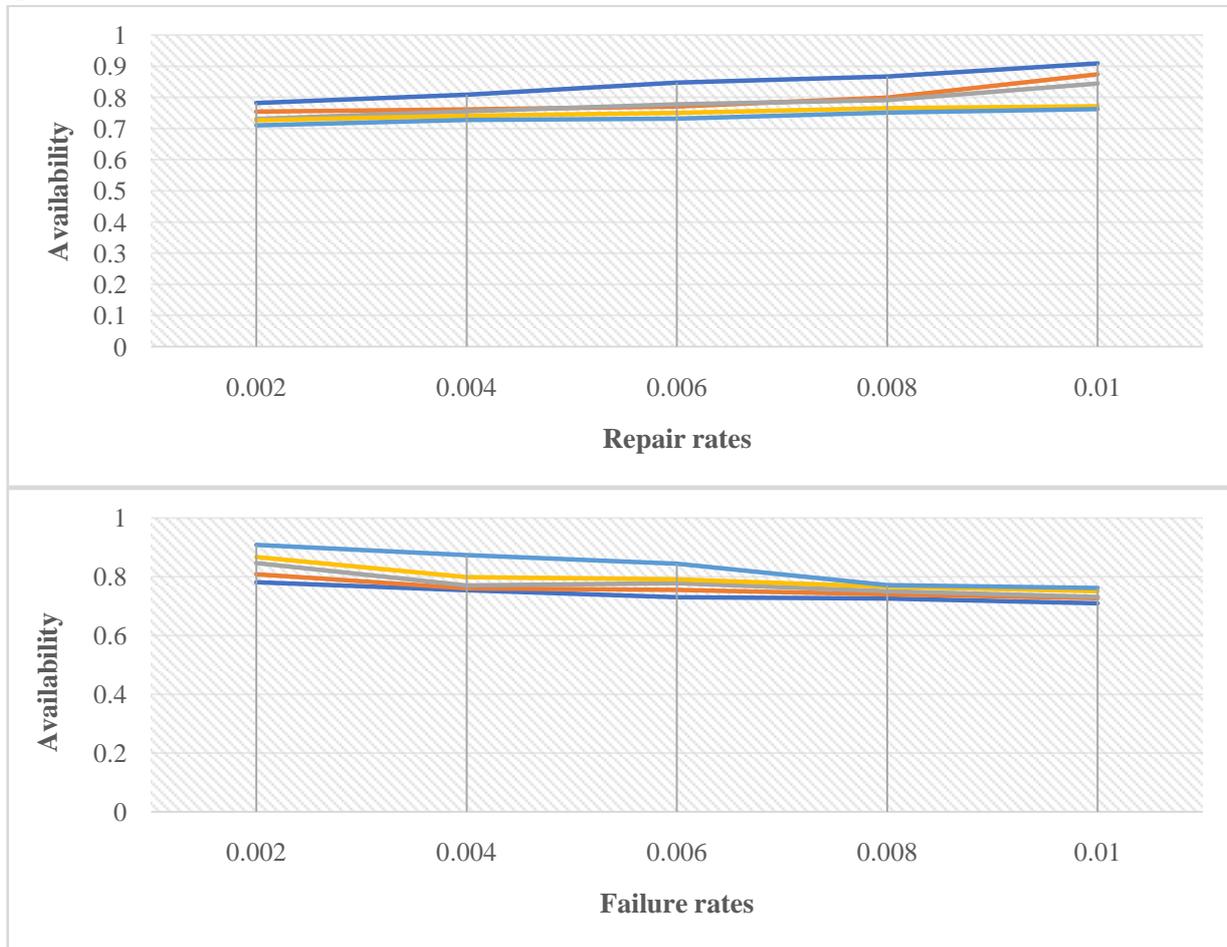

Figure 4: Variation of availability w.r.t. failure and repair rates of Sand Core Making machine

The table 4 is developed by fixed the ($h_2 = 0.02$, $m_2 = 0.002$, $h_1 = 0.01$, $m_1 = 0.001$, $h_4 = 0.04$, $m_4 = 0.004$, $h_5 = 0.05$, $m_5 = 0.005$) as a constant and varying the value of (h_i, m_i), where i run from 1 to 5.

