Performance Modeling and Availability Analysis of Ammonia Cylinder Manufacturing Plant

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Abstract

In the present work, time dependent availability and steady state availability of ammonia cylinder manufacturing plant is estimated. Here, System modeling 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 is solved to estimate the availability of the system. The failure rates and the repair rates of the subsystems are taken constant and are statically 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. These equations are further solved using recursive method and normalizing condition so as to estimate the steady state availability of the system concerned. This performance model deals with quantitative study of all aspects which influence all maintenance decisions associated with ammonia cylinder manufacturing system. The results obtained in the present work are considered to be very useful for taking the best possible maintenance strategies.

Keywords

Availability, Runge-Kutta Method, Ammonia Cylinder Manufacturing, Reliability, System modeling.

I. Introduction

With the increasing demand of high quality and high performance, the modern industrial plants become more complex. These complex plants consist of systems and subsystems connected in series, parallel or in combination. For maximizing the productivity, availability and reliability of systems/subsystems in operation must be maintained at highest order. 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. Dhillon and Natesan (1983) discussed the power system in fluctuating environment. Various authors have discussed wide degree of complexities for the assessment of availability, reliability and maintainability (Balaguruswamy (1984); Singh & dayal (1991); Rajpal et al. (2006) and Zerwick (1996). Mostly these models are based on the Markovian approach, where the failure and repair rates are assumed to be constant. Kumar et al. (1988, 1989, 1990, and 1991) discussed the reliability and availability of Paper, Sugar and Fertilizer industry. They analyzed the designed and cost of a refining system in the sugar industry using supplementary variable technique. Dyal and Singh (1992) studied reliability analysis of a system in a fluctuating environment. Singh I.P. (1989) studied the reliability analysis of a complex system having four types of components with pre-emptive priority repairs. Singh and Goel (1994) studied the availability analysis of a standby complex system having imperfect switch over device. Chung (1987) presented a mathematical model for reliability analysis of repairable parallel system with standby units involving human errors and common cause failures. Singh and Mahajan (1999) examined the reliability and long run availability of a Utensils Manufacturing Plant using Laplace transforms. Gupta et al. (2005) studied the behavior of Cement manufacturing plant. Recently Modgil vikas et. al. (2010) discussed Mathematical Modeling and availability assessment of tube light industry. Most of these authors use Laplace transform method or langrange's technique to obtain the availability of the system. It is seen that at the higher value of some parameter Laplace inverse technique becomes so complex to calculate the finding of the steady state as well as time reliant availability .Similarly solving higher order integrals is very difficult in langrage's method. Therefore some alternative method is to be devised to entertain these problems. In the present work, we use a more sensitive and advance numerical technique known as adaptive step-size control Runge-Kutta method to estimate the time based availability of ammonia cylinder making plant and long term availability is estimated using recursive method and normalizing condition. The estimation of time reliant availability is done by doing programming in fortran95 and steady state availability is calculated with the help of MATLAB 7.0.4.Both the availabilities are the system's performance criterion.

II. System Description

The ammonia cylinder consists of four parts namely shell, top dish end, bottom dish end and foot ring which are joined to get its final shape. The making of these parts is shown below: For making the shell, the metal plate is cut with the help of shearing machine in to the rectangular shape. After that fetching of corners, is performed on the fetching machine. Then sheet is fed to the rollers on the rolling machine to get the round shell of the cylinder. To join the edges of the shell internal & external Sub Merged Arc welding (SAW) is done. Back chipping is also performed to remove distortion in the welding. Then the shell is sending to x-ray room for quality check. For making both the dish ends (top & bottom) of the cylinder, metal plate is cut in to circular section with welding gas cutter machine. The circular shape metal piece is converted in to hemispherical shape (also called as dish end) with the help of hydraulic press. The top dish end is drilled at the centre so the release valve may be attached to it further.both the dish end are joined to the shell with the help of circumferential SAW welding.

The metal sheet is cut, rolled and joined into proper shape to get the foot ring of the cylinder, which provides standing arrangement for the cylinder. Finally all these parts are joined to get the final cylinder, which is further send to inspection centre for quality checking.

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1. Shearing Machine (A)
Consists of one unit which is subjected to minor and major failure.

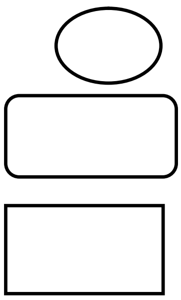
2. Rolling Machine (B)
Consists of one unit which are subjected to minor and major failure.