Table 4: Effect of availability w.r.t. failure and repair rates of Moulding line Machine

$h_3 \rightarrow m_3$ ↓	0.03	0.06	0.09	0.12	0.15	Constant Value
0.003	0.7606	0.7501	0.7420	0.7360	0.7206	$h_1 = 0.01$, $m_1 = 0.001$,
0.006	0.7902	0.7690	0.7518	0.7440	0.7305	$h_2 = 0.02$, $m_2 = 0.002$,
0.009	0.8309	0.7740	0.7631	0.7520	0.7450	$h_4 = 0.04$, $m_4 =$
0.012	0.8591	0.7820	0.7780	0.7608	0.7510	$0.004, h_5 = 0.05$, $m_5 =$
0.015	0.8910	0.7904	0.7895	0.7715	0.7670	0.005

Table no. 4, shows the values of the availability for various values of failure and repair rates. The values of availability vary from 0.7206 to 0.8910. The values of table are expressed in form of graph 5.
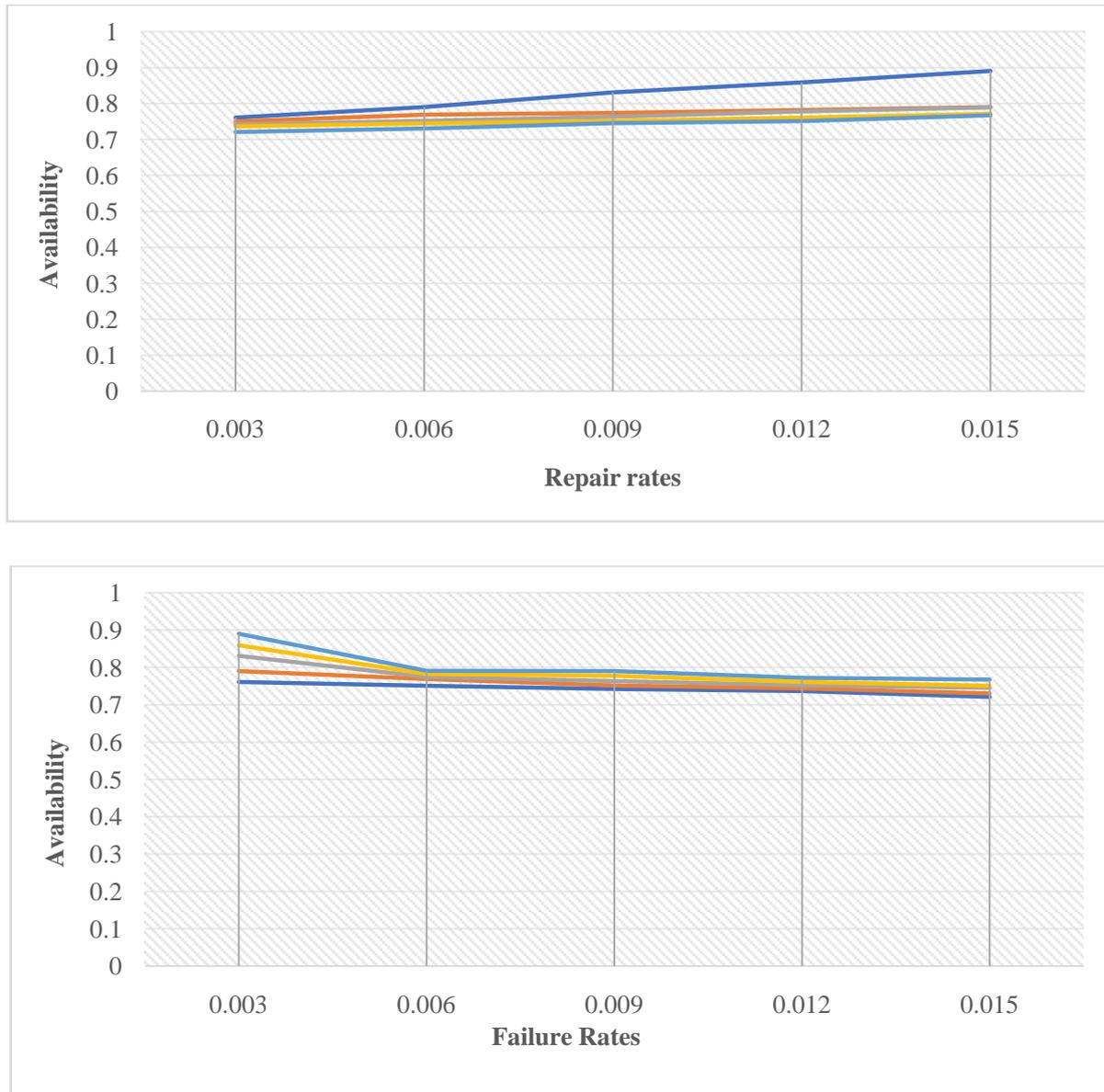

Fig. 5: Variation of availability w.r.t. failure and repair rates of Moulding line machine

The table 5 is developed by fixed the ($h_2 = 0.02$, $m_2 = 0.002$, $h_1 = 0.01$, $m_1 = 0.001$, $h_3 = 0.03$, $m_3 = 0.003$, $h_5 = 0.05$, $m_5 = 0.005$) as a constant and varying the value of (h_i, m_i), where i run from 1 to 5.

Table 5: Effect of availability w.r.t. failure and repair rates of Sand extractor machine

$h_4 \rightarrow$ $m_4 \downarrow$	0.04	0.08	0.12	0.16	0.20	Constant Value

0.004	0.7708	0.7301	0.7230	0.7104	0.7004	$h_1 = 0.01,$ $m_1 = 0.001,$
0.008	0.7999	0.7490	0.7332	0.7207	0.7191	$h_2 = 0.02,$ $m_2 = 0.002,$
0.012	0.8303	0.7595	0.7405	0.7320	0.7250	$h_3 = 0.03,$ $m_3 =$
0.016	0.8720	0.7601	0.7514	0.7401	0.7305	$0.003, h_5 =$ $0.05,$
0.020	0.8920	0.7801	0.7604	0.7480	0.7415	$m_5 = 0.005$

Table no. 5, shows the values of the availability for various values of failure and repairrates. The values of availability vary from 0.7004 to 0.8920. The values of table are expressed in form of graph 6 as shown below:
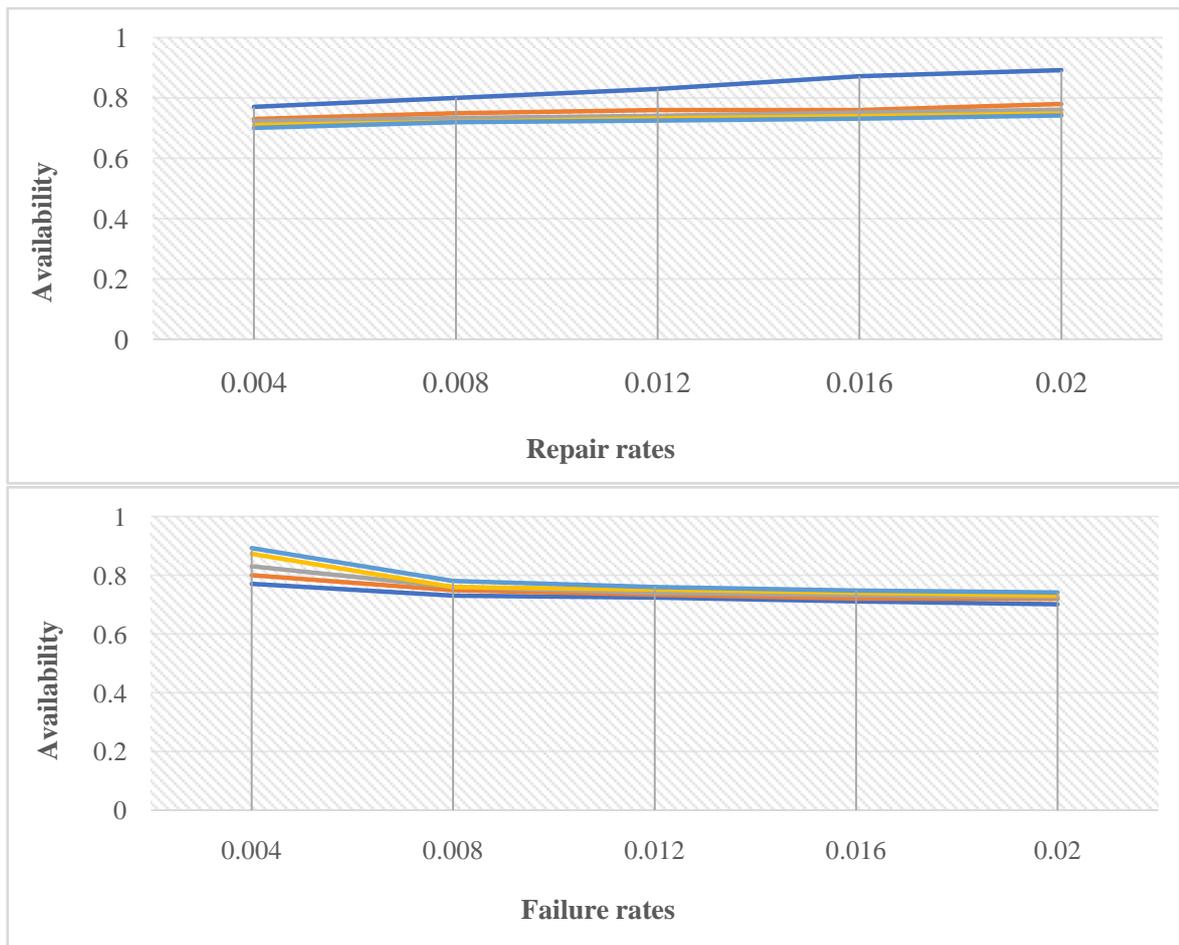