3. Welding Gas cutter Machine (C)
Consists of two identical units which are subjected to minor and major failure.

4. Hydraulic press Machine (D)
Consists of two identical units which are subjected to minor and major failure.

5. Submerged arc welding Machine (E)
Consists of one unit which is subjected to major failure only.

A. Assumptions and Notations



System working In Full Capacity.
System working In Reduced Capacity.
System working In the Fail/Breakdown state.
A^O, B^O, C^O, D^O, E^O : Subsystems in good operating state.
A^F, B^F, C^F, D^F, E^F : Indicates the failed state of A,B,C, D and E.
C^R, D^R : Indicates that the subsystems C, D are working at reduced capacity.
λ_i : Mean constant failure rates from states A^O, B^O,C^O,D^O, C^R, D^R, C^R to the states
A^F, B^F, C^F, D^F, E^F.
μ_i : Mean constant repair rates from
A^F, B^F, C^F, D^F, E^F and C^R, D^R to the state
A^O, B^O, C^O, D^O, E^O.
$P_i(t)$: Probability that at time‘t’ all units are
good and the system is in ith state.
‘ : Derivatives w.r.t. ‘t’
The assumptions used in developing the performance model are as follows:

- Failure rates and repair rates are constant over time and statistically independent.
- A repaired unit as good as new, performance wise, for a specified duration.
- Sufficient repair facilities are provided.
- Standby units are of the same nature as that of active units.
- Service includes repair and/or replacement.
- System may work at reduced capacity.

Based on these assumptions and notations following state transition diagram is developed as shown in Fig. No.-1

III. Time Dependent Availability of the System

In order to find both the types of availability of this system, we have developed a system of linear differential Equations by means of mnemonic rule. The differential equations for state 1 to 5 can be written as,

$$P_1'(t)+\left(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5\right)P_1(t)=\mu_1P_5(t)+\mu_2P_6(t)+\mu_5P_7(t)+\mu_3P_2(t)+\mu_4P_3(t) \quad (1)$$

$$P_2'(t)+\left(\lambda_1+\lambda_2+\lambda_5+\lambda_6+\mu_3+\lambda_4\right)P_2(t)=\mu_1P_8(t)+\mu_2P_9(t)+\mu_5P_{11}(t)+\mu_6P_{10}(t)+\lambda_3P_1(t)+\mu_4P_4(t) \quad (2)$$

$$P_3'(t)+\left(\lambda_1+\lambda_2+\lambda_5+\lambda_7+\lambda_3+\mu_4\right)P_3(t)=\mu_1P_{12}(t)+\mu_2P_{13}(t)+\mu_5P_{14}(t)+\mu_7P_{15}(t)+\mu_3P_4(t)+\lambda_4P_1(t) \quad (3)$$

$$P_4'(t)+\left(\lambda_1+\lambda_2+\lambda_5+\lambda_6+\mu_4+\mu_3+\lambda_7\right)P_4(t)=\mu_1P_{16}(t)+\mu_2P_{17}(t)+\mu_5P_{18}(t)+\mu_6P_{19}(t)+\lambda_3P_3(t)+\mu_7P_{20}(t)+\lambda_4P_2(t) \quad (4)$$

$$P_j'(t)+\mu_iP_j(t)=\lambda_iP_k(t) \quad (5)$$

Where, (for i=1,2,5 : j=5,6,7 when k=1),(for i=1,2,5,6 : j=8,911,10 when k=2) ,(for i=1,2,5,7 : j=12,13,14,15 when k=3) ,(for i=1,2,5,6,7 : j=16,17,18,19,20 when k=4)
Initial conditions at time (6)
t = 0 are $P_i(t)=1$ for i = 0 and $P_i(t)=0$ for $i \neq 0$

Theequations from (1) to (5) have been solved using initial condition (6) and a more sensitive and advance numerical method known as adaptive step-size control Runge-Kutta method is used to estimate the time reliant availability. However, for steady state availability these equations are solved using recursive method and normalizing condition.
The availability of the system is given by (7)
$A(t) = P_1(t)) + P_2(t) + P_3(t) + P_4(t)$

The availability of the system is calculated for different values of the failure and repair rates. The value of failure and repair rates are taken constant as: (λ_1= 0.002), (λ_2=0.001), (λ_3=0.001), (λ_4=0.001), (λ_5=0.002), (λ_6=0.001), (λ_7=0.001), (μ_1=0.025), (μ_2=0.020). (μ_3=0.010), (μ_4=0.015), (μ_5=0.025), (μ_6=0.010), (μ_7=0.015). After varying each of these parameters individually and taking other as constant as given above. Their effect on the availability of the system for each parameter is counted and shown in tables no. 1 to 6 in the time horizon of 30 to 180 days and in table 9 to 11 for long run (when time t, tends to infinity). It has been observed from the calculation not only the failure rate but ageing effect also decreases the availability of the system as seen from table No. 1 to 3. However, by increasing the repair rate the availability of the system increases significantly as observed from table No. 4 to 6.

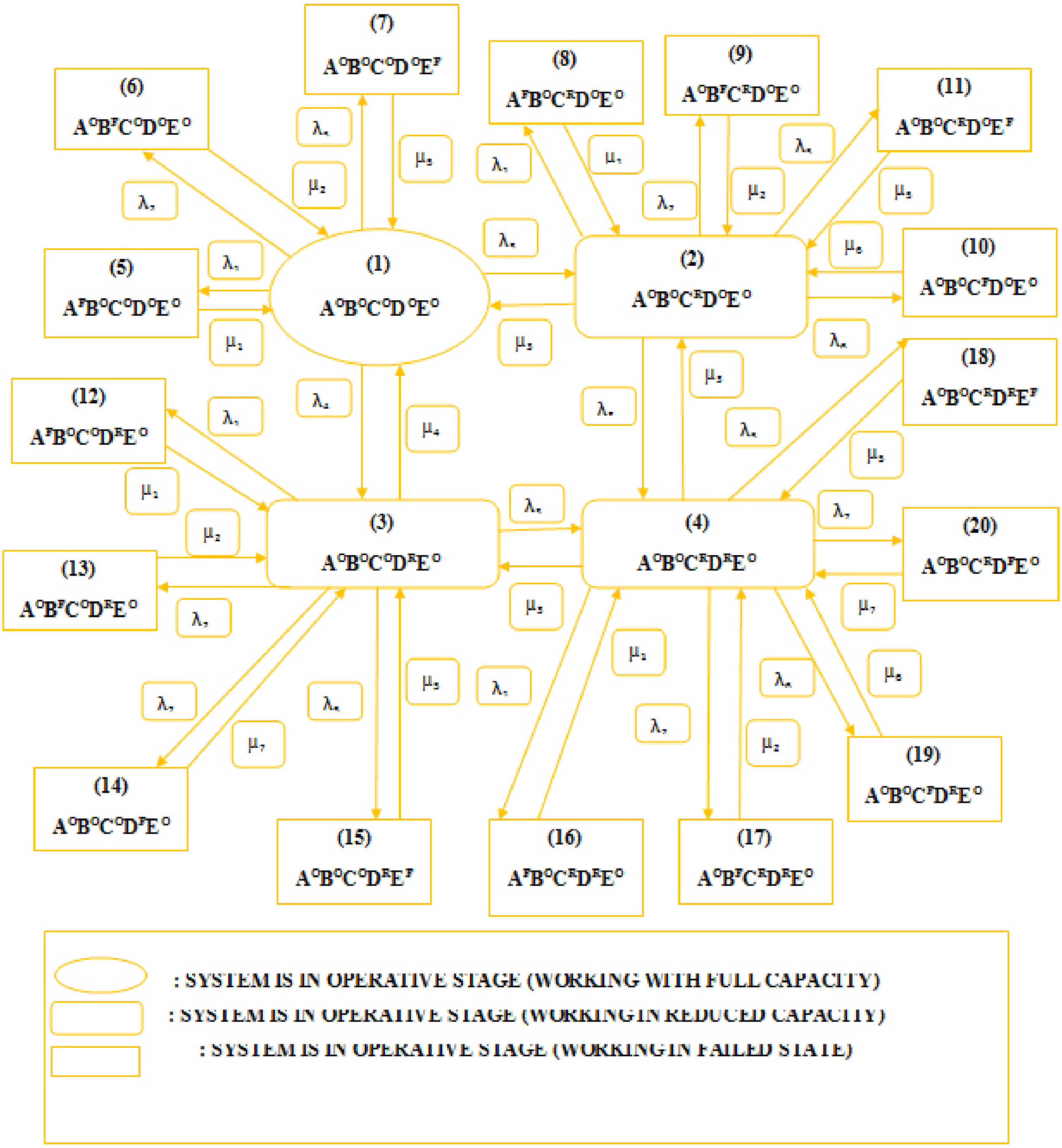


Table1: Effect of failure rate of Shearing Machine (λ1) on the availability of the system