Fig. 6: Variation of availability w.r.t. failure and repair rates of Sand extractor machine

The table 6 is developed by fixed the ($h_2 = 0.02$, $m_2 = 0.002$, $h_1 = 0.01$, $m_1 = 0.001$, $h_3 = 0.03$, $m_3 = 0.003, h_4 = 0.04$, $m_4 = 0.004$) as a constant and varying the value of (h_i, m_i), where i run from 1 to 5.

Table 6: Effect of availability w.r.t. failure and repair rates of Fettling machine

$h_5 \rightarrow$ $m_5 \downarrow$	0.04	0.08	0.12	0.16	0.20	Constant Value

0.004	0.7808	0.7701	0.7530	0.7404	0.7104	$h_1 = 0.01,$ $\quad m_1 = 0.001,$
0.008	0.8099	0.7990	0.7632	0.7507	0.7291	$h_2 = 0.02,$ $\quad m_2 = 0.002,$ $h_3 = 0.03,$ $\qquad m_3 =$
0.012	0.8403	0.8295	0.7705	0.7620	0.7350	$0.003, h_4 =$ $\qquad 0.04,$ $m_4 = 0.004$
0.016	0.8620	0.7801	0.7714	0.7700	0.7405	
0.020	0.8920	0.8201	0.7504	0.7480	0.7515	