λ_1/days	0.002	0.003	0.004	0.005
30	0.892290	0.870512	0.855339	0.831507
60	0.846251	0.827976	0.798064	0.781200
90	0.834072	0.807138	0.784154	0.758965
120	0.826512	0.799805	0.773615	0.751803
150	0.822507	0.796125	0.771979	0.748442
180	0.820647	0.795123	0.770208	0.747053

Table No.1 shows the effect of failure rate of subsystem (A) on the availability of the system, when system goes to reduced state from working state, the availability of the system decreases significantly by 16.27% by varying the failure rate from 0.002 to 0.005 in a step size of 0.001.

Table 2: Effect of failure rate of Rolling Machine (λ2) on the availability of the system

λ_2/days	0.001	0.002	0.003	0.004
30	0.892290	0.863777	0.851008	0.824864
60	0.846251	0.820718	0.790094	0.770317
90	0.834072	0.800298	0.774763	0.745209
120	0.826512	0.793211	0.762749	0.736729
150	0.822507	0.789681	0.760828	0.732610
180	0.820647	0.788741	0.758728	0.731526

Table No.2 shows the effect of failure rate of subsystem (B) on the availability of the system, when system goes to reduced state from working state. The availability of the system decreases by 18% by varying the failure rate from 0.001 to 0.004 in a step size of 0.001.

Table 3: Effect of failure rate of Welding Gas Cutter Machine (λ3) on the availability of system

λ_3/days	0.001	0.002	0.003	0.004
30	0.892290	0.891237	0.887263	0.887148
60	0.846251	0.844434	0.848607	0.847782
90	0.834072	0.831792	0.828144	0.826470
120	0.826512	0.823561	0.819868	0.817540
150	0.822507	0.818825	0.814903	0.811955
180	0.820647	0.816291	0.813274	0.808662

Table No. 3 shows the effect of failure rate of subsystem (C) on the availability of the system, when system goes to reduced state from working state. The availability of the system decreases by 9.3% by varying the failure rate from 0.001 to 0.004 in a step size of 0.001.

Similarly others tables are drawn showing the effect of failure rates of other subsystems. It has been observed the availability of the system decreases by 8.3% by varying the failure rate of subsystem (D) from 0.001 to 0.004 in a step size of 0.001.while the availability of the system decreases by 16.9% by varying the failure rate of subsystem (E) from 0.002 to 0.005 in a step size of 0.001. The availability of the system decreases by 7.45% with variation of failure rate of subsystem C, when system goes to Breakdown/Fail state from reduced state, from 0.001 to 0.004 in a step size of 0.001. It is seen the availability of the system decreases by 8.49% as failure rate of the subsystem D, when system goes to Breakdown/Fail state from reduced state varies from 0.001 to 0.004 in a step size of 0.001.

Table 4: Effect of repair rate of Shearing Machine (μ1) on the availability of the system

μ_1/days	0.025	0.050	0.075	0.100
30	0.892290	0.906329	0.913036	0.917620
60	0.846251	0.871532	0.883280	0.885866
90	0.834072	0.859302	0.867977	0.873936
120	0.826512	0.852138	0.862820	0.868290
150	0.822507	0.849393	0.859555	0.864735
180	0.820647	0.848591	0.858577	0.863668

The Table no. 4 reveals the effect of repair rate of shearing Machine (μ1) on the Availability of the system with variation of repair rate from 0.025 to 0.100 in a step size of 0.025. The Availability of the system increases by 2.83% and 5.24% in a span of 180 days.

Table 5: Effect of repair rate of Rolling Machine (μ2) on the availability of the system

μ_2/days	0.020	0.030	0.040	0.050
30	0.892290	0.888778	0.894865	0.901371
60	0.846251	0.855651	0.862921	0.863721
90	0.834072	0.840628	0.848197	0.851056
120	0.826512	0.835556	0.840918	0.844225
150	0.822507	0.832873	0.838491	0.842840
180	0.820647	0.832110	0.837785	0.841199

Table no. 5 shows the effect of repair rate of Rolling Machine (μ2) on the availability of the system by varying the repair rate 0.020 to 0.050 in a step size of 0.010.It has been observed, the availability of the system increases marginally by 1.01% & 2.5% in a span of 180 days.

Table 6: Effect of repair rate of Welding Gas Cutter Machine (μ3) on the availability of the system

μ_3/days	0.010	0.020	0.030	0.040
30	0.892290	0.889490	0.886496	0.890286
60	0.846251	0.852642	0.851157	0.847596
90	0.834072	0.834222	0.833933	0.832688
120	0.826512	0.825245	0.827707	0.827316
150	0.822507	0.823835	0.824509	0.824563
180	0.820647	0.822398	0.823260	0.823952

The effect of repair rate of Gas Welding Cutter Machine (μ3) on the availability of the system by varying the repair rate 0.010 to 0.040 in a step size of 0.010 is shown in table no. 6. The availability of the system increases marginally by 0.4%.

Similarly others tables are drawn showing the effect of repair rates of other subsystems. It has been observed the availability of the system increases slightly by 0.17%& 0.15% in 180 days with the variation of repair rate of subsystem D, from 0.15 to 0.035. while , The availability of the system increases by 0.6% & 1.94% with variation of repair rate of submerged arc welding Machine (μ5) from 0.025 to 0.040 in a step size of 0.005. Similarly, the availability of the system increases slightly by 0.64% with variation of repair rate of gas welding cutter Machine (μ6) from 0.010 to 0.040 in a step size of 0.010. The availability of the system increases slightly by 0.24% & 0.53% by varying repair rate of hydraulic press.

IV. Steady State Availability

The Long Term availability of the system can be analyzed by setting $t \to \infty$ and $d/d \to 0$ the limiting probabilities from equations 1 to 5 are given as:

$$(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)P_1=\mu_1P_5+\mu_2P_6+\mu_3P_2+\mu_4P_3+\mu_5P_7$$

$$(\lambda_1+\lambda_2+\lambda_5+\lambda_6+\mu_3+\lambda_4)P_2=\mu_1P_8+\mu_2P_9+\mu_5P_{11}+\mu_6P_{10}+\lambda_3P_1+\mu_4P_4$$

$$(\lambda_1+\lambda_2+\lambda_5+\lambda_7+\mu_4+\lambda_3)P_3=\mu_1P_{12}+\mu_2P_{13}+\mu_5P_{14}+\mu_7P_{15}+\lambda_4P_1+\mu_3P_4$$

$$(\lambda_1+\lambda_2+\lambda_5+\lambda_6+\lambda_7+\mu_4+\mu_3)P_4=\mu_1P_{16}+\mu_2P_{17}+\mu_5P_{18}+\mu_6P_{19}+\mu_7P_{20}+\lambda_3P_3+\lambda_4P_2$$

$$\mu_iP_j=\lambda_iP_k$$

(for i=1,2,5 : j=5,6,7 when k=1),(for i=1,2,5,6 : j=8,911,10 when k=2) ,(for i=1,2,5,7 : j=12,13,14,15 when k=3) ,(for i=1,2,5,6,7 : j=16,17,18,19,20 when k=4)
Solving above equations, we get;

$$P_4=L_1P_1,\ P_3=L_2P_1,\ P_2=L_3P_1,$$

$$P_j=\frac{\lambda_i}{\mu_i}P_1(j=5,6,7:i=1,2,5)$$

$$P_k=\frac{\lambda_i}{\mu_i}L_3P_1(k=8,9,10,11:i=1,2,5,6)$$

$$P_l=\frac{\lambda_i}{\mu_i}L_2P_1(l=12,13,14,15:i=1,2,5,7),$$

$$P_m=\frac{\lambda_i}{\mu_i}L_1P_1(m=16,17,18,19,20:i=1,2,5,6,7),$$

Where

$$L_1=\frac{\lambda_3\lambda_4}{\mu_3\mu_4},\ L_2=\frac{\mu_3L_1+\lambda_4}{\lambda_3+\mu_4},\ L_3=\frac{\mu_4L_1+\lambda_3}{\lambda_4+\mu_3},$$