Table no. 6, shows the values of the availability for various values of failure and repair rates. The values of availability vary from 0.7104 to 0.8920. The values of table are expressed in form of graph 7as shown below:
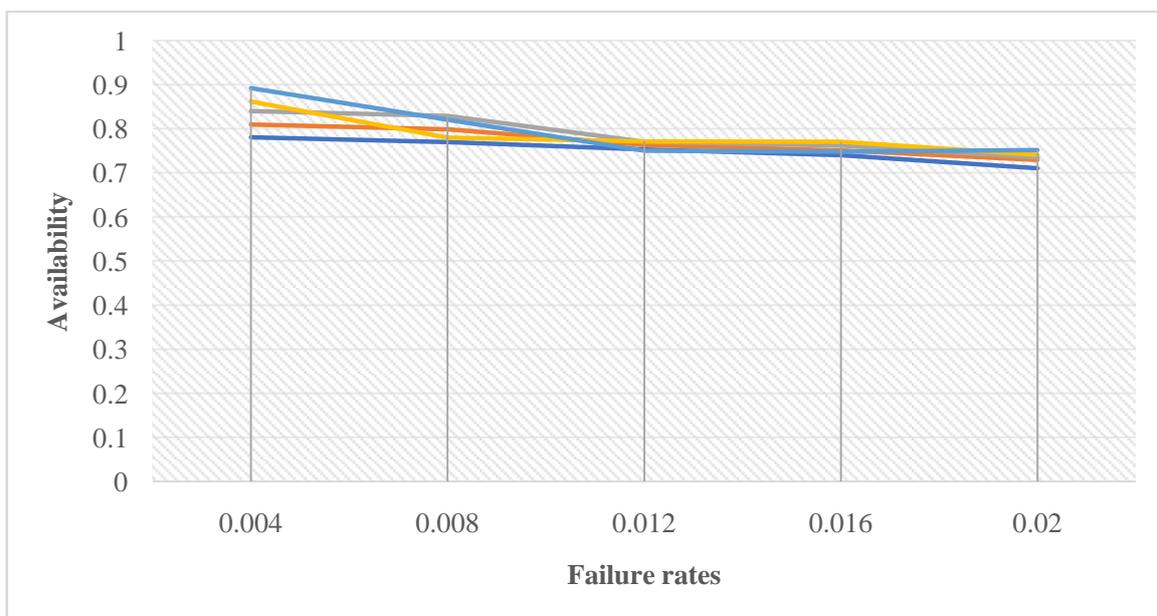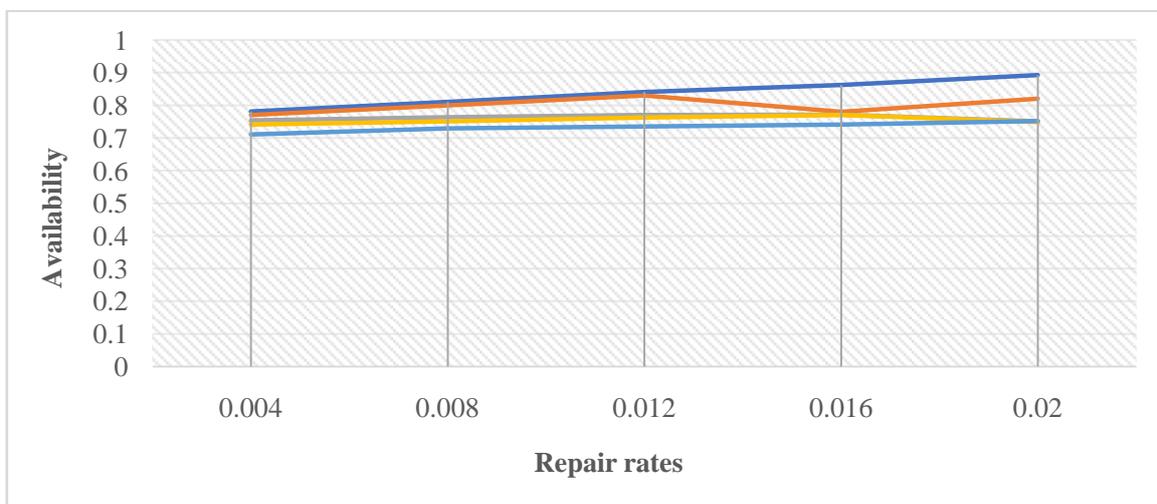

Fig. 7: Variation of availability w.r.t. failure and repair rates of Fettling machine

4. Conclusion:

It is seen that the subsystem A is the most critical subsystem as far as maintenance is concerned. So, subsystem A should be given priority as the result of its repair rate on the availability is much higher than other subsystems.

From table 1, It is concluded that as time passes, the system's time-dependent availability reduces. From table 2, the maximum value of availability is 0.9530 which is obtained when failure rate is minimum (0.01) and repair rate is maximum (0.009). From table 3, the maximized availability is 0.9082. Likewise, from table 4, the maximum value of availability is 0.8810, and from table 5 the maximum availability is 0.8910 which is obtained when the failure rate is minimum (0.04) and repair rate is maximum (0.020). From the above results it is concluded that the optimal availability is 0.9530.

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