Now using normalizing condition i.e. sum of all the probabilities is equal to one, we get:

$$\sum_{i=1}^{20}P_i=1$$

$$P_1=\left[\begin{array}{l}1+L_1+L_2+L_3+\frac{\lambda_1}{\mu_1}+\frac{\lambda_2}{\mu_2}+\frac{\lambda_5}{\mu_5}+\frac{\lambda_1}{\mu_1}L_3\\+\frac{\lambda_2}{\mu_2}L_3+\frac{\lambda_5}{\mu_5}L_5+\frac{\lambda_6}{\mu_6}L_3+\frac{\lambda_1}{\mu_1}L_2+\frac{\lambda_2}{\mu_2}L_2\\+\frac{\lambda_5}{\mu_5}L_2+\frac{\lambda_7}{\mu_7}L_2+\frac{\lambda_1}{\mu_1}L_1+\frac{\lambda_2}{\mu_2}L_1+\frac{\lambda_5}{\mu_5}L_1\\+\frac{\lambda_6}{\mu_6}L_1+\frac{\lambda_7}{\mu_7}L_1\end{array}\right]^{-1}$$

The steady state availability of the system is given by

$$A_V=P_1+P_2+P_3+P_4$$

$$=[1+L_1+L_2+L_3+L_4]P_1$$

A. Steady State Analysis

For steady state availability assessment the limiting probabilities from equations 1 to 5 have been solved by using recursive method and normalizing condition taking time t tends to infinity. The performance matrices have been developed which are represented in tables from 9 to 11. These matrices show various availability levels for the various combinations of failure and repair rates. The value of failure and repair rates are taken same as mentioned earlier.

Table 7: Effect of failure rate and repair rate of Shearing Machine on the availability

λ_1/μ_1	.025	.050	.075	.10
.002	.8175	.8451	.8548	.8597
.003	.7916	.8311	.8451	.8523
.004	.7673	.8175	.8357	.8451
.005	.7445	.8043	.8265	.8380

Table no. 7 shows that there is an increase in the availability by 5.16% to 12.5% with increase in the repair rate from 0.025 to 0.10 of Subsystem (A), On the other side availability decreases by 8.92% ,if failure rate increases from 0.002 to 0.005 .

Table 8 : Effect of failure rate and repair rate of Rolling Machine on the availability

λ_2/μ_2	.020	.030	.040	0.050
.001	.8175	.8288	.8345	.8380
.002	.7854	.8065	.8175	.8242
.003	.7557	.7854	.8011	.8109
.004	.7282	.7654	.7854	.7979

A close study of the table no.8 reveals that with the increase in repair rate of subsystem(B) from 0.020 to 0.050 ,there is increment in the availability of the system i.e. 2.5% to 9.57% .whereas increase in failure rate from 0.001 to 0.004 decreases the availability of the system by10.92%.

Table 9 : Effect of failure rate and repair rate of Welding Gas Cutter Machine on the availability

λ_3/μ_3	.010	.020	0.030	0.040
.001	.8175	.8204	.8214	.8220
.002	.8125	.8175	.8194	.8204
.003	.8082	.8149.	.8175	.8189
.004	.8047	.8125	.8157	.8175

Similarly, it has been observed from table no.9, the availability of the system increases by 0.55% & 1.56% by increasing the repair rate of subsystem (C) from 0.010 to 0.040, whereas if failure rate of subsystem (C) varies from 0.001 to 0.004 the availability decreases by 1.56%.Similarly, other performance matrices have been drawn showing the effect of failure and repair rate of various subsystems. With increase in repair rate of subsystem (D) from 0.015 to 0.035, there is an increase in the availability by 0.80 & 0.59%. On the other side if there is increase in failure rate of subsystem (D) from 0.001 to 0.004, the availability decreases by 0.80%.The availability of the system increases by 2.5% & 5.19% with increase in repair rate of subsystem E ,from 0.025 to 0.10, whereas, there is small decrease in the availability of the system by 8.92% with increase in failure rate (E) from 0.025 to 0.040.

with increase in repair rate of subsystem C when system works in reduced capacity varies from 0.010 to 0.040 the availability increases by 0.56% to 2.22%, whereas increase in failure rate of subsystem (C) from 0.001 to 0.004 the availability decreases slightly by 2.22%.A close examination shows that with increase in repair rate of subsystem (D) from 0.015 to 0.035 increases the availability by 0.19% to 0.77%, whereas increase in failure rate of same subsystem from 0.001 to 0.004 decreases the availability slightly by 1.74%.

V. Conclusion

A relative study of table No. 1 to 9 shows that the subsystem (B) i.e. Rolling Machine has the maximum impact on performance of the whole System. The other subsystems (shearing machine and submerged arc welding machine) and (welding gas cutter machine and hydraulic press machine) almost have the same effect on the performance of the system respectively. Thus, it is recommended that management should pay more attention to the subsystem (B) to improve the overall performance of the system.

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